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Performance testing to identify climate-ready trees

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ABSTRACT

Urban forests produce ecosystem services that can benefit city dwellers, but are especially vulnerable to climate change stressors such as heat, drought, extreme winds and pests. Tree selection is an important decision point for managers wanting to transition to a more stable and resilient urban forest structure. This study describes a five-step process to identify and evaluate the performance of promising but infrequently used tree species. The approach is illustrated for the Central Valley of California, USA and has been implemented in the Inland Empire and Southern Coastal regions of California. Horticultural advisors nominated 134 taxon for consideration. A filtering process eliminated taxon that were relatively abundant in a compilation of 8 municipal tree inventories, then those with low adaptive capacity when scored on habitat suitability, physiology and biological interactions. In 2015, 144 trees were planted, with 2 trees of each of 12 species planted in 4 Sacramento parks and 4 replicates planted in the Davis, California reference site. This approach can serve as an international model for cities interested in climate adaptation through urban forestry.

1. Introduction

One of the most important urban forest climate adaption strategy is planting and stewardship of tree species well-suited to site growing conditions in the future as well as the present (Roloff et al., 2009; Yang, 2009). Having a diverse mix of species well-adapted to future conditions, what we call climate-ready trees, is critical to fostering a smooth transition to a more stable and resilient urban forest. This paper describes a five-step process to identify and evaluate the performance of promising tree species. It illustrates application of this approach in one California region. Because it will take decades to gradually shift the planting palette to climate-ready trees, the ultimate value of this research will be borne out in healthier and more resilient urban forests witnessed generations from now.

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. Stressors associated with climate change, such as drought, heat, pests and extreme weather events are already increasing mortality in forests (Allen et al., 2010). In cities, climate change can amplify the impacts of existing stressors such as inadequate soils, polluted air, contaminated runoff and mechanical damage from cars and vandals. Although researchers have predicted how forests respond to climate change (Allen et al., 2010; Iverson et al., 2008), patterns of disturbance to urban forests are largely unknown because their species composition is extremely diverse and largely non-native in origin (Tubby and Webber, 2010). 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.

1.1. Tree performance testing

Long-term performance testing of tree species and cultivars is fundamental to successful tree establishment (Trowbridge and Bassuk, 2004). Nevertheless, limited testing of potential planting stock and lack of availability in local nurseries have long been challenges to urban forest diversification. Descriptions of site conditions and management activities can be used with multivariate statistics to explain their influence on growth and performance. 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 the Street Tree Evaluation Project began evaluating street tree species in five Ohio cities, as well as trees planted in research plots. The study includes 89 revisited sites and supplies valuable "then and now" information on survival and growth, as well as photographic records of visual impacts as trees mature

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(Sydnor et al., 2010).

In 1987 the Municipal Tree Restoration Program began testing trees planted under electric conductors to compare performance in 11 Pennsylvania communities (Gerhold, 2007). Twelve years of standardized performance data helped utilities select the most appropriate cultivars that did not exceed 8 m height to plant under conductors.

The National Elm Trial began in 2005 and has produced standardized information on the performance of 20 Dutch elm disease (*Ceratocystis ulmi*) resistant cultivars in 18 plots across the U.S. Reports from this research include information on survival and growth, as well as damage from pests, disease, abiotic disorders and pruning requirements (Griffin et al., 2017; McPherson et al., 2009). Results are helping managers determine which cultivars may perform best in their regions.

1.2. *Tree selection and anticipated performance*

Selecting the right tree requires consideration of how a myriad of factors may influence performance in the future. Species-specific information on tolerances and responses of trees is frequently incomplete, adding uncertainty to decision-making (Sjoman and Nielsen, 2010). Harris et al. (1999) noted that, “Selection is a compromise among proposed function of the plant, its adaptation to the site, and the amount of care it will receive.” Miller (1997) proposed a species selection model that included site (i.e., environmental and cultural constraints), social (i.e., aesthetics, functions and disservices) and economic factors (i.e., costs to plant and maintain). Asgarzadeh et al. (2014) extended this approach by using horticultural experts to grade species for each selection parameter and adding relative weights to selection parameters. Huber et al. (2015) developed an interactive computer tool that used vegetation data from the USDA Plant Database and a spatial database for Baltimore, Maryland that included site-specific environmental, situational and risk factors. Although greening programs strive to improve climate and quality of life through tree planting, there is a surprising disconnect when it comes to specifying trees with traits, such as low water use and large canopy size, that are most likely to achieve those goals (Pincetl et al., 2013).

Climate adaptation was recognized as a primary selection criteria for street and park trees by Sæbø et al. (2005), along with growth and pest resistance. Yang (2009) evaluated the potential effects of climate change on the biology of pests in Philadelphia, Pennsylvania, as well as the suitability of tree species to predicted climate at midcentury. Climate envelopes were derived from the dendrological literature for most species and incorporated temperature and precipitation. Although future climate was predicted to be less optimal for 10 species, overall it was likely to increase diversity. Species recommendations are difficult to make because large amounts of variability in response to stressors, such as extreme drought, reflects characteristics of the individual plants (e.g., age, size) and local site conditions (Fahey et al., 2013).

Roloff et al. (2009) focused on drought tolerance and cold hardiness as critical to future tree survival in a changing climate. Their analysis examined annual precipitation and minimum temperatures in the species' climate of origin to assure that it will be adapted to increased frequency and severity of drought, as well as late frosts. The conflicting assessment for honey locust (*Gleditsia triacanthos*) is instructive. Although honey locust's native habitat is moist bottomlands, it has proven to tolerate hot and dry situations. This contradiction highlights the importance of distinguishing between a tree species' optimum habitat of origin and its physiological plasticity, defined as the range of habitats to which it can adapt.

Lanza and Stone (2016) found that the projected northward migration of hardiness zones with climate change resulted in about a 6% average tree species loss across all cities. Interestingly, Atlanta and Washington D.C. lost the most species, while cities in the Southwest did not lose any tree species.

The System for Assessing Vulnerability of Species (SAVS) was developed as a tool for managers to identify the relative resilience of species to climate change (Bagne et al., 2011). The user scores level of resilience for habitat, physiology, phenology and biotic interactions, as well as an uncertainty score that reflects confidence in the predicted response. The SAVS framework was evaluated by Rowland et al. (2011), who noted that every assessment approach is limited by data and resource requirements, as well as sources of uncertainty that constrain their application. The SAVS approach is applied in this study for urban trees.

1.3. *Climate change, urban forests and human health and well-being*

The types of effects climate change is having on urban forests differs geographically. For example, in large cities local urban heat island effects are playing a greater role in overall warming than greenhouse gas emissions (Stone, 2012). The coupling of urban warming from both these sources has cascading effects on tree health. For example, warmer temperatures can increase evapotranspiration demand and drought stress, predispose trees to pest attacks, and increase developmental rates and reduce winter mortality for many insects (Dale and Frank, 2014; Tubby and Webber, 2010). Warmer winter temperatures may increase the susceptibility of some species to late spring frosts (Miller-Rushing and Primack, 2008). Extreme weather events are likely to increase in the future, exposing trees to intense winds, rain, and hail, as well as flooding, storm surges and heavy snow and ice loads (Burley et al., 2008; Yang, 2009). Salinity from recycled irrigation water or coastal flooding can adversely affect soil health and tree growth. Hence, exposure to climate change disturbances are likely to exacerbate the stress already afflicting many urban trees. Species with narrow ranges of tolerance may be most adversely affected. Trees have little genetic capacity to adapt because of their long life span. Most cultivars have been bred for ornamental traits related to form, foliage, flower and fruit rather than tolerance of stresses caused by limited root space, poor soil, drought, pollutants and pests (Gerhold, 1985). As the role of urban forests expands to include enhancement of environmental quality, human health and well-being, trees may need to be bred to withstand stressors associated with climate change (Brummer et al., 2011; Kontogianni et al., 2011).

If urban forests are healthy and extensive, they can produce services that mitigate the impacts of climate change and improve well-being of city dwellers (Jim et al., 2015). Increasing doses of nature in cities have positive effects on an individual's emotional state and cognitive functioning (Bratman et al., 2015; Ulrich, 1981). Urban forests store carbon dioxide (CO_2) in their biomass, reduce energy used to heat and cool buildings and intercept rainfall to reduce stormwater runoff and protect water quality (McPherson and Simpson, 2003) (Xiao et al., 1998). By reducing urban heat islands, trees can improve human thermal comfort and reduce exposure to extreme weather events (Brown et al., 2015; de Abreu-Harbich et al., 2015; Klemm et al., 2015). However, a growing body of research indicates that there is substantial disparity among those who benefit from tree canopy cover based on socioeconomic characteristics (Danford et al., 2014; Watkins et al., 2016). For example, a number of studies have found positive relations between tree canopy and income (Heynen et al., 2006; Schwarz et al., 2015). These data suggest that communities of color and low income have disproportionate exposure to climate change risk factors (Shonkoff et al., 2011). Over the past several years California's Greenhouse Gas Reduction Fund has targeted $15 million annually for tree planting grants to benefit disadvantaged communities. The future success of these plantings depend in part on their vulnerability to climate change, as well as the extent to which they reflect the values of participating citizens (Ordóñez, 2015). Closing the social gap in ecosystem services delivered by urban forests will require that these plantings achieve high survival rates and vigorous growth in a changing climate.

There is impetus to develop an international network of tree performance evaluation sites for long-term monitoring (Vogt et al., 2015). Without such science-based data it may be difficult to identify the high-