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Research paper

Long-term monitoring of Sacramento Shade program trees: Tree survival, growth and energy-saving performance

Yekang Ko[a,*], Jun-Hak Lee[b], E. Gregory McPherson[c], Lara A. Roman[d]

[a] Department of Planning and Landscape Architecture, University of Texas at Arlington, Arlington, TX, USA
[b] Department of Earth and Environmental Science, University of Texas at Arlington, Arlington, TX, USA
[c] USDA Forest Service, Pacific Southwest Research Station, Davis, CA, USA
[d] USDA Forest Service, Northern Research Station, Philadelphia Field Station, Philadelphia, PA, USA

HIGHLIGHTS

- We assessed tree survivorship, growth, and energy performance over 22 years.
- Survivorship was 42.4%, substantially lower than the initial projection.
- Annual cooling saving per property and per tree were 23% and 52% of the initial projection.
- Lower survivorship was the major factor affecting lower cooling savings.
- Planting medium stature trees and rapidly growing large trees achieve the greatest long-term energy savings.

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ABSTRACT

Long-term survival and growth of urban forests are critical to achieve the targeted benefits of urban tree planting programs, such as building energy savings from tree shade. However, little is known about how trees perform in the long-term, especially in residential areas. Given this gap in the literature, we monitored 22-years of post-planting survival, growth, and energy saving performance of shade trees in Sacramento, California. Using field surveys, aerial photo interpretation and survival analysis, we calculated cumulative survivorship and compared measured with projected tree growth. Using Shadow Pattern Simulator and Micropas (building energy simulation), combined with survival and growth observations, we modeled the current energy savings produced by the program trees and then compared this result with initial projections from the early years of the program. The 22-year post planting survivorship was 42.4%, considerably less than the initial projection. On average, measured growth rates were within expected ranges to provide shading benefits; 22-year old trees reached 74.6% and 68.8% of the projected 30-year mature size for tree heights and crown diameters, respectively. Annual energy savings were 107 kW h per property and 80 kW h per tree, which were 23% and 52% of the initial projection, respectively. Lower survivorship was the primary factor influencing lower cooling savings. Medium-sized trees had higher survivorship and growth attainment compared to other trees. This study contributes to more accurate quantification of urban greening performance, helping urban forest managers make data-driven decisions.

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1. Introduction

Urban tree planting has received increasing attention over the past few decades, fueled by numerous studies that quantified and monetized the benefits of urban trees (McPherson et al., 1997; McPherson, Simpson, Xiao, & Wu, 2011; McPherson, Simpson, Peper, Maco, & Xiao, 2005; Roy, Byrne, & Pickering, 2012). These benefits encompass environmental, social, and economic aspects, including improving air quality (Brack, 2002; Morani, Nowak, Hirabayashi, & Calfapietra, 2011; Nowak, Crane, & Stevens, 2006; Scott, Simpson, & McPherson, 1998; Rowntree & Nowak, 1991; Scott, Simpson, & McPherson, 1999), improving water quality, reducing surface stormwater runoff (Bartens, Day, Harris, Dove, & Wynn, 2008; Xiao, McPherson, Simpson, & Ustin, 1998), mitigating the urban heat island (Armson, Stringer, & Ennos, 2012; McPherson, 1994; McPherson & Muchnick, 2005), reducing energy consumption (Akbari, 2002; Donovan & Butry, 2009; Huang, Akbari, Taha, & Rosenfeld, 1987; Ko, 2013; Ko & Radke, 2014; McPherson

* Corresponding author. Tel.: +1 817 272 1260; fax: +1 817 272 5098.
E-mail address: yekangko@uta.edu (Y. Ko).

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& Rowntree, 1993; McPherson & Simpson, 2003; Pandit & Laband, 2010a,b; Sawka, Millward, Mckay, & Sarkovich, 2013; Simpson & McPherson, 1998), sequestering carbon (Nowak & Crane, 2002), increasing property value (Anderson & Cordell, 1988; Sander, Polasky, & Haight, 2010; Tyrväinen, 1997), enhancing thermal comfort (Shashua-Bar & Hoffman, 2000; Shashua-Bar, Pearlmutter, & Erell, 2011), and improving mental and physical well-being (Donovan et al., 2013; Gidlöf-Gunnarsson & Öhrström, 2007; Maas, Van Dillen, Verheij, & Groenewegen, 2009; Schroeder & Anderson, 1984; Van den Berg, Maas, Verheij, & Groenewegen, 2010). Cities and metropolitan regions including Los Angeles, CA; Sacramento, CA; Denver, CO; New York City, NY; and Philadelphia, PA have initiated tree planting campaigns with ambitious goals for "planting one million trees" to capitalize on the reported benefits of urban forests and associated monetary values (Young & McPherson, 2013). Many of these claimed ecosystem services are derived from generalized models with numerous assumptions. There is need for locality-specific empirical evidence to more fully evaluate the performance of tree planting initiatives (Pataki et al., 2011; Setälä, Viippola, Rantalainen, Pennanen, & Yli-Pelkonen, 2013).

Tree survival, longevity and growth are major factors that can significantly affect the performance of urban forests, as well as projections of their population numbers and ecosystem services. For contemporary million tree campaigns, ecosystem services projections have been conducted for Los Angeles, CA with a 35–40 year time horizon (McPherson et al., 2011) and New York City, NY with a 100-year time horizon (Morani et al., 2011). Both studies concluded that long-term mortality is a major source of uncertainty in the models. For example, Morani et al. (2011) reported that doubling the annual mortality rate from 4 to 8% resulted in a 72.7% reduction in the total pollutant removal of newly planted trees through the MillionTreesNYC initiative. Indeed, since the massive urban planting campaigns are a relatively recent phenomena, performance data is only beginning to become available (McPherson, 2014). Urban-specific growth rates and allometric relationships are also important components of ecosystem services models that require new empirical evidence (McHale, Burke, Lefsky, Peper, & McPherson, 2009; Troxel, Piana, Ashton, & Murphy-Dunning, 2013). Given the importance of benefits projection to policy-makers and urban greening organizations, and the need for locality-specific performance data, our study re-visits early projections from a multi-decade tree planting initiative in Sacramento, CA. This program provides a compelling case study for the comparison of expected versus achieved benefits.

1.1. Sacramento Shade Tree Program

The Sacramento Shade Tree Program, referred to as Sacramento Shade, is the largest and the oldest utility-sponsored shade tree planting initiative in the United States that specifically targets plantings to reduce cooling energy use by buildings (Sarkovich, 2009). Begun in 1990 as a partnership between the Sacramento Tree Foundation (STF) and Sacramento Municipal Utility Districts (SMUD), the program has distributed 500,000 deciduous trees to homes, businesses, and public spaces for free throughout Sacramento County and a part of Placer County (SMUD, 2014). Residents are responsible for planting and maintenance of shade trees as advised by community foresters.

When the trees in our study were distributed, participating residents were required to attend a 40-min educational session about shade benefits, as well as tree planting and maintenance techniques. This was followed by a site visit to each residential property several weeks later, and residents then attended shade tree distribution events at a centralized neighborhood location after another several weeks (R. Tretheway and L. Leineke, pers. comm.). Notably, these operations differ from more recent program procedures, in which residents and community foresters primarily interact through a brief home visit followed by tree delivery directly to the property (Roman, Battles, & McBride, 2014); the educational workshops and neighborhood distribution events are no longer used.

1.2. Initial energy-saving simulations

In 1995, SMUD contracted with the USDA Forest Service to evaluate the cooling energy (kW h) and capacity (kW) provided by the Sacramento Shade Program. Computer simulations of tree shade and space conditioning energy use were completed for a random sample of 254 residential properties. The sample was found to be representative of the 20,123 Sacramento Shade participants for years 1991 to 1993. During site visits by SMUD staff, information on the species, sizes and locations of program trees was recorded. Diagrams of building footprints and tree locations were augmented with additional information on glazing, location of existing trees and adjacent buildings that shaded the target building (Hildebrandt and Sarkovich, 1998). The energy impacts of 787 trees planted at the 254 participating homes from 1991 to 1993 were analyzed using shade and building simulation models (Simpson & McPherson, 1998).

On average, 3.1 trees per property reduced annual cooling energy use by 153 kW h (7.1%) and peak demand by 0.08 kW (2.3%) per tree. Annual heating loads were projected to increase by 0.85 GJ (1.9%) per tree. Using 1998 energy rates ($0.10/kW h and $6.15/MMBtu), these energy impacts converted to $15.25 for annual cooling saving and $5.25 for annual heating penalty per tree. After deducting the heating penalty, the net annual energy savings was $10.00 per tree. Adjusting Simpson and McPherson's results (e.g., accounting for participants with no central air conditioning (AC) system and effects of shade trees on neighboring houses), Hildebrandt and Sarkovich (1998) calculated the average annual energy and demand savings and the monetary value of load impacts over 30 years. They assumed that 57.5% of the trees delivered were alive after 30 years (called "survivability" by the Sacramento Shade program; for survival terminology in the program, see Roman et al., 2014). The average annual energy and demand savings per tree was 106 kW h and 0.041 kW for homes with central AC system and 95 kW h and 0.038 kW for all homes, including those without central AC. The average annual value of cooling energy savings was $39 per tree. In their sensitivity analysis, they estimated that differences between rapid tree growth rates (achieving 100% of shade at maturity in 18 years) and slow growth rates (100% of shade at maturity in 24 years) resulted in energy savings that varied by ±8%. Differences between high and low survivability rates (72.5% vs. 57.5%) over 30 years resulted in energy savings that varied by ±9%. Roman et al. (2014)'s recent study of more recently planted Sacramento Shade trees reported that only 58.9% of delivered trees were alive after five years. Given these new findings, it is reasonable to expect that actual survival rates and cooling energy savings are less than projected by these early studies.

Our study helps fill the gap between early projections and actual results by measuring survival and growth rates for shade trees planted 22 years ago. These rates, as well as simulated energy effects of program trees, are compared with findings from the initial study (Simpson & McPherson, 1998). We addressed four questions: (1) how many of the shade trees planted between 1991 and 1993 were alive in 2013? (2) how large did they grow? (3) what are their effects on cooling and heating energy use? and (4) how do these current estimates differ from the initial simulations (Simpson & McPherson, 1998)? This study is unique because it documents survival, growth, and performance of residential shade trees over the long-term. With historic data in hand, planners, utilities and policy-makers can better evaluate potential return on investment from

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