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Accounting for benefits and costs of urban greenspace

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ABSTRACT

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Urban greenspace provides many environmental and social services that contribute to the quality of life in cities. Economic approaches used to estimate value of greenspace services include travel cost, willingness to pay, hedonic pricing, and tree valuation. These methods have limited utility for policy-makers, planners, and managers because the underlying values they estimate only indirectly reflect the flow of multiple benefits and costs. A greenspace accounting approach to partially address this deficiency is described using benefit–cost analysis for a proposed tree-planting project in Tucson, AZ. The approach directly connects vegetation structure with the spatial–temporal flow of functional benefits and costs. Prices are assigned to each cost (i.e. planting, pruning, removal, irrigation) and benefit (i.e. cooling energy savings, interception of particulates, stormwater runoff reduction) through direct estimation and implied valuation of benefits as environmental externalities. The approach can be used to evaluate net economic benefits associated with capital investments in urban forests vs. other investments in the urban infrastructure or traditional environmental control technologies.

INTRODUCTION

The contribution of vegetation to improving the climate, air, hydrology and quality of life in cities is well documented (Bernatzky, 1982; Rowntree, 1986). However, efforts to preserve natural areas, acquire new greenspace, initiate plantings, and manage existing greenspace resources are frequently hampered by our inability to fully appraise the environmental services greenspace (i.e. the urban forest) provides. Recent budget cuts to municipal forestry programs in Washington DC, New York City and Los Angeles suggest the need for more persuasive arguments to justify adequate funding for greenspace management. One approach is to directly link vegetation structure with the multiple environmental functions it provides, and to express these benefits in monetary terms. If a capital investment in urban forestry provides an attractive rate of return, decision-makers might provide the funding required to maintain a healthy forest and maximize environmental benefits. A complete accounting of benefits also could help change our view of urban forests from amenity to living technology, thereby redefining greenspace as a key component of the urban infrastructure that helps maintain a healthy environment for city dwellers.

This paper reviews traditional accounting frameworks such as cost-effectiveness and benefit–cost analysis, and economic approaches used to estimate benefits produced by urban greenspace. A greenspace accounting system that addresses the deficiencies of these approaches is described and illustrated using planned tree planting in Tucson, AZ. The multi-year flow of tree costs and environmental services from 500 000 trees to be planted in yards, parks and streets is evaluated using ben-

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efit–cost analysis. This example answers policy-related questions regarding impact of urban reforestation on scarce water resources, air quality, and future tree care costs.

COST-EFFECTIVENESS AND BENEFIT-COST ANALYSIS

Well-managed urban forests can reduce demands for natural resources by producing food and conserving energy, water and carbon dioxide (Heisler, 1986; McPherson, 1990; Meier, 1991; Rowntree and Nowak, 1991). Also, they can mitigate the impact of urban development by moderating urban climate (Oke, 1989), improving air quality (Smith, 1981), controlling rainfall runoff and flooding (Sanders, 1986), lowering noise levels (Cook, 1978), harboring wildlife (Johnson, 1988), reducing human stress levels (Ulrich, 1984), and enhancing the attractiveness of cities (Schroeder, 1989). However, these benefits can be partially offset by problems such as pollen production, hydrocarbon emissions, green waste disposal, water consumption, and displacement of native species by aggressive exotics. To balance these benefits and costs, urban foresters need an accounting system in which the quantified connections among plants, humans and flows of materials and energy can be expressed in monetary terms without ambiguity or double counting, and at any scale the manager chooses (Hannon, 1991). Cost-effectiveness and benefit–cost analysis provide accepted frameworks for evaluating the short- and long-term feasibility of capital investments in greenspace resources.

Benefit–cost analysis is used by US federal agencies to define and defend proposed regulatory changes, and by others to protect threatened environmental resources (Tietenberg, 1984). To compare investment alternatives, tangible benefits and costs are quantified and other intangible effects are described. Benefits are usually harder to estimate than costs, and are estimated directly or as avoided costs. Investment alternatives are evaluated using the benefit–cost ratio (ratio of the present value of benefits to costs), maximum net present value (maximum present value of net benefits; NPV), and less frequently, internal rate of return (rate of return needed to offset an initial investment; IRR).

Generally, cost-effectiveness analysis differs from benefit–cost analysis in two ways: (1) the objective, such as an air quality standard, already exists; (2) benefits are not calculated. In a least-cost study, the costs of realizing a given objective using alternative strategies are compared. In a constant-cost study, the outputs of alternative strategies are compared assuming identical cost commitments. When either cost-effectiveness or benefit–cost analysis are used, costs or benefits will occur over a number of years into the future, and a time horizon, reference date and rate of discount must be selected.

Although I am unaware of benefit–cost analysis used for greenspace investment analysis, cost-effectiveness analysis has been applied. For example, DeSanto and others (1976) used the least-cost approach to compare trees and mechanical air pollution control devices to maintain air quality standards for particulates and sulfur dioxide in St. Louis, MO. They determined that open space plantings were over three times as cost-effective for controlling sulfur dioxide as scrubbers located in power plants, but less cost-effective than electrostatic precipitators for control of particulates.

The usefulness of cost-effectiveness and benefit–cost analysis depends on accurate and unbiased estimates of benefits and costs. Bias can be introduced by selecting or omitting certain benefits or costs, which intentionally slant the analysis. Our limited understanding of urban ecosystem processes adds uncertainty to most estimates of greenspace benefits and costs. Market prices tend to undervalue greenspace services relative to traditional controls because we do not pay nature for its services. At the same time, market costs can miss a substantial portion of the actual embodied energy costs associated with production, distribution and operation of high-tech environmental controls. Perhaps most importantly, many benefits and costs are difficult to quantify (e.g. benefits related to aesthetics, wildlife, psychological–spiritual restoration, and costs related to physical damage to property and person, pollen production, litter clean-up and debris disposal, etc.). The following section of this paper deals with approaches used to quantify and express monetarily benefits and costs of urban greenspace.

ESTIMATING GREENSPACE BENEFITS AND COSTS

In standard economic terms, the economic value of the urban forest is defined as the amount consumers are willing to pay for its services (a measure of utility or satisfaction received) above their costs for its use. Urban forest benefits have been measured using the travel cost method, the contingent valuation method, and the hedonic pricing (or land value) method (Sinden and Worrell, 1979; Allen et al., 1986). The travel cost method assumes that the economic value of benefits is equivalent to the cost of travel. Although used by Dwyer et al. (1983) to estimate the value of urban parks, travel costs do not work well when variation in travel and costs are small, as for a neighborhood park. Contingent valuation estimates net benefits as the difference between what people would be willing to pay and what they are currently paying (Dwyer et al., 1989). Surveys on willingness to pay are used to price resources for which there are no technological alternatives or prescribed standards, such as the aesthetic, wildlife and spiritual benefits of greenspace (Coughlin and Strong, 1983). One of several problems with this technique arises because reported attitudes do not always correspond with actual behavior (More et al., 1988). The hedonic pricing method infers greenspace benefits from the costs and prices of related market transactions. The premise is that land prices should reflect the extra amount people are willing to pay for wooded property, land that is near parks, or land that otherwise benefits from greenspace attributes. Hedonic pricing has been widely applied (Payne and Strom, 1975; Morales, 1980; Morales et al., 1983; Anderson and Cordell, 1985), and has advantages compared with travel cost and contingent valuation because it captures some of the external benefits that occur off-site (e.g. reductions in air pollution, temperature, noise, and greater diversity of wildlife) and utilizes data from actual market transactions. However, property price differences may not adequately measure vegetation benefits because vegetation effects are difficult to distinguish from the many other variables influencing real estate prices. None of these greenspace accounting alternatives are entirely desirable because of their inability to directly incorporate the ecological and economic connections between plants, people and the urban environment.

Tree pricing

A second approach to pricing urban forests uses the sum of individual plant prices. The price of a specific plant becomes an issue when a loss in property value from an injured or destroyed plant can be recovered. But, until the mid-1960s, the US Internal Revenue Service (IRS) accepted only reduced real estate prices when property owners had tree casualties (Neely, 1988). The IRS now accepts that a tree itself is worth something, and appraisals based on methods prescribed by the Council of Tree and Landscape Appraisers (CTLA) and the Tree Council of the United Kingdom (Helliwell, 1976) are used regularly by landscape professionals. The CTLA method involves establishing a base price using either replacement cost or a size-based formula (Neely, 1988). This base price is then adjusted by various percentage factors for species, condition and location. The value of environmental services provided by a tree are indirectly expressed through these adjustment factors. For instance, a tree whose shade reduces a building's air-conditioning energy usage should have a higher location code and thus a higher price than an identical tree that does not shade the building. However, guidelines for landscape plant appraisers (Neely, 1988) provide little information regarding influences of tree location, species and condition on the generation of specific environmental benefits and costs.

Although the CTLA valuation method was originally developed to compensate for casualty losses, municipal foresters have used the approach with tree inventory data to estimate the total value of trees that they manage. This value represents the capital asset value of the stock of standing biomass at the time of the inventory. However, to evaluate the economic and ecologic impacts of trees over time, management costs and environmental benefits must be accounted for over time. Miller and Sylvester (1981) modeled time-dependent relations between pruning costs and street tree value. Using the CTLA tree valuation approach, they calculated that longer pruning intervals reduced tree values (Fig. 1). Although their model accounted for temporal changes in street tree pruning costs and resulting tree values, it did not explicitly account for the flow of multiple environmental benefits (e.g. energy savings, air quality benefits, etc.). Tree price is based on indirect and ambiguous connections between trees and their services.

Appraising benefits as environmental externalities

Benefits from trees are environmental externalities because these benefits are not reflected in consumer prices – we do not pay money to trees for cooling homes, but only to people for their fossil-fuel powered air-conditioners (Odum, 1971; Hall and Bradley, 1990). Two basic approaches are used to estimate values for external environmental benefits from trees:

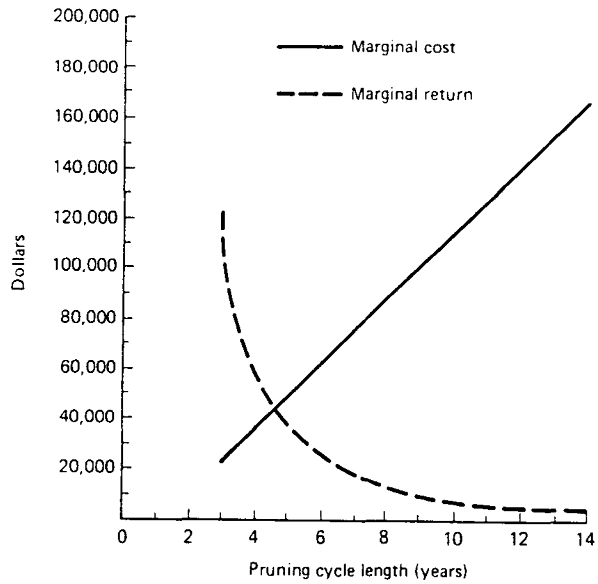

Fig. 1. Comparison of loss in street tree value (marginal cost due to lower condition codes of trees) vs. savings in pruning costs (marginal return due to less frequent pruning) for various pruning cycles in Milwaukee, WI from model developed by Miller and Sylvester (1981).

direct estimation and implied valuation. The first approach estimates the benefits of externalities from first principles. Environmental effects are estimated, a price is assigned to each effect, and summed to calculate a benefit incurred due to the externality. Direct estimation has been used to quantify the effects of trees on residential energy use for heating and cooling (McPherson and Dougherty, 1989; Heisler, 1991). For example, computer simulation was used to quantify air-conditioning energy savings due to shading, wind speed reductions, and cooler air temperatures resulting from trees located near typical residential buildings (Huang et al., 1987). However, direct estimation is seldom used to measure other urban forest externalities, such as air cleansing from trees, because of uncertainty regarding dose–response relationships between the pollutants and humans, effects of degraded health on health care costs, and the localized effects of climate, air pollution concentrations, and pollution absorption rates by plants.

The second approach, implied valuation, relies on the costs of required or anticipated environmental control measures or regulations to estimate a societal benefit of reducing externalities such as air pollution, stormwater runoff, and highway noise (Chernick and Caverhill, 1991). Control costs are assumed to estimate the price society is willing to pay to reduce an externality at the margin. Hence, if society is willing to pay US\$5 kg^{-1} for current or planned air pollution control, then a tree that intercepts or absorbs a kilogram of pollution should also be worth US\$5.

Implied valuation was used to estimate the cost of constructing detention basins to control excess stormwater runoff resulting from the conversion of rural vegetation to urban land use in Kennett County, PA (Coughlin and Strong, 1983). Ordinances in many communities require that post-development runoff volumes cannot exceed pre-development volumes. Costs incurred by developers to detain stormwater runoff and comply with this regulation provide information on the social benefit of stormwater control. Pending regulations for stormwater runoff quality (Non-Point Source Discharge Standards) could increase the implied benefit of the urban forest because reduced runoff volumes are likely to lower overall stormwater treatment costs.

Implied valuation was also adopted to examine the extent to which environmental services from urban vegetation in Capital Park, Sacramento, CA (or ultimately, from solar energy manifest in plants) can substitute for equivalent functions provided by fossil-fuel based technologies (Merriam and Gilliland, 1981). Ranges of annual dollar and fossil-fuel energy savings were roughly estimated for four types of Capital Park environmental services: avoidance of space heating/cooling, avoidance of sewage treatment capacity due to reduced runoff, avoidance of stationary source air pollution control systems, and avoidance of fertilization and soil catchment basins. Annual environmental benefits were calculated to range from US\$10 000 to US\$137 300 for the park (US\$30–389 per tree), and the capital asset value of the 350 trees was estimated to range from US\$400 000 to US\$2 million (US\$1140–5700 per tree). This approach, which innovatively coupled economics with the energetics of greenspace, seems to have been largely undiscovered and unutilized by landscape researchers and planners.

In the Capital Park example, the direct application of implied benefits assumed a substantial local demand for the four environmental services provided by vegetation. A more solid basis for implied valuation exists when environmental standards and regulations (e.g. Clean Air Bill and National Ambient Air Quality Standards) provide information about what society is willing to pay to improve environmental quality. When standards or regulations exist, the appropriate estimate of the social cost of control is the highest-cost control for residual pollutants, since greenspace allows the most expensive measure to be avoided. However, regulations and associated control costs do not always match reasonably defined benefits because they are products of a complex political process and subject to non-uniform enactment (Chernick and Caverhill, 1991).

Summary

To obtain and sustain the maximum net benefits greenspace can produce, managers need accounting tools that connect vegetation structure with the spatial–temporal flows of functional benefits and costs. Ideally, these flows should be quantifiable at scales ranging from the individual plant to the urbanized region. To the greatest extent possible, dollars should be unambiguously assigned to each benefit and cost through direct estimation and implied valuation. Although cost-effectiveness and benefit–cost analysis are accepted frameworks for economic evaluation, they have not been widely used to evaluate greenspace investments and its environmental services. Most greenspace and tree valuation approaches are of little use to public policy-makers or managers because they derive a single quantity that only indirectly reflects the historic flow of multiple benefits and costs. A greenspace accounting approach that addresses this deficiency is described and illustrated in the following section.

BENEFIT–COST ANALYSIS OF A LARGE-SCALE TREE-PLANTING PROJECT

Trees for Tucson/Global ReLeaf (TFT/GR) is a volunteer-based program founded in 1989 with the goal of planting 500 000 desert-adapted trees throughout the city by 1996. The program promotes planting as a way to conserve energy and improve environmental quality. Tucson Water, a municipal utility with a strong water conservation program, expressed concern about the impact of these trees on water supplies. An ecologic–economic accounting approach was developed to examine water costs, as well as a range of other costs and benefits over a 40-year planning horizon.

Accounting approach

The accounting approach used for the large-scale tree-planting project is shown in Fig. 2 and completely described in another paper (McPherson, 1991). The three major components of the model are tree number, tree size and benefit–cost analysis. The tree number component calculates the number of trees at each location based on expected planting and mortality rates. The tree size component calculates total leaf area using data on tree numbers, growth and irrigation rates. In the Tucson example, a leaf-area index (LAI) of three is assumed based on preliminary research data from a mature mesquite tree in a park. Leaf area (LA) is calculated using a ground projection (GP) term, where GP is the area under the tree crown dripline

$$LA = LAI \times GP \tag{1}$$

The third component projects benefits and costs per unit LA and per stem. A variety of local and non-local benefits and costs are calculated for plantings in park, yard and residential street locations. Trees in park-type locations were assumed to receive professional care and have the highest survival and growth rates. Street trees were assumed to have the slowest growth rates and highest mortality rates because the city prohibits irrigation systems along roadsides. Yard trees were assumed to have intermediate growth and survival rates.

Although a wide variety of low water use tree species will be planted, the simulation was simplified by assuming planting of 500 000 mesquite trees from 5 gal containers. The native velvet mesquite (*Prosopis velutina*) was used because of its rapid growth, drought tolerance, moderately dense shade, and local popularity. The assumed lifespan of the mesquite was reduced from over 100 years in the desert to 60 years in the city. Three types of mortality were projected: establishment-related losses for young trees, age-independent losses due to weather, site modification, etc., and senescence-related losses associated with aging. About 43% (215 000) of the trees planted were projected to die during the 40-year period.

A unique aspect of this accounting system is the direct connection of selected benefits and costs to LA. Because many functional benefits of trees are related to leaf–atmosphere processes (e.g. photosynthesis, transpiration, interception), benefits increase as leaf surface area increases (Gacka-Grzesikiewicz, 1980). Similarly, pruning and removal costs usually increase with tree size. To account for this time-dependent relationship, benefits and costs are assumed to be linearly related to leaf area, although this may not always be true (e.g. removal costs may increase non-linearly when more expensive equipment is required to remove larger trees). First, the maximum poten-

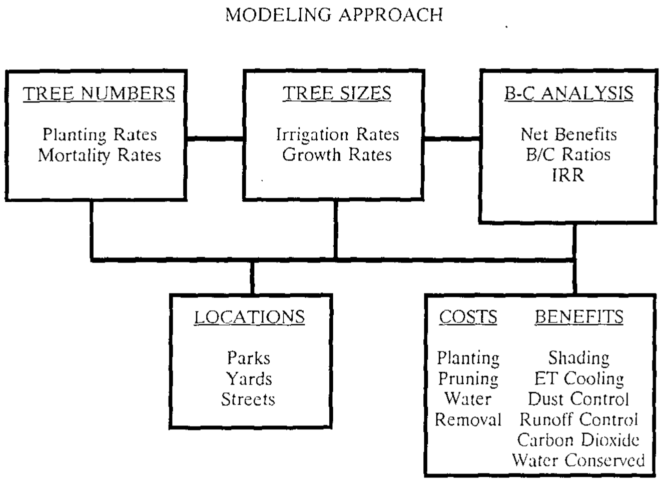

Fig. 2. Accounting approach used for the large-scale tree-planting project (from McPherson, 1991).

tial benefit or cost is determined for a mature mesquite tree (e.g. US\$300 pruning cost). This quantity is divided by the mature tree's total LA (e.g. 137 m^2) to derive base costs and benefits on a unit leaf surface area basis (e.g. US\$300 per 137 m^2=US\$2.19 per m^2). The aggregate level of a single benefit or cost is calculated when the base cost and benefit is multiplied by the total LA for all trees at one location.

Projected management costs

Temporal and locational differences in projected average annual tree management costs are shown in Fig. 3. Costs exceed benefits during the first 5 years, largely resulting from one-time planting costs. During the next 25 years, benefits are three or more times greater than costs. During the last decade, costs begin to catch up with benefits as more large trees die and are removed. Park trees were the most expensive to plant and maintain initially, but on average least expensive over the 40 years, followed by street and yard trees. This finding illustrates that funds spent initially to promote tree establishment, rapid growth and strong crown structure can reduce long-term tree care costs by prolonging the serviceable life of trees.

The average annual cost per tree for the 40-year period is US\$9.61, with removal costs averaging US\$5.09, and water (US\$2.14), pruning (US\$2.02) and planting costs (US\$0.36) being substantially less.

Projected benefits

Air-conditioning energy savings are projected to be the tree-planting program's greatest benefit. Average annual cooling savings are about US\$21 per tree (288 kW). Although substantial energy savings from direct building shade are predicted, larger community benefits are projected for the aggregate effect of trees on urban climate (i.e. trees can lower temperatures through evapotranspiration). Planting 500 000 trees will increase Tucson's canopy cover by about 10% (from 20 to 30%) in 10–15 years, and this increase is projected to reduce city temperatures by 1.7°C (3°F). Although this reduction appears small, computer simulations for typical residential buildings in Tucson indicate that it can lower annual cooling costs by up to 25% (McPherson, 1991).

The reduced demand for power to run air-conditioners can lower carbon dioxide emissions from burning coal and water lost to evaporation in electric power plants. On average,

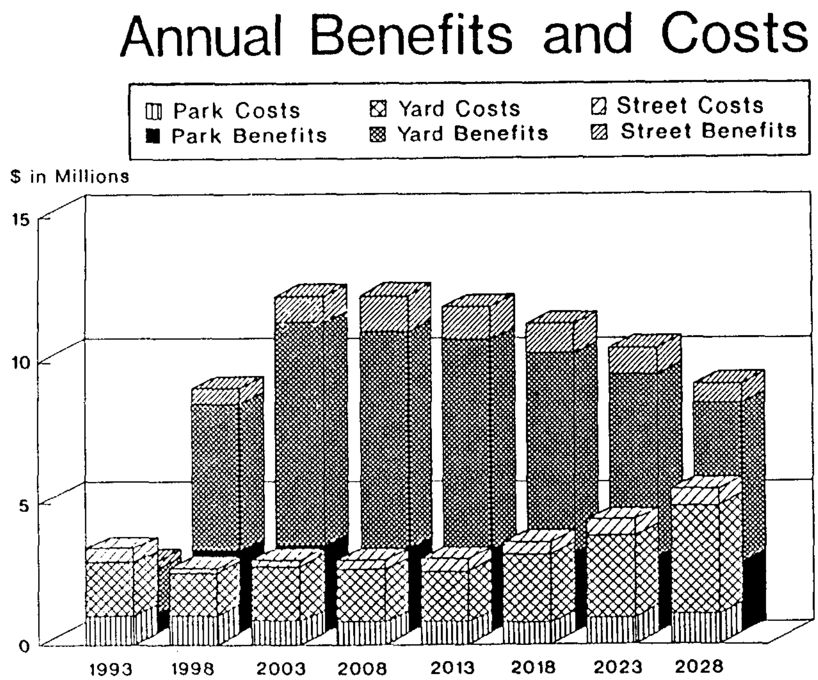

Fig. 3. Projected average annual benefits and costs for the large-scale tree-planting project (from McPherson, 1991).

trees are projected to conserve 16% (647 l per tree or 171 gal) of their annual water requirement and reduce annual carbon emissions by 181 kg (400 lb) per tree. Since each US citizen is responsible for adding 2087 kg (2.3 tons) of carbon to the atmosphere annually (Flavin, 1988), one individual in Tucson could offset his/her annual carbon dioxide emissions by planting and caring for approximately 12 mesquite trees.

On average, each tree is projected to intercept nearly 16 kg (35 lb) of dust and 276 l (73 gal) of stormwater runoff annually (Aston, 1979; Madders and Lawrence, 1985). These environmental benefits are implied using control costs for traditional programs. Because concentrations of particulate matter have exceeded federal health standards, Tucson has a road-paving program that reduces fugitive dust. Similarly, flood control regulations require developers to construct retention–detention basins so that runoff does not exceed predevelopment conditions. Using the paving and 40-year maintenance costs for the road-paving program, the average annual cost of dust control is about US\$0.264 kg^{-1} of particulates (US\$0.12 lb^{-1}). The average annual cost to control stormwater runoff through constructing and maintaining retention–detention basins in Tucson is US\$0.66 m^{-3} of water (US\$0.02 ft^{-3}). The average annual implied benefits of dust and rainfall interception per mature mesquite tree are calculated to be US\$4.16 and US\$0.18, respectively. Average annual per tree benefits for cooling savings from shade (US\$4.41) and cooler temperatures (US\$16.34), dust interception, and runoff reduction totaled US\$25.09.

Projected net benefits

Average annual benefits from the selected environmental services are projected to exceed costs by US\$15.48 per tree (2.6 benefit–cost ratio). However, many of the costs are incurred early on, while the benefits grow with the trees. Discounting the benefits and costs to present value will reduce the benefit–cost ratio. But what is an appropriate discount rate? Public, private and corporate entities will all be involved in the program, making selection of a single discount rate problematic. Also, if tree planting is viewed as primarily a redistribution of environmental benefits to future generations, discounting is inappropriate (Norgaard and Howarth, 1991). In this analysis, the time value of money was considered by calculating internal rate of returns (IRR). An IRR of 7.1% is projected for the tree-planting project, well above the 3–5% return rate for most risk-free investments. Investment in yard trees provides the highest rate of return (14%) and street trees the lowest (2%). The higher IRR for yard trees compared with street trees is due to lower planting costs and mortality rates, faster growth rates, and more effective building shade from yard trees.

Results from this benefit–cost analysis helped convince Tucson Water that the tree-planting program would not adversely affect its conservation program. The average annual water use per tree was estimated to be about the same amount of water as used by a single person inside the home for 10 days (4054 l or 1071 gal). The findings also contributed to development of a partnership between TFT/GR and the Tucson Urban League to plant yard trees at low income housing for cooling energy savings.

CONCLUSIONS

These findings illustrate the utility of greenspace accounting for urban forests. This approach can be used to: (1) estimate net benefits of investments in urban forests vs. other alternatives; (2) compare net benefits of plantings in different locations and with different species; (3) address management issues such as rotation lengths, pruning intervals, initial planting sizes, etc.; (4) assist with budget planning. Clearly, as city dwellers become increasingly concerned with quality-of-life issues, expressing the environmental benefits of urban forests monetarily puts trees on a more equal standing with other capital investment options. This approach also increases the status of trees relative to other investments in urban infrastructure and high-tech environmental controls because trees become more cost-effective as they grow larger. All infrastructure improvements depreciate as they age, and many traditional controls become progressively less efficient as they age, especially compared with long-lived trees. For instance, using this greenspace accounting approach, shade from trees at bus stops was found to be 20% more cost-effective than shade from traditional metal bus shelters in Tucson (McPherson and Biedenbender, 1991).

Despite uncertainty due to inadequate scientific knowledge about urban ecosystems and the inherent limitations of benefit–cost analysis, the approach described here offers decision-makers a timely and relatively sophisticated tool for evaluating some of the economic and environmental implications of proposed urban forestry programs and projects. To improve this accounting tool, we should begin to monitor the effects of trees on urban environments, as well as the effects of urban environments on trees. This basic information is critical to validating these models and subsequent development of better accounting procedures.

Although this greenspace accounting approach succeeds at connecting trees and some of their ecological processes with several of their resulting environmental services, it is only a small beginning. These flows are accounted for independently, when in fact they are interconnected – trees influence climate, climate influences air quality, air quality influences trees. The environmental role of natural systems other than trees needs to be incorporated into the model. The functions and services provided by soils, grasslands, wetlands, watersheds, riparian corridors, greenways and other types of greenspace are significant, and should be accounted for as well. The future challenge lies in expanding our understanding of the urban ecosystem, its processes, and how to value its many tangible and intangible benefits.

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