EXPENDITURES ASSOCIATED WITH CONFLICTS BETWEEN STREET TREE ROOT GROWTH AND HARDSCAPE IN CALIFORNIA, UNITED STATES

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Abstract. A survey of 18 California cities indicated that approximately $70.7 million (se $11.1 million) was spent annually statewide due to conflicts between street tree root growth and sidewalks, curbs and gutters, and street pavement. The largest single expenditure was for sidewalk repair ($23 million, se $9.5 million), followed by curb and gutter repair ($11.8 million, se $2.6 million), and trip and fall payments and legal staff time ($10.1 million, se $2.2 million). Property owners paid 39% and 17% of tree-related sidewalk and curb and gutter repair costs, respectively. Substantial funds were invested to remove and replace trees in conflict with hardscape ($6.8 million, se $3.6 million), and for inspection and repair administration programs ($5.9 million, se $1.3 million). Root pruning ($2.5 million, se $2.0 million) and root barriers ($676,854, se $175,655) were the most important mitigation and prevention measures. Restricted planting space and the type of tree species selected were reported as the most important factors responsible for hardscape damage.

Key Words. Root growth; sidewalk damage; tree–sidewalk interaction; urban forestry.

Street trees are integral to the green infrastructure of our cities. No other infrastructure element can so dramatically transform the character of a neighborhood at so little cost. Without trees, streetscapes are dominated by paving, wires, buildings, and signs. With trees, they are verdant corridors of life. More than 30 million people live in California, and 90% of them live in urbanized areas. Residents appreciate the important role street trees play in enhancing quality of life. California has approximately 6 million street trees, and 80% of all California cities have municipal tree programs (Bernhardt and Swiecki 1993).

Although street trees provide a host of environmental, social, economic, and aesthetic benefits, the wrong tree in the wrong location can be costly. A survey of 15 cities in the United States and Canada found that annual concrete and sewer repair costs attributed to tree roots averaged $4.28 per street tree, equivalent to 25% of annual tree program expenditures. Sidewalk repair costs were the single largest expense, averaging $3 per tree (McPherson and Peper 1995).

Conflicts between tree root growth and hardscape can result in other costs that have not been studied. For example, cities fund root pruning and installation of root barriers to alleviate conflicts, remove and replace trees that become liabilities, and pay trip and fall claims. The magnitude of these "external" costs is unknown. Therefore, the objective of this study was to obtain a complete accounting of annual expenditures associated with street tree root-related hardscape damage in California. It is hoped that a better understanding of this problem will spur development of cost effective solutions.

METHODS

In 1996, a mail questionnaire was developed and sent to 40 municipal arborists known to have computerized tree inventories. The survey requested information on tree-related infrastructure repair costs averaged over the last three years. Follow-up telephone calls were made to nonrespondents after the survey instrument was mailed. Eighteen surveys were returned for a 45% response rate.

The level of response to specific questions varied due to the availability of information. For instance, four cities refused to disclose information on trip and fall payments, and nine cities were unable to account for legal fees associated with trip and fall claims.

Data are reported as total dollar expenditures (U.S. dollars), as well as average dollars per capita, dollars per tree, and dollars per repair for comparison purposes. Because subsample sizes varied for different questions, weighted averages were calculated using the population, tree, and repair numbers for cities that responded to each question. For example, to calculate the average annual per capita cost (y) of an expenditure x weighted to account for human population (p) size of reporting cities,

$$y = \frac{\sum x_i}{\sum p_i} \quad (1)$$

where i identifies the cities with nonmissing data.

The standard error $se(y)$ is

$$\hat{s}e(y) = \left(\frac{y}{\sqrt{n}}\right) \cdot \left(\frac{s_X^2}{\overline{X}^2} + \frac{s_P^2}{\overline{P}^2} - 2\hat{\rho}\frac{s_X}{\overline{X}}\frac{s_P}{\overline{P}}\right)^{1/2} \quad (2)$$

where

n = the number of cities reporting on expenditure x

$\overline{X}$ and $\overline{P}$ = the respective sample means of expenditure and human population

s_x^2 and s_p^2 = the respective sample variances

$\hat{\rho}$ = the sample correlation coefficient between expenditures and human population

Because per-capita expenditures were used to infer statewide costs, it was important to account for differences in population and tree numbers among cities. The weighted average does this, whereas the standard mean does not. Street tree numbers were obtained from the survey, and city populations were from census data (California Department of Finance 1996).

Prior to inferring from the 18-city sample to the statewide population, all the expenditures per capita and their standard errors were calculated from the sample using formulas (1) and (2). This calculation used reported expenditures for repairs, prevention and mitigation, and tree removal and replacement. Average dollars per capita for legal and program administration expenditures were estimated with the available data from reporting cities.

The sample did not include unincorporated areas (i.e., counties), wherein reside 6.3 million (P_t) of California's 32.3 million population (California Department of Finance 1996). Cities spend much more on tree programs than do counties, so applying a per-capita cost derived from a sample of cities to 20% of the state's population in counties would overestimate statewide expenditures. The average annual per-capita expenditure for city and county tree programs was reported as \$4.36 (l_c) and \$0.32 (l_t), respectively (Bernhardt and Swiecki 1993). Given the lack of information on actual expenditures in counties, it was assumed that city–county spending on hardscape repairs, mitigation, and prevention was proportionate to their tree program expenditures. Hence, total annual spending in California (z) was calculated as

$$z = y \times \left(P_c + P_t \frac{l_t}{l_c}\right) \quad (3)$$

and Pc is the population of California cities. The standard error of z is

$$se(z) = se(y) \times \left(P_c + P_t \frac{l_t}{l_c}\right) \quad (4)$$

The annual rate (r) at which repairs and other activities occurred was calculated for the reporting subsample as the ratio of street trees in the subsample population (t_i) to the number of activities (a_i):

$$r = \frac{t_i}{a_i} \quad (5)$$

RESULTS

The Sample

The sample consisted of 18 cities ranging in population from 14,000 (Carpenteria) to 3.6 million (Los Angeles), with a median population of 130,000. Half of the sample cities were located in the San Francisco Bay area and Central Valley, with the remainder in southern California and the Central Coast.

The sample contained proportionately more large cities than small cities (Table 1). Six of the thirteen cities in California with populations greater than 200,000 were included in the sample, and these six accounted for 69% of the total population in all 13 large cities. Overall, the sample included 4% of all cities and 29% of the total population living in cities.

To evaluate representativeness of the sample, the number of street trees per capita and annual tree program spending per capita were compared with results from a statewide survey with 361 cities responding (Bernhardt and Swiecki 1993). The sample contained 0.24 (se 0.04) street trees per resident (7.5 million residents and 1.8 million trees), exactly matching the number reported as the statewide average. Annual tree program expenditures per capita were \$3.29 (se \$0.53) for the sample and \$4.36 in cities statewide. Hence,

Table 1. Demographic characteristics of all California cities and the sample cities.

City population class	No. cities in CA	Total population in CA cities	No. in sample	No. in sample (%)	Population in sample	Population in sample (%)
> 200,000	13	9,321,500	6	46.2	6,411,900	68.8
100,000–200,000	38	4,971,500	5	13.2	733,900	14.8
50,000–99,999	82	5,645,400	4	4.9	271,400	4.8
< 50,000	337	5,883,870	3	0.9	89,550	1.5
Total	**470**	**25,822,270**	**18**	**3.8**	**7,506,750**	**29.1**

average annual tree program budgets are 25% less per capita for the sample, suggesting that if spending on infrastructure repair tracks spending on trees, these results may underestimate statewide expenditures.

Planting Site Characteristics

The sample contained 1.8 million street tree sites, with 54% located between curb and sidewalk, 15% in front-yard easements, and 31% as sidewalk cutouts. In San Francisco and Oakland, nearly all sites were cutouts. In Claremont, Davis, Modesto, and Sacramento, the majority of sites were front-yard easements. The weighted average planting site width was 1.7 m (5.6 ft).

Repair Expenditures

Eleven cities provided a breakdown of total in-house repair costs for sidewalks, curb and gutter, and street pavement. These in-house expenditures were not related to capital improvement projects and this subsample excluded the larger cities, for which information on total repair costs was unavailable. Total repair costs for these 11 cities were $20.5 million. Street pavement repairs accounted for 71% of the total, sidewalk repair 20%, and curb and gutter repair 9%.

Tree root-related repair expenditures. For the 11-city subsample, tree-related expenditures totaled $4.3 million, or 21% of the total amount spent on infrastructure repair. Tree root growth was responsible for only 3% of total repair costs for street pavement but accounted for 48% of curb and gutter repair costs and 70% of sidewalk repair costs.

Two additional cities that did not report total repair costs did report expenditures for repair that they attributed to tree root growth. For this 13-city subsample, a total of $3.8 million (66%) was spent for sidewalk repair, $1.2 million (21%) for repair of curb and gutters, and $0.8 million (13%) for street pavement repair. Tree-related expenditures totaled $5.9 million.

When expenditures for the remaining five cities (Los Angeles, San Francisco, Oakland, Rancho Cucamonga, and Davis) that reported only tree-related sidewalk repairs were included, total annual tree root-related repair costs were $8.6 million, or $1.64 per capita (se $0.38) on average (Table 2). Annual expenditures ranged from $0.21 per capita in Los Angeles to $5.85 per capita in Lompoc.

Sidewalk repair expenditures. Eighteen cities reported spending a total of $6.58 million ($0.88 per capita, se $0.36) on sidewalk and driveway apron repair associated with tree root growth. The number of annual sidewalk repairs attributed to tree root growth was 17,941, with a repair rate of 1:99 (one repair for every 99 street trees on average). The mean sidewalk repair cost was $480, and average costs were reported to range from $140 in Modesto to $1,500 in Los Angeles. In Sunnyvale, typical costs were $65 per m^2 ($6 per ft^2) for removing and disposing of concrete and roots, installing base rock, forming the new walk, and pouring concrete (Dunn 1996).

Who pays for sidewalk repair is an increasingly contentious issue in some California communities. State code provides that local jurisdictions may elect to require property owners to maintain sidewalks. In this sample, Los Angeles and San Jose passed through the full cost of sidewalk repair to abutting property owners. Residents in San Francisco are responsible for approximately 70% of the street trees and for sidewalk repair costs associated with those trees. In seven other cities, residents paid something less than 15% of the repair bill. Only eight cities fully funded sidewalk repairs attributed to municipal street trees. Of the total $6.58 million spent on sidewalk repair, 61% was paid with municipal funds and 39% by property owners.

Curb and gutter repair expenditures. Fourteen cities that reported curb and gutter repair expenditures associated with tree root growth were a total of $1.2 million annually, or $0.45 per capita (se $0.10). The curb and gutter repair rate was 1:169, less frequent than reported for sidewalks. The average repair cost

Table 2. Program data and annual expenditures for each city in the sample (all values in 1000s).

City	Population	Street trees	Tree budget	Repair	Mitigate/ prevent	Legal	Remove/ replace	Admininstration	Total
Carpenteria	14.5	3.0	55.0	49.0	8.1	1.9	18.0	1.0	78.0
Claremont	34.1	21.0	533.0	142.1	1.1	14.7	0.6	–	158.5
Lompoc	41.0	12.0	756.1	240.0	100.0	0.4	57.2	39.9	437.5
Davis	52.6	20.0	315.0	22.1	1.4	–	2.3	50.0	75.8
Lake Forest	57.6	8.0	90.0	45.5	8.5	3.0	17.6	22.5	97.1
Redwood City	71.8	21.0	629.0	344.4	69.5	21.0	24.2	47.3	506.4
Santa Barbara	89.4	22.5	650.0	326.6	47.8	28.8	25.4	24.0	452.6
Rancho Cucamonga	115.9	60.0	351.0	165.8	15.9	–	51.9	5.1	238.6
Sunnyvale	126.1	40.8	1,146.8	482.5	153.2	13.0	0.3	121.2	770.2
Orange	119.7	26.0	378.0	470.0	26.3	90.0	53.3	145.1	784.7
Modesto	178.7	76.0	2,200.0	386.8	79.7	42.0	77.3	76.0	661.8
Glendale	193.5	36.8	944.6	861.6	54.5	–	6.8	20.4	943.3
Oakland	383.9	225.0	23.9	1,000.0	50.0	–	36.9	1.5	1,088.4
Sacramento	384.8	115.0	2,453.1	930.0	50.9	7.7	29.7	43.3	1,061.6
Fresno	400.4	90.0	735.0	584.0	8.8	49.0	10.3	0.4	652.6
San Francisco	755.3	77.0	2,200.0	773.3	522.1	286.0	270.7	101.3	1,953.3
San Jose	849.4	250.0	1,700.0	1,040.0	0.0	208.0	1,109.5	130.0	2,487.5
Los Angeles	3,638.1	680.0	9,500.0	750.0	78.0	1,300.0	164.8	234.6	2,527.4
Total	**7,506.8**	**1,784.1**	**24,660.5**	**8,613.8**	**1,275.7**	**2,065.6**	**1,956.7**	**1,063.6**	**14,975.4**
Mean $/capita				1.64	0.17	0.38	0.26	0.22	2.68
Std error				0.38	0.08	0.08	0.14	0.05	0.42

was $277, or 58% of the average amount spent on each sidewalk repair. Although the cost of repair varied considerably, the average cost in Sunnyvale was $82 per m ($25 per linear ft) for removing and disposing of concrete, excavating and disposing of roots, installing base rock, and forming and pouring concrete (Dunn 1996).

In Los Angeles and San Jose, all curb and gutter repair costs associated with street tree root growth were passed through to the adjacent property owner. Residents paid 13% and 5% of these repair costs in Redwood City and Oakland, respectively. For the 15 cities that reported curb and gutter repair expenditures, property owners paid 17% of the total $1.2 million.

Street pavement repair expenditures. Thirteen cities that reported tree-related street paving repair expenditures spent $808,000, or $0.32 per capita (se $0.05) on average. The number of repairs were 20% of those reported for sidewalks, and the average cost was $288. Every municipality in this sample paid for the full cost of tree-related street pavement repairs.

Expenditures for Mitigation and Prevention Measures

Seventeen cities reported spending $1.28 million, or $0.17 per capita (se $0.08) on mitigation and prevention measures to reduce conflicts between street tree roots and nearby hardscape (Table 2). Fifty-six percent of reported expenditures were for root pruning. Root pruning occurred more frequently than sidewalk repair (rate of 1:86), and the average cost was $79 per root pruning. Twenty-one percent of total dollars spent on mitigation and prevention was for grinding and ramping of sidewalks to reduce displacement that might result in trip and fall accidents. Although grinding occurred in only two cities (Lompoc and Sunnyvale), it was the most frequently applied mitigation measure (1:72 in these cities) and averaged $44 per tree. Ramping or tapering the walk with asphaltic concrete or a similar product was reported as a relatively infrequently applied measure (1:13,782) in nine cities, with an average unit cost of $31. Installation of root barriers was a common prevention measure. Use of root barriers in 12 cities accounted for 15% of total costs for mitigation and prevention, with an average unit cost of $40 and a frequency of 1:293. Tree well engineering, water jetting, and several other measures were implemented in three cities at a rate of 1:200 and an average unit cost of $106. These measures amounted to 5% of total expenditures for mitigation and prevention. Narrowing sidewalks to accommodate flared tree trunks and shallow roots was the most expensive measure, costing $151 per job on average. Because sidewalk narrowing was practiced in just three cities, it accounted for only 3% of total expenditures.

Expenditures for Trip and Fall Cases and Legal Staff Time

Fourteen cities reported average annual trip and fall payments associated with sidewalk damage caused by tree root growth as $1.77 million ($0.26 per capita, se $0.06), and nine cities reported the dollar value of legal staff time spent on tree-related trip and fall cases as $292,770 ($0.12 per capita, se $0.06). Total legal expenditures were $2.1 million, or $0.38 per capita (se $0.08) (Table 2). Annual expenditures ranged from $400 in Lompoc to $1.3 million in Los Angeles. The highest single payment reported was $120,000, and the average payment was $6,245. Payments were relatively infrequent (1:8,923).

Tree Removal and Replacement Expenditures

The 18 cities in the survey reported spending a total of $1.6 million for removal of trees due to conflicts with hardscape and $0.3 million for replacement of these trees. Tree removal and replacement totaled $1.96 million, or $0.26 per capita (se $0.14) (Table 2). A total of 2,993 trees were reported removed at an average cost of $537. Removed trees were typically 50 to 64 cm dbh (20 to 25 in.) and 30 to 35 years old. San Jose's aggressive removal and replacement plan resulted in removal of 1,000 trees per year at a total cost of $900,000. San Francisco and Los Angeles spent $100,000 to $200,000 each on tree removal, while Claremont and Sunnyvale spent less than $1,000 annually.

Replacement trees numbered 2,257, for a 75% replacement rate. The average replacement cost was $154, and 92% of the total replacement expenditures were for #15 container trees. Larger 60-cm (24-in.) boxed trees accounted for 5% of the remaining amount spent on replacements. Expenditures were less than $1,000 in Claremont, Davis, and Sunnyvale, and over $200,000 in San Jose.

Inspection and Administration Costs

Expenditures for inspectors and staff administering repair programs totaled $1.1 million, or $0.22 per capita (se $0.05) (Table 2). Inspection costs accounted for 55% of the total expenditure.

Statewide Expenditures

In 1996, approximately $70.7 million (se $11.1 million) was spent statewide resolving conflicts between street tree root growth and hardscape (Table 3). This estimate is based on the 18-city sample's average expenditure of $2.68 per capita (se $0.42) (Table 2) and a substantially lower $0.20 per capita for unincorporated areas. Although 20% of the state's 32.2 million population lived in unincorporated areas, the total expenditure was only $1.2 million statewide because relatively little is spent on tree programs compared to such expenditures by cities. The statewide average expenditure was $2.19 per capita and $11.22 per tree, assuming 32.2 million residents and 6.3 million street

Table 3. Estimated annual statewide expenditures, tree-related damage.

Cost category	$1,000s	se ($1,000s)	% subtotal	$/capita[z]	$/tree[y]
Direct repair costs					
Sidewalk	23,123	9,536	53.5	0.72	3.67
Curb and gutter	11,811	2,604	27.3	0.37	1.87
Street pavement	8,314	1,254	19.2	0.26	1.32
Subtotal	43,248	9,964	100.0	1.34	6.86
Mitigation and prevention					
Root prune	2,519	2,068	56.2	0.08	0.40
Barriers	677	176	15.1	0.02	0.11
Grind	599	539	13.4	0.02	0.10
Ramp/taper	332	218	7.4	0.01	0.05
Tree well eng./other	141	125	3.2	0.00	0.02
Width reduction	212	190	4.7	0.01	0.03
Subtotal	4,481	2,168	100.0	0.14	0.71
Trip and fall payments and legal staff					
Claims payments	6,914	1,586	68.2	0.21	1.10
Legal staff	3,230	1,531	31.8	0.10	0.51
Subtotal	10,143	2,205	100.0	0.31	1.61
Tree removal and replacement					
Removal	5,650	3,527	82.2	0.18	0.90
Replacement	1,223	805	17.8	0.04	0.19
Subtotal	6,872	3,618	100.0	0.21	1.09
Other costs					
Inspection	2,168	580	36.6	0.07	0.34
Admininstration	3,749	1,148	63.4	0.12	0.60
Subtotal	5,917	1,286	100.0	0.18	0.94
Grand total	**70,661**	**11,117**		**2.19**	**11.22**

[z]Assumes statewide population of 32,231,000 (California Department of Finance 1996).
[y]Assumes statewide street tree population of 6,300,000 (Bernhardt and Swiecki 1993).

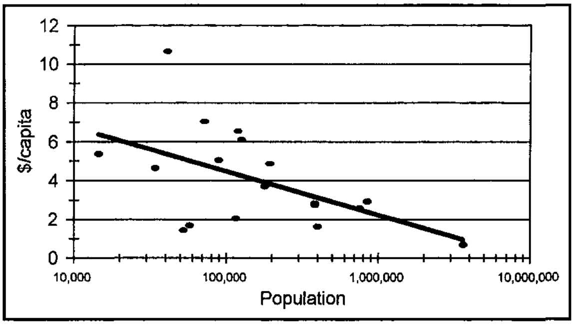

Figure 1. Per-capita expenditures for tree-related damage tended to decrease with increasing city populations.

trees (Bernhardt and Swiecki 1993). Most funds were spent repairing damaged infrastructure ($43 million, se $10 million, 61%), with sidewalk repair the single greatest cost category ($23 million, se $9.5 million). The second largest type of expenditure was paying claims and legal fees associated with trip and fall accidents ($10 million, se $2.2 million, 14%). Tree removal and replacement accounted for 10% of total expenditures ($6.9 million, se $3.6 million), followed by inspection and administration (8%), and mitigation and prevention (6%).

Per-capita expenditures tended to decrease with increasing city population (Figure 1). The $70.7 million estimate is probably conservative because Los Angeles, the largest city in the sample, had the lowest total expenditure on a per-capita basis. For example, the per-capita expenditure calculated as a simple mean of the 18 sample cities was $4.32 compared to the value of $2.68 calculated as the weighted average.

Ranking of Factors Responsible for Tree-Related Damage

Respondents ranked six factors associated with sidewalk damage in order of importance. Restricted planting space was identified as the most important factor associated with hardscape damage by 56% (se 12%) of the respondents and listed as the second factor by another 33% (se 11%) of the respondents. Tree species was ranked as the number-one factor by 39% (se 11%) of the respondents and as the second most important factor by 28% (se 11%). Shallow soil (i.e., soil with hardpan or other root-limiting zone) was ranked first by 6% (se 5%) and second by 17% (se 9%). Tree size (after a tree reaches a certain size it causes damage, regardless of species) and soils with restricted macropore space (e.g., fine-textured soils such as clays, compacted, sodic soils) received lower rankings. The least important factor cited by respondents was inadequate design or engineering (e.g., hardscape cannot withstand minimal root pressure). This last finding suggests that poor sidewalk construction practices are less of a problem in California than reported in Cincinnati (Sydnor et al. 2000). Other factors mentioned were surface watering, ground coverings such as plastic sheeting, root pruning, and absence of soil trenches to lead roots away from or under hardscape materials.

DISCUSSION

There are over 6 million street trees in California and these trees are associated with approximately $70 million in expenditures to remedy conflicts between root growth and hardscape. This is a conservative estimate because it does not include repair costs for damage to irrigation and water meters, sewer lines, building foundations, parking lots, and pavement on private property. Although data are lacking, a full accounting of repair costs associated with trees on private lands as well as along streets in California would probably exceed $100 million.

In 1992, California cities spent an average of $4.36 per capita on street tree programs (Bernhardt and Swiecki 1993). This 18-city sample found an average per-capita expenditure of $2.68 (se $0.42) on problems related to tree root growth. Californians are spending 50% to 70% as much money repairing, preventing, and litigating problems caused by street tree root growth as they are planting and maintaining their street trees. However, it should be noted that in many cities only a small percentage of expenditures for sidewalk repair and trip and fall payments come from tree program budgets. Frequently, these funds come from departmental budgets for public works and legal services. Therefore, fluctuations in these infrastructure-related expenditures may not substantially detract from tree planting and stewardship activities.

For the sample, tree-related repair costs for sidewalk and curb and gutter repair averaged $1.33 per capita (se $0.46). This amount could represent 23% to 65% of the $3.29 per-capita (se $0.52) average tree program expenditure given standard errors of the estimates. In comparison, these percentages are significantly greater than the mean value of 23% reported for sidewalk and curb and gutter repair for 15 cities in the United States and Canada (McPherson and Peper 1995).

One of this study's surprising findings was that property owners paid 39% of tree-related sidewalk repair costs and 17% of curb and gutter repair costs. Previous surveys conducted by the cities of Hayward (Santos 1995) and Los Angeles (City of Los Angeles Department of Public Works 1996) found that municipalities paid for repair of sidewalks damaged by trees in 10 of 14 San Francisco Bay area communities and 8 of 12 southern California cities. Requiring residents to pay repair costs for public sidewalks damaged by city street trees can cause resentment of local government and local trees. It has been noted that after residents paid for the first repair they preferred having the tree removed rather than pay for a second repair (Santos 1995). These economic and attitudinal impacts are greatest on residents in older areas, where trees are larger, infrastructure has deteriorated, and tree root–sidewalk conflicts are most severe. Often, people living in these areas are among those least able to pay these repair costs.

Another interesting finding was the relatively large cost for trip and fall payments and legal staff (14%). This result suggests that cities spend $2.26 on legal remedies for every $1 spent on mitigation and prevention. The amount spent resolving conflicts between tree root growth and hardscape varied by city, reflecting how cities have dealt with the problem historically, as well as each city's ability and willingness to fund repair activities at the present time. The City of Los Angeles had an estimated $375 million sidewalk repair backlog due to inadequate funds for repairs beginning in 1976 (City of Los Angeles Department of Public Works 1996). Only recently has funding become available to begin to alleviate this problem. As a result, Los Angeles spent only $0.69 per capita, and 51% of this amount ($1.3 million) was spent to pay claims and legal fees.

The City of Lompoc spent an average of $10.67 per capita on tree root–infrastructure conflict issues, the largest amount reported for the 18-city sample. Although Lompoc spent the most for repair ($5.85) and for mitigation and prevention ($2.44), it had the lowest expenditure rate for trip and fall payments and legal fees ($0.01 per capita).

Lompoc spent $863 for repair and prevention for each $1 spent for trip and fall. Other cities with relatively high ratios of dollars spent on repairs and preventive measures to dollars spent paying trip and fall claims were Sacramento (127), Sunnyvale (49), and Carpenteria (30). The cities of Claremont, Lake Forest, Redwood City, Santa Barbara, Modesto, and Fresno spent $10 to $20 each on repairs and on mitigation and prevention for each $1 spent on litigation and payments, while Orange and San Jose spent about $5. These results indicate that resources were allocated in a variety of ways to address the public safety issues surrounding tree root conflicts with infrastructure. There is need to better understand how risk managers value investments in risk reduction and how various strategies to reduce conflicts translate into reduced legal expenditures.

Expenditures for removal and replacement of trees causing hardscape damage were relatively high (10%). This finding was expected. An earlier survey reported that hardscape damage was the second most common reason for tree removal, accounting for 22% of all removals (Bernhardt and Swiecki 1988). Although data are not available to establish relationships between root pruning and subsequent tree removal (either planned or after tree failure), repeated or improper root pruning can increase the likelihood of tree failure (Carlson 1999). Root pruning was the most commonly practiced preventive measure. Community foresters often face public opposition when forced to remove hazardous trees that appear healthy. Usually, conflicts between street trees and sidewalks result in premature tree removal, and this is often a losing proposition when it comes to public relations.

The relatively low replacement rate of 75% could indicate that funds for new transplants are lacking or that some sites should not have been planted with trees in the first place. Respondents to this survey indicated that most hardscape problems can be traced to the "wrong tree in the wrong place." Presumably, community foresters are selecting deeper-rooting species, trees with less aggressive root systems, and species with smaller trunk sizes where planting space is restricted. This may be one reason why the most recent statewide survey reported a "downsizing" of the municipal urban forest (Bernhardt and Swiecki 1993). Compared to 1988, fewer large-growing "problem trees" were being planted, such as sweetgum

(*Liquidamber styraciflua*), Modesto ash (*Fraxinus velutina 'Modesto'*), carrotwood (*Cupaniopsis anacardiodes*), mulberry (*Morus alba*), Chinese elm (*Ulmus parvi-folia*), and carob (*Ceratonia siliqua*). Planting of smaller-statured trees, such as pistache (*Pistacia chinensis*) and Bradford pear (*Pyrus calleryana* 'Bradford'), were on the increase, and the most frequently planted species along streets was crape myrtle (*Lagerstroemia indica*).

Planting smaller-statured trees can minimize public safety issues and associated expenses, especially in cities where cutouts or narrow tree lawns are ubiquitous. Although studies have not fully examined the costs and benefits of this "downsizing" trend, benefits forgone by planting small-statured trees exceed their savings under normal conditions. For example, an analysis for San Joaquin Valley street trees found that the average annual cost for maintaining a small tree (crape myrtle) over a 40-year period was $9 (no infrastructure repair costs), while the tree produced average annual benefits valued at $10 (McPherson et al. 1999). In contrast, the large tree (*Platanus acerifolia*, London plane) costs considerably more to maintain ($21 per year total, $3 per year for infrastructure repair) but produced average annual benefits valued at $69.

CONCLUSIONS

Conflicts between street tree root growth and hardscape are constraining the development of healthy and productive urban forests in California. Millions of dollars that could be better spent improving tree health are spent on hardscape repair and damage mitigation. To some extent, these conflicts are also expressed as a "downsizing" of California's urban forest and a loss of benefits associated with diminished tree canopy cover. Community foresters make valiant efforts to extend the useful lifespan of problem trees, but conflicts with hardscape often result in the premature removal of trees, which engenders anger and sense of loss among residents. Furthermore, some property owners who are required pay for repairs may refuse replacements, thereby contributing to the loss of canopy and erosion of support for community forestry.

The problem is complicated; solutions need to address the science of tree root growth and infrastructure engineering, as well as urban forest policy and management. The former issues were addressed under three types of strategies at a recent symposium: soil and root management that direct roots away from the infrastructure, site and planting designs that minimize potential for root–infrastructure contact, and infrastructure engineering that creates materials that withstand root damage (Costello et al., in press). Policy and management issues relate to the structure and function of municipal governments. For example, the tree program budgeting process is more closely tied to controlling management costs than maximizing the potential benefits that trees can produce. If the budgeting process were performance based and provided incentives for expanding a city's tree canopy cover as well as controlling management costs, there could be more for support for retrofitting existing planting sites and designing new sites that support large-statured trees. Greater coordination is needed between street or public works departments that repair damage and community forestry departments that manage trees. Utilizing a common database that includes information on both trees and the adjacent infrastructure could provide a practical focus for collaborative management. Similarly, greater collaboration is needed between community forestry and planning departments to develop landscape ordinances and review site plans with the common goal of reducing future conflicts while magnifying benefits from a growing urban forest.

Conflicts between tree root growth and hardscape cost Californians economically, environmentally, aesthetically, and socially. Not only are millions of dollars spent to remedy the problem, but sometimes the remedies result in the loss of other benefits that healthy, large-statured shade trees could be providing. Clearly, this is a lose-lose situation that calls for increased collaboration in the management of the gray and green infrastructure, as well as research and development of cost-effective strategies to retain benefits from a healthy street tree population while reducing costs associated with root-sidewalk conflicts.

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Résume. Une enquête dans 18 villes de Californie indique que 70,7 millions de dollars sont dépensés annuellement dans l'ensemble de l'état pour les conflits entre la croissance des racines d'arbres de rues avec les trottoirs, les bordures de ciment le long des rues et le pavage des rues. Le plus gros des dépenses va pour la réparation des trottoirs (23 millions de dollars), suivi de celle des bordure de ciment (11,8 millions de dollars), et pour les paiements lors de chutes après avoir trébuché et les frais légaux inhérents (10,1 millions de dollars). Les propriétaires résidentiels paient respectivement 39% et 17% des coûts de réparation des dommages aux trottoirs et aux bordures de ciment par les arbres. Des fonds importants ont été investis pour abattre et remplacer les arbres en conflit avec ces infrastructures (6,8 millions), ainsi que pour l'inspection et l'administration des programmes de réparation (5,9 millions). La coupe des racines (2,5 millions) et la pose de barrières racinaires (676854 $) sont les deux plus importantes mesures de mitigation et de prévention. Les espaces de plantation restreints et l'espèce de l'arbre planté sont les deux principaux facteurs responsables des dommages aux infrastructures.

Zusammenfassung. Eine Studie aus 18 kalifornischen Städten zeigte, daß jährlich schätzungsweise $ 70.7 Millionen (se $11.1 Mill.) im ganzen Bundesstaat für Schäden durch Baumwurzeln an Straßenbelag, Gehwegen, Abflußrohren usw. ausgegeben werden. Die größte Einzelausgabe war für Gehwegreparatur ($23 Millionen, se $9.5 Millionen), gefolgt von Abflußrohrreparatur ($11.8 Mill., se $2.6 Mill.) und Zahlungen für Beschäftigte ($10.1 Mill., se$2.2 Mill.). Die Eigentümer zahlten 39 % und 17 % der baumverursachten Schäden an Gehwegen und Abflußrohren. Erhebliche Mittel wurden investiert, um Bäume, die im Konflikt mit der Bebauung stehen, zu entfernen und zu ersetzen ($6.8 Mill., se $3.6 Mill.) und für Bauminspektionen und Administrationsprogramme ($5.9 Milll., se$1.3 Mill.). Der Rückschnitt von Wurzeln ($2.5 Mill., se 2.0 Mill.) und Wurzelbarrieren ($676.854, se $175.665) waren die wichtigsten Präventionsmaßnahmen. Der begrenzte Pflanzraum und die Art der ausgewählten Bäume sind dem Report zufolge dier wichtigste Faktor bei den Schäden an der Bebauung.

Resumen. Una encuesta de 18 ciudades de California, U.S.A. indicó que aproximadamente $70.7 millones (se $11.1 millones) fueron gastados anualmente por todo el estado debido a conflictos con las raíces de los árboles que crecen en las calles y las aceras, guarniciones, cunetas, y calles pavimentadas. El más grande desembolso individual fue por reparación de aceras ($23 millones, se $9.5 millones), seguido por reparación de guarniciones y cunetas ($11.8 millones, se $2.6 millones), caídas, fletes y tiempo del staff ($10.1 millones, se $2.2 millones). Los dueños de las propiedades pagaron 39% y 17% de los costos de reparación del árbol-acera y guarnición-cuneta, respectivamente. Se invirtieron fondos considerables en remover y reemplazar árboles en conflicto con el pavimento ($6.8 millones, se $3.6 millones), y por administración de programas de inspección y reparación ($5.9 millones, se $1.3 millones). La poda de raíces ($2.5 millones, se $2.0 millones) y las barreras de raíces ($676,854, se $175,665) fueron las medidas más importantes de mitigación y prevención. Se reportaron los espacios restringidos de plantación y el tipo de especie seleccionada como los factores más importantes responsables por los daños al pavimento.