Climate-ready tree study – Update for Central Valley communities

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Introduction

Trees in cities provide valuable ecosystem services that can improve quality of life, but also face a variety of stressors that can threaten these benefits. Urban forests are especially vulnerable to climate change stressors because predominant species may rely on irrigation and other intensive management practices, and rates of climate change may be more rapid and extreme in cities than in rural areas (Van der Veken et al., 2008). Identifying and testing the resilience of tree species to climate change stressors is critical to the long-term stability of urban forests. By gradually shifting the planting palette to climate-ready trees, future generations can enjoy healthier and more resilient urban forests. This paper describes our initial evaluation of 12 species of trees tested for Central Valley communities as part of the Climate-Ready Tree study (McPherson & Berry, 2015).

Methods

Trees were obtained from three nurseries, ranging in size from bare-root to 24" box, and were planted during spring 2015. The Sacramento Tree Foundation coordinated local volunteers in planting three parks, while staff with City of Sacramento Urban Forestry Division and UC Davis Ground Department planted trees in the remaining park and UC Davis reference site. Planting sites were randomly assigned to each species and trees were watered and staked at the time of planting. Mulch was applied at the reference site, but not at the park sites until 2016.

Four replicates were planted in the reference site (4 replicates x 12 species, 48 trees), a UC Cooperative Extension (UCCE) Field Station plot in Davis, with all trees receiving the same irrigation, pruning, and other maintenance activities. An additional 96 trees were planted in four Sacramento parks (2 replicates per park, 24 trees per park) where growing conditions and maintenance activities were more variable between parks. Trees that died within the first few weeks after planting, due to substandard stock or transplanting stress, were replaced during the second year of the project. Trees that died for other reasons were removed and not replaced. Trees were measured and their performance evaluated during May and June in 2015, 2016, and 2017. Further information on criteria for selecting the 12 species, experimental design and monitoring can be found in the publication "***Performance Testing to Identify Climate-Ready Trees***" (McPherson et al., In Press).

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The UC Davis reference plot is a flat field site. The loam soil has a nearly neutral pH (6.81). Trees received plenty of drip irrigation 3 days a week during the first summer from March to November. The trees received ample irrigation in 2015. In 2016 the site was irrigated in April and then on a regular basis August through November. In 2017, trees were not irrigated until September.

Laguna Creek Park in south Sacramento is a flat turf area that receives heavy recreational use. One area is shaded by a grove of mature trees and standing water accumulates. The clay loam has a neutral pH (6.72) and sprinklers watered the trees 3 days a week for 20 minutes during summer months with an average rate of 48 cm per year.

Trees planted in Regency Park in north Sacramento were on a west-facing slope with deep fescue grass and various broad-leaved weeds. The sandy silt loam soil has a neutral pH (7.10), with a very low level of available nitrate (2.26 ppm) and relatively high level of sodium. Trees were watered by sprinklers on two valves, and rates varied depending on tree location. The average rate in 2016 was 58 cm per year.

Trees at Fisherman's Lake in north Sacramento were planted on an east-facing slope and the soil was clay loam with neutral pH (7.39). This area was bare soil when trees were planted, but over the past two years broad-leaved weeds have emerged. Sprinklers were on three valves and in 2016 the average irrigation rate was 24 cm per year.

At Kohl's bike path in north Sacramento the trees were planted along

a west-facing slope and in a weedy swale. The bike path gets heavy use. The soil is clay loam with neutral pH (6.97). In 2016 the trees received drip irrigation 2 days a week during the summer with an annual rate of 7,340 cm per year.

Data from the CIMIS station closest to the reference site collected during 2015-17 indicated that transplants were not exposed to extremely low air temperatures. The lowest hourly temperatures were -2.3°C and -2.2°C [around 28°F] in December 2015 and 2016, respectively. During both these times temperatures were below 0°C for eight hours. Over the past 25 years the average minimum annual temperature at the Davis site was -3.1°C. Minimum temperatures at the CIMIS site in Sacramento (Bryte) were consistently warmer than at the Davis site. During 2015 annual precipitation at the Davis site (180.5 mm) was less than the historic normal (466.5 mm) and ET_o was slightly higher than normal (1,496.7 mm versus 1,440.3 mm). In 2016, annual precipitation (466.7 mm) was similar to the historic norm and ET_o (1,422.3 mm) was slightly less than the norm.

Results and discussion

Survival

Survival rates for trees in Park (88%) and Reference (90%) sites were similar (Table 1). Survival rates were lowest for ghost gum (50%, *Corymbia papuana*) and Desert Museum palo verde (67%, *Parkinsonia* x *'Desert Museum'*). Two Ghost gums at the reference site died of *Phytophthora spp.*, a soil-borne pathogen. It is not clear if this disease caused the loss of park trees as well. Three Desert Museum palo verde were lost at the reference site to limb breakage and blow-over. Ample irrigation resulted in rampant growth with weak branch attachments and a too lush crown. Root growth wasn't sufficient to keep the crown from toppling during strong wind events.

Abiotic disorders appear to have adversely impacted tree health and survival at Regency Park. In particular, soil with very low nitrate and high sodium levels inhibited growth and resulted in yellowing of foliage and necrosis believed due to drought stress.

Growth

On average the tallest taxon (> 4 m) were the shoestring acacia (*Acacia stenophylla*), Canby's oak (*Quercus canbyi*) and rosewood (*Dalbergia sissoo*) (Table 2). Species with shrubby habits were the shortest; Texas ebony (*Ebenopsis ebano*), mulga (*Acacia aneura*) and netleaf hackberry (*Celtis reticulata*). Species with the greatest girth (> 5 cm dbh) were shoestring acacia, Maverick mesquite (*Prosopis glandulosa* x *'Maverick'*), Canby's oak, Desert Museum palo verde and netleaf hackberry. Species that grew progressively larger each year and seemed quick to establish were the mulga, shoestring acacia, rosewood and Desert Museum palo verde. (Table 2)

Table 1. Numbers of alive and dead trees, and survival rates (%) for park (P) and reference sites (R). Subjective grades for each species range from A (best) to D (worst) for the amount of pruning required and overall performance.

Survival (2015-2017)	P-Alive	P-Dead	P-S%	R-Alive	R-Dead	R-S%	Tot-S%	Prune Req.	Perform
Acacia aneura	8	0	100	4	0	100	100	B	B
Acacia stenophylla	8	0	100	4	0	100	100	A	A
Chilopsis linearis 'Bubba'	6	2	75	4	0	100	83	A	A
Corymbia papuana	4	4	50	2	2	50	50	B	B
Celtis reticulata	8	0	100	4	0	100	100	C	C
Dalbergia sissoo	5	3	63	4	0	100	75	B	B
Ebenopsis ebano	6	2	75	4	0	100	83	C	D
Maclura pomifera 'White Shield'	11	0	100	4	0	100	100	B	B
Parkinsonia x 'Desert Museum'	7	1	88	1	3	25	67	C	C
Prosopis glandulosa x Maverick	8	0	100	4	0	100	100	D	B
Quercus canbyi	8	0	100	4	0	100	100	B	A
Ulmus propinqua	8	0	100	4	0	100	100	B	B
	87	12	88	43	5	90	88		

Table 2. Mean sizes (numbers) and standard errors (SE) of park and reference site trees in 2017						
	DBH (cm)	SE	Height (m)	SE	Crown Dia. (m)	SE
Acacia aneura (12)	6.43	0.85	2.97	0.24	2.34	0.34
Acacia stenophylla (12)	8.51	0.38	4.52	0.15	3.23	0.20
Chilopsis linearis 'Bubba' (10)	5.44	0.65	3.23	0.14	1.87	0.18
Corymbia papuana (6)	7.15	0.80	3.68	0.28	2.01	0.22
Celtis reticulata (12)	5.70	0.44	2.45	0.13	3.06	0.36
Dalbergia sissoo (9)	7.49	0.59	4.17	0.14	3.05	0.26
Ebenopsis ebano (10)	4.59	0.59	1.49	0.14	1.83	0.20
Maclura pomifera 'White Shield' (15)	3.89	0.38	3.36	0.15	1.42	0.13
Parkinsonia x 'Desert Museum' (8)	6.80	0.76	3.73	0.19	4.13	0.38
Prosopis glandulosa x Maverick (12)	10.08	0.61	3.43	0.11	3.33	0.19
Quercus canbyi (12)	6.59	0.62	5.10	0.43	3.16	0.31
Ulmus propinqua (12)	4.67	0.48	3.82	0.24	2.15	0.27

The average annual increase in size for the two full growing seasons across all trees (n=145) averaged 1.81-cm dbh (0.11 se), 0.52-m tree height (0.06 se), and 0.70-m crown diameter (0.06 se). The average annual dbh, height and crown diameter growth rates of park trees (n=83) were 16%, 12% and 17% below the overall averages, while the rates for reference site trees (n=42) were 42%, 31% and 39% above the overall averages, respectively. Deep soils and ample irrigation at the reference site has had an impact on tree growth rates, relative to the parks. Near optimal growing conditions at the reference sites have resulted in growth rates nearly twice those measured in parks. (**Fig. 1**)

Usually relatively rapid or slow growth for a species was expressed in several variables, such as dbh and height. Species exhibiting the greatest average annual dbh growth in parks (> 2 cm per year) were shoestring acacia, ghost gum and Maverick mesquite. Canby's oak, shoestring acacia and rosewood exhibited the most rapid height growth (> 0.9 m per year) and were among the fastest in terms of dbh and crown diameter growth (Figure 2). The slowest growing species in dbh and other growth variables were Texas ebony and Bubba desert willow (*Chilopsis linearis 'Bubba'*). Exceptions were relatively rapid annual tree height growth for ghost gum and slow crown diameter growth, as well as slow height growth for Desert Museum palo verde, but rapid dbh and crown diameter growth in parks. (**Fig. 2**)

Our climate-ready tree's mean growth was less than reported for elm cultivars during their first two years after planting as whips on a nearby UC Davis plot (McPherson et al., 2009). Elm tree growth averaged 2.52-cm dbh, 1.14-m tree height, and 0.96-m crown diameter, substantially greater than overall averages for the climate-ready trees. However, average annual dbh (2.47 cm) and crown diameter (0.95 m) growth of climate-ready trees at the UCD reference plot

Figure 1. These images were all taken in July, 2017, two full seasons after planting, and illustrate differences in growth of Bubba desert willow (*Chilopsis linearis* 'Bubba') across a range of growing conditions. Clockwise from the top left to bottom left, locations are the UCD reference site, Regency Park, Fisherman's Lake and Laguna Creek Park.

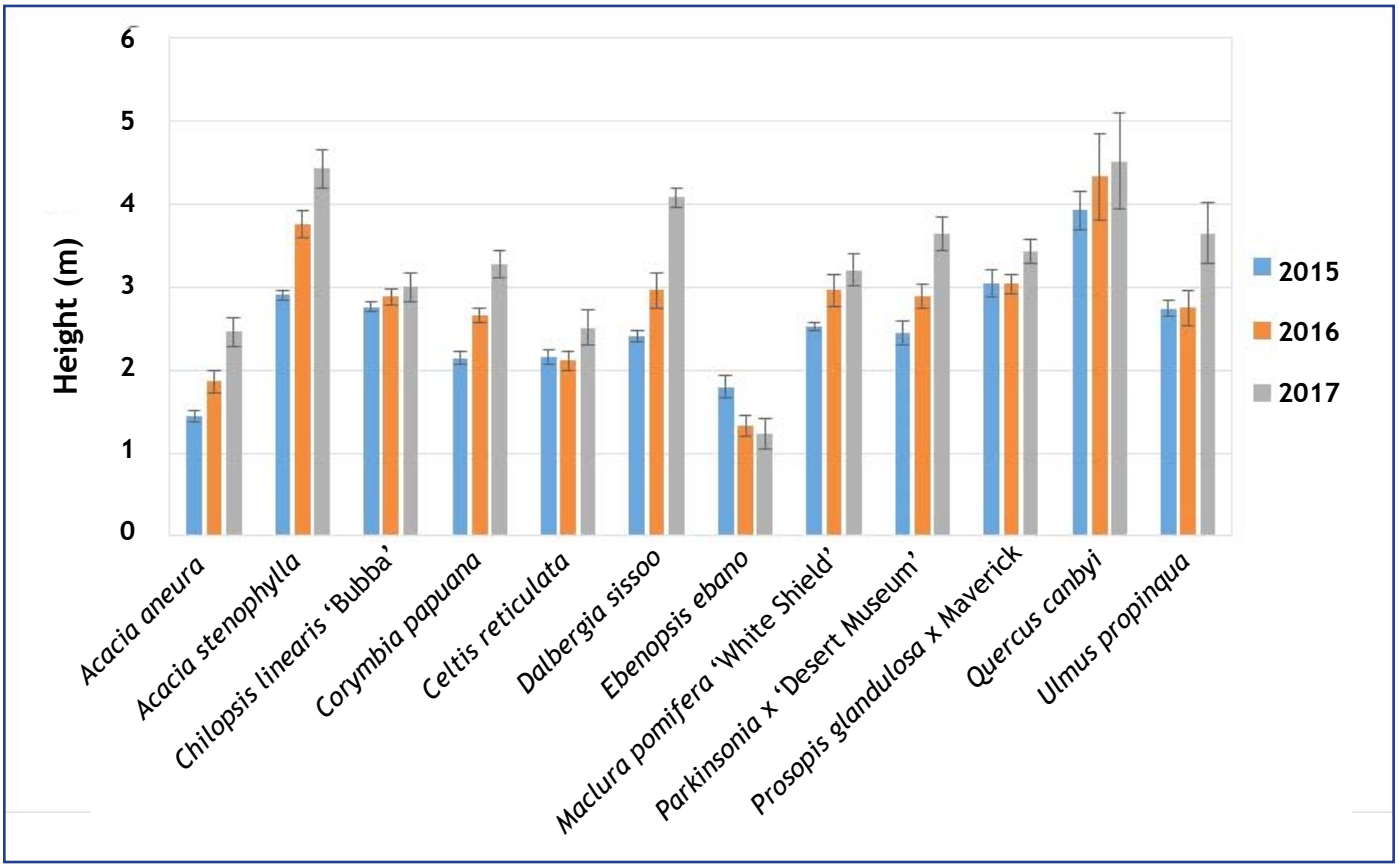

Figure 2. Mean tree heights and standard error bars for each species of climate-ready trees in Sacramento parks. The average height of *Ebenopsis ebano* decreased because taller trees were lost each year after planting.

were comparable to initial growth rates of elms. These growth rates are surprisingly rapid, primarily because most trees became well established after only one growing season in the highly productive agricultural soils.

The growth rates of climate-ready park trees were more similar to those reported for seven species of desert trees planted in Sacramento and Davis parks and yards in 1999 (McPherson & Albers, 2014). Over their first two full growing seasons the desert tree's average annual dbh, height and crown diameter growth rates were 0.71 cm, 0.46 m and 0.88 m, respectively. Average annual height (0.45 m) and crown diameter (0.57 m) growth of climate-ready park trees were slightly less than for the desert trees, but dbh (1.46 cm) was twice the rate of the desert trees.

One issue that can confound interpretation of growth is the difference in girth and height between bare root ¾-inch, Emerald Sunshine elm [*Ulmus propinqua*] and White Shield osage orange [*Maclura pomifera* '*White Shield*')) and 24" box (1 ½ - 2 ½-inch) stock at planting. Moreover, replacements for the dead bare root stock were planted one year later and 15-gal. These differences are becoming less apparent with time. In the reference site, the girth of the bare root stock has nearly caught up to the girth of the 24" box stock.

Pruning requirements

Pruning requirement is an important consideration when selecting trees. Species that require extensive pruning to develop strong structure will be more costly to maintain than those that require little pruning. In this study, all species were subjectively evaluated for pruning requirement based on assessments of structural characteristics and growth rate. Species assessed as having a high pruning requirement exhibited poor structural characteristics (e.g., codominant stems, branches with included bark, and branches with a large diameter relative to the trunk) and were found to have a relatively rapid growth rate. Bubba desert willow and shoestring acacia were evaluated as having relatively low pruning requirements, while Maverick mesquite, netleaf hackberry, Texas ebony and Desert Museum palo verde were considered to have relatively high requirements (Table 1). The remaining species exhibited intermediate traits. As these trees continue to develop, growth rates and structural characteristics likely will change, and pruning requirement may increase or decline accordingly.

Overall performance

Subjective performance ratings were performed for each species after visits to each park and reference site. Scoring incorporated observations

of survival, growth rate, branching patterns, form, pruning requirements, aesthetics, and insect and disease damage. Shoestring acacia, Bubba desert willow and Canby's oak stood out as the top performers (Table 1). They exhibited the best survival, growth and appearance across a wide range of conditions, and required the least pruning. Texas ebony, netleaf hackberry and Desert Museum palo verde received the lowest scores because of high mortality rates and substantial management needs. White Shield osage orange, Emerald Sunshine elm, ghost gum and rosewood show a great deal of promise, but more time is needed to gauge their adaptability, pest vulnerability and pruning requirements. Mulga and Maverick mesquite are very tough plants, but both species require extensive pruning to train into trees with clear, single or multiple trunks. A brief description of each specie's performance follows.

Mulga (*Acacia aneura*)

This thornless evergreen is native to Western Australia where it tolerates hot and dry conditions. All of the mulga we planted survived and are growing at a moderate rate. Their habit is relatively shrub-like, with dense branching to the ground. Substantial pruning for clearance is required if planted as a street tree. Mulga appears to be relatively quick to establish, and tolerant of moist and dry sites. It is among the shortest of the trees being tested. The yellow flowers are showy in the spring and summer. Although mulga is very tough, it received a B- evaluation because of its short, shrubby form and the care required to prune it into a street/park tree.

Mulga
(*Acacia aneura*)

Netleaf hackberry
(*Celtis reticulata)*

Netleaf Hackberry (*Celtis reticulata*)

The Netleaf Hackberry is native to riparian areas in the Southwest. A resilient, deciduous tree, all 12 of the hackberry we planted are thriving. They are among the shortest of trees thus far due to their spreading or weeping habit, but their girth is among the largest. They appear quick to establish, drought tolerant and able to thrive in a variety of soil types. One tree in the reference site was infested with aphids. The red drupes attract birds. Netleaf hackberry received a C evaluation because of its shrubby form, requiring substantial pruning to train into street/park trees.

Desert Willow (*Chilopsis linearis* 'Bubba')

The Desert Willow is native to California and the Southwest and is very drought and heat tolerant. Two of the trees along the Kohl's bike path have died, but the survivors are quick to establish and vigorous growing. The cultivar Bubba is upright in form and the average height is about 3-m, with a mature height of 5-m. The showy pink and white flowers are profuse and long-lasting. The Desert Willow received an A evaluation because of its adaptability, minimal pruning requirement and attractive form and flowers. This species shows promise as a possible replacement for crape myrtle (*Lagerstroemia indica*), which is frequently overplanted.

Desert Willow
(*Chilopsis linearis* 'Bubba')

Texas Ebony (*Ebenopsis ebano*)

The Texas Ebony is native to Texas and Northern Mexico. Two of the park trees we planted have died, perhaps because this species is relatively tender to frost. The Texas ebony are among the shortest trees measured and relatively slow to establish. Once mature they can reach a height of 10 meters. Their evergreen foliage is an attractive apple green, but the thorns are sharp. Fragrant yellow flowers

Texas ebony
(*Ebenopsis ebano*)

Ghost Gum
(*Corymbia papuana*)

mature into large woody pods. Texas ebony received a D evaluation because of its lack of hardiness and its shrubby form. Substantial pruning is required and made difficult by its thorny branches.

Ghost Gum (Corymbia papuana)

The Ghost Gum is native to Australia and is a smaller gum tree with a trunk that becomes smooth and snow white. Unfortunately, only 58% of the trees planted in our study have survived the first three years. The two trees lost at the UCD reference site appear to have been infected with *Phytophthora*, a soil-borne pathogen. A single Ghost Gum died in each of three parks, causes unknown. Surviving trees are growing relatively vigorously in dry and well-irrigated landscapes. The tree's upright and narrow form does not demand frequent pruning. Ghost gum received a B- evaluation because of its poor survival rate and disease vulnerability.

Shoestring Acacia
(*Acacia stenophylla*)

Shoestring Acacia (*Acacia stenophylla*)

This evergreen thornless acacia from Australia grows into an arresting specimen. Shoestring acacia was quick to establish and exhibited rapid growth without sacrificing strong branch attachments. Park trees already average 4.4-m tall and may exceed their advertised mature height of 7.6 m. The canopy is open with weeping, linear leaves. Density varies from tree to tree, even at the reference site. Fragrant and showy yellow flowers grow in clusters from fall to spring. Although the tree is drought tolerant, it appears to do well in irrigated landscapes and clay loam soil. Shoestring acacia received an A evaluation because of its outstanding resilience, growth and form.

White Shield Osage Orange (*Maclura pomifera* 'White Shield')

Osage orange is native to the western Great Plains. It appears to establish quickly and is tolerant of dry and well-irrigated sites. Park trees average nearly 4-m tall, although most were planted as bare root whips. The deciduous foliage is glossy green and our White Shield cultivars are thornless and fruitless as advertised. However, two trees that were planted too

White Shield Osage Orange (*Maclura pomifera* 'White Shield')

Rosewood
(*Dalbergia sissoo*)

high are sending up thorny suckers from the rootstock. Trees require little pruning. White Shield osage orange received a B+ evaluation because of its better than average survival, growth and form.

Rosewood (*Dalbergia sissoo*)

The Rosewood is among the tallest trees in the trial thus far, showing steady height growth since planting. At maturity they reach a height of 9 to 15 meters with a 12-meter crown spread. Three of the 12 park trees have died from unknown causes. Although native to Northern India and cold tender, trees have not been damaged by frost thus far. The evergreen foliage is lush green, but several trees exhibit yellowing, a symptom of nutrient deficiency. Overall, the rosewood are vigorous growing, tolerant of drought and ample irrigation, as well as clay and loam soils. They have not required extensive pruning or care. In one moist site the tree is regenerating, a sign that it may be invasive when growing in near optimal conditions. The rosewood received a B- evaluation because of its higher than normal mortality rate.

Canby's Oak (*Quercus canbyi*)

The Canby oak is native to northern Mexico and Texas. Once established it grows rapidly, and is now the tallest species in our trial, on average. It has an upright habit and will reach 9 to 12 meters. It appears to be heat toler-

Canby's Oak
(*Quercus canbyi*)

ant and can thrive in well-irrigated landscapes. The thick leathery leaves are semi-evergreen and acorns are small and narrow. The Canby's oak received an A- evaluation because of its 100% survival rate, rapid growth, and low maintenance requirement.

Thornless Honey Mesquite (*Prosopis glandulosa* x Maverick)

The Honey Mesquite is native to the southwestern United States. Maverick is a thornless cultivar of the species. All of the Maverick mesquite have survived thus far, and their average girth is among the largest of all 12 species. This species is one of the few that are growing as well in the park sites as the reference site, indicating adaptability to a range of soil types and moisture regimes. Maverick mesquite has spreading branches close

Thornless Honey Mesquite
(*Prosopis glandulosa* x Maverick)

Desert Museum Palo Verde
(*Parkinsonia* x 'Desert Museum')

to the ground and requires regular pruning if clearance under the crown is desired. This species received a B evaluation primarily because of its pruning requirement.

Desert Museum Palo Verde (*Parkinsonia* x 'Desert Museum')

The Desert Museum is a Palo Verde hybrid that is thornless, has attractive yellow flowers and little litter. Desert Museum has been quick to establish, but has had a relatively low survival rate (67%). Three of the four trees in the reference site were removed because they were damaged by winter winds. Desert Museum branches close to the ground and will require frequent pruning for clearance. This species received a C evaluation because of its low survival rate and high pruning requirement.

Emerald Sunshine Elm
(*Ulmus propinqua*)

Emerald Sunshine Elm (*Ulmus propinqua*)

The Emerald Sunshine Elm is among the tallest park trees (3.8 m) despite planting from bare root and 15-gal stock. It will reach 10.7 meters in height with a 7.6-meter spread and already exhibits a vase shaped growth habit. Emerald Sunshine is quick to establish, showing steady growth each year. Emerald Sunshine appears to be tolerant of hot and dry conditions, as well as amply irrigated soils. All 12 of the trees remain alive. This species received a B evaluation because of its high survival rate and moderate pruning requirement.

Conclusions

After two years into a twenty year experiment, it is far too early to make definitive statements about tree performance. These evaluations reflect growth and maintenance required during the early years, and are likely to change as the trees age. Nevertheless, trends in survival and growth are emerging. Among the most obvious is the substantially faster growth of trees in near optimal conditions at the reference site versus those in parks. Regency Park's poor soil, has had markedly adverse impacts on tree survival, growth and health. Species that are beginning to stand out because of their high survival rates, good growth in a range of conditions, and minimal pruning needs include shoestring acacia, Bubba desert willow and Canby's oak. In contrast, Texas ebony, netleaf hackberry, Desert Museum palo verde, Maverick mesquite and mulga will require substantial training at the nursery or pruning after planting, if tree-like form is desired. Future research by Drs. Downer and Berry will identify the relative pruning needs of each species as it matures. Continued monitoring of growth and survival will determine whether emerging trends will continue or change as each species matures according to its own time.

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