1. Title: **Selecting Trees Fit for the Future**

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2. **Objectives**

The goal of this study is to evaluate the growth and survival of climate ready trees in three climate zones in California: Inland Empire, Inland Valley, and Southern California Coast. By identifying trees that perform best under stressors associated with climate change, we can help shift the palette of trees commonly planted to species that will provide the most environmental, social and economic value in the future. There is a need for science-based information on tree species that could be planted as replacements of highly vulnerable species to increase the resilience of the urban forest.

The specific goals of this study are to:

1) Develop and implement a scoring system to identify tree species most resilient to increased heat, severe drought, and disturbances from pests, storms, and other stressors.
2) Establish a network of collaborators and experimental sites where the most promising species are planted and evaluated via repeated measurements.
3) Communicate information on tree species performance to production nurseries, arborists, urban forests, NGOs, landscape architects and others who grow, plant and maintain trees.

Background: This study falls within the Pacific Southwest Research Station's (PSW) Urban Ecosystems and Social Dynamics (UESD) program of research. It addresses UESD's first problem area: (1) Realize an abundant and sustainable supply of ecosystems by examining the relationships among human uses, human values, ecosystem services, and management. Research to shift the palette of trees commonly planted to species that will provide the most environmental, social and economic value in the future also falls within the U.S. Forest Service Research & Development's priority area Urban Natural Resource Stewardship.

Due in part to PSW's participation in California's Cap & Trade Forestry Workgroup, the Governor's 2014-15 Budget included $15 million to CalFire for Urban Forestry from cap and trade auction revenue. The current budget includes $15 million for urban forestry. A large portion of these funds will be spent for tree planting in disadvantaged communities. Expected outcomes include increased tree canopy and carbon storage, reduced urban heat islands and energy use, improved air quality and human health, water quality protection and new employment opportunities. One obstacle to successful implementation of this unique statewide program is the absence of science-based information on tree species to plant that are least vulnerable to urban stressors, especially those associated with future climate change.

3. Review of Literature

The science informing the design, selection, and management of high performing trees is relatively limited. Few long-term tree growth studies have been conducted. Although the arboriculture literature is rife with studies that focus on effects of tree growth regulators (Burch et al. 1996, Sachs et al. 1986) and a variety of individual environmental stressors on growth (Clark and Kjelgren 1990, Goodfellow et al. 1987, Grabosky and Gilman 2004, Nielson et. al 2007) the relative effects of multiple stressors remains largely unknown. Much of the research has been carried out on young trees in controlled settings that are very different from the heterogeneous conditions found in cities (Sjöman and Nielsen 2010).

Long-term performance evaluation of tree species and cultivars is fundamental to selecting trees best suited for different growing conditions. Thorough descriptions of site conditions and management activities can be used with multivariate statistics to explain their influence on growth and performance. For centuries foresters have been measuring the effects of site factors and management interventions on stand dynamics. The Forest Inventory and Analysis (FIA) program has been monitoring U.S. forests since 1928 (Smith 2002). Recently FIA plots have been located in some urban areas. However, long-term studies of urban tree growth first began in the U.S. a half-century ago by arboreta, universities, and foundations. In the mid-1960s Dr. L.C. Chadwick of Ohio State University and Mr. Bif Stapes of the Davey Tree Expert Company began evaluating street tree species in five Ohio cities, as well as trees planted in research plots. Now called the Street Tree Evaluation Project, the study expanded to include 89 revisited sites and continues to supply valuable “then and now” information on survival and growth, as well as photographic records of visual impacts as trees mature (Sydnor et al. 1999).

In 1987 Dr. Henry Gerhold of Pennsylvania State University partnered with several electric utilities to begin the Municipal Tree Restoration Program. Test trees were planted in plots along streets and under electric conductors to compare performance in 11 Pennsylvania communities (Gerhold 2007). Twelve years of standardized performance data have helped utilities to select the most appropriate cultivars, and the plantings serve as living demonstrations. The primary tree performance metric for this program was tree height, because utilities wanted trees that did not exceed 8m height to plant under conductors.

In 2005 the National Elm Trial began producing standardized information on the performance of 20 Dutch elm disease (*Ceratocystis ulmi*) resistant cultivars in 18 plots across the US. Reports from this research included information on survival and growth, as well as damage from pests, disease, abiotic disorders and pruning requirements (McPherson et al. 2009, 2014). High-performing cultivars required minimal treatment for pest infestations or pruning to develop strong structure.

Criteria for evaluating and selecting trees for urban landscapes have traditionally focused on enhancing tree form and aesthetics (e.g., columnar habit for streets, floral and fruit display), as well as reducing maintenance (fruitless, retain fruit). A new criteria recognizes that trees planted today will be exposed to a different climate in the future. Climate change poses challenges for California, where an already parched region is expected to get hotter and, in its southern half, significantly drier (Garfin et al., 2013). Increased heat and sustained drought will stress water sources and redefine its urban landscapes. Impacts of heat stress are greatest for those who suffer from respiratory and heart disease, and for residents in less affluent neighborhoods, which typically lack shade trees. Tradeoffs are inevitable between conserving water to meet the demands of an increasing population and providing adequate water for urban greenery to reduce increasing urban temperatures (Niinemets & Penuelas, 2008). Increased use of saline reclaimed water will adversely impact the health of sensitive tree species. In addition, there is increased probability of extreme weather events, which could increase the number of tree failures, exacerbating power outages, traffic congestion and loss of benefits from mature trees.

New alien pests represent a growing threat. Los Angeles-Long Beach-Santa Ana, California is a top commodity import region at risk of establishing new alien forest insects at a rate of one every four to five years (Tubby & Webber 2010). Moreover, urban warming is reported to be a key driver of pest outbreaks on urban trees (Meineke et al., 2013). For landscape architects, arborists and urban foresters, the best means to reduce future threats from pests and climate change is to adapt their planting plans (Laćan & McBride, 2008). By selecting tree species that have internal genetic traits that promote resilience to external threats, they can effectively reduce the vulnerability of the future urban forest.

This study is unique in that it is the first to evaluate city trees in a Mediterranean-type climate and with adaptability to climate change as a driving criterion. Also, it is more carefully designed as an experiment than previous efforts. It extends previous research that developed the Pest Vulnerability Matrix and Municipal Forest Report Card by expanding analyses beyond pest threat to include tolerances to heat, drought, storms and salinity (McPherson & Kotow, 2013). Also, it builds on the experience gained from a 14-year evaluation of drought tolerant tree species that were obtained from a nursery in the arid southwest and planted in central California (McPherson and Albers, 2014). The study assessed the survival, growth, and water tolerance of seven different species with six individuals of each species planted in a variety of site conditions in Modesto, Sacramento and Davis. The proposed study will be conducted on a much larger scale with more species, replicates and climate zones.

4. **Methods**

<u>Tree species selection:</u>

Two approaches will be used to identify promising, underutilized species. Expert horticulturalists were asked to list the species that they recommend for testing because of their potential resilience to climate change. We also compiled existing tree inventories for 6 to 12 cities in each climate zone: Southwest Desert, Tropical, Inland Valley, Inland Empire and Coastal Southern California. From the inventory data we identified minor species that are promising because they have a few individuals in larger size classes or are relatively new introductions. Using these two lists, we identified the major species to evaluate in each climate zone.

This study adapts an approach previously used to score the vulnerability to climate change of forest trees in the Pacific Northwest (Devine et al., 2012) and applies it to urban trees in the Inland Empire, lnland Valleys, and Southern California Coast climate zones. We identified selection factors for tree species evaluation and scoring system (potential factors include following):

- Habitat
  - Soil moisture
  - Soil texture and pH
  - Sunlight exposure
- Physiology
  - Drought tolerance
  - Wind tolerance
  - Salt tolerance
  - Cold hardiness
- Biological interactions

- Invasiveness
- Major and minor pest and disease threats
- Emerging pests and disease threats

Selection factors were evaluated for 16 to 24 of the promising species in each climate zone. Planting stock of each selection had to be available for planting during winters 2014-15 and 2015-16 or the species was dropped from the list. Twelve species with the highest scores were advanced for field evaluation in each climate zone.

The following species were selected in each climate zone:

Species	Common Name	Inland Valley (12)	Southern CA Coast (12)	Inland Empire (12)
Acacia aneura	Mulga	+	+	+
Acacia stenophylla	Shoestring acacia	+		
Cedrela fissilis	Brazilian cedarwood		+	
Celtis reticulate	Netleaf Hackberry	+	+	+
Chilopsis linearis 'Bubba'	Desert Willow	+		+
Corymbia papuana	Ghost Gum	+	+	+
Dalbergia sissoo	Rosewood	+	+	+
Ebenopsis ebano	Texas Ebony	+		
Hesperocyparis forbesii	Tecate cypress		+	+
Maclura pomifera ‘White Shield’	White Shield Osage Orange	+		
Mariosousa willardiana	Palo Blanco		+	+
Parkinsonia x Desert Museum	Desert Museum Palo Verde	+		+
Pistacia 'Red Push'	Red Push Pistache		+	+
Propospis glandulosa Maverick	Maverick mesquite	+	+	+
Prunus ilicifolia subsp. lyonii	Catalina Cherry		+	
Quercus canbyi	Canby’s oak	+		
Quercus fusiformis	Escarpment Live Oak		+	+
Quercus tomentella	Island Oak		+	+
Ulmus propinqua	Emerald Sunshine Elm	+		

The following park sites and control sites were selected in each climate zone:

	Inland Valley	**Inland Empire**	**Southern CA Coast**
Control site:	UC Davis Plant Sciences Field Facility	UC Riverside Citrus Research Center	South Coast Research and Extension Center
Park sites:	Fisherman's Lake	Holleigh Bernson Memorial Park	Vista Del Mar Park
	Kohl's Bikepath	Hansen Dam Recreation Area	Jim Gilliam Recreation Center
	Laguna Creek Park	Valley Plaza Recreation Center	Bogdanovich Park

	Regency Park	Woodley Park	Westchester Park

<u>Field testing</u>:

Field testing of 12 species in each climate zone will utilize UC Cooperative Extension (UCCE) Field Station plots in Davis (Inland Valleys), Irvine (Southern California Coast) and Riverside (Inland Empire) for side-by-side comparisons under similar growing and maintenance conditions. At each reference site, four replicates are planted in a complete randomized block design, with all 48 (4 replicates x 12 species in each site) trees receiving the same irrigation, pruning and other maintenance activities. Within each climate zone, an additional 96 trees are planted in 4 parks (2 replicates per park, 24 trees per park) where growing conditions and maintenance activities are more variable. Standard monitoring protocols will be followed to record information on each site, tree size, health and management. All trees will be evaluated annually for the first ten years after planting, and biannually thereafter. The trees are expected to remain in the ground for at least 20 years.

<u>Statistical design</u>:

Two statistical consultations were conducted (March 10, 2014 & Sept. 24, 2014). Our final study design resulted from these consultations. Randomized complete block design (RCBD) was chosen to control variation in the trial by accounting for spatial effects. Within each climate zone, each of the 4 parks is a block, and the entire reference site is a block in and of itself. Within each climate zone, there are 2 replicates per species at each park and 4 at each reference site (24 trees total per park; 48 total per reference site). The role of blocking is to partition off systematic variability that would otherwise be inflating the residual error in the analysis. It was suggested that we should not subdivide the parks into blocks unless there were really different growing conditions or maintenance practices within a park. Similarly, the reference sites were treated as a single block because growing conditions and maintenance practices are uniform within each site. Overall, this is a balanced design because each of the 12 species is planted in equal number at a given site.

The analysis of the data will be a repeated measures ANOVA. Those models can be generalized (as unbalanced mixed models) in case there are missing values in the data, or to accommodate a more complex correlation structure (such as spatial power or first degree autoregressive) than is used in a traditional repeated measures analysis.

Example of how data will be organized in each climate zone:

Block (park site and control)	Treatment (Species)	Tree individual	Relative growth at year 1	Relative growth at year 2	Relative growth at year 3	….
1	1	1	0.5	1	1.2	
1	2	2	1.2	0.5	0.3	
1	3	3	…	…	…	
1	4	4				
1	5	5				
1	6	6				
1	7	7				
1	8	8				
1	9	9				

1	10	10				
1	11	11				
1	12	12				
2	1	13				
2	2	14				
…	…	…				
5	12	144				

General approach to maintenance in reference vs park sites:

We recognize that the level of maintenance trees receive will influence their growth, and can vary considerably in the landscape. Our approach is to apply a consistent level of maintenance to trees in the reference plots (i.e., field stations) and to record and compare differences across species, such as amount of pruning, staking and pest control required. In the case of pruning, we support a minimal pruning approach so that we can discern the underlying branching pattern of these species. We will develop and apply relatively rigorous prescriptions for the care of trees in the reference plots. By applying a uniform level of maintenance we can assess the amount of resources required to establish and maintain each tree species in good to excellent condition throughout the 20-year period.

Trees located in the parks will be treated similar to other trees in the parks. We anticipate that the level of care will vary from park to park and year to year based on the individuals involved and financial resources available. Hence, our park trees will likely be subject to lower levels of maintenance than trees in the reference plots, and their conditions will vary, reflecting the response of each species to the specific stressors and maintenance activities it receives. Park personnel will periodically describe the level of care provided to trees.

Specific approaches to maintenance:

1. Pruning
    a. In the reference sites in Year 1 (Y1), there will be no pruning except if there are interfering or broken branches. In Year 2 (Y2), there will be only minimal pruning, restricted to removing or subduing a codominant or competing leader; and removing or subduing (depending on species) extremely vigorous lower laterals, or single vigorous laterals that may outcompete the rest of the branches. Some species need almost no pruning in Y2. As the experiment progresses (Y3 and onward), we will reassess the tree structure and prune as needed. In parks, although we have expressed the desire to keep pruning to a minimum, it will be up to the park managers to decide pruning needs. This will be part of the variability we expect in this study and will be monitored.

2. Watering
    a. In general, trees in the reference sites will be irrigated for at least 1 year and at most 2 years after time of planting to ensure successful establishment.
    b. A similar approach will be suggested to the parks but ultimately the watering regimes at park sites will be determined by the park site managers.
    c. Watering at reference sites is as follows: At the UC Davis Plant Sciences Field Facility in the first year after planting, the station staff inspected trees on a regular basis and irrigated when needed. At all reference sites in Southern California the trees will be maintained at 75-80% ETo (reference evapotranspiration) the first year and 25-50% ETo

the second year. During the third year ETo will be reduced through the season commensurate with minimum acceptable quality to maintain tree health. This is expected to be below 25% ETo for some of the species.

   d. Estimating water application: We are working with cooperators to develop a survey of irrigation managers and protocol for catch can measurements to quantify the amount of water applied to park sites. Irrigation run times and frequency will be reported by on-site staff in parks and reference sites. In addition, we will track amount of rainfall per month per location from CIMIS data (for details see section on monitoring below)

3. Pests and diseases. In parks, pests or diseases will be treated only if parks are treating other trees. Managers will inform cooperators as to what management actions have occurred in parks. Integrated pest management principals will be followed in the reference sites, which includes regular monitoring.

4. Tree replacements. Trees that died within the first few weeks after planting, due to substandard stock or transplanting stress, will be replaced within the first year of the project (i.e. emerald sunshine elm in Inland Valley and escarpment live oak in Inland Empire and Southern California Coast). Mortality occurring after the successful establishment will count towards the species evaluation in our experimental design.

5. Staking. Nursery stakes were removed at planting. All park trees in Inland Empire and Southern California Coast and nearly all park trees in Inland Valleys received two (in some cases three) support stakes. In the reference sites, two support stakes per tree were installed at the time of planting.

<u>Monitoring</u>:

1) See attached "Climate-Ready Trees Field Protocol.docx" for monitoring observations we recorded in the Inland Valleys study. A similar protocol will be used in the other two climate zones.
2) California Irrigation Management Information System (CIMIS): Hourly meteorological data from the CIMIS system will be accessed each year for sites closest to park and reference plots. These data will be used to identify the climatic conditions influencing growth. Data will be analyzed to determine the following for each year (Sept. 1 to Aug. 31):

   - Monthly and annual precipitation
   - Minimum air temperature (day and number of hours it persisted)
   - Average monthly minimum air temperature (to measure hardiness)
   - Chilling hours (to assess dormancy) from the chilling hour calculator
   - Average monthly maximum air temperature
   - Minimum annual temperature
   - Monthly reference ET (ETo, environmental demand for evapotranspiration) for the year

<u>Soil sampling</u>:

See attached "Soil sampling methods.docx". In the statistical consultation, it was recommended that we collect soil moisture measurements to use as a covariate in the analysis, as it will potentially help with the interpretation of the responses.

In general, 10 representative soil cores will be taken from each site and immediately dried in a drying over. Each core sample will be ground individually and sieved through a 2-mm sieve. Samples will be shipped to UC Davis for soil analysis. The UCANR Analytical Lab will analyze for major nutrients, pH, % organic matter, and soil texture.

Performance rating:

Subjective performance ratings (1-5) (1=poor and 5=excellent) of each species will be performed every five years or more frequently. Scoring will incorporate observations of survival, growth rate, branching patterns, form, pruning requirements, aesthetics, and insect and disease damage. After or during the course of visits to each reference and park site within a climate zone, project scientists and cooperators will independently score each species. Within each climate zone, the mean and standard error of ratings will be calculated for each species across all sites, as well as independently for reference and park sites.

The relative amount of pruning level required for each species will be evaluated as the average score for the sum of three criteria:
Pruning Requirement: 1 = low, 3 = high
Growth: 1 = slow, 3 = rapid
Structure: 1 = best, 3 =worst

5. Quality Assurance/Quality Control Procedures

Measurements will be taken following the field manual developed by the Urban Tree Growth and Longevity Working Group called “Urban Tree Monitoring Protocols: Field Manual for the Minimum Data Set” (http://www.urbantreegrowth.org/uploads/1/1/1/7/11172919/utm_minimumdataset_061614.pdf). The manual describes field collection procedures for a core set of variables that are essential to any long-term urban tree study. The standardized urban tree monitoring protocol will allow for the longitudinal study of tree growth, longevity, and health.

6. Personnel Assignments and Costs

Inland Valley phase: $73,500 total
Greg hours: 250
Natalie hours: 100
UC Davis grad student salary: $54,600 for UC Davis grad student salary (25% Oct-Jun & 100% Jul-Sep)
Travel: $3,000
Supplies/materials: $14,000 for planting 144 trees, field space, soil sampling
Other: $2,900

Inland Empire and Southern CA Coast phase: $100,000 total
Greg hours: 140
Natalie hours: 140
Travel: $5,200 for travel
Salaries for student and UC investigators: $10,469.59
Supplies/materials $63,498.92 for planting 288 trees, field space, soil sampling

7. **Application of Research Results**

This study will generate and transfer new knowledge about the performance of underutilized trees with potentially high resilience to climate change. Application of this science will result in planting of trees more likely to thrive in future urban environments. Improved tree performance will increase production of ecosystem services, improve environmental quality, promote human health and enhance the economic vitality of communities. As a result, the USDA Forest Service, PSW, UCCE and the state's urban forestry organizations will be valued for their critical contributions to the well-being of California's 40 million residents.

8. **Presentation of Expected Results**

A network of UCCE collaborators will participate in research at each set of paired sites. These partners will facilitate knowledge exchange and technology transfer at their local Field Day events and other UC Extension activities. Study results will be presented at Western Chapter ISA annual and regional meetings, in their quarterly publication Western Arborist and other venues.

Presentations have already been made at the:

- Western Chapter ISA annual meeting near Yosemite National Park on April 28th, 2015
- Western Chapter ISA's "Climate Change: The Limits of Adaptive Response in Trees" conference at Stanford University on October 8, 2015
- Society of Municipal Arborists 51st Annual International Conference and Trade Show in Denver, CO on November 17th, 2015
- Western Tree Management Symposium in San Marino, CA on February 3, 2016.

9. **Health and Safety**

There are no unusual safety risks.

10. **NEPA Compliance**

Not applicable.

11. **Literature Cited**

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