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Sacramento's parking lot shading ordinance: environmental and economic costs of compliance

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Abstract

A survey of 15 Sacramento parking lots and computer modeling were used to evaluate parking capacity and compliance with the 1983 ordinance requiring 50% shade of paved areas (PA) 15 years after development. There were 6% more parking spaces than required by ordinance, and 36% were vacant during peak use periods. Current shade was 14% with 44% of this amount provided by covered parking. Shade was projected to increase to 27% (95% CI 24–37%) when all lots in the sample were 15-year-old. Annual benefits associated with the corresponding level of tree shade were estimated to be US$ 1.8 million (CI US$ 1.5–2.6 million) annually citywide, or US$ 2.2 million less than benefits from 50% shade (CI US$ 1.4–2.5 million). The cost of replacing dying trees and addressing other health issues was US$ 1.1 million. Planting 116,000 trees needed to achieve 50% shade was estimated to cost approximately US$ 20 million. Strategies for revising parking ordinances to enhance their effectiveness are presented. Published by Elsevier Science B.V.

Keywords: Planning; Tree shade; Natural resource valuation

1. Introduction

Planners who write parking lot ordinances balance the need for parking with other community goals such as a more compact urban form, enhanced urban design, and an improved environment. Communities want businesses to provide adequate on-site parking to prevent spillover parking in surrounding neighborhoods, reduce traffic congestion on public streets, and promote economic development. However, providing adequate parking can conflict with other goals when large surface parking lots contribute to drainage and flooding problems, increase urban heat islands, create "eyesores", or encourage people to abandon mass transit, thereby, accentuating air quality problems (Smith, 1988).

Parking lots occupy about 10% of the land in our cities and as cities build outward parking is expected to cover relatively more area (Schiavo, 1991; Wells, 1995). To size parking lots planners use parking demand ratios that specify the minimum and, in some cases, the maximum number of spaces per gross square foot of leaseable floor area (GFA) or dwelling unit (DU) (Bergman, 1991). Parking ratios have been based on surveys of parking rates (Institute of Transportation Engineers, 1987), and result in parking built to handle peak demand, for example, the number of cars that will use a shopping mall on weekends between Thanksgiving and Christmas. Parking lot standards specify minimum stall and aisle dimensions, landscaping, lighting, and signage requirements (ULI-NPA, 2000).

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The 1970s energy crisis spurred implementation of parking lot shading ordinances in cities such as Sacramento, Davis, Los Angeles and California. These ordinances required that 50% of the total paved area (PA) be shaded within 15 years of the issuance of development permits. Tree List contains the 15 years crown diameter and crown projection area (i.e. area under a tree's dripline) of species recommended for planting, data used by planners to calculate PA that would be shaded under each tree. Many parking lot ordinances specify one tree for a certain number of parking spaces or a certain amount of landscaped area per space, but trees can be clustered in islands or along the parking lot perimeter, often resulting in large areas of unshaded pavement (Beatty, 1989). The Sacramento ordinance, adopted in 1983, is a performance standard that ensures a distribution of shade throughout the lot. It has not been evaluated or amended since its inception. Examples of the Sacramento and Davis ordinances are available on the Internet (http://cufr.ucdavis.edu/parkordinance.htm and shaderevised.htm).

Sacramento is one of several US cities in the Cool Communities Program. The goal of this program is to improve air quality by lowering summertime temperatures through tree planting and light-colored surfacing. In Sacramento, where summer temperatures exceed 32.2 °C an average of 73.6 days per year (Western Regional Climate Center, 2000), tree planting is one of the most cost-effective means of mitigating urban heat islands and associated expenditures for air conditioning (Huang et al., 1987; Akbari et al., 1992; Simpson and McPherson, 1998). Trees are considered essential to moderating the heat gained by asphalt parking lots (Asaeda et al., 1996). Cooler air temperatures reduce ozone (O_3) concentrations by lowering emissions of hydrocarbons (HCs) that are involved in O_3 formation. For instance, trees in a Davis, CA, parking lot reduced air temperatures 0.5–1.5 °C (Scott et al., 1999), which in turn reduced HC emissions from gasoline that evaporated out of leaky fuel tanks and worn hoses. Planting trees in parking lots throughout the Sacramento region so as to achieve 50% shade on PAs was estimated to reduce HC emissions by 0.9 tonnes per day, comparable to the levels achieved through some of the local air quality district's currently funded programs (e.g. graphic arts, waste burning, vehicle scrappage). Results from other modeling studies indicate that air quality benefits associated with pollutant uptake and climate modification by urban forests can be substantial (Taha, 1996; McPherson et al., 1998; Rosenfeld et al., 1998; Nowak et al., 2000).

Reducing the amount of parking-related impervious surface can reduce the volume of polluted run-off, and the size and costs of stormwater facilities needed to store and treat the run-off (Ferguson and Debo, 1990; Arnold and Gibbons, 1996; Schueler, 1997). The quantity of pollutants in parking lot run-off is related to vehicular traffic, vehicle condition, and atmospheric deposition. Parking lot run-off has relatively high concentrations of trace metals, oil, and grease (Bannerman et al., 1993; Hahn and Pfeifer, 1994).

Given the many benefits associated with parking lot shade and anecdotal evidence that the amount of shading stipulated in the 16-year-old Sacramento ordinance was not being attained, this study was designed to answer the following policy and planning questions.

1. Are current parking demand ratios adequate?
2. Are requirements for parking lot shade being met, and if not, why?
3. What are the environmental and economic costs of compliance and non-compliance?
4. How can the ordinance and its implementation be modified to increase effectiveness?

2. Methods

Tasks undertaken in this study are illustrated (Fig. 1) and described in this section.

2.1. Citywide parking lot assessment

Data from interpretation of a 1992 black and white aerial photograph of Sacramento (print scale 1:6857) were used to describe the relations among parking lots, impervious services, and land uses. Random dots (5262) were laid on photos for the entire city (249 km^2) and the point below each dot was classified by land-use type and cover type (i.e. parking lot) (US Forest Service, 1997).

2.2. Parking capacity analysis

Parking ratios were obtained from the city ordinance (City of Sacramento, 1992). Multi-family

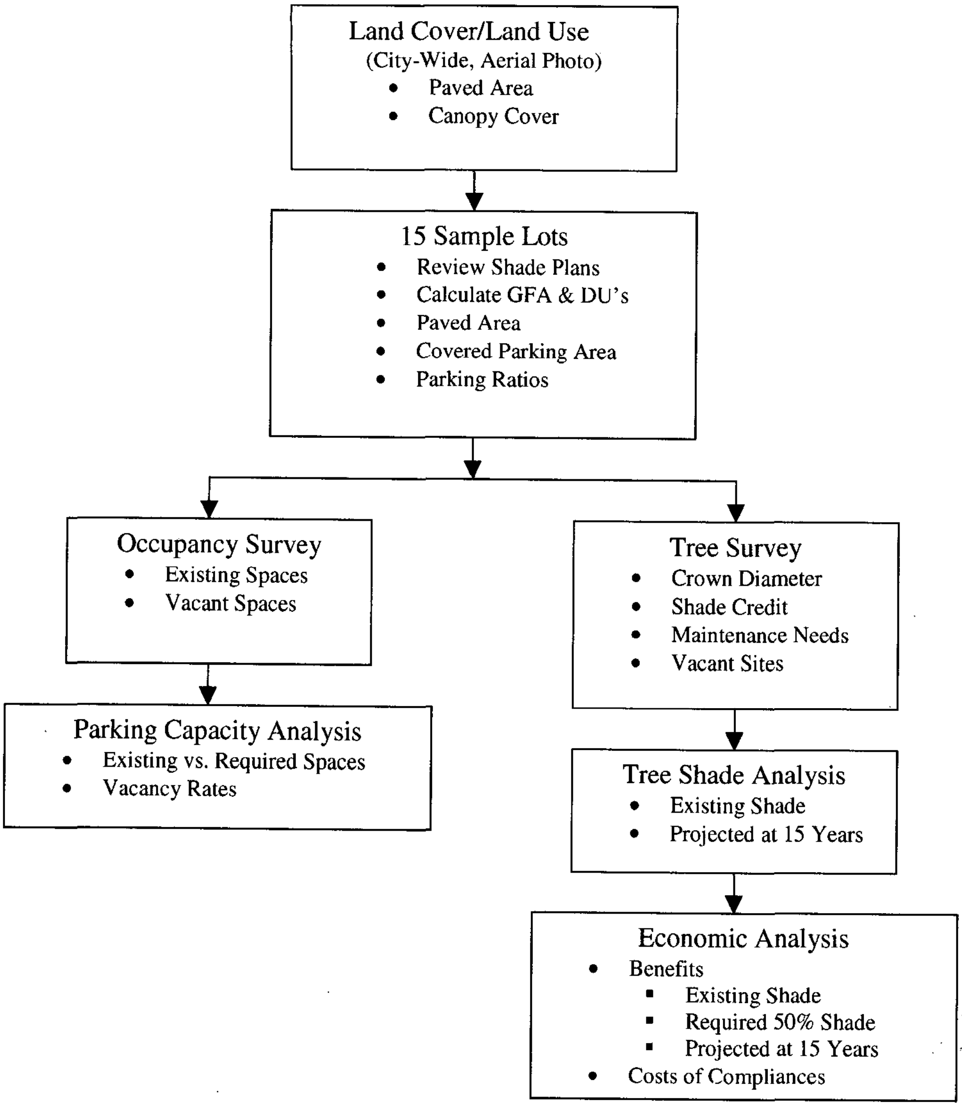

Fig. 1. Tasks and data collected for this study.

residential (apartment) lots were required to have 1.5 spaces/DU and 1 guest space/15 DUs. The parking requirement for retail stores was one space for each 23.2 m^2 (250 ft^2) of GFA. A new shopping center with theater (Laguna Village) was designated a planned unit development and required to provide a minimum and maximum of one space/92.9 m^2 (1000 ft^2) and 46.5 m^2 (500 ft^2) of GFA, respectively as well as one space/six theater seats. The ordinance also establishes a minimum and maximum for offices of one space/37.2 m^2 (400 ft^2) and 23.2 m^2 (250 ft^2) of GFA, respectively. GFA and the number of DUs were obtained from site design plans and property managers. The number of required parking spaces was calculated and the number of actual spaces were counted in each lot. A survey was conducted between 30 November and 26 December 1999 to count vacant spaces during peak use periods. Apartment and office lots were surveyed on week days, the former between 00:00 and 2:00 h and the latter from 9:30 to 11:00 h and 13:30 to 15:00 h. Retail lots were surveyed at least twice, a week day from 16:00 to 18:30 h and a weekend day from 13:30 to 16:30 h. The number of vacant spaces are reported when parking occupancy was highest.

2.3. Tree survey and shading analysis

A random sample of 15 parking lots was selected by the City of Sacramento Planning Department staff. During summer 1999 the trees in each lot were surveyed to obtain the following information: species, diameter at breast height (dbh, to nearest 0.1 cm by tape), average crown diameter (two radii measurements at 90° to the nearest 0.5 m by tape), shade credit (SC or percentage of crown that shades parking lot pavement to the nearest 25% excluding overlapping shade), management needs, and vacant planting sites.

PA was calculated as the average of three measurements taken off the site plan with a planimeter. Covered parking area (CPA) was measured off site plans and field checked. Adjusted paved area (APA) was calculated as PA − CPAand represents the area where trees could be planted for shade. Required shaded area (RSA) was defined as 50% of the PA. The effective tree shaded area (ETSA) was calculated for each tree i as

$$\mathrm{ETSA}_i = \mathrm{TSA}_i \times \mathrm{SC}_i \qquad (1)$$

where tree shaded area (TSA_i) is the area under the dripline of tree i. TSA was calculated with measured average crown diameter assuming a circular crown. Actual shaded area (ASA) for parking lot j was defined as the amount of PA shaded at the time of the survey and calculated as

$$\mathrm{ASA}_i = \mathrm{CPA}_i + \sum_{i=1}^{n_j} \mathrm{ESTA}_{ji} \qquad (2)$$

The means and standard deviations (S.D.) of CPA, ETSA, and ASA were calculated for the 15 lot sample.

Projected tree shaded area (PTSA) was estimated at 15 years after planting for trees in lots less than 15-year-old. Each tree was "grown" to it's projected crown diameter 15 years after planting using annual dimensional data for street trees in nearby Modesto, CA (Peper et al., in press). The Modesto data were derived from a sample of 616 trees representing 22 species and dimensions were available for seven of the eight most abundant species in the Sacramento parking lots. In cases where dimensional data for the species were unavailable, dimensions from a species with comparable mature size and growth rate were applied. The crown diameter at 15 years after planting was estimated by adding the increment of growth for the period of years remaining until it reached 15 years. Inventoried crown diameter dimensions were directly applied for trees in lots that were 15 and 16-year-old. The total amount of TSA projected 15 years after development was calculated for each tree_i in lot_j as

$$\sum_{i=1}^{n_j} \mathrm{PTSA}_{ji} \times \mathrm{SC}_{ji} \qquad (3)$$

Variability of this estimated parameter was calculated using the 95% confidence limits for each species (Peper et al., in press).

2.4. Economic analysis of tree shade

An economic analysis was conducted to estimate the value of benefits associated with (1) 50% tree shade, as per the ordinance, (2) amount of tree shade typically achieved after 15 years under current conditions (PTSA) and (3) amount of tree shade that exists at present (ETSA). Because the effects of shade from covered parking on energy, air quality, hydrology, and aesthetics are unknown they were excluded from this analysis.

Annual benefits were estimated from results of the Sacramento Urban Forest Ecosystem Study (SUFES) on a unit tree canopy cover (CC) basis. SUFES combined aerial photo analysis and ground sampling of vegetation to characterize urban forest cover, species composition, age structure, and condition (McPherson, 1998a). This information was combined with hourly data on local meteorology, air pollutant concentrations, and other information in computer models to simulate impacts of the urban forest on environment.

To ascribe dollar values to benefits, air conditioning savings were directly estimated, while air quality, stormwater run-off, and other benefits were implied. Implied valuation is used to price society's willingness to pay for environmental services not directly priced by market transactions. Because trees are not paid for pollutant uptake their air quality benefits are estimated using prices that reflect the costs of reducing stationary source emissions in the Sacramento region (SMAQMD, 1993). If it is cost-effective for a corporation to pay US$ 1/kg to reduce future emissions, then

Table 1
Metrics for estimating the value of benefits from parking lot tree shade in Sacramento

	RU/m^2 CC[a]	Price (US\$/RU[b])	Value (US\$/m^2 CC)
Air conditioning (kWh)	0.80	0.08	0.064
CO_2	3.10	0.03	0.102
Stormwater (m^3)	0.02	0.83	0.020
Aesthetic (retail)			0.154
Aesthetic (office/apartment)			0.175
O_3	4.01	27.01	0.108
PM_{10}	4.10	11.68	0.048
NO_2	1.13	27.01	0.030
SO_2	0.15	20.17	0.003
HC avoided	5.92	19.29	0.114
HC released	0.90	19.29	0.017
BVOC (low)	0.09	19.29	0.002
BVOC (medium)	0.86	19.29	0.017
BVOC (high)	4.28	19.29	0.083

[a] All resource units (RU) in g/unit CC unless otherwise noted.
[b] All prices in US$/kg unless otherwise noted.

the air pollution mitigation value of a tree that absorbs or intercepts 1 kg of air pollution should be US$ 1. Costs for tree planting and care were obtained from a municipal urban forest benefit–cost analysis (McPherson et al., 1999).

The annual rate of dry deposition of gaseous pollutants (O_3, nitrogen dioxide (NO_2), sulfur dioxide (SO_2)) to the tree canopy was estimated, as was interception of particulate matter (PM_{10}). For example, 3078 ha of existing CC (1.73 million trees) in the City of Sacramento was estimated to remove 34.7 metric tonnes of NO_2 pollutant annually, or 1.1 g/m^2 CC (Scott et al., 1998). The implied value of this benefit was estimated as US$ 0.03/m^2 CC given the control cost (US$ 27,007/tonne) (Table 1). Annual uptake rates and implied values were calculated in the same manner for other criteria pollutants.

Simpson (1998) found that 467 ha of existing CC in Sacramento's small commercial and industrial lands reduced summer air conditioning from 314 to 297 GWh, with savings of 17 GWh attributed to air temperature reductions. In this study it is assumed that trees do not shade buildings during summer and impacts on winter heating are negligible. Given current parking lot CC of 8.2 or 0.4% citywide (US Forest Service, 1997), increasing parking lot cover to 50% will result in a 2.2% increase in citywide CC. Previous studies indicate that a 10% increase in tree cover is associated with a 1 °C air temperature reduction and this results in a 6.7% reduction in commercial/industrial air conditioning consumption (Simpson, 1998). Therefore, a 2.2% increase in CC (536 ha) is estimated to reduce air temperature 0.21 °C, thereby, reducing air conditioning use by 1.4% or 4.28 GWh. This savings translates into 0.8 kWh/m^2 CC. Electricity sold to the commercial sector is priced at US$ 0.081/kWh.

McPherson (1998b) reported that Sacramento's existing urban forest reduced atmospheric carbon dioxide (CO_2) by 103 tonnes per year. Trees sequestered 74 tonnes, provided avoided power plant emissions through energy savings in the amount of 33 tonnes, and 4 tonnes were released through tree care activities (e.g. chain saws, chippers, vehicles). This analysis assumes that parking lot trees have the same annual sequestration (2.4 kg/m^2 CC) and release rates (0.1 kg/m^2 CC) per unit of CC as the average for trees throughout Sacramento. The avoided emission rate accounts for the tree-related parking lot air conditioning savings, as well as the Sacramento Municipal Utility District's emission factor of 400 tonnes CO_2/GWh. The average annual avoided emissions rate is 0.8/kg m^2 CC and the net CO_2 reduction is 3.1 kg/m^2 CC (Table 1). The implied value of CO_2 reduction is US$ 0.03/kg (California Energy Commission, 1994).

Using a numerical interception model Xiao et al. (1998) estimated that 1.73 million trees in Sacramento reduced 728,500 m^3 of annual stormwater run-off by storing 23.5 mm of rainfall in the urban forest canopy. Annual interception for the largely deciduous canopy was 0.024 m^3/m^2 CC, a relatively small amount due to the winter rainfall pattern when most trees are leafless. Sacramento's Department of Utilities requires that parking lots be designed to retain the first 19 mm of run-off on-site for flood control and water quality protection. Expenditures for two common best management practices were annualized to estimate the implied value of rainfall intercepted by parking lot trees. The capital cost of an infiltration basin and vegetated swale designed to retain 19 mm of run-off on a 2 ha site in a US$ 6.5 million commercial project was US$ 17,550 and the annual maintenance cost was US$ 1350 (California Regional Water Quality Control Board, 2000). The total cost for a 10-year-period was US$ 31,050. Average annual rainfall in Sacramento is 393 mm and an analysis of the distribution of rainfall by event indicates that approximately 50% of this would be treated by the basin and swale, the remainder falling during events that exceed the system's capacity, or during small events that generate a negligible amount of run-off. The volume of rainfall treated was 37,347 m^3 and the control cost was US$ 0.83/m^3 of run-off (Table 1).

Scott et al. (1998) reported that increasing parking lot tree CC in Sacramento to the 50% standard would reduce evaporative HC emission reductions from parked cars by 0.96 g/car per day. Based on a comparison of BVOC emissions peak per day and per year, an average annual reduction of 192 g was calculated assuming emissions occurred 180 days per year (May–October). A large tree (12 m crown diameter) can nearly shade eight facing spaces, each 5.8 m × 2.4 m. Research indicates that as air temperatures increase the occupancy rate of shaded spaces increases (Elliott, 1986). Therefore, this analysis assumes that a large tree shades four cars (50% stall occupancy), producing a benefit of 691 g/tree per year or 5.9 g/m^2 CC (Table 1).

The annual release of biogenic volatile organic compounds (BVOCs) was estimated for each tree because these HCs are involved in O_3 formation. Each tree species was categorized based on hourly isoprene and monoterpene emission rates normalized to a per tree basis: low emitter 0.1 g/tree per day (0.086 g/m^2 CC), medium emitter 1 g/tree per day (0.86 g/m^2 CC), and high emitter 5 g/tree per day (4.28 g/m^2 CC) (Benjamin et al., 1996) (Table 1). BVOC emissions were estimated for 100 days per year (July–September) and priced at US$ 19.29/kg for HCs.

Chain saws and chippers release HCs during operation. It takes approximately 30 min to prune a large tree (46 cm dbh) with a 33 cm^3 chain saw at 50% load and this results in 145 g HC emissions (Martin Fitch, Sacramento Tree Services Division, personal communication). To chip the pruned wood takes a chipper (65 hp, four-stroke, gas powered) approximately 15 min operating at 50% load and results in 65 g HC emissions. Assuming the parking lot trees are pruned biannually the average annual HC emissions is 0.105 kg/tree or 0.9 kg/m^2 CC (Table 1).

Some of the benefits associated with trees in commercial settings are difficult to translate into economic terms. Survey research found that consumer preference ratings increased with the presence of trees in the commercial streetscape and well-landscaped business districts had significantly higher priced goods and increased patronage compared to a no-tree district (Wolf, 1999). A study of change over a 25-year-period for 30 San Jose area shopping centers found a high degree of association between urban tree cover and the presence of high-end offerings of goods and services (Ellefsen et al., 1998). Most of the obviously successful shopping centers and downtowns had many trees, while the least successful had few trees.

Lacking research that directly links parking lot tree cover to economic indicators of value such as selling price, rents, leases, and occupancy rates, this study adjusts the results of research that compared differences in sales prices of residential properties to statistically quantify the amount of difference associated with trees. Anderson and Cordell (1988) surveyed 844 single family residences and found that each large front yard tree was associated with a US$ 336 increase in sales price or nearly 1% of the average sales price of US$ 38,100 (in 1978 US$). In this study the 1% of sales price figure is adjusted downward because trees can create more conflicts in commercial, office, and multi-family residential properties than in single family properties. For example, in retail settings trees can screen signs, storefronts, and window displays. Trees reduce usable outdoor space and their debris can dirty sidewalks, parked cars, and pedestrians. Trees in cutouts or small tree wells can buckle sidewalks and crack curbs, in the process creating trip and fall hazards. The crowns of trees can grow into pole-mounted lights, thereby, reducing nighttime illumination and personal security.

The median sales price of residential properties in Sacramento was US$ 109,000 (California Association of Realtors, 1999). The value of a large tree that adds 1% to the sales price of such a property is US$ 109,000. Assuming the large front yard tree has a 12 m crown diameter and is 40-year-old the annualized benefit per unit CC is US$ 0.23/m^3 CC. This value was multiplied by 0.75 for office and multi-family residential land uses and by 0.66 for retail land uses. Reduction factors were arbitrarily determined after discussion with local real estate agents and they reflect the observation that trees contribute more to the value of office and apartment properties than retail properties. Thus, the average annual aesthetic benefit for a parking lot tree on retail property was US$ 0.15/m^2

CC, and US\$ 0.18/m^2 CC for a tree on office and multi-family residential property (Table 1).

The economic value of annual benefits produced by a tree y_i with dimensions measured or anticipated 15 years after planting was calculated as

$$\mathrm{PAN}_{ji} = (e + a + c + h + o) \times \mathrm{PTSA}_{ji} \quad (4)$$

where e is the implied value (Table 1) of air conditioning benefits (US\$/kWh m^2 CC); a the implied value of each air pollutant (US\$/kg m^2 CC); c the implied value of net carbon dioxide reduction (US\$/kg m^2 CC); h the implied value of stormwater run-off reduction (US\$/m^3 m^2 CC); o is the implied value of aesthetics and other benefits (US\$/m^2 CC).

The benefits produced by each tree i in lot j were summed to capture the total value of annual benefits PAB_j assuming tree dimensions typically achieved after 15 years. Total annual benefits PAB were summed for the 15 lot sample and this result was scaled up to the city using the ratio of paved parking lot area in the sample to paved parking lot area in Sacramento (2%).

The ratio of total PAB to total PTSA served as the basis for calculating the total annual value of benefits assuming existing tree dimensions EAB, and for the 50% tree shade scenario RAB as

$$\mathrm{EAB} = \mathrm{ETSA} \times \frac{\mathrm{PAB}}{\mathrm{PTSA}} \quad (5)$$

$$\mathrm{RAB} = 0.50 \times \mathrm{APA} \times \frac{\mathrm{PAB}}{\mathrm{PTSA}} \quad (6)$$

Citywide results were similarly inferred from the sample totals. Measures of variability rely on variances in the amount of shade per unit PA for EAB and 95% confidence limits of tree crown diameter estimates for PAB.

3. Results

3.1. Citywide parking lot assessment

Aerial photo analysis indicated that 38% (9580 ha) of the city was covered with impervious surfaces, 48% (11,850 ha) pervious surfaces, and 14% (3512 ha) tree CC. Parking lots accounted for 13% (1280 ha) of the city's total impervious surfaces, with the remainder being roofs (40%), streets/walks (31%), and other (15%) impervious surfaces. As expected, parking lots themselves were largely impervious pavement (91%), with 7% tree canopy and 1% other pervious landscaping materials. Approximately 70% (976 ha) of total parking lot area was associated with commercial/industrial land uses, 16% (228 ha) with institutional land uses, and 11% (156 ha) with multi-family residential land uses. Citywide, parking lots occupied 5.6% (1403 ha) of the total land area.

3.2. Sample parking lots

The 15 sample parking lots contained a diverse mix of types, ages, and sizes (Table 2). Six lots were retail shopping centers, six were office uses, and three were multi-family residential units. Five lots were 15 or 16-year-old, and thus, supposed to provide 50% shading of PAs. Four lots were 11–14-year-old. The remaining six lots were one to 7-year-old. Six lots contained 100–300 spaces, five had 301–600 spaces, two had 601–900 spaces, and two had 901–1247 spaces. The sample contained 28.7 ha of PA, or 2% of the citywide total parking lot PA. Covered parking occurred on all three apartment lots occupying 1.8 ha (6.3%) of PA. Two office lots (Cal Farm and Tribute) had parking underneath the buildings. Based on discussion with Planning Department Staff, the portion of PA under buildings was excluded from the shading analysis, while these parking spaces were included in the parking capacity analysis.

3.3. Parking capacity analysis

The total number of existing parking spaces for the 15 lots sample (7271) was 6% more than the number required (6836), assuming the maximum numbers for seven lots with both minimums and maximums specified (Table 3). Ten lots had more spaces than required and excess spaces totaled to more than 20% of the number required in six of these lots. Five lots had fewer spaces than the maximum required. One lot (Riverlake) had a 24% parking deficit. There was little systematic variation in surplus and deficit parking by lot size or age.

Sacramento's parking ordinance limited the maximum number of spaces for six office lots and one PUD lot. The number of existing spaces fell within the range specified by ordinance in three of the seven lots.

Table 2
Information on the sample lots

Lot	Type	Age (years)	PA[a] (ha)	GFA[b]/DUs (m^2)
Kaiser	Office	4	3.0	21367
Arden	Office	14	1.2	12939
Campus	Office	16	0.8	7209
Cal Farm	Office	2	0.8	9222
Sutter	Office	15	0.6	3623
Tribute	Office	15	0.1	2290
Costco	Retail	4	3.7	13055
Home Depot	Retail	3	1.9	11713
Promenade	Shopping center	12	1.7	12636
Laguna	Shopping center	1	6.9	7143
Riverlake	Shopping center	11	1.6	6214
Norwood	Shopping center	8	0.7	6322
Tameron	Apartment	15	3.5	796
Hidden Lake	Apartment	15	1.6	190
Landing	Apartment	13	0.6	145
Total			28.7	

[a] PA: paved area.
[b] GFA: gross square foot of leaseable floor area and number of DUs for apartments.

Four lots had more existing spaces than the maximum number allowed. Laguna Village had 45% more spaces than the maximum allowed.

A total of 36% (2593) of the existing spaces were vacant when surveyed during peak occupancy periods (Table 3). Vacancy rates were near or above 50% for four lots (one office, two retail, one apartment lot) and less than 25% for three lots (one office, retail, and apartment lot). Vacancy rates at retail lots were relatively high (32–66%), except for the Costco lot (21%).

Inference from the sample indicates that there were approximately 351,000 parking spaces in Sacramento,

Table 3
Numbers of required and existing parking spaces and number of vacant spaces during peak use periods

Lot	Required spaces		Existing spaces	Difference from maximum required (%)	Number of vacant spaces	Vacant spaces (%)
	Minimum	Maximum				
Kaiser	575	828	840	1.4	292	34.8
Arden	348	506	374	−26.2	155	41.4
Campus	194	279	232	−17.0	81	34.9
Cal Farm	248	357	251	−29.8	138	55.0
Sutter	98	142	184	29.7	31	16.8
Tribute	62	90	108	20.5	36	33.3
Costco	562	0	759	35.0	161	21.2
Home Depot	504	0	528	4.7	262	49.6
Promenade	544	0	591	8.6	220	37.2
Laguna	638	711	1029	44.7	404	39.3
Riverlake	268	0	204	−23.8	65	31.9
Norwood	272	0	327	20.1	216	66.1
Tameron	1247	0	1180	−5.4	277	23.5
Hidden Lake	298	0	436	46.5	99	22.7
Landing	227	0	228	0.4	156	68.4
Total	6085	2914	7271	6.0	2593	35.7

Table 4
Shading analysis[a,b]

Lot	CPA (ha)	CPA as % of PA	ETSA (ha)	ETSA as % of PA	ASA (ha)	ASA as % of PA	PTSA (ha)	PTSA as % of PA	PSA (%)
Kaiser			0.1	2.7	0.1	2.7	0.7	21.8	21.8
Arden			0.3	23.5	0.3	23.5	0.3	25.1	25.1
Campus			0.2	23.9	0.2	23.9	0.2	23.9	23.9
Cal Farm			0.0	3.6	0.0	3.6	0.4	48.7	48.7
Sutter			0.1	18.5	0.1	18.5	0.1	18.5	18.5
Tribute			0.0	30.9	0.0	30.9	0.0	30.9	30.9
Costco			0.1	2.6	0.1	2.6	0.7	18.0	18.0
Home Depot			0.0	2.1	0.0	2.1	0.6	29.3	29.3
Promenade			0.2	11.6	0.2	11.6	0.3	15.0	15.0
Laguna			0.1	2.0	0.1	2.0	1.5	22.3	22.3
Riverlake			0.1	3.6	0.1	3.6	0.1	6.5	6.5
Norwood			0.1	14.2	0.1	14.2	0.2	30.7	30.7
Tameron	1.2	34.9	0.4	12.2	1.7	47.1	0.4	12.2	47.1
Hidden Lake	0.4	27.9	0.4	27.4	0.9	55.3	0.4	27.4	55.3
Landing	0.1	22.3	0.1	18.7	0.2	41.0	0.1	20.6	42.9
Total	1.8	6.3	2.3	8.1	4.1	14.4	6.0	20.9	27.3
Mean (upper CI)	0.60	28.4	0.16	13.2	0.28	18.8	8.8	30.5	36.8
S.D. (lower CI)	0.56	6.3	0.13	10.2	0.44	17.8	5.0	17.5	23.8

[a] Upper and lower confidence intervals (95%) apply to estimates of PTSA and PSA only. Mean and S.D. are listed for other parameters.
[b] CPA: covered paved area; PA: paved area; ETSA: effective tree shade area (PA shaded at present); ASA: adjusted shade area (PA − CPA); PTSA: projected tree shade area at 15 years after development; PSA: projected shade area (covered + tree) at 15 years after development.

or nearly one space per resident (1999 population: 388,333). The average amount of PA per space was 40.8 m^2. Knowing that 36% of all spaces are not used during the peak-period and assuming that 25% of all spaces are "excess parking" that could be converted to impervious surfaces, it was calculated that the sample's 1818 "excess spaces" occupy 7.4 ha. City-wide, approximately 35,000 "excess spaces" occupy 141 ha.

It is important to note that this analysis assumed that the number of spaces required followed parking ratios stipulated in the ordinance. In four cases, parking ratios shown on the site plans differed from those in the ordinance. Three office sites used ratios for retail sites that increased allowable parking spaces. The Planning Commission approved changing the parking ratio for a theater in the Laguna Village shopping center from 1:6 to 1:3 seats. These actions increased the number of required spaces by 12%, from 6836 to 7640. Hence, the 7640 spaces approved for construction by Planning Department Staff exceeded the number of existing spaces (7271) by 5%.

3.4. Shading analysis

RSA (50% of PA) was 14.4 ha and ASA for all lots was 4.1 ha or 14.4% of total PA (Table 4). ETSA was 8.1% (2.3 ha) and effective crown diameter averaged only 3.9 m. The sample mean ETSA was 13% and large variance among lots was reflected in a S.D. of 10%. Five lots were 15 and 16-year-old, but only one exceeded the 50% shade requirement (Hidden Lake, 55%). Tameron apartment nearly complied, achieving 47% shade. Tree shade (ETSA) ranged from 18 to 31% in the three office lots and from 2 to 14% in the six retail lots. The role of covered parking was surprisingly important. Although only the three apartment lots had covered parking, these were the shadiest lots. CPA ranged from 22 to 35% of PA, thus, reducing the need for extensive tree shade. Covered parking in the three lots (1.8 ha) provided 44% of the total shade in all 15 lots.

After "growing" trees in lots less than 15-year-old to their projected 15 years size, tree shade (PTSA) increased from 2.3 ha (8%) to 6 ha (21%) and average effective crown diameter increased to 6 m. Lower and upper confidence limits for estimated PTSA were 5 ha (18%) and 8.8 ha (31%), respectively. With covered parking added, projected shaded area (PSA) increased to 27% (7.8 ha) from 14% (4.2 ha) ASA, still well short of the 50% goal. Only Hidden Lake (55%) was projected to achieve 50% shade, but an additional lot nearly complied (Cal Farm 49%) and two other lots were projected to shade more than 40% of PA (Tameron 47%, Landing 43%). These relatively shady lots included all three apartments and one office, but no retail lots.

On average, tree shade was projected to achieve only 21% (18–31% CI) shade after 15 years (Table 4). Younger lots were projected to achieve the most tree shade (i.e. Cal Farm 49%, Norwood 31% and Home Depot 29%). In part, this was due to application of tree growth data derived from street trees in Modesto front yards that tended to over estimate the growth of parking lot trees (see Section 4). Many large-statured trees in these younger lots were projected to produce substantial shade during the next 8–12 years. Riverlake (6% PTSA) was a notable exception. This 11-year-old lot contained many smaller growing species (crab apple, pear) that were projected to provide relatively little increase in shade during the remaining 4 years.

To better understand relations between parking lot planting design and tree shade, means and S.D. were calculated for three design parameters by lot: (1) tree density (trees/100 m^2 APA), (2) shade credit and (3) 15 years crown diameter. Tree density reflects the relative abundance of trees, whereas shade credit and crown diameter influence the amount of PA shaded by each tree.

The tree survey found 2031 tree sites and 1918 trees, or an average tree density of 0.92 (S.D. 0.35). The mean tree density for retail lots was 0.64 (S.D. 0.22), significantly lower than for office (1.13, S.D. 0.35) and multi-family residential (0.91, S.D. 0.27) lots. On the other hand, in retail lots the mean shade credit was 79.9% (S.D. 8.3%) compared to 62% (S.D. 14.8%) and 57.8% (S.D. 8.4%) for office and apartment lots, respectively. Mean crown diameters were not significantly different among the three types of lots. In summary, although retail lots had fewer trees per unit area compared to office or apartment lots, each tree crown shaded a greater percentage of PA on average. The finding that trees in retail lots produced more shade per tree is supported by the observation that retail lots tended to be larger and contain more double-loaded spaces than the other types of lots. Also, the ratio of interior to perimeter trees appeared to be greater in retail lots than office or apartment lots.

3.5. Economic analysis of tree shade

3.5.1. Projected annual benefits for sample lots

Projected annual benefit (PAB) from all trees after 15 years was projected to total US$ 36,829 (US$ 19.20/tree average). Trees in the three largest lots accounted for 47% of total benefits (Fig. 2). A total of 69% benefits were related to air quality (42%) and aesthetic improvements (27%), while remaining benefits were due to atmospheric CO_2 reduction (17%), cooling energy savings (11%), and stormwater run-off reduction (3%). Assuming that trees in the sample shaded 50% of APA as per the ordinance, required annual benefits (RAB) totaled US$ 81,722 (US$ 42.61/tree). Hence, benefits foregone due to non-compliance were valued at US$ 44,893, or 55% of total RAB (Fig. 2).

3.5.2. Benefits foregone citywide

Citywide, current CC from approximately 93,700 trees (9% APA) was estimated to produce annual benefits valued between US$ 545,000 and 853,000 with a mean of US$ 699,000. Annual benefits increased to a mean value of US$ 1.8 million (US$ 19.20/tree) with lower and upper limits of US$ 1.5 million and US$ 2.6 million, assuming tree shade increased to the amount projected when all lots were 15-year-old (22% APA) (Table 5). At 50% tree shade annual benefits were US$ 4 million. Therefore, not achieving the ordinance's 50% shade target after 15 years resulted in forgone benefits priced between US$ 1.4 million and US$ 2.5 million annually.

Current tree shade for the 15 lots sample (8% ETSA) was similar to that observed from aerial photos for the city (7%). This suggests that the amount of shade associated with the mix of old and young lots in the sample reflects that found throughout the city. The discrepancy between current shade and the 50% stipulated by ordinance corresponds to US$ 3.2–3.5 million in foregone benefits annually. Since the ordinance is over 15-year-old, a large increase in overall parking lot tree shade is not likely in the near future.

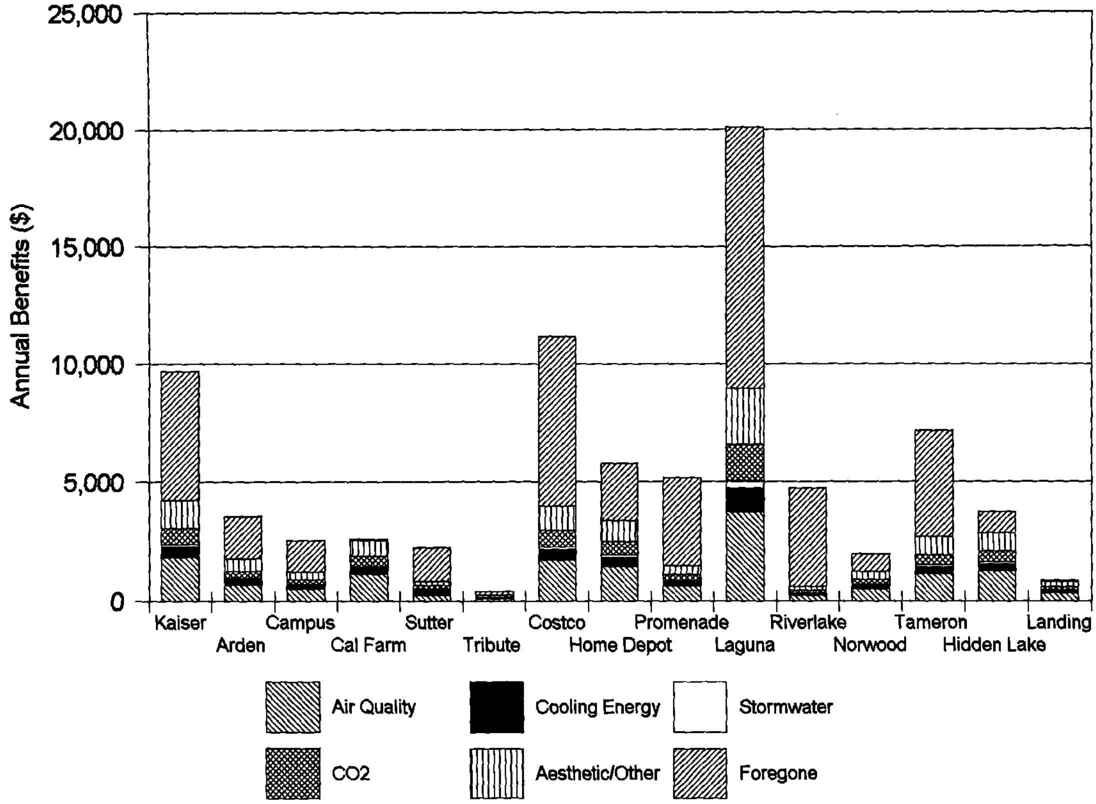

Fig. 2. PAB after 15 years by type for each sample lot and benefits foregone. Benefits foregone are the difference between RAB from 50% tree shade and PAB.

Table 5
Estimated annual benefits citywide from tree shade after trees reach dimensions projected for 15 years after planting given current design and management[a]

Benefit type	Total RU	Total US$	Average RU/tree	Average US$/tree
Air conditioning (MWh)	2347	194723	25.05	2.08
CO_2	9094	302688	0.10	3.23
Stormwater (m^3)	69084	57320	0.74	0.61
Aesthetic/other	0	479093		5.11
O_3	11793	317799	0.13	3.39
PM_{10}	12060	140498	0.13	1.50
NO_2	3313	89285	0.04	0.95
SO_2	430	8672	0.00	0.09
Total uptake	27596	556254	0.29	5.94
HC avoided	17395	332133	0.19	3.55
HC released	2642	50590	−0.03	−0.54
BVOC	3766	72654	−0.04	−0.78
Total HC	10986	208888	0.12	2.23
Grand total		1798965		19.20

[a] All resource units (RU) in kg unless otherwise noted.

The distribution of benefits were analyzed assuming trees reached their projected sizes in 15-year-old lots (Table 5). Dry deposition of air pollutants to the tree canopy totaled US$ 556,000, with O_3 uptake the single largest value (US$ 318,000). Total annual aesthetic and other benefits were US$ 479,000. Net atmospheric carbon dioxide reduction and air conditioning savings were estimated to produce combined benefits valued at about US$ 500,000. The net HC benefit was valued at US$ 208,000, with avoided evaporative emissions from motor vehicles due to tree shade (17,400 kg) nearly three times greater than the sum of BVOC emissions from trees and HC emissions associated with tree care (6400 kg). Stormwater run-off reduction attributed to rainfall interception averaged 0.74 m^3 (214 gal) per tree (US$ 57,000).

3.5.3. Costs of compliance

Greater benefits from increased tree shade will be offset to some extent by increased tree care costs. Although tree care costs were not available for this sample of parking lots, it is likely that in well-maintained lots expenditures are similar to those for street and park trees due to high amounts of public use and significant liability. California cities spent US$ 19/tree on average in 1997 (Thompson and Ahern, 2000), while the US average was US$ 4.64/tree (Tschantz and Sacamano, 1994). These costs do not fully account for other expenditures associated with trees, such as repair of pavement and curbs damaged by tree roots, litter clean-up, and property damage caused by tree failures during storms. In general, maintenance expenditures increase as the number and size of trees increase. Parking lot property managers are investing in maintenance of the existing canopy, but this investment may not be actualizing an increase in tree CC and health, as when tree crowns are headed back to reduce their size (Fig. 3).

Improving the health of existing trees and replacing removed or dying trees is a first step toward increasing CC in existing lots. The survey identified 42 trees to remove and replace and this will cost approximately US$ 13,400 (US$ 144/tree for removal, US$ 175 for replacement). Removing and adjusting staking on 235 trees will cost about US$ 1410 (US$ 6/tree), while trimming 41 trees will cost US$ 2255 (US$ 55/tree). Initially addressing other tree health problems such as

Fig. 3. Coast live oak (*Quercus agrifolia*) trimmed to control size rather than shade PAs.

trunk wounds, sparse foliage, and lack of irrigation for 620 trees will cost approximately US$ 6200 (US$ 10/tree). The total cost is US$ 23,265 for the 15 lots sample. By inference the citywide total is US$ 1.1 million. This amount is less than the US$ 1.4–2.5 million in benefits foregone annually because trees are only producing 14–27% shade after 15 years.

Although this finding provides some economic rationale for investing in restoration of tree health, such an investment may not in itself be sufficient to achieve 50% shade. For example, replacing the 42 dead or stunted trees increases CC by only 0.01% assuming an effective average 15 years crown spread of 6.3 m. To promote more extensive shade it may be necessary to increase tree numbers, provide more soil volume for tree roots, and provide information to property managers and arborists on tree care practices that increase CC.

Assuming that other investments in tree health and replacement increase shade from 9 to 22% APA, it will cost an additional US$ 20 million to plant enough trees citywide (116,000 at US$ 175 each) to achieve 50% shade. This US$ 20 million is equivalent to about 10 years of foregone benefits. Securing US$ 20 million to retrofit parking lot landscapes will require cost-sharing among stakeholders such as the local air quality district, electric utility, business community, city, and non-profit tree planting organization.

4. Discussion

Retrofitting existing parking lot landscapes will be a relatively expensive and long-term proposition. A complementary strategy that may be easier and less costly to implement is to modify the existing parking lot shade ordinance.

4.1. Plan review and tree installation

Only four of the 15 parking lots had completed shade plans. Planning staff did not require shade plans or lacked the time necessary to fully review them. A comparison of these three plans with the ordinance's Tree List and field survey results identified following several concerns to address during ordinance revision.

- Over estimated tree shade because overlapping shade was double-counted.
- Commonly used species omitted from the Tree List. Four of the seventeen species frequently observed in the sample are not on the ordinance's Tree List (Table 6).
- Incorrect crown diameters used in the plan. On two plans pear trees were incorrectly shown with diameters of 10.7 m, not 6.1 m as specified in the Tree List.
- Over stated crown diameters in the Tree List. Crown diameters measured in 14–16-year-old lots were significantly smaller for the five most common species than their corresponding dimensions cited in the ordinance (Table 6). In most cases, diameters for 15-year-old Modesto street trees were greater than measured for parking lot trees, indicating that previously cited estimates of tree shade after 15 years are liberal.
- Trees shown on the plan were not planted or removed shortly after planting, especially at sites near store fronts where trees could obstruct signs.
- Instead of trees planted as per the plan, substitute tree species were used. In one lot, palm trees and pears were substituted for larger-growing tallows.
- Parking ratios approved in planning documents allowed for more spaces than stipulated in the ordinance.

These findings suggest that updating the ordinance's Tree List to include more accurate estimates of 15 years crown diameter for a wider range of species should be a high priority. Providing planning staff with adequate time and training to review shade plans and parking ratios is essential to successful implementation of the ordinance. Although the existing ordinance requires a site check after construction to ensure consistency with the plan, inspections may not be as systematic and thorough as needed. Teaching inspectors how to identify common problems is one-way to remediate this problem. Requiring certification by the landscape architect that parking spaces and trees are located as per the ordinance and plan is another means of promoting compliance.

4.2. Site planning and design issues

Findings from this sample suggest that even during peak use periods a substantial amount of parking goes unoccupied. Reducing unnecessary impervious

Table 6
Species composition of sample trees, 15 years crown diameter specified in the Sacramento ordinance, measured means (S.D.) for 14–16-year-old trees in Sacramento parking lots, and predicted (95% confidence intervals) dimensions for street trees 15 years after planting in nearby Modesto, CA

Tree species	Sacramento lots			Ordinance 15 years crown diameter (m)	Sacramento lots		Modesto streets[a] crown diameter (m)
	Sample number	% of total	Number of lots		Number of trees	Crown diameter (m)	
Chinese hackberry	284	14.8	6	10.7	6	7.4 (1.3)	10.9 (0.7)
Southern magnolia	200	10.4	3	10.7	87	5.1 (1.5)	5.0 (0.5)
Chinese pistache	196	10.2	7	10.7	31	7.3 (2.0)	9.1 (0.6)
Chinese tallow	132	6.9	5	9.1	16	3.9 (0.8)	
Plane/sycamore	110	5.7	6	10.7	77	6.3 (2.2)	10.2 (0.8)
Holly oak	108	5.6	1	10.7			7.9 (1.0)
Bradford pear	107	5.6	6	6.1	46	6.0 (2.4)	7.9 (1.0)
Raywood ash	101	5.3	3		100	8.8 (2.5)	9.1 (0.5)
Coast redwood	77	4.0	6	7.6	77	6.1 (2.0)	
Southern live oak	66	3.4	4	10.7			
Golden rain	58	3.0	3	9.1			6.8 (0.5)
Sweet gum	55	2.9	6	6.1	32	7.0 (1.5)	5.5 (0.6)
Flowering plum	30	1.6	5	7.6	10	7.6 (1.4)	6.3 (1.0)
Crape myrtle	24	1.3	5	6.1	5	2.0 (1.9)	3.4 (0.3)
Honey locust	22	1.1	2		22	4.2 (1.7)	8.3 (1.2)
White birch	19	1.0	2		15	8.7 (1.6)	5.9 (0.4)
Chinese elm	17	0.9	2		24	9.4 (3.0)	

[a] Data adopted from Peper et al. (in press).

surfaces can produce environmental benefits. Also, parking lot environments are hostile conditions in which trees will never reach their mature size unless provided adequate space both above and below ground. During construction top soil is removed and subsoil is compacted. Debris is often disposed of in planting islands and soils can become polluted from deicing salts and run-off. A parking lot tree growing 25–60 cm dbh in 15 years requires 14–28 m^3 of soil (Urban, 1992), while the standard tree well (1.8 m × 2.4 m× 0.6 m) provides only 3 m^3. Above ground conditions are hot and arid during summer, windy and cold during winter. Strategies to promote tree growth, reduce the amount of paved impervious surfaces, and increase environmental benefits are illustrated for the Home Depot lot (Figs. 4–6) and described as follows.

- Reduce parking ratios to decrease the number of unused parking spaces.
- Identify peripheral and overflow parking areas, especially in retail lots, and determine the appropriate landscape treatment (e.g. pervious paving, stormwater infiltration areas) (Girling et al., 2000).
- Narrow the width of aisles between rows of spaces. In many cases aisle widths exceeded the standard 7.9 m.
- Increase the ratio of compact to full-sized spaces. Although Sacramento's ordinance allows for up to 40% compact spaces, only 16% of all spaces in the sample were designated for compact cars.
- Convert double-loaded full-sized spaces to compact spaces with a tree in between to increase shade without reducing the number of spaces.
- Increase use of one-way aisles, angled parking spaces, and shared parking to reduce overall imperviousness (ULI, 1983; Center for Watershed Protection, 1998).
- Increase soil volume and reduce soil compaction. Increase tree well and planting island minimum dimensions to 2.4 m. Use structural soil mix under paving to retain parking spaces while increasing soil volume (Grabosky and Bassuk, 1996). Require soil in tree wells be excavated to a depth of 1 m and amended as necessary.
- Use vegetated swales instead of tree wells or convex-shaped islands to treat stormwater, promote

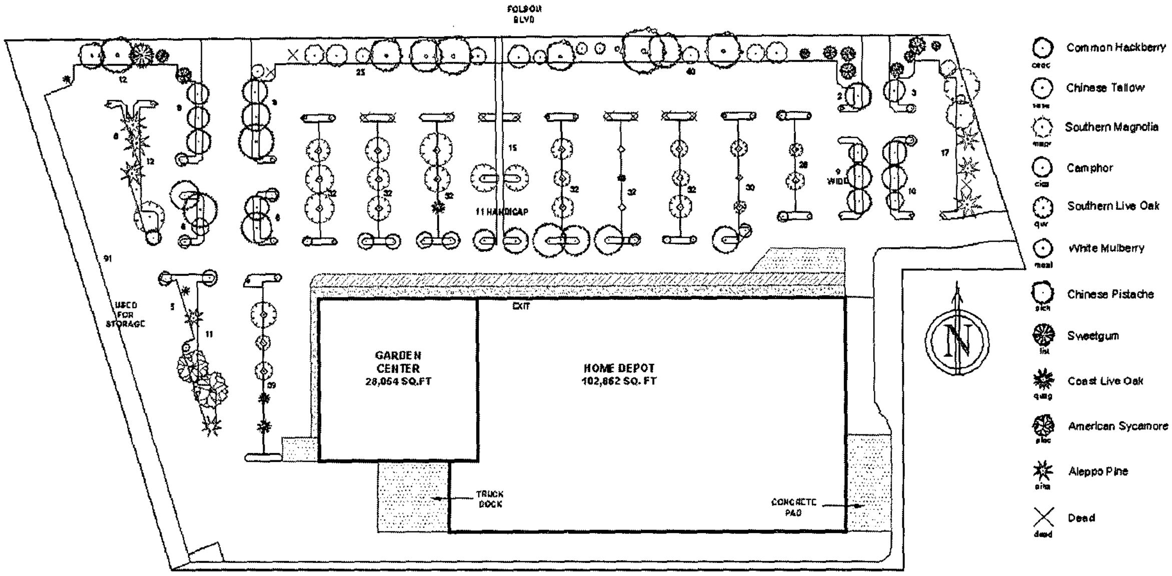

Fig. 4. Based on growth and condition at time of the survey, trees in the Home Depot lot were projected to shade only 29% of the PA after 15 years. The lot was 3-year-old when surveyed, had 1.9 ha PA, 528 parking spaces, and 156 trees that shaded 2.1% of PA. At the time of the survey 28 trees were stunted or dead, 83 required staking removal or adjustment, and 22 needed pruning (lifting or thinning). There were 24 more parking spaces than planned for, and stalls on the west side of the lot were seldom used. During the peak-period occupancy survey 50% of all stalls were vacant. Trees were planned to shade 42% of PA after 15 years.

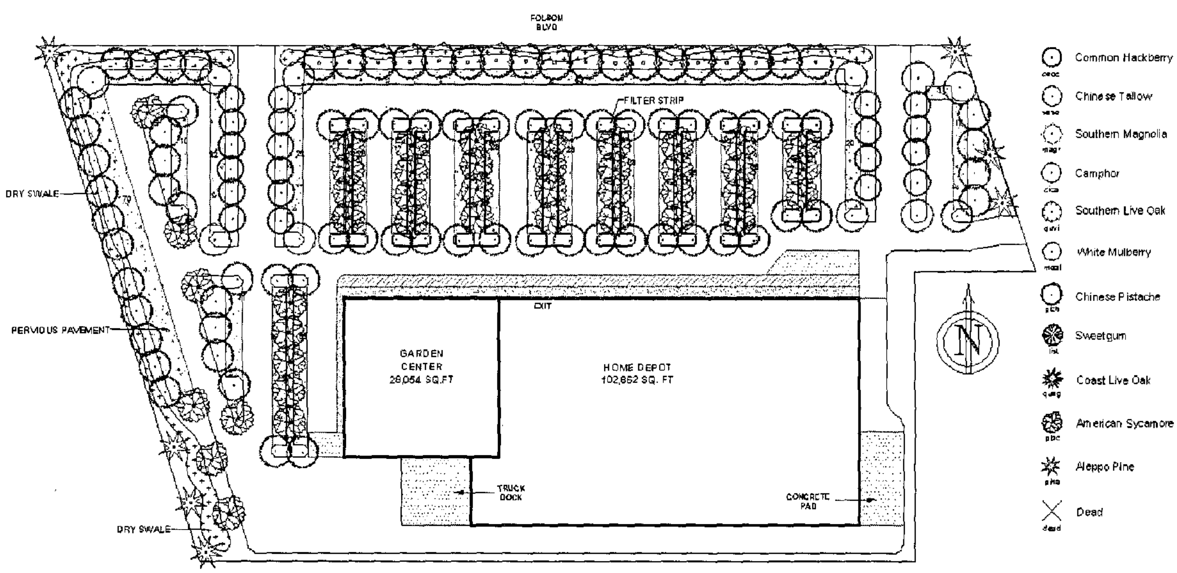

Fig. 5. The redesigned Home Depot lot increases planned tree shade to 58% and pervious cover by 18%. There are 106 fewer parking spaces (20%), creating new areas for perimeter swales to reduce stormwater run-off. Interior planting islands replace tree wells and contain with filter strips over infiltration trenches. Pervious concrete is shown where cars park. Tree species that have proven to grow well in other Sacramento parking lots are featured in the redesign.

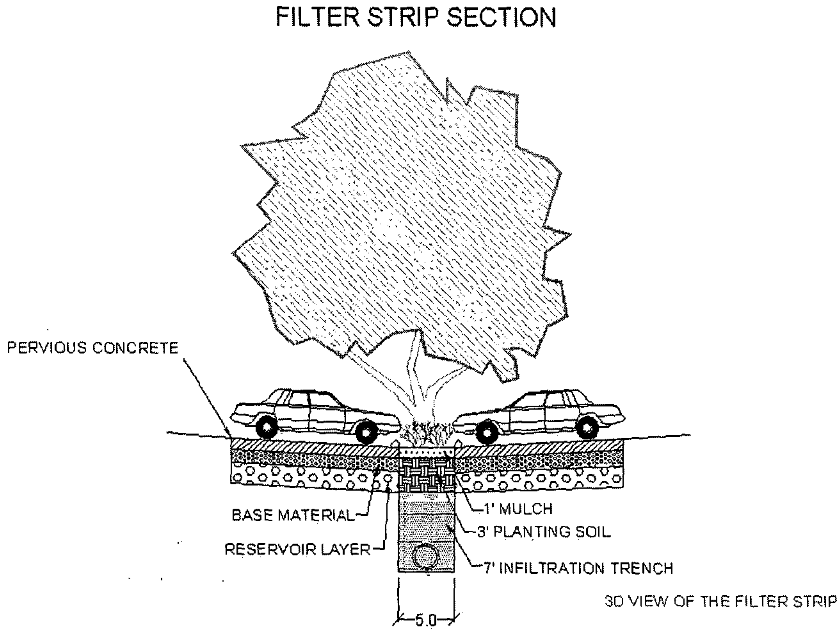

Fig. 6. Planting island with pervious concrete, filter strip, and infiltration bed to promote better tree growth through increased soil volume and enhanced on-site stormwater retention.

infiltration, and increase soil volume for trees (Richman, 1997) (Figs. 5 and 6).

- Reduce conflicts between trees, lighting, and signage. Coordinate location of trees, light poles, and signs. Reduce the maximum height of parking lot light poles from 7.6 to 4.9 m, the height trees are typically pruned for clearance. Amend sign ordinances to allow monument signs (eye-level signs located near the street) to have the names of major tenants listed on them and promote site designs that locate businesses closer to the street and move parking behind the buildings.
- Insure adequate species diversity. A total of 90% (64) of all trees in one lot were the same species. A guideline under consideration for the revised Sacramento ordinance is if 20–40 trees are required no more than 50% are the same type, and if more than 40 trees are required no more than 25% are the same type.
- Develop a master Tree List, omit species that are not suitable for parking lots (e.g. pines, poplars, birch), and consider specifying recommended tree spacing and minimum planting island widths for each species.
- Encourage covered parking as the most reliable and quickest means of achieving parking lot shade. Multi-level parking structures achieve desired shade and reduce impervious surface area compared to surface parking, but are expensive to construct.

4.3. Post installation issues

Lack of adequate tree care after installation reduces tree vigor, crown growth, and shade density. Nearly half of the trees surveyed (938) required some kind of management action and 2% (42) required removal because they were dead, dying, or hazardous. Removing stakes and pruning trees were the most common maintenance needs in younger lots. In older lots more trees had sparse or discolored foliage, and roots were heaving paving and curbs. In several lots pruning practices kept the crowns of large growing trees such as oaks from reaching their potential size (Fig. 3). Achieving ample parking lot tree shade requires awareness of shade benefits by property owners, managers, and arborists, as well as a commitment to professional tree care on a regular basis. Enforcement is critical to success of the ordinance. Timely enforcement should insure that trees are growing at acceptable rates, properly pruned and watered, and promptly replaced after removal. The current ordinance should be revised to address the following issues.

- Require that proper tree care practices are used by qualified professionals.
- Replace removed trees with trees of equivalent size or value according to a replacement schedule (e.g. a 10 cm tree is replaced by a tree in a 0.9 m box or a 15 gal tree and a US$ 350 replacement fee).
- Develop an enforcement and monitoring program that records information on the management needs of every tree, and results in a letter sent to the property manager requesting corrective measures be made within a specific time frame. Inspections should be conducted several times over the 15-year-period. An inspection fee could be collected at the time of building permit issuance to avoid an on-going billing process. Failure to make the requested improvements could result in a fine or a lien on the property. Alternatively, an interest-bearing bond could be required initially to pay for landscape improvements throughout the life of the project.

Although well intentioned, the current ordinance is not effective as implemented. Achieving 50% shade will come with a price. Policy-makers must determine what price is appropriate and who will pay given societal benefits associated with different levels of tree shade. For instance, a least-cost alternative is to continue business-as-usual and reduce the shade requirement to a more feasible 40%. This strategy minimizes costs to parking lot developers but increases foregone benefits to society. A second strategy is to maintain the 50% target, but encourage more covered parking, revise the ordinance to promote tree growth, and verify compliance in new parking lots. This will increase costs for developers of new lots relative to existing non-compliant lots, as well as increase societal benefits associated with greater parking lot tree shade in the long-term. Expenditures for monitoring and enforcement could be borne by the city or developer. A third option could add a retrofit component that brings shade deficient lots into compliance. This option could become mandatory when building permits are requested, or voluntary based on availability of funding and other incentives. Owners of existing lots could pay part of the retrofit costs, as well as other stakeholders that benefit from increased shade, reduced electricity demand for air conditioning, cleaner air, and reduced run-off.

5. Conclusion

Fifteen years after development average parking lot shade was 22% (CI 14–27%), not 50% as stipulated by ordinance. Citywide, this deficiency translated into US$ 1.4–2.5 million in foregone benefits from tree shade annually. Replacing non-functional trees and addressing other tree health issues that limit their growth citywide will cost approximately US$ 1 million, while planting 116,000 new trees needed to achieve 50% shade in the future will cost about US$ 20 million. Hence, the US$ 21 million investment needed to bring parking lots into compliance is approximately equivalent to 10 years of foregone benefits assuming 15-year-old lots with 22% tree shade.

The significance of this research is three-fold. First, it presents a new approach for evaluating the effectiveness of parking lot shade ordinances that is transferable to other cities with similar requirements. Second, many of the observations concerning causes and remedies for non-compliance can be generally applied. Third, quantifying foregone benefits of non-compliance makes the consequences more tangible. This assists those evaluating policy alternatives and provides a scientific basis for leveraging investment from other stakeholders. Quantifying the "green" infrastructure's impacts on quality of life and the environment is fundamental to its integration with other more readily perceived and measured infrastructure components such as streets, buildings, and parking lots.

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