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URBAN FORESTRY & URBAN GREENING

A comparison of municipal forest benefits and costs in Modesto and Santa Monica, California, USA*

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Abstract: This paper presents a comparison of the structure, function, and value of street and park tree populations in two California cities. Trees provided net annual benefits valued at $ 2.2 million in Modesto and $ 805,732 in Santa Monica. Benefit-cost ratios were 1.85:1 and 1.52:1 in Modesto and Santa Monica, respectively. Residents received $ 1.85 and $ 1.52 in annual benefits for every $ 1 invested in management. Aesthetic and other benefits accounted for 50% to 80% of total annual benefits, while expenditures for pruning accounted for about 50% of total annual costs. Although these results were similar, benefits and costs were distributed quite differently in each city. Variations in tree sizes and growth rates, foliation characteristics, prices, residential property values, and climate were chiefly responsible for different benefits and costs calculated on a per tree basis.

Key words: Urban forest valuation, economic analysis, natural resource economics

Introduction

Cities need to grow to maintain vigorous local economies, but their ability to grow is influenced by environmental constraints and competition with other regions in terms of quality of life. Research quantifying the benefits of healthy municipal urban forests is showing that trees can mitigate impacts of development on air quality, climate, energy for heating and cooling buildings, and stormwater runoff. Healthy street trees increase real estate values, provide neighborhoods with a sense of place, and foster psychological well-being (Dwyer et al. 1992). Street and park trees are associated with other intangible benefits such as increased community attractiveness and recreational opportunities that make cities more enjoyable places to work and play.

The motivation for this study is to provide cities with a comprehensive accounting of municipal forest benefits and associated management costs. We build upon previous benefit-cost analyses in Chicago, IL and Modesto, CA (McPherson et al. 1997, 1999a) that were applied to:

- assess the adequacy of management programs and justify their funding,
- provide baseline information for the evaluation of program cost-efficiency,
- highlight the relevance of the urban forest to local quality of life,
- develop alternative funding sources through electric utilities, air quality districts, federal or state agencies, legislative initiatives, or local assessment fees.

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This paper compares the structure, function, and value of municipal urban forests in Modesto and Santa Monica, CA.

Operational Definitions of Structure, Function, and Value

The 'structure' of an urban forest is defined as the species composition and spatial array of vegetation in relation to other objects such as buildings (Rowntree 1984). Urban forest structure reflects historic interactions between a host of cultural and ecological factors (Sanders 1984). Ecological measures of the structure of street and park tree populations include species and age diversity, stocking level, health, and importance value (Barbour et al. 1980; McPherson & Rowntree 1989).

The term urban forest 'function' refers in general to the services that urban forests provide such as pollution removal, temperature modification, and property value increase (Rowntree 1986). Tree location and type (i.e., structure) influence function. For instance, a tree located south of a building can increase heating costs, but the same tree west of the building will reduce cooling costs and provide substantial net energy benefits. We measure function in terms of resource units (RU) – kilograms of pollutant uptake, kilowatt-hours of electricity savings for cooling, etc.

'Value' refers to the benefits and costs society derives from the urban forest. Tyrvainen (2001) reviewed different approaches to determine the value of urban forest benefits. Hedonic pricing relies on differences in housing prices to reflect the value of nearby greenspace. Contingent valuation is based on surveys that ask what people are willing to pay for greenspace. Average willingness to pay is multiplied by the total number of consumers to estimate greenspace value. The travel-cost method uses the costs of travel as a proxy for the price that people are willing to pay for recreational benefits of greenspace. Each of these methods have their advantages and limitations (Tyravinen 2001). However, these approaches have not been applied to street and park tree populations because they do not isolate the benefits of individual trees within forest stands.

Several methods have been developed to value benefits from individual trees. The most common approach calculates asset value, the current worth of previous investments, using the cost of replacing trees. Prices for individual trees are summed to calculate the total asset value for all street and park trees. This method is also called the depreciated cost approach because the tree's replacement cost is depreciated to account for the difference in benefits that would result from a new tree compared to the existing tree. The cost of replacing a tree may be more or less than what people are willing to pay for the existing tree. Because this approach is cost-based it does designate prices for individual benefits produced by the existing tree population.

External benefit valuation quantifies specific impacts of trees on the urban environment, such as climate modification and air pollutant removal (McPherson 1992). Benefits are priced through alternative costs of environmental control that reflect people's willingness to pay for air pollution control or stormwater runoff reduction. Energy savings for heating and cooling are calculated directly using marginal prices for electricity and natural gas. This approach excludes non-environmental values such as aesthetics, recreation, environmental education, stress reduction, and spiritual renewal. Also, it requires large amounts of data for numerical modeling, and these models simplify the complex interactions between trees and the surrounding urban environment.

Performance Variables for Structure, Function, and Value

Performance variables provide a standard metric to measure and compare urban forest structure, function, and value across cities. These indicators should address factors that are most important to efficient management of street and park trees. Also, they should be based on information that is widely available through standard tree inventories, surveys of municipal services, modeling algorithms and output, and other sources. To facilitate comparisons across cities in this study, findings are presented on a per tree basis. As knowledge grows with future research, more definitive sets of performance variables will be identified.

Study Sites

The cities of Modesto and Santa Monica were chosen for this study because of their extensive tree inventories and detailed information on tree program expenditures. Their tree programs are not typical of most U.S. cities, but rather examples to emulate. Modesto, California (latitude: 37°38′10″ N, longitude: 121°11′10″ W) is located in the Central Valley and has a population of 182,260 within the 9,065 ha city limits. The City of Santa Monica (latitude: 34°02′00″ N, longitude: 118°29′00″ W), is located along the Pacific Ocean and adjacent to the City of Los Angeles. A population of 92,578 reside in the 2,176 ha city. The average elevation of both cities is about 10 m. For purposes of comparison, the trees and climate in Santa Monica are similar to coastal Mediterranean cities such as Lisbon, Valencia, and Naples, while conditions in Modesto more closely resemble those of inland cities like Madrid and Florence.

Methods

Data collection and computer modeling procedures have been described in previous publications (McPherson et al. 1999a, 1999b). Therefore, this paper summarizes the modeling approach and identifies salient differences between its application in Modesto and Santa Monica.

☐ *Tree inventories and growth curves.* Modesto's tree inventory database contained 75,649 street trees and 184 species. Because park trees were not inventoried the city surveyed trees in 23 parks and estimated the total park tree population to be 15,550. Santa Monica's inventory contained 21,698 street trees, 3,721 park trees, and 215 species.

After stratifying by age/size class, a sample of approximately 30 randomly selected trees from each of the 22 most abundant species were surveyed in each city to 1) establish relations between tree age, size, leaf area and biomass for important species, 2) estimate growth rates, and 3) collect other data on tree health, site conditions, and sidewalk damage. Measurements were taken of diameter at breast height (dbh), tree and bole height, crown radius, tree condition and location, severity of pruning, etc. for 648 trees in Modesto and 606 in Santa Monica.

Crown volume and leaf area were estimated from computer processing of digital images of tree crowns (Peper & McPherson 1998). Curve fitting models were tested for best fit to predict dbh as a function of age for each species. Tree leaf area, crown diameter, and tree height were then modeled as a function of dbh (Peper et al. 2001a, 2001b). Dimensional measurements of park trees indicated that their growth rates were similar to street trees.

To infer from the 22 species sampled to the remaining species, called Other Trees, each species was categorized based on life form and mature size. Twelve tree type categories were created with 3 size classes (large (>15 m), medium (8–15 m), small (<8 m) mature height) for each of 4 life forms: broadleaf deciduous, broadleaf evergreen, conifer, and palm.

☐ *Importance values.* The Importance Value (IV) for each species was calculated as the sum of relative abundance, crown projection area (CPA), and leaf surface area (LA), divided by three. The IV provides a more robust indicator of a species importance than does relative abundance or size alone.

☐ *Annual costs.* Expenditures reported by the Community Forestry Divisions during fiscal years 1997–1998 in Modesto and 1998–1999 in Santa Monica were compiled. Tree related expenses captured by other departments for sidewalk and curb repair, leaf clean-up, and trip and fall claims were also included.

☐ *Annual benefits.* Growth rate information was used to "grow" the tree population for one year. Population numbers were assumed to remain constant. The modeling approach directly connected benefits with tree size variables such as dbh and LA (Fig. 1). Prices were assigned to each benefit through direct estimation and implied valuation of benefits as environmental externalities.

☐ *Energy savings.* Changes in building energy use from tree shade were based on computer simulations that incorporated building, climate, and shading effects (McPherson and Simpson 1999). Building characteristics (e.g., cooling and heating equipment saturations, floor area, number of stories, insulation, window area, etc.) were differentiated by building vintage. In Modesto the analysis was limited to three single family vintages (date of construction: pre–1950, 1950–1980 and post–1980). In Santa Monica, where more residents live in apartments, it was extended to include multifamily residences, commercial/industrial, and institutional buildings. Typical meteorological year (TMY) weather data for Fresno (Modesto) and Los Angeles International Airport (Santa Monica) were used. The distribution of street trees with respect to buildings was based on analysis of aerial photos for both cities. It was assumed that street trees within 18 m of homes provided direct shade on walls and windows. In addition to localized shade effects from street trees, climate effects on energy use, air temperature, and wind speed reductions were estimated as a function of neighborhood canopy cover following McPherson & Simpson (1999). The dollar value of electrical energy and natural gas savings were based on marginal electricity and natural gas prices supplied by local utilities.

☐ *Atmospheric carbon dioxide reductions.* Sequestration, the net rate of CO_2 storage in above- and belowground biomass over the course of one growing season (kg/tree), was calculated with tree growth data and biomass equations for urban trees (Pillsbury et al. 1998). To calculate CO_2 released through decomposition of dead woody biomass we conservatively estimated that dead trees were removed and mulched in the year that death occurred, and that 80% of their stored carbon was released to the atmosphere as CO_2 in the same year. To estimate CO_2 released due to tree maintenance activities, annual consumption of gasoline and diesel fuel by the community forestry divisions was converted into CO_2 equivalent emissions.

Reductions in building energy use result in reduced emissions of CO_2. Emission reductions were calculated as the product of energy savings and CO_2 emission factors for electricity and heating. Heating fuel was natural gas, while the fuel mixes for electrical generation in Modesto and Santa Monica were substantially different. The price of CO_2 reductions was based on the implied value of external costs associated with increased global warming (California Energy Commission 1994).

□ *Air quality benefits.* The hourly pollutant dry deposition per tree was expressed as the product of a deposition velocity $V_d = 1/(R_a + R_b + R_c)$, a pollutant concentration C, a canopy projection area CPA, and a time step. Hourly deposition velocities for ozone (O_3), nitrogen dioxide (NO_2), and particulate matter of <10 micron diameter (PM_{10}) were calculated using estimates for the resistances R_a, R_b, and R_c for each hour throughout a "base year" (Scott et al. 1998). A 9-month in-leaf season was assumed for all trees in Modesto (89% of LA was deciduous) and a 12-month in-leaf season for all trees in Santa Monica (93% of LA evergreen). A 50% re-suspension rate was applied to PM_{10} deposition. Hourly meteorological data for wind speed, solar radiation and precipitation, as well as hourly concentrations for NO_2, O_3, and PM_{10} were obtained from local monitoring stations. 1991 was selected as the base year for both cities because the number of days when pollutant concentrations exceeded federal standards was near average for 1991–2000.

Energy savings result in reduced emissions of criteria air pollutants (volatile organic hydrocarbons [VOC's], NO_2, PM_{10}) from power plants and space heating equipment. These avoided emissions were calculated using utility-specific emission factors for electricity and heating fuels.

Emission of biogenic volatile organic carbon (BVOCs, sometimes called biogenic hydrocarbons) were included in the Santa Monica analysis because of local concerns about their impact on ozone formation (McPherson et al. 1998). The hourly emissions of carbon as isoprene and monoterpene were expressed as products of base emission factors and leaf biomass factors adjusted for sunlight and temperature (isoprene) or temperature (monoterpene). This approach did not account for the benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from anthropogenic and biogenic sources.

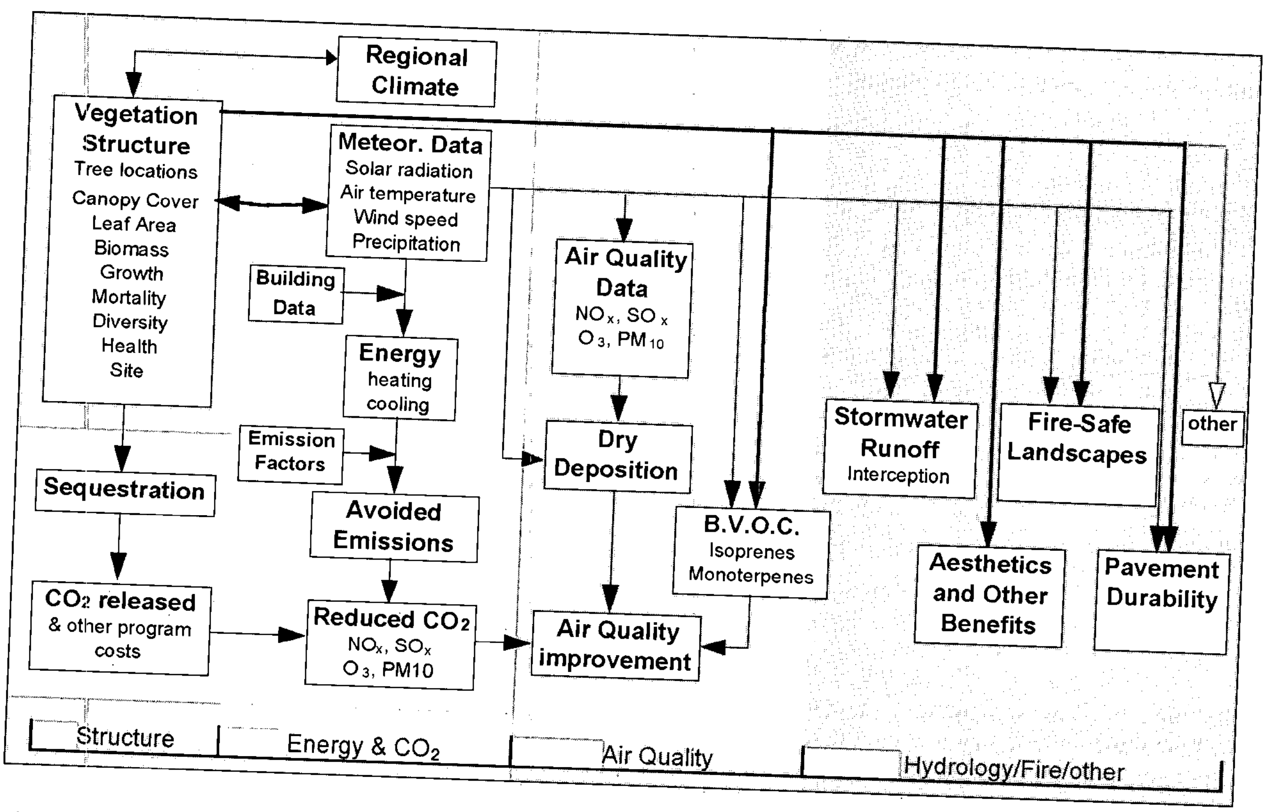

Fig. 1. Conceptual approach to modeling urban forest benefits. Information on vegetation structure is primary input for modeling functions such as energy savings, atmospheric CO_2 reductions, air quality improvement, stormwater runoff reduction, aesthetic and other benefits.

Air quality benefits were priced based on emission reduction transaction costs specific to each city's air quality management district (California EPA 1998, Cantor Fitzgerald Environmental Brokerage Services, 1999). Because O_3 credits are not traded, NO_2 costs were used for O_3. Ozone control measures are primarily aimed at NO_x reduction.

□ *Stormwater runoff reductions.* A numerical interception model accounted for the amount of annual rainfall intercepted by trees, as well as throughfall and stem flow (Xiao et al. 1998). The volume of water stored in tree crowns (m^3/tree) was calculated from crown projection areas (area under tree dripline), leaf areas, and water depths on canopy surfaces. Hourly meteorological and rainfall data for 1995 (Modesto) and 1996 (Santa Monica) were used as input. Total precipitation during 1995 in Modesto was 315 mm, close to the average annual amount of 310 mm. In Santa Monica, precipitation during 1996 was 570 mm, somewhat greater than the average annual amount of 451 mm (U.S. Dept. of Commerce 1968).

Pricing stormwater reduction benefits involved impacts on water quality and flood control. In Modesto, water quality benefits were priced based on annual costs for water quality monitoring and education, while flood control benefits were based on local costs for constructing and maintaining stormwater retention/detention basins (McPherson et al. 1999a). In Santa Monica, water quality benefits were based on the cost of treating sanitary waste water, while flood control benefits were based on the amount of money spent to control local flooding during a 25-year storm event (Condon & Moriarty 1999).

□ *Aesthetics and other benefits.* Many benefits attributed to urban trees are difficult to price (e.g., beautification, privacy, wildlife habitat, sense of place, well-being). However, the value of some of these benefits can be captured in the differences in sales prices of properties that are associated with trees. Anderson & Cordell (1988) found that each large front-yard tree was associated with a 0.88% increase in sales price ($ 336 or $ 508 in 1998 dollars). Initially for Modesto, $ 508 was used as an indicator of the additional value a Modesto resident would gain from the sale of residential property with a large street tree in front of their home (McPherson et al. 1999b). However, subsequent analysis showed that differences in residential property values among cities and associated tree benefits were best modeled by applying the 0.88% sales price increase to the city's median home sales price. Hence, in this analysis aesthetic (A) benefits ($/tree/year) reflect differences in the contribution to residential sales prices of a large front yard tree, the distribution of street and park trees, and the growth rates of trees in each city. These relationships are expressed for a single street tree as:

$$A = L * P$$

Where

L = annual increase in tree LA
P = adjusted price ($/$m^2$ LA),

$$P = (T \times C) / M$$

where

T = Large tree contribution to home sales price = 0.88% × median sales price
C = Tree location factor that depreciates the benefit for trees in non-residential sites
M = Large tree leaf area.

In August 1998 the median sales prices of homes in Modesto and Santa Monica were $ 102,000 and $ 450,000, respectively (California Association of Realtors 1999). The value T of a large tree that added 0.88% to the sales price of such homes was $ 900 and $ 3,969. Based on growth data for 40-year old plane (*Platanus acerifolia* in Modesto) and camphor (*Cinnamomum camphora* in Santa Monica) trees, such a tree was about 13-m tall, with 50-cm trunk diameter, and 250 m^2 (2,675 ft^2) of leaf surface area M. C was calculated to be 0.87 in Modesto and 0.84 in Santa Monica due to differences in street tree distribution by land use. After reviewing the literature and recognizing an absence of data, C was arbitrarily assumed to be 0.50 for park trees.

□ *Total benefits.* To capture the total value of annual benefits B, each benefit was summed:

$$B = E + AQ + CO_2 + H + O$$

where

E = price of net annual energy savings (cooling and heating)
AQ = price of annual air quality improvement (pollutant uptake, avoided power plant emissions, BVOC emissions in Santa Monica)
CO_2 = price of annual carbon dioxide reductions
H = price of annual stormwater runoff reductions
O = price of aesthetics and other benefits.

Results

Municipal forest structure

□ *City demographics.* The population of Modesto (182,260) is about two times greater than the population of Santa Monica (92,578). However, population density in Santa Monica is four times greater than Modesto (Table 1).

□ *Tree stocking and canopy cover.* In Modesto there were 91,179 street and park trees, or 0.50/capita (Table 1). In Santa Monica there were 29,229 trees, or 0.32/capita. Street trees accounted for 83% and 87% of all public trees in Modesto and Santa Monica, respectively.

Assuming full street tree stocking is average spacing of two trees every 15 m of street length (both sides of street), or 133 trees/km, stocking levels were 31% and 41% in Modesto and Santa Monica, respectively (Table 1). These values do not differ markedly from the mean street tree stocking level reported for U.S. cities of 38% (48.5 trees/km) (Kielbaso & Cotrone 1989). Park tree densities were greater in Santa Monica (52.5/ha) than Modesto (34.0/ha) (Table 1).

Street and park tree densities were higher in Santa Monica than Modesto, perhaps reflecting the increased abundance and role of public trees in more densely populated urban areas (Nowak 1994, McPherson 1998). This observation applies to tree canopy cover as well. Public tree canopy cover accounted for 28% of citywide tree cover in Modesto and 40% in Santa Monica.

Table 1. Demographic, stocking, and canopy cover

	Modesto	Santa Monica
City population	182,260	92,578
City area (ha)	9,065	2,176
Population density	20.1	83.8
Total street trees	75,629	25,508
Total street + park trees	91,179	29,229
Sreet trees/km (both sides)	40.8	54.3
Park trees/ha	34.0	52.5
Trees/capita	0.50	0.32
City tree cover (%)	31	15
Street & park tree cover (%)	8.6	6.0

Table 2. Street tree location and condition (all values are percentages)

Street tree location	Modesto	Santa Monica
Cutout	2.2	25.2
Strip <1 m	10.5	24.4
Strip 1–3 m	23	24.8
Front yard	62.8	24.4
Mulched	1.5	1.2
Street tree condition:		
Excellent	18.1	20.5
Good	57.7	43.9
Fair	21.1	22.9
Poor	3.1	10.7
Dead/Dying	0.0	2.0

□ *Tree location and condition.* In Modesto, 63% of all trees were in front yards with relatively favorable growing conditions (Table 2). In Santa Monica, 50% of the street trees were in cutouts (1.2 m × 1.2 m) and planting strips less than 1m wide. Growing conditions were less favorable for these trees and many were subject to root pruning and frequent crown reduction to remediate conflicts between roots and nearby hardscape.

In Modesto and Santa Monica, 76% and 64% of all street trees surveyed were in good and excellent condition. In Santa Monica, where growing conditions were more restrictive, 13% of the trees were classified as in poor condition, dead, or dying, while only 3% were classified as such in Modesto.

□ *Importance values.* In Modesto the IV of Modesto ash (*Fraxinus velutina* 'Modesto') was 25.1, indicating that the species accounted for 25.1% of total importance. The second most important species was Chinese pistache (*Pistacia chinensis*) (11.0). Modesto ash clearly dominated the tree population in Modesto. In Santa Monica, laurel fig (*Ficus microcarpa* 'Nitida') was the dominant species but its IV was only 16. Other street tree species, each comprising less than 1% of the population, had a total importance of 30.5. Compared to Modesto, importance was more evenly distributed among species in Santa Monica. From a management perspective, a more equitable distribution of importance indicates that the tree population may be more stable and the future stream of benefits more continuous.

□ *Age structure.* The age structure of municipal urban forests influences their population stability and management needs (McBride & Jacobs 1986, Richards 1982/83). Modesto had fewer young trees and about twice the number of large, old trees as Santa Monica (Fig. 2). Modesto's population differed from Richard's proposed "ideal" distribution in that it had too few young trees and too many old trees. Richard's distribution has the largest fraction of trees in the smallest dbh class (40% with dbh <20 cm) and the smallest fraction in the largest class. Santa Monica's population matched the "ideal" distribution quite well.

□ *Tree size, growth, and management.* Generally, trees in Modesto grew faster, were larger, and contained more leaf area than similar aged trees of the same species in Santa Monica (Peper et al. 2001a, 2001b).

Trees in Santa Monica were pruned intensively to protect ocean views and visibility of signage, as well as to reduce tree root-hardscape conflicts. As a result, crown volumes and leaf areas were less in Santa Monica than Modesto (Fig. 3).

In this study results are presented on a per tree basis to facilitate comparison between cities with different tree population numbers. Traits of the "typical" or average tree were calculated by dividing total crown projection area (CPA), leaf area (LA), etc. by total tree numbers. The typical Modesto tree had about two times more LA and CPA than its Santa Monica counterpart, although the leaf area indexes of both trees were about 3. The average annual leaf area increase in Modesto was nearly twice the rate in Santa Monica. Nearly 90% of the typical Modesto tree's foliage was deciduous, while 93% was evergreen in Santa Monica. The Modesto tree provided annual ecological and economic services that benefited 2.0 people on average, while those produced by the smaller Santa Monica tree benefited 3.2 people.

Municipal forest benefits and expenditures

Annual benefits from Modesto's and Santa Monica's municipal urban forests totaled $ 4.8 million ($ 53.17/tree) and $ 2.3 million ($ 80.39/tree), respectively (Table 3). Aesthetic and other benefits in Santa Monica accounted for 80% of total benefits and were nearly $ 39/tree greater than in Modesto. The dollar value of energy and air quality benefits were the same in Santa Monica, while in Modesto energy benefits were nearly twice the amount of air quality benefits. On a dollar per tree basis, CO_2 and stormwater runoff reductions were about two times greater in Modesto than Santa Monica.

In both cities, average per tree benefits increased with tree age and size (Fig. 4). In Modesto, about 50% of total benefits were due to increased property values and associated aesthetic benefits. The remaining benefits were quite evenly distributed among energy savings, stormwater runoff reduction, and air quality improvement. Moreover, environmental benefits increased relative to aesthetic benefits as trees grew larger, accounting for 80% of total per tree benefits 55 years after planting. In Santa Monica, total benefits were closely tied to aesthetic benefits through all tree size classes. Aesthetic benefits dominated total benefits, even for trees in the largest size classes, where they accounted for 80% of total benefits.

The dollar value of benefits were similarly distributed among species in both cities. In Modesto, Modesto ash (*Fraxinus velutina* 'Modesto', 17%), Chinese pistache (*Pistacia chinensis*, 9%), and Chinese hackberry (*Celtis sinensis*, 9%) accounted for 35% of total benefits. In Santa Monica, Deodar cedar (*Cedrus deodara*, 14%), laurel fig (*Ficus microcarpa* 'Nitida', 11%), eucalyptus (*Eucalyptus ficifolia*, 7%), and Canary Island pine (*Pinus canariensis*, 7%) accounted for 39% of total benefits.

Total annual expenditures were $ 2.6 million ($ 28.77/tree) in Modesto and $ 1.5 million ($ 52.82/tree) in Santa Monica (Table 3). Program expenditures alone were $ 24 and $ 38 per tree, considerably greater than the statewide average of $ 19/tree (Thompson & Ahern 2000). Non-program expenditures accounted for 20% to 30% of total costs, and were higher on a per tree basis in Santa Monica than Modesto because of more hardscape repairs and trip and fall claims.

Net benefits totaled $ 2.2 million ($ 24.40/tree) in Modesto and $ 0.8 million ($ 27.57/tree) in Santa Monica (Table 3). Although annual expenditures averaged $ 24/tree more in Santa Monica than Modesto, benefits were $ 27/tree greater. The $ 3 greater net benefit per tree in Santa Monica reflects increased

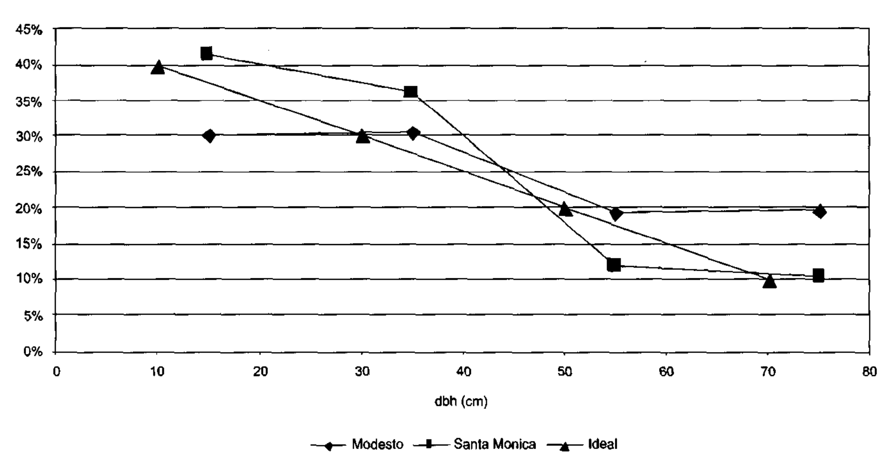

Fig. 2. The age structure of public trees in Modesto and Santa Monica compared to an "ideal" distribution (Richards 1982/83).

spending and larger returns. However, the benefit-cost ratio was greater in Modesto, 1.85 versus 1.52 in Santa Monica. Trees in Modesto produced more benefits relative to management costs than trees in Santa Monica.

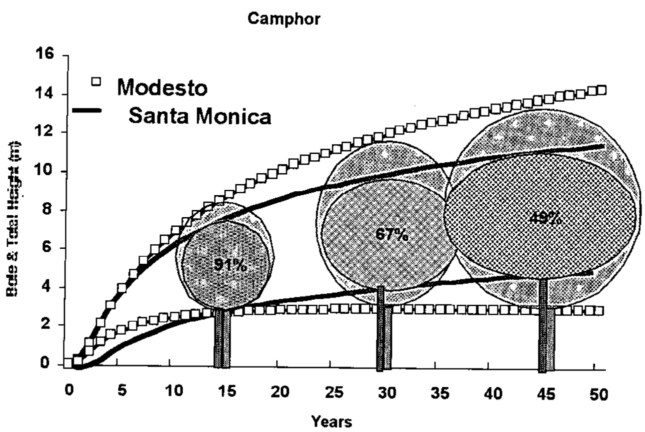

Fig. 3. Predicted tree and bole height of camphor (*Cinnamomum camphora*) in Modesto and Santa Monica (Peper et al. 2001a, 2001b). At 15, 30, and 45 years after planting leaf area of the tree in Santa Monica is 91%, 67%, and 49% of the tree in Modesto, respectively.

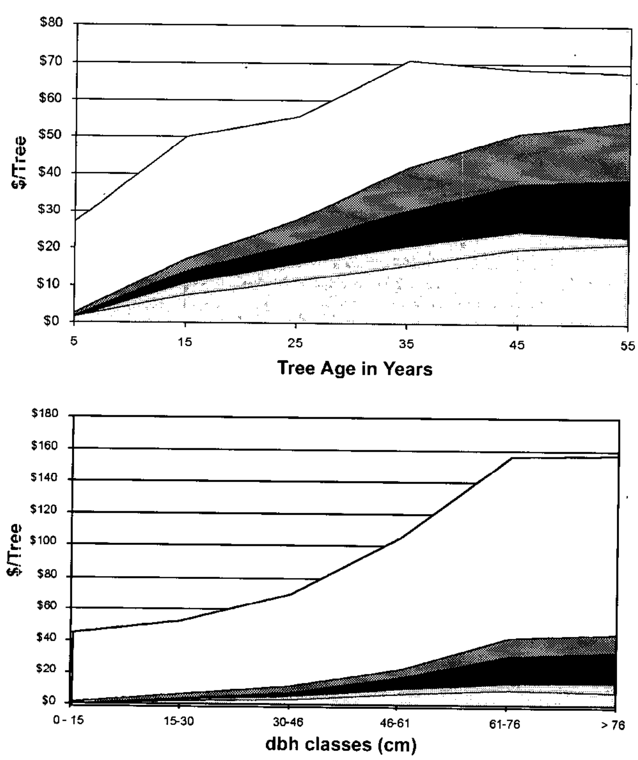

Fig. 4. The value of annual benefits on a per tree basis in Modesto (above) and Santa Monica (below). □ Energy, □ CO_2, ■ Air Quality, ▩ Stormwater, □ Aesthetic.

Comparison of costs and benefits using performance pariables

□ *Expenditures.* Three cost categories had the greatest impacts on overall costs: pruning, removal, and hardscape repairs. Pruning was the single largest cost category, accounting for 46% and 56% of total expenditures in Modesto and Santa Monica, respectively. The average annual per tree pruning expenditure in Santa Monica was over twice the cost in Modesto. Performance variables that explain this $ 16.35/tree difference in pruning expenditure were the average cost per tree pruned and pruning frequency (Table 4). In Santa Monica, the average cost per tree pruned was $ 90 compared to $ 69 in Modesto. Trees were pruned on a three- to four-year cycle in Modesto versus a one- to three-year cycle in Santa Monica.

Table 3. Total annual benefits and costs in Dollars (U.S.)

Benefit Category	Modesto	Santa Monica
Energy	1,000,560	147,534
Carbon dioxide	312,920	48,974
Air quality	538,106	147,682
Stormwater	616,139	110,784
Property/Other	2,380,415	1,894,758
Total Benefits	4,848,140	2,349,732
Program Expenditures:		
Planting	167,062	22,900
Pruning	1,202,252	863,380
Removals	342,896	49,500
Other	186,722	73,764
Administration	315,572	102,404
Total Program	2,214,504	1,111,948
Non-Program Expenditures:		
Hardscape repair	297,586	271,344
Leaf clean-up	106,426	27,808
Claims and legal	68,000	132,900
Total Non-Program	472,012	432,052
Revenues	63,132	-
Net Expenditures	2,623,384	1,544,000
Net Benefits	2,224,756	805,732
Benefit-Cost Ratio	1.85	1.52

Expenditures for tree removal and disposal were 13% of total costs in Modesto but only 3% in Santa Monica. Although the average tree removal cost was substantially higher in Santa Monica ($396) than Modesto ($264), the much higher annual tree removal rate in Modesto (1.4% versus 0.4%) was responsible for its higher overall per tree expenditure ($3.76/tree versus $1.69/tree)

Hardscape repair costs comprised 18% of total expenditures in Santa Monica and were about three times greater per tree than in Modesto ($9.28 vs. $3.26). Although many interacting factors were responsible for this result (e.g., soils, tree species, aggressiveness of the repair program), the percentage of street trees located in restricted sites (cutouts or planting strips <1m wide) was selected as one indicator. In the case of these two cities, there was a good relationship between the difference in relative cost (35%) and restricted tree sites (26%) (Table 4).

☐ *Energy savings.* Electricity savings for cooling were estimated to average 138 kWh/tree in Modesto and about 31% of this amount on a per tree basis in Santa Monica (43 kWh/tree) (Table 5). Approximately 25% of the total cooling savings in both cities was due to shade on buildings, with the remaining 75% due to reduced summertime air temperatures.

In both cities the urban forest was responsible for a slight increase in natural gas consumption for space heating. The deleterious effect of tree shade in the winter was greater than the benefit from less infiltration of cold air due to reduced wind speeds. However, the annual monetary cost of increased heating was negligible ($0.01–$0.08/tree).

Performance variables were identified for cooling and heating, but described here for cooling only. The number of cooling degree days (CDD) is an indicator of climatic influence on building energy performance. One cooling degree day accumulates for every degree that the mean outside temperature is above 18.3 °C for a 24-hr period. Lower cooling loads in Santa Monica were indicated by fewer CDDs. It had 17% of the CDDs recorded for Modesto (Table 5).

Table 4. Annual expenditures for tree pruning, removal, and hardscape repair in Dollars (U.S.)

Expenditures	Modesto	Santa Monica
Pruning ($/tree)	13.19	29.54
Pruning ($/tree pruned)	69	90
Pruning frequency (yrs)	3–4	1–3
Removal ($/tree)	3.76	1.69
Removal ($/tree removed)	264	396
Removal frequency (%) ann mortality)	1.4	0.4
Hardscape repair ($/tree)	3.26	9.28
% trees in restricted sites (< 1 m × 1 m)	13	50

Table 5. Selected performance variables for Annual Energy Savings and Atmospheric CO_2 Reductions (units in parentheses)

Energy savings	Modesto	Santa Monica
Cooling (kWh/tree)	138	43
Price ($/kWh)	0.079	0.114
Cooling ($/tree)	10.90	4.90
Cooling DD	1,926	319
Cooling savings (kWh/tree)		
Post 1980, no adjust.	316	176
Post 1980, w/adjust.	279	168
All vintages, w/adjust.	138	37
All trees & buildings	N.A.	43
Heating (MJ/tree)	-1	-11
Price ($/MJ)	0.0085	0.0073
Heating ($/tree)	-0.01	-0.08
Heating DD	2,360	1,675
Heating savings (MJ/tree)		
Post 1980, no adjust.	-141	-350
Post 1980, w/adjust.	-101	-240
All vintages, w/adjust.	-1	-24
All trees & buildings	N.A.	-11
CO_2 Reductions		
CO_2 (kg/tree)	103.8	50.7
Price ($/kg)	0.033	0.033
CO_2 ($/tree)	3.42	1.67
Seq CO_2 (kg/tree)	96.0	41.7
Ann. Growth LA (m^2)	8.9	5.1
Avoided CO_2 (kg/tree)	28.8	18.5
Cooling savings (kWh/tree)	138	43
Elec. E.F. (kg/MWh)	181	444
Decomp./tree (kg)	16.2	0.6
Annual mortality (%)	1.43	0.44
Maint/tree (kg)	4.9	8.9
CO_2 release (kg/cm dbh)	0.14	0.23

The second set of performance variables compared the cooling energy savings from a single large tree (54 cm dbh) located 6 m west of a post-1980 vintage single family detached residence. Savings of 316 kWh/tree and 176 kWh/tree in Modesto and Santa Monica, respectively revealed that climate alone had a substantial effect on cooling savings. After adjustments that accounted for differences in the percentage of post-1980 homes with air conditioning, amount of existing tree cover, and change in cover from additional trees, savings dropped 12% in Modesto (to 279 kWh/tree) and 5% in Santa Monica (to 168 kWh/tree). The decrease was relatively less in Santa Monica because existing tree cover was less, meaning that benefits produced by public trees were relatively greater than in Modesto.

The second set of adjustments included differences in the proportion of single family residential vintages and the mix of tree species, sizes, and locations. Cooling savings dropped 50% in Modesto and 78% in Santa Monica (to 37 kWh/tree). The disproportionately large drop in tree performance in Santa Monica was primarily due to its relatively smaller trees (CPA 39 m^2 vs. 85 m^2 in Modesto). Smaller trees cast less shade and produced less air temperature reduction than larger trees in Modesto.

Energy saving estimates for Santa Monica included effects from trees on buildings in multifamily residential, commercial/industrial, and institutional/transportation land uses. After cooling savings were adjusted to account for the mix of land uses, average per tree cooling savings increased from 37 kWh/tree to 43 kWh/tree. This increase was largely due to the effectiveness of trees at reducing cooling use by commercial and institutional buildings, which consumed more electricity for air conditioning than residential buildings per unit floor area. Savings associated with this increased air conditioning use made up for the reduced effectiveness of tree shade on commercial structures.

In summary, this analysis suggests that the large functional difference in per tree cooling savings was largely due to two factors. Santa Monica's temperate, coastal climate was the primary reason cooling savings were less than in Modesto, which is very hot during summer. Also, more diminutive tree sizes in Santa Monica caused cooling savings to be less than in Modesto. The relatively poor cooling performance of trees in Santa Monica was somewhat offset when value was calculated by a 30% higher electricity price than in Modesto.

☐ *Atmospheric carbon dioxide reduction.* Street and park trees were estimated to reduce atmospheric CO_2 by 104 kg/tree in Modesto and 51 kg/tree in Santa Monica (Table 5). Sequestration accounted for 82% to 92% of net CO_2 reductions, and was substantially more important than avoided emissions. Carbon dioxide released through decomposition and tree maintenance was about 20% of total net reductions. The price of CO_2 reductions was the same in both cities. Performance variables that help explain the 50% lower per tree CO_2 reduction in Santa Monica included tree growth and mortality rates, cooling savings, and electricity emission factors.

Differences in tree growth rates were important because they influenced sequestration rates. The estimated 54 kg/tree difference in per tree sequestration rates was comparable to the 53 kg/tree net total difference between cities. In Modesto, trees added more leaf area than in Santa Monica, as evidenced by average annual leaf area accumulation of 8.9 m^2 versus 5.1 m^2 (Table 5).

The difference in avoided CO_2 emissions due to energy savings was 10 kg/tree. As noted above, cooling savings were relatively greater in Modesto than Santa Monica. However, this benefit was partially offset by a 40% lower electricity emission factor for CO_2 in Modesto (181 kg/MWh vs. 444).

The large difference (15.6 kg/tree) in CO_2 released through decomposition was due to Modesto's much higher annual tree mortality rate (1.43% vs. 0.44%), especially for trees in the largest size classes. The 4 kg/tree difference in CO_2 released from tree maintenance was indicated by a 0.9 kg difference per cm dbh. Santa Monica's higher release rate for tree maintenance was largely due to aerial lift trucks whose engines were kept running throughout the day while trees were pruned.

☐ *Air quality improvement.* Public trees in Modesto and Santa Monica had net pollutant removal rates of 0.61 kg/tree and 0.11 kg/tree of air pollutants, respectively (Table 6). Although the typical tree in Modesto removed over five times more pollutants than its counterpart in Santa Monica, the value of this service was comparable, $5.90/tree in Modesto, $5.05/tree in Santa Monica. The prices for O_3 and NO_2 reductions in Santa Monica were about twice those in Modesto. In both cities, trees were most effective reducing O_3 and PM_{10}. In Modesto, cooling savings resulted in avoided NO_2 emissions from power plants that averaged 0.06 kg/tree or 67% of NO_2 uptake. Avoided power plant emissions were negligible in Santa Monica. BVOC emissions from trees in Santa Monica averaged 0.13 kg/tree, nearly offsetting their estimated annual O_3 and NO_2 uptake.

Three indicators of air quality improvement performance were pollutant concentrations, deposition velocities, and CPA. Pollutant deposition rates increase as the value of each indicator increases. Concentrations and deposition velocities for O_3 and NO_2 were slightly greater in Santa Monica than Modesto, but values for these indicators were slightly less in Santa Monica for PM_{10} (Table 6). These findings alone indicate that deposition rates should be higher in Santa Monica per m^2 of CPA. However, uptake rates were two to three times greater in Modesto because CPA was over two times greater for the typical tree. Thus, tree size differences had the greatest influence on pollutant uptake differences given the similar pollutant concentrations and deposition velocities.

A performance variable related to BVOC release was the percentage of foliar biomass considered to belong to a high-emitting species (Benjamin et al. 1996). In Santa Monica, 30% of total foliar biomass belonged to high-emitters, including laurel fig (8%) and eucalyptus (4%).

□ *Stormwater runoff reduction.* Municipal urban forests in Modesto and Santa Monica were estimated to reduce stormwater runoff by 3.2 m^3/tree and 7.0 m^3/tree, respectively. However, the implied value of runoff reduction was four times greater in Modesto than Santa Monica (Table 7). As a result, benefits were priced at $6.75/tree in Modesto and $3.78/tree in Santa Monica.

Table 6. Selected performance variables for Annual Air Quality Benefits

Air quality improvement	Modesto	Santa Monica
O_3 uptake (kg/tree)	0.25	0.11
Price ($/kg)	11.03	27.54
O_3 ($/tree)	2.79	2.92
O_3 concentration (µg/m^3)	55.6	66.5
O_3 dep. velocity (m/second)	0.0029	0.0034
NO_2 uptake (kg/tree)	0.09	0.05
NO_2 avoided (kg/tree)	0.06	0.00
Price ($/kg)	11.03	27.54
NO_2 ($/tree)	1.71	1.51
NO_2 concentration (µg/m^3)	43.2	51.6
NO_2 dep. velocity (m/second)	0.0019	0.0023
PM 10 uptake (kg/tree)	0.19	0.07
PM 10 avoided (kg/tree)	0.00	0.01
Price ($/kg)	6.98	13.67
PM 10 ($/tree)	1.37	1.03
PM 10 concentration (µg/m^3)	48.3	33.1
PM 10 dep. velocity (m/second)	0.0061	0.0063
BVOC release (kg/tree)		0.13
VOC avoided (kg/tree)	0.00	0.00
Price ($/kg)	6.13	4.23
VOC ($/tree)	0.03	0.55
CPA (m^2/tree)	85.3	39.3
Leaf biomass (% high emitters)		30

Interception differed between cities because of differences in 1) the character and magnitude of rainfall events, 2) tree species and their architecture, and 3) weather factors that influence rainfall storage in the canopy and evaporation rates (Xiao et al. 2000). Complex interactions among these factors make it difficult to identify performance variables that fully explain these findings. Two variables that influenced results were annual rainfall pattern and tree foliation periods.

Seasonality of rainfall was important because deciduous trees that are in-leaf intercept more rainfall than during their leaf-off period. Also, because annual interception tends to increase as total annual precipitation increases, the total amount of annual rainfall was a better indicator of interception effectiveness than rainfall amounts during peak events. Trees produce more benefits through water quality protection by reducing runoff during normal storm events than through flood control during extreme events (Xiao et al. 1998). The second performance variable was the fraction of deciduous and evergreen LA. Leaves act like reservoirs that store rainfall, so the amount of interception is directly linked to the amount of leaf area (Xiao et al. 2000). However, most rainfall comes during the winter in California, when deciduous trees are without their leaves. Total LA during summer is less important than total LA during winter in California.

Seasonality of rainfall was similar for Modesto and Santa Monica, with 25% and 22% falling during the leaf-on period, respectively. However, total annual rainfall in Santa Monica was nearly twice the amount in Modesto. In Santa Monica 93% of total LA was evergreen, but in Modesto only 11% was evergreen. Although the typical tree in Modesto had twice the LA of its Santa Monica counterpart, the Modesto trees were largely leafless when rainfall was greatest. This largely explains why interception on a per tree basis was over twice as much in Santa Monica than Modesto.

Aesthetics and other benefits

Modesto and Santa Monica's municipal urban forests were estimated to produce annual aesthetic and other benefits valued at $26/tree and $65/tree, respectively (Table 7). Two performance variables that help explain why the per tree benefit in Modesto was 40% of the benefit in Santa Monica was the value of *P* for street and park trees and differences in mean annual street tree growth rates.

The value of *P* was approximately four times greater in Santa Monica ($3,969) than Modesto ($900) for street trees (Table 7). This finding is primarily due to

Table 7. Selected performance variables for stormwater runoff reductions and aesthetic and other benefits

Stormwater runoff reductions	Modesto	Santa Monica
Interception (m^3/tree)	3.2	7.0
Price ($/$m^3$)	2.11	0.54
Interception ($/tree)	6.75	3.78
Total rainfall (mm)	315	570
% Leaf-on (Mar 15–Nov 15)	25	22
LA/tree (m^2)	244	119
LA Deciduous (%)	89	7
LA Evergreen (%)	11	93
$A = Lx ((T \times C)/M)$	Modesto	Santa Monica
A = Aesthetic/Other ($/tree)	26.11	64.82
L = Leaf area increase (m^2/yr)	8.9	5.1
T = Sales price increase by large tree ($)	900	3,969
C = Street tree location reduction (%)	78	84
M = Large tree leaf area (m^2)	250	250
Median home sales prices ($)	102,000	450,000

Santa Monica's higher median home sales price of $450,000 compared to $102,000 in Modesto. Street tree location factor *C* was slightly greater in Santa Monica.

The impact of adjusted price *P* on aesthetic benefit *A* was influenced by *L*, the annual increase in leaf area. Citywide, the mean increase in LA in Modesto was 8.9 m^2, nearly twice the mean rate for trees in Santa Monica (5.1 m^2). Faster tree growth in Modesto offset to some extent its lower *P*, however, growth rates varied by species and age. Modesto's population of large Modesto ash accounted for 22% of total LA, but their contribution to this benefit was limited because of relatively slow growth at their advanced age.

Discussion

Prices can be key performance variables because of their effect on the value of urban forest benefits. Price differences between cities were substantial, especially for stormwater, air quality, and aesthetic benefits. Average annual transaction costs for O_3 and NO_2 were two to three times higher in Santa Monica than Modesto (Table 6). Avoided stormwater runoff reduction benefits were priced four times higher in Modesto than Santa Monica (Table 7). Modesto's implied values were associated with retention/detention costs of about $2/$m^3$, while most of the hydrologic benefits in Santa Monica were priced based on much lower costs for treating sanitary waste ($0.48/$m^3$).

The relatively large differences in per tree costs and benefits became less when considered on a per capita basis. For example, the difference in per tree annual expenditures ($52.82 – $28.77 = $24.05) is substantially greater than the per capita difference ($16.68 – $14.39 = $2.29). Evaluating benefits and costs on a per capita basis incorporates differences in population densities and tree stocking levels. Santa Monica is four times more densely populated and has 37% fewer public trees per capita than Modesto. Because of more intensive urbanization, trees in Santa Monica may require more intensive care than trees in Modesto. Fewer trees per capita in Santa Monica mean that management costs and benefits are distributed among more people.

The benefit-cost analyses resulted in similar management recommendations for both cities:

- increase stability of the population to promote long-term net benefits from continuous levels of tree canopy cover
- control program and non-program costs to increase net benefits.

In Modesto and Santa Monica a large percentage of total benefits were produced by species nearing the end of their life cycles (i.e., Modesto ash, Chinese hackberry, Deodar cedar). Selective removal and replacement is required to avoid substantial short-term loss of canopy cover and to hasten the transition to a more stable population. Although removing large trees may reduce net benefits in the short-term, it provides long-term protection against catastrophic losses that could decimate tree canopy cover and magnify tree removal costs.

In Modesto, there was need to discontinue heavy planting of Chinese pistache, already 18% of all trees in the 20–40 cm dbh class. The city nursery should continue to grow and test new tree species and cultivars. Selecting trees that are well-matched to site conditions, will grow as large as possible given space restrictions, and enhance overall diversity are keys to transitioning into a more stable forest.

Conflicts between tree roots and hardscape were paramount in Santa Monica due to the large number of cutouts and narrow planting strips. One recommendation was to plant larger-statured trees in front yards where feasible. Another suggestion was to continue experimenting with strategies to reduce conflicts and repair costs such as rubberized "flexible" paving, meandering sidewalks around trees, using structural soils in commercial areas, and deep irrigation to direct roots away from the soil surface (Costello et al. 2000).

Extensive crown reduction, thinning, and lifting of older trees was substantially reducing their crown volume, leaf area, and growth rates in Santa Monica. Therefore, it was recommended that heavy pruning be discontinued as a standard practice. Reducing pruning frequency and intensity should promote healthier trees that produce greater benefits at less cost to the city.

The approach taken here to value municipal trees has limitations. The value of benefits found in these two California cities cannot be directly transferred to municipal trees in other Mediterranean cities because of differences in tree management practices, air pollution concentrations, air conditioning use, stormwater runoff control measures, and average residential sales prices. Moreover, the procedure is difficult to replicate because it requires detailed information on trees, environment, and management costs. Many cities lack this information and it may be too costly to obtain.

The accuracy and precision of the numerical models is uneven. For example, tree location and species traits such as crown density are very important to energy results, but they are not well integrated into the air quality and rainfall interception models. The greatest uncertainty lies in estimates of aesthetic and other benefits, which were found to be the single largest type of benefit. Sources of this uncertainty include inferring from research conducted in Georgia to California, extrapolating to street and park trees, and linking benefits to average homes sales prices. Additional research is needed to strengthen the scientific underpinnings of these estimates.

Because this approach explicitly accounts for each benefit and cost, the findings do not reflect a complete accounting of tree value. For example, trees that emit aeroallergens may be responsible for health care costs not accounted for here. Similarly, benefits of trees related to crime reduction, psychological well-being, and community building are omitted from this analysis. Also, quantitative results have limited utility. Unlike CITYGreen (Moll 1995), a GIS-based software package, this approach does not help planners visualize the spatial distribution of benefits or how tree canopy cover will change as trees grow.

Findings from these studies were used by municipal foresters in Modesto and Santa Monica to increase public awareness about the benefits produced by street and park trees. Also, the results helped convince policy-makers in Modesto to retain full funding for the tree program when funding for most other city programs was cut. When used thus, benefit-cost analyses need not be accurate to the dollar. They function as decision-support tools to assist municipal officials develop policy, set priorities, and make choices.

Summary and Conclusion

Although net benefits per tree and benefit-cost ratios were relatively similar for the two cities, benefits and costs were distributed differently. Aesthetic and other benefits accounted for 80% of total benefits in Santa Monica, an artifact of the model's sensitivity to relatively high residential real estate prices. Energy savings and air quality improvement benefits were relatively more important in Modesto, where the inland climate was less salubrious.

Performance variables helped explain differences in the value and function of annual benefits and costs on a per tree basis. On average, trees in Modesto were larger than similar aged trees in Santa Monica. As a result, trees in Modesto had higher pollutant uptake and CO_2 sequestration rates than in Santa Monica. However, the relatively large number of broadleaf evergreens, palms, and conifers in Santa Monica resulted in greater winter rainfall interception than in Modesto.

This systematic analysis of benefits and costs produced management recommendations aimed at increasing net benefits of the street and park tree resource. For instance, the extensive pruning of street trees in Santa Monica was discouraged, while increased experimentation to reduce costs associated with conflicts between tree roots and hardscape was promoted.

Although this approach requires large amounts of data and intensive numerical modeling, it can provide cities with a comprehensive accounting of municipal tree benefits and associated management costs. Such information is fundamental to gaining widespread recognition of the value of greenspace and implementing programs that maximize return on taxpayer investments.

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