Chapter 2

Understanding the Benefits and Costs of Urban Forest Ecosystems

David J. Nowak[1] and John F. Dwyer[2]

1. Introduction

One of the first considerations in developing a strong and comprehensive urban forestry program is determining the desired outcomes from managing vegetation in cities. Urban trees can provide a wide range of benefits to the urban environment and well-being of people. However, there are also a wide range of potential costs and as with all ecosystems, numerous interactions that must be understood if one is to optimize the net benefits from urban vegetation. Inadequate understanding of the wide range of benefits, costs, and expected outcomes of urban vegetation management options, as well as interactions among them, may drastically reduce the contribution of vegetation toward improving urban environments and quality of life.

By altering the type and arrangement of trees in a city (i.e., the urban forest structure), one can affect the city's physical, biological, and socioeconomic environments. Management plans can be developed and implemented to address specific problems within cities. Although trees can provide multiple benefits at one site, not all benefits can necessarily be realized in each location. Individual management plans should focus on optimizing, in a particular area, the mix of benefits that are most important.

2. Urban Land in the United States

The importance of urban forests and their benefits in the United States is increasing because of the expansion of urban land. The percentage of the coterminous land in United States, classified as urban, increased from 2.5% in 1990 to 3.1% in 2000, an area about the size of Vermont and New Hampshire combined. The states with the

---

David J. Nowak USDA Forest Service, Northeastern Research Station, Syracuse, New York
John F. Dwyer The Morton Arboretum, Lisle, Illinois

Urban and Community Forestry in the Northeast, 2nd ed., edited by, J. E. Kuser.

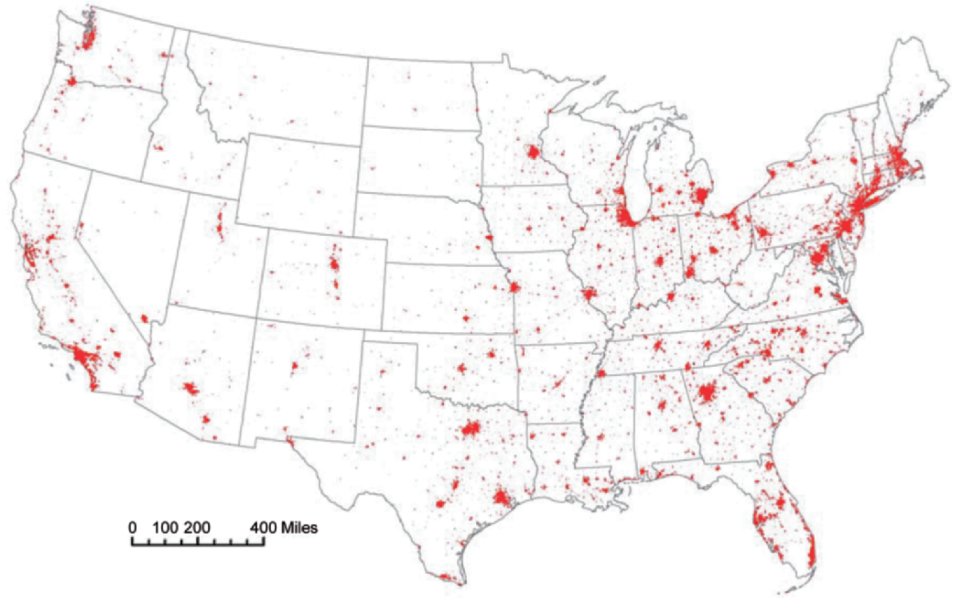

FIGURE 1. Urban areas in coterminous United States (2000) based on the US Census Bureau Definition of Urban Land.

highest percentage of urban land are New Jersey (36.2%), Rhode Island (35.9 %), Connecticut (35.5%), and Massachusetts (34.2%) with 7 of the top 10, most urbanized states in the Northeast United States (Fig. 1) (Nowak et al., 2005).

The most urbanized regions of the United States are the Northeast (9.7%) and the Southeast (7.5%), with these regions also exhibiting the greatest increase in percentage of urban land between 1990 and 2000 (1.5% and 1.8%, respectively). States with the greatest increase in percentage of urban land between 1990 and 2000 were Rhode Island (5.7%), New Jersey (5.1%), Connecticut (5.0%), Massachusetts (5.0%), Delaware (4.1%), Maryland (3.0%), and Florida (2.5%) (Nowak *et al.*, 2005). Nationally, urban tree cover in the United States averages 27.1%. However, urban tree cover tends to be highest in forested regions (34.4% urban tree cover), followed by grasslands (17.8%), and deserts (9.3%) (Dwyer et al., 2000; Nowak et al., 2001).

Patterns of urban growth reveal that increased growth rates are likely in the future (Nowak *et al.*, 2005). As the Northeast is the most urbanized region of the country and is likely to have some of the greatest increases in urban land growth over the next several decades, understanding the benefits and costs of urban vegetation is paramount to sustain human health and environmental quality in this region.

3. Physical/Biological Benefits and Costs of Urban Vegetation

Through proper planning, design, and management, urban trees can mitigate many of the environmental impacts of urban development by moderating climate, reducing building energy-use and atmospheric carbon dioxide (CO_2), improving air quality, lowering rainfall runoff and flooding, and reducing noise levels. However, inappropriate landscape designs, tree selection, and tree maintenance can increase environmental costs, such as pollen production and chemical emissions from trees and maintenance activities that contribute to air pollution, and also increase building energy-use, waste disposal, infrastructure repair, and water consumption. These potential costs must be weighed against the environmental benefits in developing management programs.

3.1. Urban Atmosphere

Trees influence the urban atmosphere in the following four general, interactive ways that can be remembered by using the word TREE (Nowak, 1995): (1) **T**emperature and microclimatic effects, (2) **R**emoval of air pollutants, (3) **E**mission of volatile organic compounds by trees and emissions due to tree maintenance, and (4) **E**nergy conservation in buildings and consequent effects on emissions from power plants. The cumulative effect of these four factors determines the overall impact of urban trees on the urban atmosphere and particularly air pollution.

3.1.1. Temperature and Microclimatic Modifications

Trees influence climate at a range of scales, from an individual tree to a forest covering an entire metropolitan area. By transpiring water, altering windspeeds, shading surfaces, and modifying the storage and exchanges of heat among urban surfaces, trees affect local climate and thereby influence thermal comfort and air quality. Often, one or more of these microclimatic influences of trees produces an important benefit, while other influences can reduce benefits or increase costs (Heisler *et al.*, 1995).

Trees alter windspeed and direction. Dense tree crowns have a significant impact on wind, but for isolated trees, their influence nearly disappears within a few crown diameters downwind (Heisler *et al.*, 1995). Several trees on a residential lot, in conjunction with trees throughout the neighborhood, reduce windspeed significantly. In a residential neighborhood in central Pennsylvania with 67% tree cover, windspeeds at 2 m above ground level were reduced by 60% in winter and 67% in summer compared to windspeeds in a comparable neighborhood with no trees (Heisler, 1990a).

Trees also have a dramatic influence on incoming solar radiation, and can reduce it by 90% or more (Heisler, 1986). Some of the radiation absorbed by tree canopies leads to the evaporation and transpiration of water from leaves. This evapotranspiration cools tree leaves and the air. Despite large amounts of energy used for evapotranspiration on sunny days, air movement rapidly disperses cooled air, thereby dispersing the overall cooling effect. Under individual and small groups of trees, air temperature at 1.5 m above the ground is usually within 1°C of the air temperatures in an open area (Souch and Souch, 1993). Along with transpirational cooling, tree shade can help cool the local environment by reducing the solar heating of some below-canopy artificial surfaces (e.g., buildings, parking lots). Together these effects can reduce air temperatures by as much as 5°C (Akbari *et al.*, 1992).

Although trees usually contribute to cooler summer air temperatures, their presence can increase air temperatures in some instances (Myrup *et al.*, 1991). 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 (Heisler *et al.*, 1995). Thus, it is important to recognize that it is the combined effects of trees on radiation, wind, and transpirational cooling that affect local air temperatures and climate.

Besides providing for transpirational cooling, the physical mass and thermal/radiative properties of trees can affect other aspects of local meteorology and microclimate, such as ultraviolet radiation loads, relative humidity, turbulence, albedo, and boundary-layer heights (i.e., the height of the layer of atmosphere that, because of turbulence, interacts with the earth's surface on a time scale of a few hours or less (Lenschow, 1986)).

3.1.2. Removal of Air Pollutants

Trees remove gaseous air pollution primarily by uptake through leaf stomata, though some gases are removed by the plant surface (Smith, 1990). Once inside the leaf, gases diffuse into intercellular spaces and may be absorbed by water films to form acids or react with the inner surfaces of leaves. Trees also remove pollution by intercepting airborne particles. Some particles can be absorbed into the tree (Ziegler, 1973; Rolfe, 1974), though most intercepted particles are retained on the plant surface. Often vegetation is only a temporary retention site for atmospheric particles as the intercepted particles may be resuspended to the atmosphere, washed off by rain, or dropped to the ground with leaf and twig fall (Smith, 1990).

Pollution removal by trees in a city varies throughout the year (Fig. 2).

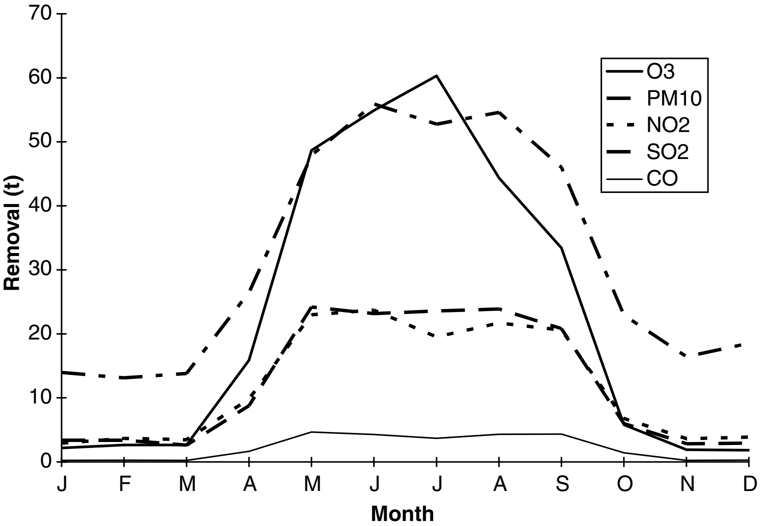

FIGURE 2. Monthly pollution removal by trees (metric tons) in Philadelphia, PA (1994). PM10 = particulate matter <10 microns; O_3 = ozone; NO_2 = nitrogen dioxide; SO_2 = sulfur dioxide; CO = carbon monoxide. PM10 removal assumes 50% resuspension of particles. City area = 350 km^2; tree cover = 21.6%.

Factors that affect pollution removal by trees include the amount of healthy leaf-surface area, concentrations of local pollutants, and local meteorology. Computer simulations using the Urban Forest Effects Model (Nowak and Crane, 2000, Nowak *et al.*, 2002b) with local field data reveal that pollution removal by urban trees in various cities range from 19 metric tons per year in Freehold, New Jersey to over 1500 metric tons per year in Atlanta and New York (Table 1). Pollution removal was typically greatest for ozone, followed by particulate matter less than 10 microns, nitrogen dioxide, sulfur dioxide, and carbon monoxide. Value of pollution removal, based on national median externality values for each pollutant (Murray *et al.*, 1994), ranged from $109,000 in Freehold to $8.3 million in Atlanta.

Average annual pollution removal per square meter of canopy cover was 9.3 g, but ranged between 6.6 g/m^2 in Syracuse and 12.0 g/m^2 in Atlanta (Table 1). The average annual dollar value per hectare of tree cover was $500, but ranged between $378/ha cover in Syracuse and $663/ha cover in Atlanta. As existing canopy cover in cities remove significant amounts of air pollution, increasing tree cover in urban areas will lead to greater pollution removal, as well as reduced air temperatures that can help improve urban air quality.

Average improvement in air quality from pollution removal by trees during the daytime of the in-leaf season among 14 cities (Table 1) was 0.62% for particulate matter less than 10 microns (PM10), 0.61% for ozone (O_3), 0.60% for sulfur dioxide (SO_2), 0.39% for nitrogen dioxide (NO_2), and 0.002% for carbon monoxide (CO). Air quality improvement increases with increased percentage of tree cover and decreased boundary-layer heights. In urban areas (Table 1) with 100% tree cover (i.e., contiguous forest stands), short-term improvements (1 h) in air quality due to pollution removal from trees were as high as 14.9% for SO_2, 14.8% for O_3, 13.6% for PM10, 8.3% for NO_2, and 0.05% for CO. In Chicago in 1991, large, healthy trees—those >77 cm in diameter at breast height (dbh)—removed an estimated 1.4 kg of pollution, about 70 times more pollution than small (<7 cm dbh) trees (Nowak, 1994a).

Trees can also reduce atmospheric CO_2 by directly storing carbon (C) from CO_2 as they grow. Large trees store approximately 3 metric tons of carbon (tC) or 1000 times more carbon than stored by small trees (Nowak, 1994b). Healthy trees continue to sequester additional carbon each year; large, healthy trees sequester about 93 kg C/year vs 1 kg C/year for small trees. Net annual sequestration by trees in the Chicago area (140,600 tC) equals the amount of carbon emitted from transportation in the Chicago area in about 1 week (Nowak, 1994b).

Urban trees in the coterminous United States currently store 700 million metric tons of carbon (335 to 980 million tC; $14,300 million value) with a gross carbon sequestration rate of 22.8 million tC/year (13.7 to 25.9 million tC/year; $460 million/year) (Nowak and Crane, 2002). These results correspond with previous analyses that estimated national carbon storage by urban trees as between 350–750 million tC (Nowak, 1993a) and 600–900 million tC (Nowak, 1994b). Carbon storage by urban trees nationally is only 4.4% of the estimated 15,900 million tC stored in trees in US nonurban forest ecosystems (Birdsey and Heath, 1995). The estimated carbon storage by urban trees in United States is equivalent to the amount of carbon emitted by the US population in about 5.5 months. National annual carbon sequestration by urban trees is equivalent to the US population emissions over a 5-day period (Nowak and Crane, 2002).

Table 1. Total Estimated Pollution Removal (Metric Tons) by Trees During Nonprecipitation Periods (Dry Deposition), and Associated Monetary Value for Various Cities (Pollutant Year = 2000)

City	Pollution removed									
	CO (t)	NO_2 (t)	O_3 (t)	PM10 (t)	SO_2 (t)	Total (t)	Range (t)	g/m^2 cover[a]	$	$/ha cover[b]
New York, NY	67	364	536	354	199	1,521	(619–2,185)	9.1	8,071,000	482
Atlanta, GA	39	181	672	528	89	1,508	(538–2,101)	12.0	8,321,000	663
Baltimore, MD	9	94	223	142	55	522	(183–725)	9.9	2,876,000	545
Philadelphia, PA	10	93	185	194	41	522	(203–742)	9.7	2,826,000	527
San Juan, PR	56	55	161	153	86	511	(222–768)	11.2	2,342,000	511
Washington, DC	18	50	152	107	51	379	(150–568)	8.3	1,956,000	429
Boston, MA	6	48	108	73	23	257	(94–346)	8.1	1,426,000	447
Woodbridge, NJ	6	42	66	62	15	191	(72–267)	10.8	1,037,000	586
San Francisco, CA	7	25	47	42	7	128	(51–195)	9.0	693,000	486
Moorestown, NJ	2	14	43	38	9	107	(41–157)	10.1	576,000	541
Syracuse, NY	2	12	55	23	7	99	(37–134)	6.6	568,000	378
Morgantown, WV	1	5	26	18	9	60	(22–98)	7.5	311,000	387
Jersey City, NJ	2	9	13	9	5	37	(16–56)	8.4	196,000	445
Freehold, NJ	1	3	9	6	1	20	(7–27)	11.4	110,000	632

Estimates are for particulate matter less than 10 microns (PM10), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO). Pollution removal model methods are described in Nowak *et al.* (1998). Monetary value of pollution removal by trees was estimated using the median externality values for United States for each pollutant. Externality values are: NO_2 = \$6750 t^{-1}, PM10 = \$4500 t^{-1}, SO_2 = \$1650 t^{-1}, and CO = \$950 t^{-1} (Murray *et al.*, 1994). Externality values for O_3 were set to equal the value for NO_2.

[a] Average grams of pollution removal per year per square meter of canopy cover.

[b] Average dollar value of pollution removal per year per hectare of canopy cover.

Table 2. Estimated Carbon Storage, Gross and Net Annual Sequestration, Number of Trees, and Percent Tree Cover for 10 US Cities (Nowak and Crane, 2002)

City	Storage (tC)		Annual sequestration Gross (tC/yr)		Annual sequestration Net (tC/yr)		No. of trees ($\times 10^3$)		Tree cover (percent)	
	Total	SE	Total	SE	Total	SE	Total	SE	%	SE
New York, NY	1,225,200	150,500	38,400	4,300	20,800	4,500	5,212	719	20.9	2.0
Atlanta, GA	1,220,200	91,900	42,100	2,800	32,200	4,500	9,415	749	36.7	2.0
Sacramento, CA[a]	1,107,300	532,600	20,200	4,400	na	na	1,733	350	13.0	na
Chicago, IL[b]	854,800	129,100	40,100	4,900	na	na	4,128	634	11.0	0.2
Baltimore, MD	528,700	66,100	14,800	1,700	10,800	1,500	2,835	605	25.2	2.2
Philadelphia, PA	481,000	48,400	14,600	1,500	10,700	1,300	2,113	211	15.7	1.3
Boston, MA	289,800	36,700	9,500	900	6,900	900	1,183	109	22.3	1.8
Syracuse, NY	148,300	16,200	4,700	400	3,500	400	891	125	24.4	2.0
Oakland, CA[c]	145,800	4,900	na	na	na	na	1,588	51	21.0	0.2
Jersey City, NJ	19,300	2,600	800	90	600	100	136	22	11.5	1.2

[a] McPherson (1998).
[b] Nowak (1994b).
[c] Nowak (1993c).
SE = standard error.
na = not analyzed.

Carbon storage within the cities ranges from 1.2 million tC in New York City and Atlanta to 19,300 tC in Jersey City, New Jersey (Table 2).

Urban trees in the North Central, Northeast, South Central and Southeast regions of the United States store and sequester the most amount of carbon, with average carbon storage per hectare greatest in Southeast (31.1 tC/ha), North Central (30.7 tC/ha), Northeast (30.5 tC/ha), and Pacific Northwest (30.2 tC/ha) regions, respectively. The national average urban forest carbon storage density is 25.1 tC/ha as compared to 53.5 tC/ha in forest stands (Nowak and Crane, 2002).

3.1.3. Emission of Volatile Organic Compounds and Tree Maintenance Emissions

Some trees emit into the atmosphere volatile organic compounds (VOCs) such as isoprene and monoterpenes. These compounds are natural chemicals that make up essential oils, resins, and other plant products and may be useful to the tree in attracting pollinators or repelling predators (Kramer and Kozlowski, 1979). Isoprene is also believed to provide thermal protection to plants by helping prevent irreversible leaf damage at high temperatures (Sharkey and Singsaas, 1995). The VOC emissions by trees vary with species, air temperature, and other environmental factors (Tingey *et al.*, 1991; Guenther *et al.*, 1994).

Volatile organic compounds can contribute to the formation of O_3 and CO (Brasseur and Chatfield, 1991). Because the VOC emissions are temperature dependent and 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 June 4, 1984 ozone conditions in Atlanta, Georgia revealed that a 20% loss in the area's forest could lead to a 14% increase in O_3 concentrations. 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 the tree loss, increased VOC emissions from the remaining trees and anthropogenic sources and altered O_3 photochemistry such that concentrations of O_3 increased (Cardelino and Chameides, 1990).

A simulation of California's South Coast Air Basin suggested that the impact on air quality from increased urban tree cover might be locally positive or negative. The net basinwide effect of increased urban vegetation is a decrease in O_3 concentrations if the additional trees are low-VOC emitters (Taha, 1996). Examples of low-VOC emitting genera include *Fraxinus* spp., *Ilex* spp., *Malus* spp., *Prunus* spp., *Pyrus* spp., and *Ulmus* spp.; high-VOC emitters include *Eucalyptus* spp., *Quercus* spp., *Platanus* spp., *Populus* spp., *Rhamnus* spp., and *Salix* spp. (Benjamin *et al.*, 1996).

Tree management and maintenance also affects pollutant emissions. The equipment used in many maintenance activities emits pollutants and global gases such as VOCs, CO, CO_2, nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (US EPA, 1991). Thus, while evaluating the overall net change in air quality due to trees, managers and planners must consider the amount of pollution that results from tree maintenance and management activities. The greater the use of fossil fuels (e.g., from vehicles, chain saws, augers, and chippers) in establishing and maintaining a certain vegetation structure, the longer the trees must live and function to offset the pollutant emissions from vegetation maintenance.

While considering the net effect of tree growth on atmospheric CO_2, managers must also consider that nearly all of the carbon sequestered by trees will be converted back to CO_2 due to decomposition after the tree dies. Hence, the benefits of carbon sequestration will be relatively short-lived if vegetation structure is not sustained. However, if carbon (via fossil-fuel combustion) is used to maintain vegetation structure and health, urban forest ecosystems will eventually become net emitters of carbon unless secondary carbon reductions (e.g., energy conservation) or limiting decomposition via long-term carbon storage (e.g., wood products, landfills) can be accomplished to offset the carbon emissions during maintenance (Nowak *et al.*, 2002c).

Trees in parking lots can also help reduce VOCs emissions by shading parked cars and thereby reducing evaporative emissions from vehicles. Increasing parking lot tree cover from 8% to 50% could reduce Sacramento County, California, light duty vehicle VOC evaporative emission rates by 2% and nitrogen oxide start emissions by <1% (Scott *et al.*, 1999).

3.1.4. Net Effects on Ozone

Besides the studies by Cardelino and Chameides (1990) and Taha (1996), other studies reveal that increased urban tree cover can lead to reduced ozone concentrations. Modeling the effects of increased urban tree cover on ozone concentrations from Washington, DC to central Massachusetts revealed that urban trees generally reduce ozone concentrations in cities. 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 (Nowak *et al.*, 2000). Modeling of the New York City metropolitan area also revealed that increasing tree cover by 10% within urban areas could reduce maximum ozone levels by about 4 ppb, which is about 37% of the amount needed for attainment of the National Ambient Air Quality Standard (Luley and Bond, 2002).

Based on the various research on urban tree effects on ozone, the US Environmental Protection Agency (US EPA) released a guidance document that details how new measures, including "strategic tree planting," can be incorporated in State Implementation Plans as a means to help states meet National Ambient Air Quality Standards (US EPA, 2004).

3.1.5. Energy Conservation

Trees can reduce building heating and cooling energy needs, as well as consequent emissions of air pollutants and CO_2 by power plants, by shading buildings and reducing air temperatures in the summer, and by blocking winds in winter. However, trees that shade buildings in winter can also 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. However, wind reduction in the summer can lead to increased energy use for air conditioning, but wind and shade effects combined lead to reduced summer energy use for cooling (Akbari *et al.*, 1992; Heisler, 1990b). 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). It has been estimated that establishing 100 million mature trees around residences in the United States could save about $2 billion annually in reduced energy costs (Akbari *et al.*, 1988).

Proper tree placement near buildings is critical to maximize energy conservation. For example, it has been estimated that annual costs of air conditioning and heating for a typical residence in Madison, Wisconsin, would increase from $671 for an energy-efficient planting design to $700 for no trees and $769 for trees planted in locations that block winter sunlight and provide little summer shade (McPherson, 1987). In this instance, average annual energy savings with properly placed trees were about 4% more than with no trees and 13% more than with improperly placed trees.

3.2. Urban Hydrology

By intercepting and retaining or slowing the flow of precipitation reaching the ground, trees (in conjunction with soils) can play an important role in urban hydrologic processes. They can reduce the rate and volume of stormwater runoff, flooding damage, stormwater treatment costs, and other problems related to water quality. Estimates of runoff for an intensive storm in Dayton, Ohio, showed that the existing tree canopy (22%) reduced potential runoff by 7% and that a modest increase in canopy cover (to 29%) would reduce runoff by nearly 12% (Sanders, 1986). A study of the Gwynns Falls watershed in Baltimore indicated that heavily forested areas can reduce total runoff by as much as 26% and increase low-flow runoff by up to 13% compared with nontree areas in existing land cover and land-use conditions (Neville, 1996). Further, tree cover over pervious surfaces reduced total runoff by as much as 40%; while tree canopy cover over impervious surfaces had a limited effect on runoff.

In reducing runoff, trees function like retention/detention structures. In many communities, reduced runoff due to rainfall interception can also reduce costs of treating stormwater by decreasing the volume of water handled during periods of peak runoff (Sanders, 1986).

There may also be hydrologic costs associated with urban vegetation, particularly in arid environments where water is increasingly scarce or on reactive clay soils where water uptake by roots may cause localized-soil drying, shrinkage, and cracking. Increased water use in desert regions could alter the local water balance and various ecosystem functions that are tied to the desert water cycle. In addition, annual costs of water for sustaining vegetation can be twice as high as energy savings from shade for tree species that use large amounts of water, e.g., mulberry (McPherson and Dougherty, 1989). However, in Tucson, Arizona, 16% of the annual irrigation requirement of trees was offset by the amount of water conserved at power plants due to energy savings from trees (Dwyer *et al.*, 1992).

3.3. Urban Noise

Field tests have shown that properly designed plantings of trees and shrubs can significantly reduce noise. Leaves and stems reduce transmitted sound primarily by scattering it, while the ground absorbs sound (Aylor, 1972). For optimum noise reduction, trees and shrubs should be planted close to the noise source rather than the receptor area (Cook and Van Haverbeke, 1971). Wide belts (30 m) of tall, dense trees combined with soft ground surfaces can reduce apparent loudness by 50% or more (6 to 10 decibels) (Cook, 1978). For narrow planting spaces (<3 m wide), reductions of 3 to 5 decibels can be achieved with dense belts of vegetation, i.e., one row of shrubs along the road and one row of trees behind it (Reethof and McDaniel, 1978). Buffer plantings in these circumstances typically are more effective in screening views than in reducing noise.

Vegetation can also mask sounds by generating its own noise as wind moves tree leaves or as birds sing in the tree canopy. These sounds may make individuals less aware of offensive noises because people are able to filter unwanted noise while concentrating on more desirable sounds (Robinette, 1972). The perception of sounds by humans is also important. By visually blocking the sound source, vegetation can reduce individuals' perceptions of the amount of noise they actually hear (Anderson *et al.*, 1984). The ultimate effectiveness of plants in moderating noise is determined by the sound itself, the planting configuration used, the proximity of the sound source, receiver, and vegetation, as well as climatic conditions.

3.4. Urban Wildlife and Biodiversity

There are many additional benefits associated with urban vegetation that contribute to the long-term functioning of urban ecosystems and the well-being of urban residents. These include wildlife habitat and enhanced biodiversity. Urban wildlife can provide numerous benefits but also have detrimental effects (VanDruff *et al.*, 1995). Urban wildlife can serve as biological indicators of changes in the health of the environment (e.g., the decline of certain bird populations was traced to pesticides), and can provide economic benefit to individuals and society (VanDruff *et al.*, 1995). For example, bird feeding supports a $170 to $517 million American industry (DeGraff and Payne, 1975; Lyons, 1982).

Surveys have shown that most city dwellers enjoy and appreciate wildlife in their day-to-day lives (Shaw *et al.*, 1985). Among New York State's metropolitan residents, 73% showed an interest in attracting wildlife to their backyard (Brown *et al.*, 1979). Feelings of personal satisfaction from helping wildlife were the most frequently reported reason for feeding wildlife in backyards across America (Yeomans and Barclay, 1981). Detrimental wildlife effects include damage to plants and structures, droppings, threats to pets, annoyance to humans, animal bites, and transmission of diseases (VanDruff *et al.*, 1995).

Urbanization can sometimes lead to the creation and enhancement of animal and plant habitats, which, in turn, usually increases biodiversity. For example, tree species diversity and richness in Oakland, California, increased from an index value of about 1.9 (Shannon–Weiner diversity index value) and 10 species in 1850 to 5.1 and >350 species in 1988 (Nowak, 1993c). However, the introduction of new plant species into urban areas can lead to problems for managers in maintaining native plant structure, as exotic plants can invade and displace native species in forest stands. One example of exotic plant invasion in some areas of the northeastern United States is that by Norway maple (*Acer platanoides* L.) (Nowak and Rowntree, 1990). Also, altering vegetation structure in urban areas can change the prevalence of certain tree insects and diseases (Nowak and McBride, 1992) and could increase the potential for urban wildfires (East Bay Hills Vegetation Management Consortium, 1995).

Urban forests can act as reservoirs for endangered species. For example, 20 threatened or endangered faunal species and 130 plant species are listed for Cook County, the most populated county of the Chicago Metropolitan Area (Howenstine, 1993). In addition, urbanites are increasingly preserving, cultivating, and restoring rare and native species and ecosystems (Howenstine, 1993). A notable example of the involvement of a wide range of individuals and groups in the restoration and management of urban natural areas is the work of the Chicago Region Biodiversity Council, often known as Chicago Wilderness (2005).

Because of increased environmental awareness and concerns about quality of life and sustainability of natural systems, ecological benefits of the urban forest are likely to increase in significance over time (Dwyer *et al.*, 1992).

3.5 Phytoremediation

Trees and other plants show significant potential for remediating brownfields, landfills, and other contaminated sites by absorbing, transforming, and containing a number of contaminants (Westphal and Isebrands, 2001). More information about brownfields and the issues and opportunities that they present can be obtained from USEPA (2000) and De Sousa (2003).

4. Social and Economic Benefits and Costs of Urban Vegetation

In conjunction with the many effects of urban trees on the physical/biological environment, trees and associated forest resources can significantly influence the social and economic environment of a city. These influences range from altered aesthetic surroundings and increased enjoyment with everyday life to improved health and a greater sense of meaningful connection between people and the natural environment. The benefits and costs associated with these influences are highly variable within and among urban areas and often difficult to measure. Nevertheless, they reflect important contributions of trees and forests to the quality of life for urban dwellers.

4.1. Benefits to Individuals

Urban forest environments provide aesthetic surroundings and are among the most important features contributing to the aesthetic quality of residential streets and community parks (Schroeder, 1989). Perceptions of aesthetic quality and personal safety are related to features of the urban forest such as number of trees per acre and viewing distance (Schroeder and Anderson, 1984). Urban trees and forests provide significant emotional and spiritual experiences that are important in people's lives and can foster a strong attachment to particular places and trees (Chenoweth and Gobster, 1990; Dwyer *et al.*, 1991; Schroeder, 1991, 2002, 2004). A wide range of individual benefits has been associated with volunteer tree planting and care (Westphal, 1993). Volunteers continue to play an increasingly important role in urban forestry efforts, such as inventory (Bloniarz and Ryan, 1996), and Sommer (2003) encourages exploration of expanding opportunities for resident involvement in tree planting and care.

Nearby nature, even when viewed from an office window, can provide substantial psychological benefits that affect job satisfaction and a person's well-being (Kaplan, 1993). Reduced stress and improved physical health for urban residents have been associated with the presence of urban trees and forests in a number of environments. Living in a green environment has been associated with a wide range of individual benefits, including improved learning and behavior by children in urban areas (Taylor, Kuo, and Sullivan, 2001a, b; Wells, 2000). Experiences in urban parks have been shown to change moods and reduce stress (Hull, 1992a; Kaplan and Kaplan, 1989), and to provide privacy refuges (Hammitt, 2002). Hospital patients with window views of trees have been shown to recover significantly faster and with fewer complications than the patients without such views (Ulrich, 1984). In addition, tree shade reduces ultraviolet radiation and thus can help reduce health problems associated with increased ultraviolet radiation exposure, e.g., cataracts, skin cancer (Heisler *et al.*, 1995).

Many of the benefits associated with urban trees contribute to improved human health in a wide variety of ways, ranging from improved air quality to reduction of stress and interpersonal conflict. With increased concern over obesity and the need for changing lifestyles (e.g., more exercise) to reduce obesity, trees and forests are receiving increased attention as contributing to a solution. This solution ranges from providing environments that encourage exercise (e.g., playing in well-landscaped parks or walking/running along tree-lined streets and trails) to the actual exercise experienced by the many volunteers who work with trees and associated landscapes (Librett *et al.*, 2005). A comprehensive overview of the relationship of urban design to human health and condition concluded, “There are strong public health arguments for the incorporation of greenery, natural light, and visual and physical access to open space in homes and other buildings (Jackson, 2003).”

Along with the human health benefits, such as those outlined above in this section, some decreases in well-being and increases in health care costs may be associated with urban vegetation. This negative side to urban trees is associated with allergic reactions to plants, pollen, or associated animal and insects, diseases such as Lyme disease that are carried by wildlife, injuries from branch or tree failures, and a fear of trees, forests, and associated environments.

4.2. Benefits to Communities

Urban forests can make important contributions to the economic vitality and character of a city, neighborhood, or subdivision. It is no accident that many cities, towns, and subdivisions are named after trees (e.g., Oakland, Elmhurst, Oak Acres) and that many cities strive to be a “Tree City USA.” Often, trees and forests on public lands–and on private lands to some extent–are significant “common property” resources that contribute to the economic vitality of an entire area (Dwyer *et al.*, 1992). The substantial efforts that many communities undertake to develop and enforce local tree ordinances and manage their urban forest resource attest to the substantial return that they expect from these investments.

A stronger sense of community and empowerment of inner-city residents to improve neighborhood conditions can be attributed to involvement in urban forestry efforts (Feldman and Westphal, 1999; Westphal, 1999, 2003). Active involvement in tree-planting programs has been shown to enhance a community’s sense of social identity, self-esteem, and territoriality; it teaches residents that they can work together to choose and control the condition of their environment. Planting programs also can project a visible sign of change and provide the impetus for other community renewal and action programs (Feldman and Westphal, 1999; Westphal, 1999, 2003). Several studies have shown that participation in tree-planting programs influences individuals’ perceptions of their community (Sommer *et al.*, 1994a, 1994b, 1995, 2003). Conversely, a loss of trees within a community can have a significant psychological effect on residents (Hull, 1992b). A useful framework for considering social benefits of urban and community forestry projects has been developed and illustrated with community examples (Westphal, 2003).

Urban trees and forests can help alleviate some of the hardships of inner-city living, especially for low-income groups (Dwyer *et al.*, 1992). Extensive research in inner-city areas of Chicago suggests that urban trees and forests contribute to stronger ties among neighbors, greater sense of safety and adjustment, more supervision of children in outdoor places, healthier patterns of children’s play, more use of neighborhood common spaces, fewer incivilities, fewer property crimes, and fewer violent crimes (Kuo, 2003; Kuo *et al.*, 1998; Kuo and Sullivan, 2001a,b; Sullivan and Kuo, 1996).

While there is sometimes concern over the influence of trees and other vegetation in urban areas on the incidence of crime, research has provided management guidelines that can reduce the fear of crime in urban forest areas (Schroeder and Anderson, 1984; Michael and Hull, 1995).

Consumer behavior has been found to be positively correlated with streetscape greening, suggesting important benefits to commercial establishments and a basis for partnerships with the business community in urban forest planning and management (Wolf, 2003a, 2004). However, improper landscaping of business areas can have a negative impact by blocking business signs and/or reducing the attractiveness of the area.

Regardless of the community benefits derived from urban trees, tree planting and maintenance programs might be perceived by some people as an inappropriate use of resources because of the perception that funds for such efforts could be used to address what they see as more critical urban community problems.

4.3. Real Estate Values

The sales value of real estate reflects the benefits that buyers attach to attributes of the property, including vegetation on and near the property. A survey of sales of single-family homes in Athens, Georgia indicated that landscaping with trees was associated with an increase in sales prices of 3.5% to 4.5% (Anderson and Cordell, 1988). Builders have estimated that homes on wooded lots sell on an average for 7% more than equivalent houses on unwooded lots (Selia and Anderson, 1982, 1984). Research in Baton Rouge, Louisiana indicates that mature trees contributed about 2% of the home market (Dombrow *et al.*, 2000). A recent study in Athens, Georgia indicates that an additional percentage increase in relative tree cover is associated with an increase of $296 in residential value (Sydor *et al.*, 2005). A study of small, urban-wildland interface properties in the Lake Tahoe Basin indicates that forest density and health characteristics contributed between 5% and 20% to property values (Thompson *et al.*, 1999). Shopping centers often landscape their surroundings to attract shoppers, thereby increasing the value of the business and shopping center (Dwyer *et al.*, 1992).

Parks and greenways have been associated with increases in nearby residential property values (Corrill *et al.*, 1978; More *et al.*, 1988; Crompton, 2004). Some of these increased values have been substantial, and it appears that parks with "open space character" add the most to nearby property values. Part of the contribution to the value of residential property is associated with the view from that property. A study of the value of a view in the single-family housing market suggests that a good view adds 8% to the value of a single-family house (Rodriquez and Sirmans, 1994). A premium of 5% to 12% in housing prices in the Netherlands was associated with an attractive landscape view from the property (Luttik, 2000). Although this remains to be investigated, parks also may have a negative impact on local property values if these are perceived as unmaintained or a place where undesirable/criminal activities are concentrated.

Increased real estate values generated by trees also produce direct economic gains to the local community through property taxes. A conservative estimate of a 5% increase in residential property values due to trees converts to $25/year on a tax bill of $500 and is equivalent to $1.5 billion/year based on 62 million single-family homes in the United States (Dwyer *et al.*, 1992). However, from a homeowner's perspective, increased tax expense due to trees is an additional annual cost of owning a home.

4.4. Tree Value Formulas

Various approaches and formulas are used to estimate the value of individual trees (see Chapter 19). One of the most widely used is the Council of Tree and Landscape Appraisers' (2000), *Guide for Plant Appraisal*, which estimates the compensation that landowners should receive for the loss of a tree on their property. For smaller trees, the value is the replacement cost. For larger trees, the formula calculates tree value from measured tree variables and tree assessments by professionals. The species, diameter, location, and condition of the tree are an integral part of the assessment. Because the values estimated with the tree valuation formula are not necessarily tied to the functions that trees perform in the urban environment, they do not relate directly to the values associated with the environmental, social, and economic benefits from trees. An exception is a single study that suggested that the formula produced values that were similar to a tree's contribution to residential property values (Morales *et al.*, 1983).

Compensatory values represent compensation to owners for the loss of an individual tree and can be viewed as the value of the tree as a structural asset. Compensatory value is based on the structure in place as an asset, while the functional value is an annual value based on the various functions of the particular structure. Trees can have both positive (e.g., air pollution removal) and negative functional values (e.g., trees can increase annual building energy use in certain locations). Trees also have various maintenance costs, which are essential for maintaining tree health, human safety, and overall tree functional benefits. Management of urban forests is needed to enhance functional values and improve human health and well-being, and environmental quality in cities. Maximizing net functional benefits of the urban forest will lead to the greatest value to society (Nowak *et al.*, 2002a).

Based on the data from eight cities, overall citywide compensatory values ranged between \$23 and \$64/m^2 (\$2.1–\$5.9/feet^2) of tree cover. However, 75% of the city values were between \$27 and \$39 m^2 (\$2.5–\$3.6/feet^2) of cover. The total compensatory value for the urban forests of the 48 adjacent US states is estimated at \$2.4 trillion or \$630/tree (Nowak *et al.*, 2002a).

Urban forest compensatory values can be used to estimate actual or potential loss due to catastrophic agents. For example, the loss to the urban forest in Oakland, California, due to a large fire in 1991 was estimated at \$26.5 million (Nowak 1993b). Compensatory value of potential loss due to Asian longhorned beetle *(Anoplophora glabripennis)* infestation in various US cities ranges between \$72 million (Jersey City, New Jersey) and \$2.3 billion (New York, New York). The estimated maximum potential national urban impact of infestations by *A. glabripennis* is \$669 billion (Nowak *et al.*, 2001b).

4.5. Other Benefits and Costs of Urban Trees and Forests

The presence of urban trees and forests can make the urban environment a more pleasant place to live, work, and spend leisure time. A study of urbanites that use parks and forest preserves indicated that they were willing to pay extra to have trees and forests in recreation areas (Dwyer *et al.*, 1989). For example, they would be willing to pay an addition $1.60/visit to have a site that was “mostly wooded, some open grassy areas under trees” rather than “mowed grass, very few trees anywhere.” The total contribution of trees in urban park and recreation areas to the value of the outdoor leisure and recreation experiences in the United States may exceed $2 billion/year (Dwyer, 1991).

A national survey indicated that drivers prefer trees as a screen of commercial developments along highways (Wolf, 2003b). Reduced driver aggression (Cackowski and Nasar, 2003) and stress recovery (Parsons, *et al.*, 1998) have also been associated with treed thoroughfares. These findings provide the basis for opportunities to incorporate urban forestry into the planning of high-speed urban transportation corridors (Wolf, 2003b).

Urban trees and forests often figure prominently in urban environmental education programs. The high visibility, variability, and complexity of urban forest ecosystems make an outstanding laboratory for environmental education. The lessons learned about forest ecosystems have implications for the management of public and private forest resources far beyond the city boundary (Dwyer and Schroeder, 1994).

Because trees and forests can increase the quality of the urban environment and make spending leisure time there more attractive, there can be a substantial saving in the amount of automobile fuel used because people do not need to drive long distances to reach recreation sites.

At the same time there are direct economic costs associated with urban trees. These include costs of planting, maintenance, management, and removal, as well as costs of damage from falling tree limbs and cracked sidewalks due to tree roots (Dwyer, 1995). However, these costs can be offset by economic benefits generated by trees. For example, homeowners may pay for tree care and driveway repair due to root damage, but receive savings on their utility bill from the energy conserving effects of the trees. At a larger scale, a municipality paying for street and park tree maintenance and management may receive increased tax revenues due to the contribution of trees to property values, and also may achieve savings in storm water management costs due to the influence of trees. Net benefits or costs need to be considered when developing urban vegetation designs or management plans.

5. Benefit–Cost Analyses

The wide range of important benefits and costs that may be associated with managing the urban forest and the significant interactions between the processes that produce important outcomes complicate the analysis of options available to urban forest resource managers. This complexity makes it difficult to predict the influence of trees on the urban environment for various vegetation designs and management options. In many instances, the location of trees with respect to other resources can make a substantial difference in the benefits that they provide, such as with building heating and cooling costs and the management of rights-of-way where improperly placed trees can greatly increase costs. Not all of the benefits are easily translated into monetary terms, and even when they are, it often is difficult to assess the incidence of benefits and costs, i.e., who pays and who gains? Trees planted on a residential property may provide benefits to others in the neighborhood and across the city in terms of aesthetics, reduced air temperatures, and improved air quality. Yet these very trees may present problems for one's neighbor by blocking solar heating through windows in the winter and making it difficult to grow flowers or a vegetable garden in the summer. The management of trees in public areas and rights-of-way often is intertwined with that of other resources, such as park and recreation facilities and programs, streets and roads, utilities, and other aspects of the urban infrastructure. When attempting benefit–cost analyses, one must be aware of these various interconnections, as well as the limitations of the information used in the analyses.

6. Implications for Planning, Design, and Management

It is clear that careful planning and design are critical to increasing the net benefits of trees and forests in urban environments. A change in species or location of trees with respect to each other or buildings and other components of the urban infrastructure can have a major impact on benefits and costs. Similarly, maintenance activities can greatly influence benefits and costs. It often is critical that forest resources are managed in the context of other aspects of the urban structure; including people, buildings, roads and streets, utility rights-of-way, recreation areas, and other open spaces.

Management plans must consider the potential of vegetation to improve individual site conditions or alleviate local problems (e.g., poor air quality, neighborhood revitalization) and design appropriate vegetation structure at the site with consideration of how individual sites interact across the landscape (i.e., the benefits at one site might lead to costs and benefits at other site). Determining the benefits and costs over the urban environment is a complex task that often calls for approaching problems at the landscape level (and sometimes extending beyond the urban system), particularly with respect to aesthetics, meteorology, pest problems, risk of fire, and air quality. Urban landscape designs and management plans must take account of these numerous interactions and the myriad of potential benefits and costs to implement appropriate strategies to maximize the net environmental, social, economic, and human health benefits of urban vegetation. In addition, careful attention must be given to the question of who gains and who pays as a result of forest management efforts across the urban landscape.

References

Akbari, H., Davis, S., Dorsano, S., Huang, J., and Winnett, S., 1992, *Cooling Our Communities: A Guidebook on Tree Planting and Light-colored Surfacing*, US Environmental Protection Agency, Washington, DC.

Akbari, H., Huang, J., Martien, P., Rainier, L., Rosenfeld, A., and Taha, H., 1988, The impact of summer heat islands on cooling energy consumption and CO_2 emissions, in *Proceedings of the 1988 Summer Study in Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington, DC.

Anderson, L. M., and Cordell, H. K., 1988, Influence of trees on residential property values in Athens, Georgia (USA): A survey based on actual sales prices, *Landscape Urban Plann*. **15:**153–164.

Anderson, L. M., Mulligan, B. E., and Goodman, L. S., 1984, Effects of vegetation on human response to sound, *J. Arboric*. **10**(2):45–49.

Aylor, D. E., 1972, Noise reduction by vegetation and ground, *J. Acoust. Soc. Am.* **51**(1):197–205.

Benjamin, M. T., Sudol, M., Bloch, L., and Winer, A. M., 1996, Low-emitting urban forests: A taxonomic methodology for assigning isoprene and monoterpene emission rates, *Atmos. Environ.* **30**(9):1437–1452.

Birdsey, R. A., and Heath, L. S., 1995, Carbon changes in US forests, in *Climate Change and the Productivity of America's Forests*, (L. A. Joyce, ed.), Gen. Tech. Rep. RM-271, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, pp. 56–70.

Bloniarz, D. V., and Ryan, H. D. P., 1996, The use of volunteer initiatives in conducting urban forest inventories, *J. Arboric*. **22**(2):75–82.

Brasseur, G. P., and Chatfield, R. B., 1991, The fate of biogenic trace gases in the atmosphere, in *Trace Gas Emissions by Plants* (T. D. Sharkey, E. A. Holland, and H. A. Mooney, eds.), Academic Press, New York, pp. 1–27.

Brown, T. L., Dawson, C. P., and Miller, R. C., 1979, Interests and attitudes of metropolitan New York residents about wildlife, *Trans. 44th North. Am. Wildl. and Nat. Resour. Conf.* **44:**289–297.

Cackowski, J. M., and Nassar, J. L., 2003, The restorative effects of nature: Implications for driver anger and frustration, *Env. Behav*. **25:**736–751.

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

Chicago Wilderness website at http://www.chicagowilderness.org, Last accessed May, 2005.

Chenoweth, R. E., and Gobster, P. H., 1990, The nature and ecology of aesthetic experiences in the landscape, *Landscape J*. **9:**1–18.

Cook, D. I., 1978, Trees, solid barriers, and combinations: Alternatives for noise control, in *Proceedings of the National Urban Forestry. Conference* (G. Hopkins, ed.), SUNY College of Environmental Science and Forestry, Syracuse, NY, pp. 330–339.

Cook, D. I., and Van Haverbeke, D. F., 1971, Trees and shrubs for noise abatement, in *Res. Bull*., vol. 246, *Nebraska Agricultural Experiment Station,* Lincoln.

Corrill, M., Lillydahl, J., and Single, L., 1978, The effects of greenbelts on residential property values: Some findings on the political economy of open space, *Land Econ*. **54:**207–217.

Council of Tree and Landscape Appraisers, 2000, *Guide for Plant Appraisal*, International Society of Arboriculture, Urbana, IL.

Crompton, J. L., 2004, *The Proximate Principle: The Impact of Parks, Open Space and Water Features on Residential Property Values and the Property Tax Base,* National Recreation and Park Association, Ashburn, VA, 184pp. plus appendix.

De Sousa, C. A., 2003, Turning brownfields into green space in the City of Toronto, *Env. Behav*. **63:**181–198.

DeGraff, R. M., and Payne, B. R., 1975, Economic values of nongame birds and some research needs, *Trans. North. Am. Wildl. Nat. Resour. Conf.* **40:**281–287.

Dombrow, J., Rodriquez, M., and Sirmans, C. F., 2000, The market value of mature trees in single family housing markets, *Apprais. J*. 68: 39–43.

Dwyer, J. F., 1991, Economic value of urban trees, in *A National Research Agenda for Urban Forestry in the 1990's*, International Society of Arboriculture, Urbana, IL, pp. 27–32.

Dwyer, J. F., 1995, The significance of trees and their management in built environments, in *Trees and Building Sites: Proceedings of an International Conference held in the Interest of Developing a Scientific Basis for Managing Trees in Proximity to Buildings* (G. Watson, and D. Neely, eds.), International Society of Arboriculture, Savoy, IL, pp. 3–11.

Dwyer, J. F., Nowak, D. J., Noble, M. H., and Sisinni, S. M., 2000, *Assessing our Nation's Urban Forests: Connecting People with Ecosystems in the 21st Century*, Gen. Tech. Rep. PNW-460, US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Dwyer, J. F., and Schroeder, H. W., 1994, The human dimensions of urban forestry, *J. For*. **92**(10):12–15.

Dwyer, J. F., Schroeder, H. W., and Gobster, P. H., 1991, The significance of urban trees and forests: Toward a deeper understanding of values, *J. Arboric*. **17:**276–284.

Dwyer, J. F., Schroeder, H. W., Louviere, J. J., and Anderson, D. H., 1989, Urbanites willingness to pay for trees and forests in recreation areas, *J. Arboric*. **15**(10):247–252.

Dwyer, J. F., McPherson, E. G., Schroeder, H. W., and Rowntree, R. A., 1992, Assessing the benefits and costs of the urban forest, *J. Arboric*. **18**(5):227–234.

East Bay Hills Vegetation Management Consortium, 1995, *Fire Hazard Mitigation Program and Fuel Management Plan for the East Bay Hills*, Report prepared by Amphion Environmental, Inc., Oakland, CA.

Feldman, R., and Westphal, L., 1999, Restoring participatory design and planning: Incorporating community empowerment as a tool for social justice, *Places* **12**(2):34–37.

Guenther, A., Zimmerman, P., and Wildermuth, M., 1994, Natural volatile organic compound emission rate estimates for US woodland landscapes, *Atmos. Environ*. **28**(6):1197–1210.

Hammitt, W. E., 2002, Urban forests and parks as privacy refuges, *J. Arboric*. **28**(1):19–26.

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

Heisler, G. M., 1990a, Mean wind speed below building height in residential neighborhoods with different tree densities, *ASHRAE Trans*. **96**(1):1389–1396.

Heisler, G. M., 1990b, Tree plantings that save energy, in *Proceedings of the 4th Fourth National Urban Forestry Conference* (P. Rodbell, ed.), American Forestry Association, Washington, DC, pp. 58–62.

Heisler, G. M., Grant, R. H., Grimmond, S., and Souch, C., 1995, Urban forests' cooling our communities?, in *Proceedings of the Seventh National Urban Forestry Conference* (C. Kollin, and M. Barratt, eds.), American Forests, Washington, DC, pp. 31–34.

Howenstine, W. L., 1993, Urban forests as part of the whole ecosystem, in *Proceedings of the 6th National Urban Forestry Conference* (C. Kollin, J. Mahon, and L. Frame, eds.), American Forests, Washington, DC, pp. 118–120.

Hull, R. B., 1992a, Brief encounters with urban forests produce moods that matter, *J. Arboric*. **18**(6):322–324.

Hull, R. B., 1992b, How the public values urban forests, *J. Arboric*. **18**(2):98–101.

Jackson, L. E., 2003, The relationship of urban design to human health and condition, *Landscape Urban Plan*. **64:**191–200.

Kaplan, R., 1993, Urban forestry and the workplace, in *Managing Urban and High Use Recreation Settings* (P. H. Gobster, ed.), Gen. Tech. Rep. USDA Forest Service, North Central Forest Experiment Station, NC-163, St. Paul, MN, pp. 41–45.

Kaplan, R., and Kaplan, S., 1989, *The Experience of Nature: A Psychological Approach*, Cambridge University Press, Cambridge, UK.

Kramer, P. J., and Kozlowski, T. T., 1979, *Physiology of Woody Plants*, Academic Press, New York.

Kuo, F. E., 2003, The role of arboriculture in healthy social ecology, *J. Arboric*. **29**(3):148–155.

Kuo, F. E., Bacaicoa, M., and Sullivan, W. C., 1998, Transforming inner-city landscapes: Trees, sense of safety, and preference, *Enviorn. Behav*. **30**(1):28–59.

Kuo, F. E., and Sullivan, W. C., 2001a, Environment and crime in the inner city: Does vegetation reduce crime?, *Enviorn. Behav*. **33**(3):343–365.

Kuo, F. E., and Sullivan, W. C., 2001b, Aggression and violence in the inner city: Impacts of environment via mental fatigue, *Enviorn. Behav*. **33**(4):543–571.

Lenschow, D. H. (ed.), 1986, *Probing the Atmospheric Boundary Layer*, American Meteorological Society, Boston, MA.

Librett, J., Yore, M., Buchner, D. M., and Schmid, T. L., 2005, Take pride in America's health: Volunteering as a gateway to physical activity, *Am J. Health Ed*. **36**(1):8–13.

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, 73pp.

Luttik, J., 2000, The value of trees, water, and open space as reflected by house prices in the Netherlands, *Landscape Urban Plan*. **48:**161–167.

Lyons, J. R., 1982, Nonconsumptive wildlife-associated recreation in the US: Identifying the other constituency, *Trans. North. Am. Wildl. Nat. Resour. Conf*. **47:**677–685.

McPherson, E. G., 1987*, Effects of Vegetation on Building Energy Performance*, Ph.D. Discussion, SUNY College of Environmental Science and Forestry, Syracuse, NY.

McPherson, E. G., and Dougherty, E., 1989, Selecting trees for shade in the Southwest, *J. Arboric*. **15:**35–43.

McPherson, E. G., 1998, Atmospheric carbon dioxide reduction by Sacramento's urban forest, *J. Arboric*. **24**(4):215–223.

Michael, S. E., and Hull, R. B., 1995, Effects of vegetation on crime in urban parks, *Arborist News*, February, p. 45.

Morales, D. J., Micha, R. R., and Weber, R. L., 1983, Two methods of valuating trees on residential sites, *J. Arboric*. **9:**21–24.

More, T. A., Stevens, T., and Allen, P. G., 1988, Valuation of urban parks, *Landscape Urban Plan.* **15:**139–152.

Murray, F. J., Marsh, L., and Bradford, P. A., 1994, *New York State Energy Plan,* Vol. II: *Issue Reports*, New York State Energy Office, Albany.

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.

Neville, L. R., 1996, *Urban Watershed Management: The Role of Vegetation*, Ph.D. Discussions., SUNY College of Environmental Science and Forestry, Syracuse, NY.

Nowak, D. J., 1993a, Atmospheric carbon reduction by urban trees, *J. Environ. Manage*. **37**(3):207–217.

Nowak, D. J., 1993b, Compensatory value of an urban forest: An application of tree-value formula, *J. Arboric*. **19**(3):173–177.

Nowak, D. J., 1993c, Historical vegetation change in Oakland and its implications for urban forest management, *J. Arboric*. **19**(5):313–319.

Nowak, D. J., 1994a, Air pollution removal by Chicago's urban forest, in *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project* (E. G. McPherson, D. J. Nowak, and R. A. Rowntree, eds.), Gen. Tech. Rep. NE-186, USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA, pp. 63–81.

Nowak, D. J., 1994b, Atmospheric carbon dioxide reduction by Chicago's urban forest, in *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project* (E. G. McPherson, D. J. Nowak, and R. A. Rowntree, eds.), Gen. Tech. Rep. NE-186, USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA, pp. 83–94.

Nowak, D. J., 1995, Trees pollute? A "TREE" explains it all, in *Proceedings 7th National Urban Forestry Conference* (C. Kollin, and M. Barratt, eds.), American Forests, Washington, DC, pp. 28–30.

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.

Nowak, D. J., and Crane, D. E., 2000, The Urban Forest Effects (UFORE) Model: Quantifying urban forest structure and functions, in *Proceedings of the Integrated Tools for Natural Resources Inventories in the 21st Century, IUFRO Conference, 16–20 August 1998, Boise, ID* (M. Hansen, and T. Burk eds.), Gen. Tech. Rep.NC-212, US Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN, pp. 714–720.

Nowak, D. J., and Crane, D. E., 2002, Carbon storage and sequestration by urban trees in the USA, *Environ. Poll*. **116**(3):381–389.

Nowak, D. J., Crane, D. E., and Dwyer, J. F., 2002a, Compensatory value of urban trees in the United States, *J. Arboric*. **28**(4):194–199.

Nowak, D. J., Crane, D. E., Stevens, J. C., and Ibarra, M., 2002b, *Brooklyn's Urban Forest*, Gen. Tech. Rep. NE-290, US Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, PA.

Nowak, D. J., and McBride, J. R., 1992, Differences in Monterey pine pest populations in urban and natural forests, *For. Ecol. Manage*. **50**:133–144.

Nowak, D. J., Noble, M. H., Sisinni, S. M., and Dwyer, J. F., 2001a, Assessing the US urban forest resource, *J. For*. **99**(3):37–42.

Nowak, D. J., Pasek, J., Sequeira, R., Crane, D. E., and Mastro, V., 2001b, Potential effect of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) on urban trees in the United States, *J. Econom. Entomol.* **94**(1):116–122.

Nowak, D. J., and Rowntree, R. A., 1990, History and range of Norway maple, *J. Arboric*. **16**(11):291–296.

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, and N. Chaumerliac, eds.), Plenum Press, New York, pp. 399–407.

Nowak, D. J., Stevens, J. C., Sisinni, S. M., and Luley C. J., 2002c, Effects of urban tree management and species selection on atmospheric carbon dioxide, *J. Arboric*. **28**(3):113–122.

Nowak, D. J., Walton, J. T., Dwyer, J. F., Kaya, L. G., and Myeong, S., 2005, The increasing influence of urban environments on US forest management, *J. Forestry* 103(8): 377–382.

Parsons, R., Tassinary, L. G., Ulrich, R. S., Hebl, M. R., and Grossman-Alexander, M., 1998, The view from the road: Implications for stress recovery and immunization, *J. Enviorn. Psych*. **18**(2):113–140.

Reethof, G., and McDaniel, O. H., 1978, Acoustics and the urban forest, in *Proceedings of the National Urban Forestry Conference* (G. Hopkins, ed.), SUNY College of Environmental Science and Forestry, Syracuse, NY, pp. 321–329.

Robinette, G. O., 1972, *Plants/People/ and Environmental Quality*, USDI National Park Service, Washington, DC.

Rodriquez, M., and Sirmans, C. F., 1994, Quantifying the value of a view in single-family housing markets, *Apprais. J.,* 62(4): 600–603.

Rolfe, G. L., 1974, Lead distribution in tree rings, *For. Sci*. **20**(3):283–286.

Sanders, R. A., 1986, Urban vegetation impacts on the urban hydrology of Dayton Ohio, *Urban Ecol*. **9:**361–376.

Schroeder, H. W., and Anderson, L. M., 1984, Perception of personal safety in urban recreation sites, *J. Leis. Res*. **16**(2):178–194.

Schroeder, H. W., 1989, Environment, behavior, and design research on urban forests, in *Advances in Environment, Behavior, and Design* (E. H. Zube, and G. L. Moore, eds.), Plenum Press, New York, pp. 87–107.

Schroeder, H. W., 1991, Preference and meaning of arboretum landscapes: Combining quantitative and qualitative data, *J. Environ. Psych*. **11:**231–248.

Schroeder, H. W., and Anderson, L. M., 1984, Perception of personal safety in urban recreation sites, *J. Leisure Res*. **16:**178–194.

Schroeder, H. W., 2002, Experiencing nature in special places, *J. For*. **100**(5):8–14.

Schroeder, H. W., 2004. *Special Places in the Lake Calumet Area*, USDA Forest Service North Central Research Station, General Technical Report 249, St Paul MN, 23pp.

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.

Selia, A. F., and Anderson, L. M., 1982, Estimating costs of tree preservation on residential lots, *J. Arboric*. **8:**182–185.

Selia, A. F., and Anderson, L. M., 1984, Estimating tree preservation costs on urban residential lots in metropolitan Atlanta, *Georgia For. Res. Pap*. No. 48. MACON, 6A. 6pp.

Sharkey, T. D., and Singsaas, E. L., 1995, Why plants emit isoprene, *Nature* **374(**27 April):769.

Shaw, W. W., Magnum, W. R., and Lyons, J. R., 1985, Residential enjoyment of wildlife resources by Americans*, Leisure Sci*. **7:**361–375.

Smith, W. H., 1990, *Air Pollution and Forests*, Springer-Verlag, New York.

Sommer, R., Learey, F., Summit, J., and Tirell, M., 1994a, Social benefits of resident involvement in tree planting: Compressions with developer-planted trees, *J. Arboric*. **20**(6):323–328.

Sommer, R., Learey, F., Summitt, J., Tirrell, M., 1994b, Social benefits of residential involvement in tree planting, *J. Arboric*. **20**(3):170–175.

Sommer, R., Summitt, J., Learey, R., and Tirrell, M., 1995, Social and educational benefits of a community shade tree program: A replication, *J. Arboric*. **21**(5):260.

Sommer, R., 2003, Trees and human identity, in Identity and the natural environment: The psychological significance of nature (S. Clayton, and S. Opotow, eds.), MIT Press, Cambridge and London, pp. 179–204.

Sullivan, W. C., and Kuo, F. E., 1996, Do trees strengthen urban communities, reduce domestic violence? *Arbor. News* **5**(2):33–34.

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.

Sydor, T., Bowker, J. M., Newman, D. H., and Cordell, H. K., 2005, *Valuing Trees in a Residential Setting: Revisiting Athens*, Clarke County, Georgia, draft paper, 15pp.

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.

Taylor, A. F., Kuo, F. E., and Sullivan, W. C., 2001a, Coping with ADD: The surprising connection to green play settings, *Enviorn. Behav*. **33**(1):54–77.

Taylor, A. F., Kuo, F. E., and Sullivan, W. C., 2001b, Views of nature and self-discipline: Evidence from inner-city children, *J. Enviorn. Psych*. **21:**49–63.

Thompson, R., Hanna, R., Noel, J., and Piirto, D., 1999, Valuation of tree aesthetics on small urban-interface properties, *J. Arboric*. **25**(5):225–234.

Tingey, D. T., Turner, D. P., and Weber, J. A., 1991, Factors controlling the emissions of monoterpenes and other volatile organic compounds, in *Trace Gas Emissions by Plants* (T. D. Sharkey, E. A. Holland, and H. A. Mooney, eds.), Academic Press, New York, pp. 93–119.

Ulrich, R. S., 1984, View through a window may influence recovery from surgery, *Science,* **224:**420–421.

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

US Environmental Protection Agency, 2004, *Incorporating Emerging and Voluntary Measures in a State Implementation Plan (SIP)*, USEPA Air Quality Strategies and Standards Division, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

US Environmental Protection Agency, 2000, *Introduction to Phytoremedia*tion, US EPA Office of Research and Development, Washington, DC.

VanDruff, L. W., Leedy, D. L., and Stearns, F. W., 1995, Urban wildlife and human well-being, in *Urban Ecology as the Basis of Urban Planning* (H. Sukopp, M. Numata, and A. Huber, eds.), SPB Academic Publishing, Amsterdam, pp. 203–211.

Wells, N. M., 2000, At home with nature: Effects of "greening" on children's cognitive functioning, *Enviorn. Behav*. **32**(5):775–795.

Westphal, L. M., 1993, Why trees? Urban forestry volunteers values and motivations, in *Managing Urban and High Use Recreation Settings* (P. H. Gobster, ed.), Gen. Tech. Rep. NC-163, USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN, pp. 19–23.

Westphal, L. M., 1999, Empowering people through urban greening projects: Does it happen? in *Proceedings of the 1999 National Urban Forestry Conference* (C. Kollin, ed.), American Forests, Washington, D.C, pp. 60–63.

Westphal, L. M., and Isebrands, J. G., 2001, Phytoremediation of Chicago's brownfields: Consideration of ecological approaches to social issues, in *Brownfields 2001 Proceedings*, Chicago IL, http://www.brownfields2001.org/proceedings/BB-11-02.pdf, Last accessed April, 2005.

Westphal, L. M., 2003, Urban greening and social benefits: A study of empowerment outcomes, *J. Arboric*. **29**(3):137–147.

Wolf, K. L., 2003a, Public response to the urban forest in inner-city business districts, *J. Arboric*. **29**(3):117–126.

Wolf, K. L., 2003b, Freeway roadside management: The urban forest beyond the white line, *J. Arboric*. **29**(3):127–136.

Wolf, K. L., 2004, Trees and business district preferences: A case study of Athens, Georgia US, *J. Arboric*. **30**(6):336–346.

Yeomans, J. A., and Barclay, J. S., 1981, Perceptions of residential wildlife programs, *Trans. North. Am. Wildl. Nat. Resour. Conf*. **46**:390–395.

Ziegler, I., 1973, The effect of air–polluting gases on plant metabolism, in *Environmental Quality and Safety,* vol. 2, Academic Press, New York, pp. 182–208.