Evaluation of six drought tolerant trees 17 years after planting in Northern California

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THIS ARTICLE UPDATES TREE growth and mortality data for six drought tolerant tree species previously presented in *Western Arborist* (McPherson & Albers, 2014). It extends the scope of the earlier paper by assessing the vulnerability of each species to climate change stressors, as well as their potential for use in plantings to store carbon, reduce runoff, improve air quality and cool urban heat islands.

In 1999 Mountain States Wholesale Nursery (Glendale, AZ) generously provided us with six individuals of each of seven different species for planting (24-inch box). All individuals of one species had died by 2014 (*Parkinsonia* (formerly *Cercidium*) hybrid 'Desert Museum'). Hence, we report on the performance of the remaining six species (Mountain States Wholesale Nursery, 2003).

Chilopsis linearis Lucretia Hamilton™ (LH desert willow) is a small deciduous tree 15 to 20 ft. (4.6 to 6.1 m) tall and wide with light green leaves that give it a weeping appearance (**Fig. 1**). In summer it is covered with showy deep pink to purple flowers. After flowering it produces long narrow seed pods that persist and can look messy. The tree is thornless and prefers full sun and well-drained soils.

Pistacia x 'Red Push' the Red Push pistache (RP pistache) is a hybrid between *P. atlantica* and *P. integerrima* with compound leaves that emerge with a distinctive red color, hence the name Red Push (**Fig. 2**). It has a lovely display of red, orange, and yellow color in the fall. It develops a broadly oval crown with a height and width of 30 to 40 ft. (9.1 to 12.2 m) (Figure 2). The tree can adapt to a variety of soils and is deep-rooted. Although somewhat gawky when young, it is fast growing and long-lived.

Prosopis alba Colorado™ or Colorado mesquite is grown from rooted cuttings. The result is a lush and thornless mesquite growing to 40 ft. (12.2 m) tall and wide (**Fig. 3**). The tree is cold tolerant (16°F) and briefly deciduous in the spring. It is rapid growing and will tolerate lawn irrigation. Colorado mesquite is no longer grown, having been replaced by superior clonal varietal selections

Each species adaptive capacity to climate change stressors was scored in three areas — habitat suitability, physiological tolerances and biological interactions.

Figure 1. (Left) Lucretia Hamilton desert willow at the UC Davis Arboretum, Davis, CA (2016).

Figure 2. (Right) Red Push pistache at a residence, Davis CA (2016).

Figure 3. (Left) Without pruning, this Colorado mesquite in Davis, CA has developed low branches to shade the surrounding soil (2016).

Figure 4. (Right) Texas red oak in a Sacramento, CA park setting (2016).

such as Phoenix™ and Maverick™.

Quercus buckleyi (syn. *Q. texana*) or Texas red oak is a drought tolerant west Texas native found growing in the hill country west of San Antonio and closely related to the Shumard oak (*Quercus shumardii*). It is a deciduous tree that grows 30 to 40 ft. (9.1 to 12.2 m) tall and wide with a dense, upright crown that becomes rounded with age (**Fig. 4**). The leaves are classic oak with five prominent lobes, dark green and shiny on top, paler below. They turn burgundy to brilliant scarlet in the fall.

Quercus fusiformis or escarpment live oak is native to alkaline soils in west Texas. This cold-hardy evergreen grows 40 to 50 ft. (12.2 to 15.2 m) tall and wide and its thick crown provides dense shade (**Fig. 5**). Its small leaves resemble southern live oak (*Quercus virginiana*), with which it hybridizes (**Fig. 6**). However, it is much more tolerant of high temperatures and drought.

Quercus muhlenbergii or chinquapin oak comes from seed collected in west Texas from smaller growing trees than relatives in the southeastern U.S. It grows to 30 to 40 ft. (9.1 to 12.2 m) tall and wide, forming a long-lived shade tree (Figure 6). Its crinkly, lush green leaves are deciduous and turn orange to bronze in the fall. It prefers well-drained soil and grows surprisingly fast, even in desert heat.

The trees are now 17 years old and our focus is on the trees remaining in Sacramento and Davis locations:

- Reichmuth Park in Sacramento, CA – south end of the park, moderate use area, poorly irrigated turf.
- Northstar Park in Davis, CA – in a planting bed adjacent to the soccer field, initial irrigation.
- UC Davis Arboretum and Department of Environmental Horticulture grounds – in planting beds and well-irrigated turf that has been converted to unirrigated native grassland.

Figure 5. (Left) Escarpment live oak in the UC Davis Shields Oak Grove (2016).

Figure 6. (Right) Chinquapin oak in the UC Davis Shields Oak Grove (2013).

- UC Davis Orchard Park – dry grass area adjacent to parking, minimal, if any, maintenance and irrigation.
- Two residential landscapes in Davis, CA – in a front yard with irrigated turf and areas mulched with shredded bark or decomposed granite that received very little irrigation after establishment.

Trees were surveyed annually from 2000 to 2009 and in 2013 and 2016. Tree growth is reported based on measurements of diameter at

Table 1. Survival after 17 years				
Species	Alive	Dead	Total	Survival
LH Desert Willow	2	2	4	50%
RP Pistache	2	2	4	50%
Colorado Mesquite	3	1	4	75%
Texas Red Oak	5	0	5	100%
Escarpment Live Oak	2	2	4	50%
Chinquapin Oak	5	0	5	100%
TOTAL	19	7	26	73%

Table 2. Mean sizes and standard errors (SE) at 17 years after planting						
Species	DBH (in)	SE	Height (ft)	SE	Cdia (ft)	SE
LH Desert Willow	3.8	0.21	11.8	0.33	10.9	1.39
RP Pistache	12.7	0.49	24.6	2.30	29.0	5.50
Colorado Mesquite	14.3	3.80	27.6	1.97	38.6	3.15
Texas Red Oak	11.0	1.68	31.5	2.94	30.4	3.30
Escarpment Live Oak	14.5	0.02	29.2	6.23	40.5	6.89
Chinquapin Oak	10.5	0.96	34.3	3.39	26.6	2.82

breast height (to nearest 0.1 cm with dbh tape), tree height (to nearest 0.1 m with range pole or hypsometer) and average crown diameter (average of two perpendicular measurements with tape to the nearest 0.1 m). Survival was calculated as the percentage of live trees after 17 years.

Each species adaptive capacity to climate change stressors was scored in three areas: habitat suitability, physiological tolerances and biological interactions (Bagne et al., 2011). A rating of -1, 0, or 1 (intolerant, neutral, tolerant) was assigned for each factor, as reported in the literature (McPherson et al., In Review). Scores were summed with higher scores indicating less vulnerability. It was difficult to score some species because data were lacking. Uncertainty was quantified as the percentage of factors scored. Data sources included SelecTree (**https://selectree.calpoly.edu/**), Water Use Classification of Landscape Species (WUCOLS) (Costello & Jones, 2014), Wu and Dodge (2005) and the California Invasive Plant Council (**http://www.cal-ipc.org/**). The potential for each species to produce selected ecosystem services, such as cool urban heat islands, reduce stormwater runoff, improve air quality and store carbon was assessed subjectively, based on data from the literature and our observations. The availability of each species was determined by contacting nurseries that serve the Sacramento area, as well as the SelectTree database.

Results

Survival: Nineteen (73%) of the twenty-six trees planted were alive after 17 years (**Table 1**). The Texas red oak and chinquapin oak experienced zero mortality. The survival rate for the Colorado mesquite was 75% and 50% for the desert willow, Red Push pistache and escarpment live oak.

Growth: After 17 years the mean height of the three oaks ranged from about 30 to 35 feet (**Table 2**). Mean crown diameter was greater than height for the escarpment live oak. Chinquapin oak was more upright, while crown spread and tree height were nearly equal for the Texas red

Table 3. Vulnerability to climate change scores for each species reflect relative sensitivity							
	Habitat			Physiology			
Common name	Soil texture and ph	Soil moisture	Sunlight exposure	Drought tolerance	Salt tolerance	Wind tolerance	Cold hardiness
LH Desert Willow	0	1	0	1	1	1	1
RP Pistache	1	1	0	0	-1	1	1
Colorado Mesquite	1	1	0	1	1	1	1
Texas Red Oak	1	0	-1	1	NA	NA	1
Escarpment Live Oak	1	1	0	1	0	1	1
Chinquapin Oak	1	-1	-1	0	NA	NA	1

oak. Crown spreads exceeded tree heights for both the mesquite and Red Push pistache.

Initial growth was slow for all species, but became relatively rapid three to four years after planting (**Fig. 7**). Growth rates remained rapid for all species except desert willow. The three oak species and the Colorado mesquite exhibited the most rapid height growth. Crown diameter growth was greatest for the escarpment live oak and mesquite.

Vulnerability to climate change stressors:

Climate adaptation is now recognized as an important selection criteria for street and park trees. One consideration is the species' physiological plasticity, defined as the range of habitats to which it can adapt. Species native to a wide range of habitat conditions are considered less vulnerable to climate change stressors than species with a narrow range (**Table 3**). Chinquapin oak received the lowest Habitat score (-1) because its habitat of origin is full sun and only well-drained soil. Red Push pistache, mesquite and escarpment live oak habitats contained the widest range of soil conditions and sunlight exposures. The conflicting assessment for mesquite is instructive. Although its native habitat is desert riparian areas, it has proven to tolerate hot and dry situations. This contradiction highlights the importance of distinguishing between a species optimum habitat of origin and the range of habitats to which it can adapt.

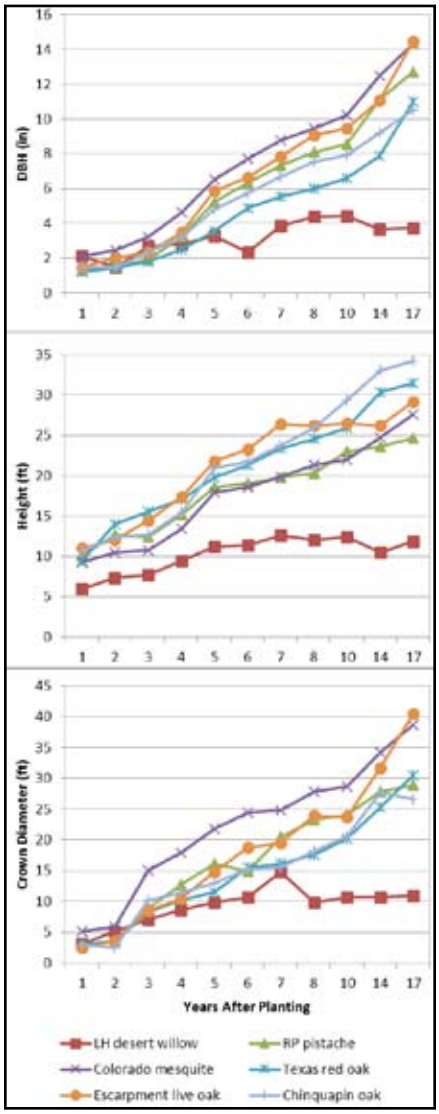

Figure 7. Mean sizes over the 17 years after planting. Decreases in size reflect the loss of trees with above average growth.

Desert willow and mesquite exhibited the greatest physiological tolerance to drought, salinity, extreme wind and cold. Red Push pistache was sensitive to salinity in recycled irrigation water. The sensitivity of Chinquapin and Texas red oaks to salinity and the relative strength of their branch attachments in the presence of high winds are unknown. Desert willow, mesquite and Red Push pistache had positive scores for Biological Interactions and the oaks had negative scores. The later was due to the large number of pests and disease that can threaten oaks. Some of the most serious and abundant pests are Asian ambrosia beetle (*Xylosandrus crassiusculus*), mildew (*Erysiphe sps.)*, Goldspotted oak borers (*Agrilus coxalis*), oak root fungus (*Armillaria mellea*) and sudden oak death (*Phytophthora ramorum*) (deciduous oaks only). Red Push pistache is susceptible to caterpillars (*Manduca sps.*), but resistant to verticillium wilt (*Verticillium sps.*).

The total scores indicate that mesquite (8) and desert willow (7) were least vulnerable to climate change stressors, while Chinquapin oak (-1) was most vulnerable. Texas red oak (1) was more vulnerable than Red Push pistache (4) and Escarpment live oak (4).

Results of this vulnerability assessment are but one of many con-

to each factor (-1 = intolerant, 0 = neutral, 1 = tolerant)

Biological Interactions			Vulnerability score				
Invasiveness	Pests & diseases	Emerging pests & diseases	Habitat score	Physiology score	Biological interactions score	(Sub)total score	Uncertainty %
1	0	1	1	4	2	7	0%
1	-1	1	2	1	1	4	0%
1	0	1	2	4	2	8	0%
1	-1	-1	0	2	-1	1	20%
1	-1	-1	2	3	-1	4	0%
1	-1	-1	-1	1	-1	-1	20%

siderations during the tree selection process. Findings may change as we learn more about the performance of each species over time. For instance, none of these taxon are listed as invasive species, but that could change if they are observed to be invasive as their use becomes more widespread.

Landscape functionality and use

The relative functionality of each species was assessed and results are summarized for each species (Table 4).

Desert willow

This utility-friendly tree is very well-adapted to difficult growing conditions. Because it is small and deciduous, it will not intercept much rainfall or create much shade. It is not solar friendly because persistent fruit pods can obstruct winter solar access. Roots are unlikely to heave sidewalks. It attracts birds and other wildlife. Although desert willow requires occasional pruning for structure and form, fragrant summer flowers and drought tolerance make it an excellent choice for sites where growing space is limited. Moreover, it is now widely available in nurseries.

Red Push pistache

This medium-stature tree is a good choice for summer shade and winter solar access. Because it is leafless during the rainy season it is not optimal for stormwater management projects. However, it is a good choice for projects to store carbon and improve air quality. It is deep-rooted and establishes an excellent branching structure with very little pruning. Unique red foliage in spring make this cultivar an excellent substitute for the overplanted Chinese pistache (*Pistacia chinensis*). Unfortunately, it is very difficult to find in California nurseries. Red Push pistache is currently being evaluated in the Southern California Climate-Ready Tree trials (http://climatereadytrees.ucdavis.edu/).

Mesquite

Mesquite is an excellent choice for green infrastructure projects because it effectively intercepts rainfall. It has a full crown that is briefly leafless in late spring, and roots can tolerate periods of inundation. This tree provides good summer shade for heat island mitigation, stores a moderate amount of carbon and is excellent for air pollutant uptake because it is a low-emitter of biogenic volatile organic compounds (BVOCs), an ozone precursor. Mesquite retained low branches and crown raising was required when located in plazas, patios, and other trafficked areas. Thinning was required when crown growth became rampant because of ample irrigation. Phoenix™ and Maverick™ are among the many improved mesquite cultivars, and the latter is currently being tested in the Climate-Ready Tree trials throughout California (McPherson & Berry, 2015).

Texas red oak

This large-stature tree establishes well-developed leaders and strong branch attachments with virtually no pruning. Although deciduous, it retains its attractive fall foliage longer than most trees. This trait increases rainfall interception, but reduces winter solar access. Texas red oak is an excellent choice for carbon storage and heat island mitigation projects. Although it produces dense shade, it is a high-emitter of BVOCs, a trait to consider when planning projects in areas with high summer ozone concentrations. Despite its many desirable features, this species is seldom found in California nurseries.

Escarpment live oak

This oak appears to be the most rapid growing and is the only evergreen of the three oak species evaluated. Unlike other rapid growing taxon, such as poplars (*Populus sps.*), escarpment live oak appears to have strong branch

Table 4. Relative functionality and potential uses for each species.

Species	Mature height	Growth rate	Water use	Carbon stored	Interception	Pollutant uptake	BVOC emitted	Summer shade
LH Desert Willow	Small	Slow	VL	L	VL	L	L	L
RP Pistache	Medium	Mod.	L	M	L	M	M	M
Colorado Mesquite	Medium	Rapid	VL	M	H	M	L	M
Texas Red Oak	Large	Mod.	L	H	M	M	H	H
Escarpment Live Oak	Medium	Rapid	VL	H	H	H	M	H
Chinquapin Oak	Large	Mod.	L	H	M	M	M	H
Legend:						Other		
Mature height (ft)		Growth rate (avg. inch dbh/yr)				VL = Very low		
Small = (<30)		Slow = <0.25				L = Low		
Medium = (30-50)		Moderate = 0.25-0.75				M = Moderate		
Large = (>50)		Rapid = >0.75				H = High		

attachments and deep roots. This oak is an excellent choice for projects aimed at reducing stormwater runoff and improving air quality. Ample foliage maintained throughout the winter maximizes rainfall interception in Mediterranean climates, while the broad crown produces dense summer shade. Because of its smaller size at maturity, it is not likely to store as much carbon as the other two oaks. Although very drought tolerant and wildlife friendly, the escarpment live oak is not currently available in nurseries. It is being evaluated in the Southern California Climate-Ready Tree trials (**http://climateready-trees.ucdavis.edu/**).

Chinquapin oak

Although native to the southeastern U.S., this oak is surprisingly drought tolerant. Chinquapin oak is a good choice for projects to store carbon, improve air quality and cool urban heat islands. It is deciduous, and as with the Texas red oak, its persistent foliage can influence rainfall interception and winter solar access. Because crown growth is irregular, chinquapin oak can benefit from occasional pruning for structure and form. Like all oaks, this species is well-anchored in the ground and has strong branch attachments. It is infrequently available in nurseries.

Conclusions

The potential for urban forests to mitigate the impacts of climate change and the threat of losing multiple benefits that trees provide are motivating the state of California and many cities to incorporate urban forestry into their climate mitigation and adaptation plans. Tree selection is an important decision-point for managers striving to reduce the future vulnerability of their urban forests. Thorough testing and long-term evaluation is a critical step in the process of diversifying our urban forests with new introductions that are well adapted and resilient to a changing climate. This 17-year evaluation of several drought tolerant species provides new information on their growth, resilience and functional use for planting projects aimed at controlling stormwater runoff, cooling urban heat islands, improving air quality and storing carbon.

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Solar friendly	Utility friendly	Wildlife friendly	Root coflicts	Pruning required	Availability
No	Yes	H	L	M	H
Yes	No	M	L	L	VL
No	No	M	L	H	VL
No	No	H	L	L	L
No	No	H	M	M	VL
No	No	H	L	M	L

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