

Understanding the Benefits and Costs of Urban Forest Ecosystems

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1. Introduction

One of the first considerations in developing a strong and comprehensive urban forestry program is determining the desired outcomes from managing and maintaining vegetation in cities. Urban trees offer a wide range of potential benefits to the urban environment and society. However, there also are a wide range of potential costs and, as with all ecosystems, numerous interactions that must be understood if society 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 designs and plans, as well as interactions among them, may drastically reduce the contribution of vegetation toward improving urban life and the environment.

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

2. Physical–Biological Benefits and Costs of Urban Vegetation

Through proper planning, designing, 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 (CO₂), improving air quality, lowering rain-

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fall runoff and flooding, and reducing noise levels. However, improper landscape design, tree selection, and tree maintenance can increase environmental costs such as pollen production and emissions from trees and maintenance activities that contribute to air pollution, as well as 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.

2.1. Urban Atmosphere

Trees influence the urban atmosphere in four general, interactive ways that can be remembered by using the word *tree* (Nowak, 1995): (1) *temperature* and microclimate effects; (2) *removal* of air pollutants; (3) *emission* of volatile organic compounds by trees and emissions due to tree maintenance; and (4) *energy* conservation in buildings and consequent effects on emissions from power plants. The cumulative effect of these factors determines the overall impact of urban trees on the urban atmosphere, particularly with respect to air pollution.

2.1.1. Temperature and Microclimate 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, 1990).

Trees also have a dramatic influence on incoming solar radiation. They can reduce solar radiation by 90% or more (e.g., 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. Below individual and small groups of trees, air temperature at 1.5 m above ground usually is within 1 °C of the air temperatures in an open area (e.g., 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)].

2.1.2. Removal of Air Pollutants

Trees remove gaseous air pollution primarily by uptake through leaf stomates, 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 (e.g., 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. 1). Factors that af-

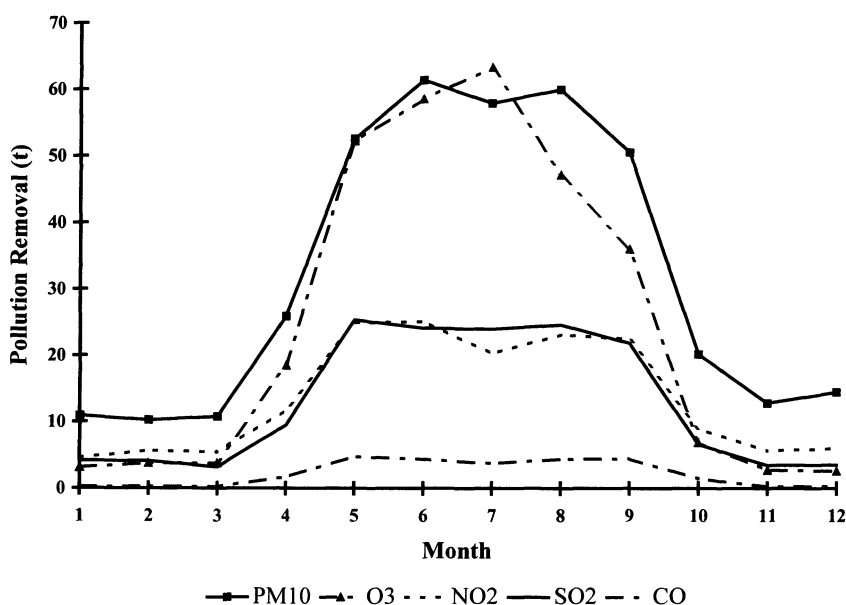


FIGURE 1. Monthly pollution removal by trees (metric tons) in Philadelphia, PA. PM10, particulate matter less than 10 microns; O₃, ozone; NO₂, nitrogen dioxide; SO₂, sulfur dioxide; CO, carbon monoxide. PM10 removal assumes 50% resuspension of particles. City area = 350 km²; tree cover = 21.6%.

fect 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 et al., 1998), revealed that average standardized pollution removal by trees in 1994—grams of pollution removed per square meter of tree canopy—was greatest in New York, NY (13.7 g/m²), followed by Philadelphia, PA (13.6 g/m²), Baltimore, MD (12.2 g/m²), and Boston, MA (10.5 g/m²). Total pollution removal ranged from 1821 metric tons in New York to 278 metric tons in Boston (Table 1). Average improvement in air quality from trees during the in-leaf season among these cities were 0.7% for particulate matter less than 10 microns (PM10); 0.3% for ozone (O₃) and sulfur dioxide (SO₂), 0.2% for nitrogen dioxide (NO₂), and 0.002% for carbon monoxide (CO). Air quality improvement increases with increased percent tree cover and decreased boundary layer heights. In urban areas with 100% tree cover (i.e., contiguous forest stands), short-term improvements (1 hour) in air quality were as high as 16% for O₃ and SO₂, 13% for PM10, 9% for NO₂, and 0.05% for CO. In Chicago in 1991, large, healthy trees—those greater than 77 cm in diameter at breast height (dbh)—removed an estimated 1.4 kg of pollution, about 70 times more pollution than small (less than 7 cm dbh) trees (Nowak, 1994a).

Trees also can reduce atmospheric CO₂ by directly storing carbon (C) from CO₂ as they grow. Large trees store approximately 3 metric tons of carbon 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 versus 1 kg C/year for small trees. Net annual sequestration by trees in the Chicago area (140,600 metric tons C) equals the amount of carbon emitted from transportation in the Chicago area in one week (Nowak, 1994b).

2.1.3. Emission of Volatile Organic Compounds and Tree Maintenance Emissions

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

VOCs can contribute to the formation of O₃ and CO (Brasseur and Chatfield, 1991). Because 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 O₃ levels in urban areas. A computer simulation of June 4, 1984, ozone conditions in Atlanta, GA, revealed that a 20% loss in the area's forest could lead to a 14% increase in O₃ concentrations. Although there were fewer trees to emit VOCs, an increase in Atlanta's air temperatures due to the urban heat island that occurred concomitantly with the tree loss increased VOC emissions from the remaining trees and anthropogenic sources and altered O₃ photochemistry such that concentrations of O₃ 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 may be locally positive or negative. The net basin-wide effect of increased urban vegetation is a decrease in O₃ concentrations if the additional trees are low VOC emitters (Taha, 1996). Examples of low VOC-emitting genera include

Table 1. Total Estimated Pollution Removal (metric tons) by Trees during Nonprecipitation Periods (dry deposition) and Associated Monetary Value (\$ × 1000), for four cities in 1994

Pollutant ^e	New York, NY ^a		Philadelphia, PA ^b		Baltimore, MD ^c		Boston, MA ^d	
	Removal	Value	Removal	Value	Removal	Value	Removal	Value
O ₃	506 (124–631)	3417 (839–4263)	299 (83–385)	2017 (563–2603)	180 (42–221)	1214 (284–1494)	105 (26–124)	708 (177–835)
NO ₂	510 (216–593)	3441 (1459–4004)	164 (80–194)	1106 (538–1311)	115 (48–134)	773 (322–907)	62 (29–72)	420 (193–485)
PM10 ^f	470 (182–834)	2120 (819–3761)	388 (149–731)	1748 (671–3297)	137 (53–239)	618 (239–1079)	72 (28–129)	322 (124–581)
SO ₂	238 (117–358)	394 (193–593)	154 (76–239)	255 (126–396)	55 (26–85)	91 (42–140)	31 (16–46)	51 (26–76)
CO	97	93	26	25	13	12	9	9
Total	1821 (736–2514)	9465 (3404–12,713)	1031 (414–1576)	5151 (1924–7631)	499 (181–692)	2709 (900–3632)	278 (107–379)	1509 (529–1985)

^aCity area = 800 km²; tree cover = 16.6%.

^bCity area = 350 km²; tree cover = 21.6%.

^cCity area = 209 km²; tree cover = 18.9%.

^dCity area = 125 km²; tree cover = 21.2%.

^eEstimates are for particulate matter less than 10 microns (PM10), ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂) and carbon monoxide (CO). Numbers in parentheses represent expected range of values (no range determined for 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: NO₂ = \$6,750 t⁻¹, PM10 = \$4,500 t⁻¹, SO₂ = \$1,650 t⁻¹, and CO = \$950 t⁻¹ (Murray *et al.*, 1994). Externality values for O₃ were set to equal the value for NO₂.

^fAssumes 50% resuspension of particles.

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, CO₂, nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter. Thus, when 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, 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.

When considering the net effect of tree growth on atmospheric CO₂, managers also must consider that nearly all of the carbon sequestered by trees eventually will be converted back to CO₂ 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 vegetation structure is sustained through maintenance techniques that use fossil fuels, benefits will be eroded by the maintenance emission of CO₂. Continual tree maintenance that uses fossil fuels will ultimately lead to vegetation systems that are net carbon emitters, unless building energy conservation derived from trees and its consequent effect on power plant emissions can offset the emissions from maintenance activities.

2.1.4. Energy Conservation

Trees can reduce building heating and cooling energy needs as well as consequent emissions of air pollutants and CO₂ 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 also can increase heating needs. Energy conservation from trees varies by regional climate, the size and amount of tree foliage, and the location of trees around buildings. Tree arrangements that save energy provide shade primarily on east and west walls and roofs and wind protection from the direction of prevailing winter winds. Energy use in a house with trees can be 20 to 25% lower per year than that for the same house in an open area (Heisler, 1986). 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, WI, 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% greater than no trees and 13% greater than improperly placed trees.

2.2. 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, storm water

treatment costs, and other problems related to water quality. Estimates of runoff for an intensive storm in Dayton, OH, 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 for existing land cover and land use conditions (Neville, 1996). Further, tree cover over pervious surfaces reduced total runoff by as much as 40%; 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 also can reduce costs of treating storm water by decreasing the volume of water handled during periods of peak runoff (Sanders, 1986).

There also may be hydrologic costs associated with urban vegetation, particularly in arid environments where water is increasingly scarce. 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 great as energy savings from shade for tree species that use large amounts of water, for example, mulberry (McPherson and Dougherty, 1989). However, in Tucson, AZ, 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).

2.3. 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 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 (less than 3 m wide), reductions of 3 to 5 decibels can be achieved with dense belts of vegetation, that is, 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 also can 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 also is 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 controlling noise is determined by the sound itself, the planting configuration used, the proximity of the sound source, receiver, and vegetation, and climatic conditions.

2.4. 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 (see Chapter 23, this volume). 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 were 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 was 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 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, CA, increased from about 1.9 (Shannon-Weiner diversity index value) and 10 species in 1850 to an index value of 5.1 and more than 350 species in 1988 (Nowak, 1993). 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 the 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). Because of increased environmental awareness and concerns about quality of life, ecological benefits of the urban forest are likely to increase in significance over time (Dwyer *et al.*, 1992).

3. Social–Economic Benefits and Costs of Urban Vegetation

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

3.1. 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).

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). Experiences in urban parks have been shown to change moods and reduce stress (Hull, 1992a; Kaplan and Kaplan, 1989). Reduced stress and improved physical health for urban residents have been associated with the presence of urban trees and forests. Studies have shown that landscapes with trees and other vegetation produce more relaxed physiological states in humans than landscapes that lack these natural features. Hospital patients with window views of trees have been shown to recover significantly faster and with fewer complications than comparable 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, for example, cataracts, skin cancer (Heisler *et al.*, 1995). Actual involvement in tree planting and related efforts also have been shown to have important benefits for people. Researchers are just beginning to explore these important benefits (Westphal, 1993).

Along with benefits, 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, and a fear of trees, forests, and associated environments.

3.2. Benefits to Communities

Urban forests can make broad 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, empowerment of inner-city residents to improve neighborhood conditions, and promotion of environmental responsibility and ethics can be attributed to involvement in urban forestry efforts (Feldman and Westphal, 1999). 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). Several studies have shown that participation in tree-planting programs influences individuals' perceptions of their community (Sommer *et al.*, 1994a,b, 1995). Conversely, a loss of trees within a community can have a significant psychological effect on residents (Hull, 1992b).

Community tree-planting programs also can help alleviate some of the hardships of

inner-city living, especially for low-income groups (Dwyer *et al.*, 1992). According to Sullivan and Kuo (1996), urban forests can help build stronger communities and may even contribute to lower levels of domestic violence. Regardless of the 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 more critical urban problems.

3.3. 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 Atlanta indicated that landscaping with trees was associated with an increase in sales prices of 3.4 to 4.5% (Anderson and Cordell, 1988). Builders have estimated that homes on wooded lots sell on average for 7% more than equivalent houses on unwooded lots (Selia and Anderson, 1982, 1984). 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 per year on a tax bill of \$500 and is equivalent to \$1.5 billion per 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.

Parks and greenways have been associated with increases in nearby residential property values (Corrill *et al.*, 1978; More *et al.*, 1988). Some of these increased values have been substantial, and it appears that parks with "open space character" add the most to nearby property values. Although this remains to be investigated, parks also may have a negative impact on local property values if they are perceived as unmaintained or a place where undesirable—criminal activities are concentrated. Shopping centers often landscape their surroundings to attract shoppers, thereby increasing the value of the business and shopping center (Dwyer *et al.*, 1992). However, improper landscaping of business areas can have a negative impact by blocking business signs and/or reducing the attractiveness of the area.

3.4. Tree Value Formulas

Various approaches and formulas are used to estimate the value of individual trees (see Chapter 19, this volume). One of the most widely used is the Council of Tree and Landscape Appraisers' (1992) *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 of 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 study that suggested that the formula produced values that were similar to a tree's contribution to residential property values (Morales *et al.*, 1983).

3.5. 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 in which to live, work, and spend leisure time. A study of urbanites who use parks and forest preserves indicated that they are 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 additional \$1.60 per 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 per year (Dwyer, 1991).

Urban trees and forests often figure prominently in urban environmental education programs. The high visibility, variability, and complexity of urban forest ecosystems makes for 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.

4. Benefit-Cost Analysis

The analysis of options available to urban forest resource managers is complicated by 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 their outcomes. 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 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, that is, 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 those very same 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. 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 cost-benefit analyses, one must be aware of these various interconnections and the limitations of the data used in the analyses.

5. 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, 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 sites). 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, and air quality. Urban landscape designs and management plans must understand and consider these numerous interactions and the myriad of potential benefits and costs to implement proper 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.

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