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Research Paper

Determinants of establishment survival for residential trees in Sacramento County, CA

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HIGHLIGHTS

- The success of urban forest planting initiatives critically depends on tree survival.
- We monitored the fate of a cohort of trees for five years to quantify tree survival rates on residential properties.
- Stable homeownership was the best predictor of tree establishment success.
- Our results suggest that tree survival rate assumptions in urban forest ecosystem services models may be overly optimistic.

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ABSTRACT

Urban forests can provide ecosystem services that motivate tree planting campaigns, and tree survival is a key element of program success and projected benefits. We studied survival in a shade tree give-away program in Sacramento, CA, monitoring a cohort of young trees for five years on single-family residential properties. We used conditional inference trees to identify the most important risk factors at different life history stages, and survival analysis to evaluate post-planting survivorship. Our analysis included socio-economic, biophysical, and maintenance characteristics. In addition to field observations of tree planting status, survival, and maintenance, we also collected property ownership information through the Multiple Listing Service and neighborhood socioeconomic characteristics from the U.S. Census. We found that 84.9% of trees were planted, with 70.9% survivorship at five years post-planting. Overall, 58.9% of delivered trees survived to five years, which the local program calls survivability. Planting rates were higher in neighborhoods with higher educational attainment, and on owner-occupied properties with stable residential ownership. Five-year survival was also higher for properties with stable homeownership, as well as for tree species with low water use demand. When we incorporated maintenance characteristics from the first year of field observations, factors related to tree care were important to survival. Many residents did not adhere to recommended maintenance practices. Our results illustrate the critical role of tree care and consistent homeownership to young tree mortality on residential properties, and suggest that survival assumptions in urban forest ecosystem services models may be overly optimistic.

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1. Introduction

Urban forests – the trees in cities, towns, and urbanized landscapes (Konijnendijk, Ricard, Kenney, & Randrup, 2006) – have been reported to provide valuable ecosystem services. For example, trees in cities can reduce stormwater runoff (Xiao & McPherson, 2002) and mitigate the urban heat island (Akbari, Pomerantz, & Taha, 2001). Urban trees can also increase property values (Donovan & Butry, 2010), and contribute to vibrant and walkable neighborhoods (Kuo, 2003; Southworth, 2005). The environmental, socioeconomic, and human health benefits from urban forests are estimated in models of ecosystem services, and the concept of ecosystem services has become mainstreamed in urban tree planting programs (Silvera Seamans, 2013; Young, 2013). Tree planting initiatives advertise these proported benefits to policy-makers and the public.

However, there is a lack of locality-specific field data for urban forest models (Pataki et al., 2011, 2013), including longitudinal data to document mortality losses in planting programs. Realistic

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survival information is essential to develop accurate estimates of projected environmental benefits from urban tree planting. Urban forest ecosystem services models are sensitive to mortality assumptions (Hildebrandt & Sarkovich, 1998; McPherson, Scott, & Simpson, 1998; McPherson & Simpson, 2001, 2003; McPherson, Simpson, Xiao, & Wu, 2008; Morani, Nowak, Hirabayashi, & Calfapietra, 2011). The mortality rates used in these models are based on extremely limited data. For example, mortality patterns embedded within the tree population projections for New York City, NY are based on a single study of *Acer* street trees from Syracuse, NY (Nowak, 1986), and survival scenarios for Los Angeles, CA (McPherson et al., 2008) do not cite any particular field studies. Yet these studies have noted that mortality rates are a major source of uncertainty in predicting urban forest change over time, and that small changes in assumed mortality can have large effects on estimated benefits. Mortality data are essential to understand tree population dynamics and associated ecological functions, and to sustainably manage urban forest resources. Similar arguments have been made to explain the importance of tree mortality studies in natural forest ecosystems (Lines, Coomes, & Purves, 2010).

Research on the factors associated with urban tree death is also important to improve our basic understanding of the mortality process and assist managers in enhancing planting program performance. Numerous risk factors for urban tree death have been reported. As part of urban ecosystems (Pickett et al., 1997), urban tree mortality is shaped by biophysical and socioeconomic forces. Biophysical factors include species, size and age class, planting site characteristics (Lawrence, Escobedo, Staudhammer, & Zipperer, 2012; Lu et al., 2010; Nowak, Crane, & Stevens, 2004; Nowak, McBride, & Beatty, 1990), soil compaction and altered microbial activity (Craul, 1999), water stress (Nielsen, Buhler, & Kristoffersen, 2007), storms (Staudhammer et al., 2011), and pests and diseases (Poland & McCullough, 2006). Human factors include land use, unemployment, rental status, vandalism (Lu et al., 2010; Nowak et al., 1990), construction damage (Hauer, Miller, & Ouimet, 1994), and community involvement in tree planting and maintenance (Boyce, 2010; Sklar & Ames, 1985). Many of these human factors are related to urban environmental stewardship (Romolini, Brinkley, & Wolf, 2012), in terms of people's sense of responsibility for tree care, and also specific actions that can be beneficial or injurious to tree health.

The relative importance of different risk factors may change as trees age and grow. During the establishment period – the first several years after planting – urban trees are considered especially vulnerable to mortality losses (Richards, 1979). Maintenance may be critical to establishment survival (Boyce, 2010). Recognizing the importance of early tree survival to the success of tree planting campaigns, urban forest researchers and practitioners are interested in quantifying the rates and causes of mortality (Leibowitz, 2012).

We studied establishment-phase mortality in the Shade Tree Program in Sacramento County, CA as a locality-specific investigation of assumptions in ecosystem services models. This program was designed to reduce building energy use through tree shade during the hot summer months (Hildebrandt & Sarkovich, 1998; McPherson et al., 1998), and tree survival is essential to achieving the desired energy savings. The program is a large-scale tree give-away, in which trees are distributed by the organization and planted by participants. An investigation of tree mortality in Sacramento has relevance to other large-scale urban tree programs (e.g., million tree campaigns, Young & McPherson, 2013), especially tree give-aways, which are a prominent component of urban forestry initiatives in other cities to add canopy to private property (e.g., Turner & Mitchell, 2013). In Sacramento, we monitored a cohort of shade trees annually for five years. We were interested in two distinct outcomes to represent life history stages of shade trees: planting status and post-planting survival. Planting status is of particular interest to give-away programs, which cannot guarantee that every distributed tree will be planted. Our research objectives were to (1) quantify tree planting rates and survivorship during the establishment period, and (2) identify the primary determinants of establishment survival. We applied analytical tools from demography and ecology that have not previously been used in urban tree mortality studies: conditional inference trees and survival analysis. The results were used by local practitioners to guide program modifications that may enhance tree performance.

2. Methods

2.1. Study system

The Sacramento area has a Mediterranean climate with mild, wet winters and hot, dry summers. The Shade Tree Program is a partnership between a local non-profit organization, the Sacramento Tree Foundation (STF), and a utility company, the Sacramento Municipal Utility District (SMUD). STF and SMUD have distributed over 500,000 trees since 1990 (C. Cadwallader, pers. comm.). The program operates in the SMUD service area, which includes Sacramento County and small parts of Placer and Yolo Counties.

Shade trees were distributed upon request to residents or property owners, who were responsible for planting and maintenance. SMUD and STF staff refer to individuals who receive trees as "shade tree customers"; we use this term throughout the remainder of this paper. Most trees are distributed to single-family residential (SFR) properties and planted in yards. After requesting free trees, customers were visited by a STF community forester and received a 15–45 min consultation about shade benefits, planting site selection, and tree maintenance. The agreed-upon planting locations were recorded on a map in a signed Tree Care Agreement. SMUD predicts energy savings based on the recorded distance and orientation to the building, along with expected mature tree size and assumed mortality rates. Customers selected tree species with STF staff guidance during the site visit, and received an educational folder about tree benefits and stewardship practices. After tree delivery, follow-up contact was not required, but customers were invited to call STF for additional tree care advice, and to participate in free urban forestry classes. Trees delivered by STF are small saplings [containerized trees in 20 L buckets (5 gallon trees), approximately 2 m tall]. Each SFR property typically receives no more than 10 trees.

2.2. Study sample

We monitored a sample of 436 trees on SFR properties randomly selected from the 13,594 shade trees distributed by STF from January–December 2007. Seven additional trees were excluded from analysis due to resident opt-out. Trees were distributed across the city of Sacramento and surrounding suburbs and small towns. The sample included 30 species (Appendix A). In lieu of species-specific analysis, we classified species by water use demand in California's Central Valley (Costello & Jones, 2014). Water use demand is especially relevant because the Sacramento region has seasonal summer drought. We also classified species by mature tree size because recent SMUD projections have included higher mortality rates for small stature trees (M. Sarkovich, pers. comm.). We refer to the trees distributed through the Shade Tree Program as a population, following convention from other urban forestry studies, while acknowledging that urban forests on residential landscapes are anthropogenically-dominated systems with multiple species, and not traditional biological populations.

STF records included the tree delivery date, which we used as a close approximation of the planting date. Because trees were delivered and planted throughout 2007, we accounted for differences in time elapsed since planting by counting the number of days between delivery date and 2008 field observation date. We also used delivery date to categorize trees as planted during the rainy season (October–April) vs. dry season (May–September). Trees planted during the dry season may need additional care and watering.

2.3. Data collection

2.3.1. Field data

Field work was conducted May–August each year, 2008–2012, with occasional additional field visits through November for unresponsive residents. We contacted study participants each spring by mail and telephone to request access to the properties. Multiple visits were often required to gain access to back yards. When residents were unresponsive, we made at least three attempts to visit the property. Unresponsive properties were visited again the subsequent year, while residents who opted-out were not visited again.

Because STF distributes trees but does not plant them, we distinguished between residential planting rates and post-planting mortality. Trees classified as never planted were either observed in their container during the summer 2008 field work, or were observed missing and determined to have never been planted. Trees that were missing in 2008 may have been planted and subsequently removed; whether a missing tree was planted was determined based on conversations with residents and observations at the properties. Post-planting mortality was a combination of standing dead and removed trees (sensu Lu et al., 2010; Nowak et al., 2004; Roman & Scatena, 2011). Standing dead trees were defined by the complete absence of green leaves and live buds. Trees observed alive during a given field year were visited again the following year and classified as alive, standing dead, or removed.

During the 2008 field season, we observed tree condition and planting site characteristics. Tree condition rating was recorded separately for foliage and wood following i-Tree Streets methods (itreetools.org): dying, poor, fair, good. We noted whether the tree was planted in the correct location, as depicted on the Tree Care Agreement. We also recorded whether the tree was planted in the front or back yard because previous studies have found that residents have distinct landscaping preferences for front yards (Larson, Casagrande, Harlan, & Yabiku, 2009; Larsen & Harlan, 2006). Lastly, we recorded ground cover type at the planting location following i-Tree Eco (itreetools.org): maintained grass, mulch, bare soil, rocks/gravel, other maintained vegetation, other unmaintained vegetation.

Adherence to recommended maintenance served as a general indication of residents' propensity to follow STF instructions, along with our observations of whether the trees were planted in the correct location (i.e., the location on the Tree Care Agreement map). Maintenance characteristics at the planting site we considered were irrigation, staking, mulching, and trunk wounds from weed wackers. These maintenance issues are central elements of arboriculture practice (Harris, Clark, & Matheny, 2004) and are also emphasized in STF outreach materials. Because our field visits took place during the summer, when there was little to no rainfall, brown lawns and dry soil were used to indicate lack of watering. We did not distinguish between varying levels of irrigation beyond presence/absence of watering (i.e., we only recorded the most extreme cases of lack of watering). STF recommends that all species receive summer irrigation in the first three years, and has species-specific suggestions for watering frequency after establishment.

In our analysis of risk factors, we used a composite rating for maintenance that gave more weight to irrigation observations. All trees that had no evidence of irrigation were classified as "poor" maintenance. Trees were classified as "good" maintenance when there was evidence of irrigation, nursery stakes were removed, structural stakes were present, mulch was present, and there was no trunk wound (i.e., maintenance generally followed STF instructions). Of the latter four maintenance characteristics, trees classified as "adequate" had one or two problems, along with some evidence of irrigation. When there were three or four problems and some evidence of irrigation, a tree was classified as "poor" maintenance.

2.3.2. Neighborhood socioeconomic data

To incorporate neighborhood socioeconomic characteristics into our analysis, we used U.S. Census data from the American Community Survey (ACS). ACS produces multi-year estimated averages of social, economic, and housing information at the census tract level. We used 2007–2011 averages (U.S. Census Bureau, 2013). Specifically, we used educational attainment (percent of population with bachelor's degree or higher), median income, and median housing value.

2.3.3. Homeownership data

STF relies on residents and property owners to plant and care for trees, therefore changes in ownership and occupancy may affect tree health and survival. Houses may be vacant and unmaintained when ownership and occupancy change, new residents may have different levels of tree maintenance, and new residents may also make different landscaping choices. To account for potential homeownership effects, we determined foreclosure status, change in residential ownership, and owner vs. renter occupancy. Homeownership data is publically available through the Sacramento County Assessor. We obtained this data via the Multiple Listing Service (MLS), a proprietary service for realtors.

For purposes of our study, we defined foreclosed properties as those that were repossessed by banks and investment companies. We did not include properties given foreclosure notices that were not repossessed, nor did we include alternatives to foreclosure (i.e., short sales), because these records were not readily available in the MLS database for all properties during the entire study period. We also recorded change in residential ownership, defined as new non-bank owners. Renter status is not formally recorded with the County Assessor, therefore we inferred renter status based on the tax address of the owner (D. Covill, pers. comm.). We interpreted a mismatch between the tax address of the owner and the physical address of the house as a rental property.

We combined these three homeowner issues into one metric to identify continuously owner-occupied properties that had the same homeowner throughout the study period; such properties had the same customers responsible for tree maintenance who originally requested the tree. When a property was owner-occupied, with no change in ownership (i.e., no foreclosures or sales to new residents), this was categorized as stable homeownership. Unstable cases had renter-occupancy, foreclosure, and/or new owners. We did not analyze the issues separately due to limited sample size. Stable homeowner situations also reflect the STF program model, in which the customers who request trees are also responsible for maintenance.

2.4. Data analysis

Our study was designed as to identify the primary drivers of establishment success in the Sacramento Shade Tree Program. Toward this end, we compiled a suite of potential biophysical and socioeconomic risk factors based on the literature and discussions with STF staff. We used conditional inference trees (CIT; introduced as Random Forests by Brieman, 2001) to identify the most important variables for planting status and post-planting survival outcomes. Subsequently, we used Chi-squared tests to test differences in planting rates, and logrank tests for differences in five-year survivorship.

2.4.1. Conditional inference trees

CIT is an extension of classification and regression trees (CART; Brieman, Friedman, Olshen, & Stone, 1984), a nonparametric binary recursive partitioning method. With classification trees, CART uses a binary outcome; in our case, planted vs. not planted, and survived vs. died. CART partitions data into homogeneous subsets in terms of the explanatory variables. CIT uses random subsets to fit many classification trees to a data set, with a random subset of the available predictors used at each node (Brieman, 2001). CIT is referred to as an ensemble technique, with results for each predictor averaged across all the trees. Ecological studies are increasingly using CIT (Cutler et al., 2007).

We used CIT because the method is well-suited to exploratory studies and can accommodate a variety of variable types. This technique also reduces the overfitting problem of CART (Brieman, 2001; Strobl, Boulesteix, Kneib, Augustin, & Zeilis, 2008). We used the 'party' package in R (Hothorn, Hornik, & Zeileis, 2006; R Core Team, 2013; Strobl, Hothorn, & Zeileis, 2009) because this method is unbiased toward different variable types, and because our explanatory variables were likely highly correlated. This package uses random sub-sampling without replacement. We used 1000 classification trees and five predictors at each node.

We used permutation importance to identify the most important explanatory variables. With the permutation technique, the values of a predictor variable are randomly permuted to break the association with the response. Variable importance is a measure of prediction accuracy for observations before and after permuting, averaged over all classification trees (Strobl et al., 2008, 2009). We selected variables for further consideration (Chi-squared tests and survival analysis) that had a higher importance value than the absolute value of the most negative score, and we ranked variable importance for each model without inferring additional information from the raw importance score outputs (Strobl et al., 2009). Because CIT results are averaged over all classification trees, this technique does not produce the easily interpretable diagrams from CART. To aid in interpretation of our CIT results, we therefore reported planting and survival outcomes for the variables identified as most important.

For CIT on planting status (model P), we considered socioeconomic characteristics (homeowner stability and neighborhood income, housing value, and educational attainment) and program records that may relate to tree maintenance (number of trees delivered). STF staff speculated that customers receiving more trees may provide less care per tree (J. Caditz, pers. comm.). With regard to CIT models for post-planting mortality, we considered three different time frames: post-planting through fifth year of observation (2007–2012; model 0–5), first year after planting (2007–2008; model 0–1), and second-through-fifth year deaths (2008–2012; model 2–5). We separated the first and second-through-fifth year mortality because more trees were lost in the first year post-planting, which is a potential time for intervention from STF staff (C. Cadwallader, pers. comm.), and because we collected tree maintenance and condition characteristics in 2008 which could only be used in model 2–5. For all of these mortality models, we included tree biophysical characteristics (species water use demand, mature tree size, days since planting, season planted), socioeconomic characteristics (homeowner stability and neighborhood income, housing value, and educational attainment), and number of trees distributed. For model 2–5, we also included tree condition and other factors observed during 2008 field work (ground cover, foliage and wood condition, yard side, correct location, maintenance rating). To assess the association between homeowner stability and 2008 maintenance, we used Pearson's chi-sq. In model 2–5, we only included trees that survived through the first year (i.e., survived to summer 2008), omitting trees for which we could not closely observe condition and maintenance (e.g., we saw the tree alive over the back yard fence, but could not gain access to the yard). Trees with unknown status in 2012 were omitted from both model 0–5 and 2–5.

2.4.2. Chi-squared tests for planting status

We used chi-squared tests on the variables identified through CIT as most important for planting status. For binary explanatory variables, we used Pearson's Chi-squared, and for ordered categorical variables, we used the Cochran–Armitage Chi-squared test. The latter technique tests for a linear trend in risk as the explanatory variable increases (Jewell, 2004).

2.4.3. Survival analysis for post-planting mortality

We used the variables identified through CIT (model 0–5 only) to test for differences in survivorship over the five-year study period. We could not determine the exact date of death for the trees in our sample, therefore mortality observations were interval censored between two annual field dates. Furthermore, we had right censored data (e.g., unknown status in the fourth and fifth years). We used Turnbull's (1976) procedure for the Kaplan–Meier or product-limit estimator to calculate survivorship curves (Gomez, Calle, Oller, & Langohr, 2009) and the weighted logrank test from the 'interval' package in R (Fay & Shaw, 2010). We constructed survivorship curves by day to account for variation in both planting dates and annual field work dates. We treated the tree delivery date as time zero, as a close approximation of the planting date. We used $\alpha = 0.05$ for both survival analysis and Chi-squared tests.

We used the results from survival analysis to report overall survivorship and annual survival over the five-year establishment period (for all trees, and for categories of the most important variables from model 0–5). Annual survival was estimated using $p = (l_x)^{1/x}$, where p is annual survival rate and l_x is survivorship to year x (after Sheil, Burnslem, & Alder, 1995), assuming constant annual survival. Annual mortality is $1 - p$. Although survival was not constant across the entire five-year period, we used the annual survival estimate to compare our field observations to establishment-phase mortality assumptions in other studies. For this calculation, we used the estimate from 'interval' at day 1825 (i.e., survivorship at 5 years).

For neighborhood socioeconomic characteristics, we used raw U.S. Census tract data for CIT. But for Chi-squared and survival analysis, we categorized census socioeconomic variables into low, medium, high and very high. Break-points for income were based on categories used by the U.S. Census, with some categories collapsed due to small sample sizes in census tracts with very high or very low values.

2.4.4. Comparison to past SMUD data

For comparison to internal program reports, we also calculated the fate of distributed trees in terms of survivability, a metric of program success used by SMUD and STF (M. Sarkovich and J. Caditz, pers. comm.). Survivability is the proportion of trees alive out of the total distributed. Trees with unknown status are omitted from this calculation. SMUD defines mortality as 1 − survivability, therefore SMUD's reported mortality rates include trees that were not planted. Understanding our different mortality and survival terminology was an integral part of early conversations with STF to develop the field data collection methods. The survivability rates from SMUD's reports are difficult to compare to other urban tree

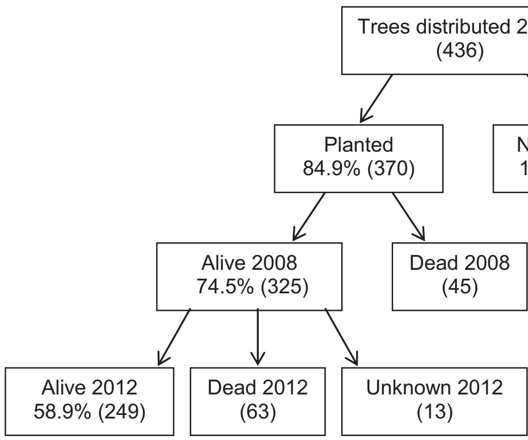

Fig. 1. The fate of shade trees distributed in Sacramento on SFR properties. Trees were distributed January–December 2007, and field observations of mortality status took place each summer 2008–2012. The numbers reported in this diagram do not represent survival rates (see Fig. 2 for post-planting survivorship curve). The proportions alive in 2008 and 2012 are given in terms of 'survivability' (i.e., proportion survived out of total distributed, omitting unknowns), a metric of success in the Sacramento program.

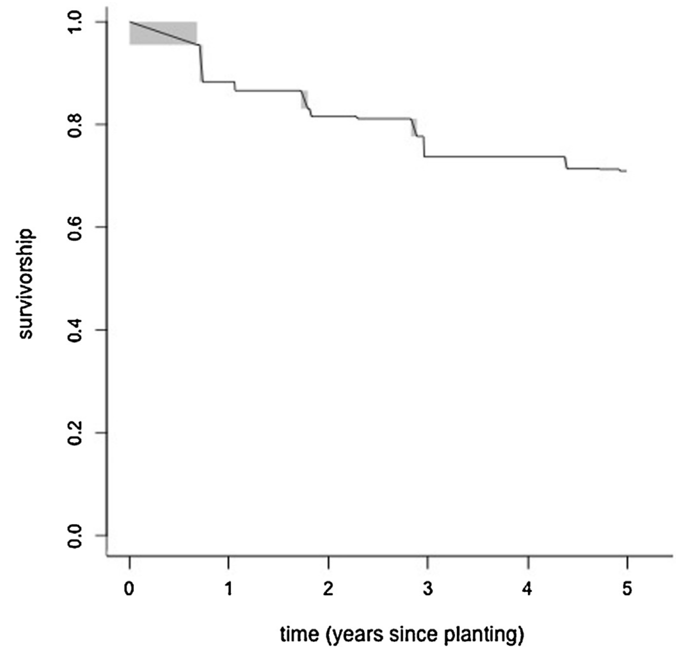

Fig. 2. Overall survivorship for all planted shade trees ($n = 370$). Survivorship was assessed from Kaplan–Meier survival analysis with Turnbull (1976) estimator for censored observations (Fay & Shaw, 2010). The gray rectangles indicate the range of possible values given censoring.

mortality studies that only consider post-planting tree survival and death.

3. Results

3.1. Overall planting and survivorship

Of the 436 trees distributed in 2007, 58.9% were still alive in 2012 (Fig. 1; this is five-year survivability following SMUD terminology). The percentage of trees never planted was 15.1%. Note that in contrast to the monitoring outcomes diagram (Fig. 1), the survivorship curve (Fig. 2) accounts for censoring, different planting dates in 2007, and variability in census intervals. For trees that were planted, survivorship steadily declined during the establishment period (Fig. 2). At five years after planting, overall survivorship was 70.9%, with 6.6% annual mortality.

3.2. Determinants of tree planting and post-planting mortality

Neighborhood educational attainment and homeowner stability were the primary determinants of planting status (Table 1). A significantly higher proportion of trees were planted in areas with more educated residents and properties with stable owner-occupied residents (Table 2).

For post-planting mortality, homeowner stability was the best predictor for each time period considered (Table 1). Over the entire five-year study (model 0–5), species water use demand, neighborhood income, season planted, mature tree size, and days since planting were also important. Higher survival rates were observed for stable properties, species with low water use demand, trees

Table 1
CIT results for each model: planting status of delivered trees ($n = 436$, model P), five-year survival of planted trees ($n = 357$, model 0–5), one-year survival of planted trees ($n = 370$, model 0–1), and four-year survival of trees which survived through the first year ($n = 291$, model 2–5). Variables are listed in rank order from permutation importance (Strobl et al., 2008, 2009). The variables in brackets have importance values less than the absolute value of the lowest negative score; variables without brackets were considered most relevant for our results (Strobl et al., 2009). Next to each of the most important variables, we indicated whether we observed higher survival (+) or lower survival (−) as the value increased (e.g., higher survival in neighborhoods with higher educational attainment, and lower survival for species with higher water use demand). For binary variables, we noted which category had higher survival (e.g., higher survival for front yard trees).

P	0–5[a]	0–1	2–5[a]
Neighborhood educ. attain. (+)	Homeowner stability (stable +)	Homeowner stability (stable +)	Homeowner stability (stable +)
Homeowner stability (stable +)	Species water use demand (−)	Days since planting (−)	Yard side (front +)
[Neighborhood income]	Neighborhood income[b]	Neighborhood income[b]	Number of trees delivered (−)
[Number of trees delivered]	Season planted (rainy +)	Neighborhood educ. Attain. (+)	Maintenance rating (+)
[Neighborhood housing value]	Mature tree size (−)	Mature tree size (−)	[Days since planting]
	Days since planting (−)	[Season planted]	[Foliage condition]
	[Neighborhood housing value]	[Number of trees delivered]	[Mature tree size]
	[Number of trees delivered]	[Species water use demand]	[Neighborhood income]
	[Neighborhood educ. attain.]	[Neighborhood housing value]	[Species water use demand]
			[Correct location]
			[Wood condition]
			[Neighborhood educ. attain.]
			[Neighborhood housing value]
			[Ground cover]

[a] Model 0–5 and 2–5 both excluded 13 right censored trees with unknown status 2012. Model 2–5 also excluded trees for which maintenance characteristics could not be observed in the first summer of field work (2008).
[b] Survival results were inconsistent across neighborhood income levels.

Table 2
Planting rates for variables identified as most important from CIT (model P, Table 1). Reported p-values are for Pearson's Chi-squared (homeowner stability) and the Chi-squared test for trend for neighborhood educational attainment (Jewell, 2004).

Explanatory variable	Planting rate, %
Neighborhood educational attainment (p = 0.0140)[a]	
Low (n = 159)	79.2
Middle (n = 76)	85.5
High (n = 98)	88.8
Very high (n = 103)	89.3
Homeowner stability (p = 0.0007)	
Stable (n = 327)	88.4
Unstable (n = 109)	74.3
All trees (n = 436)	84.9

[a] Percent of population with bachelor's degree or higher: low (<20%), middle (20–29%), high (30–39%), and very high (≥40%). Median for Sacramento County: 27.7% (U.S. Census Bureau, 2013).

planted during the rainy season, species with smaller mature size, and trees with fewer days since delivery (Table 3). However, only homeowner stability had a statistically significant difference with the weighted logrank test (Table 3 and Fig. 3). Neighborhood income did not show a consistent trend.

Focusing on the first year after planting (model 0–1), homeowner stability was again the most important variable, followed by days since delivery, neighborhood income, neighborhood educational attainment, and mature tree size (Appendix B). Considering survival of trees that were still alive at the first summer field observation (model 2–5), variables related to tree care were important: homeowner stability, yard side, number of trees delivered, and maintenance rating (Appendix C). 22.7% of the trees we observed alive in the summer after planting had "good" maintenance (Appendix C), and many customers did not adhere to recommended practices (Appendix D). Trees with "good" maintenance were significantly more likely to be found on properties with stable homeownership (Table 4).

Table 3
Survivorship and annual survival estimates for the five-year establishment phase, considering only planted trees and the variables identified as most important from CIT (model 0–5, Table 1). Survivorship was assessed from Kaplan–Meier survival analysis with Turnbull (1976) estimator for censored observations. Survivorship and estimated annual survival were based on five years after planting, which takes into account the varied planting dates and field observation dates. Unlike CIT, we included all right censored trees with unknown status 2012 (n = 370 for survival analysis, n = 357 for CIT). Reported p-values are for the weighted logrank test for interval-censored data (Fay & Shaw, 2010).

Explanatory variable	Survivorship 2007–2012, %	Est. annual survival, % (annual mortality)
Homeowner stability (p = 0.0019)		
Stable (n = 222)	76.6	94.8 (5.2)
Unstable (n = 148)	61.3	90.7 (9.3)
Species water use (p = 0.2142)[a]		
Low (n = 93)	77.1	94.9 (5.1)
Medium (n = 201)	66.6	92.2 (7.8)
High (n = 76)	72.2	93.7 (6.3)
Neighborhood income (p = 0.7877)[b]		
Low (n = 85)	70.5	93.2 (6.8)
Middle (n = 136)	73.5	94.0 (6.0)
High (n = 106)	66.1	92.1 (7.9)
Very high (n = 43)	74.2	94.2 (5.8)
Season planted (p = 0.0967)		
Dry (n = 197)	67.7	92.5 (7.5)
Rainy (n = 173)	75.5	94.5 (5.5)
Mature tree size (p = 0.1625)		
Small (n = 88)	77.7	95.1 (4.9)
Medium (n = 165)	68.5	92.7 (7.3)
Large (n = 117)	66.4	92.1 (7.9)
Days since planting (p = 0.2401)		
182–370 days (n = 192)	71.7	93.6 (6.4)
371–634 days (n = 178)	68.1	92.6 (7.4)
All trees (n = 370)	70.9	93.4 (6.6)

[a] We also tried comparing low water use to combined medium and high water use trees. In this case, p = 0.09598.
[b] Median family income, in 2011 inflation-adjusted US dollars: low (<50,000), middle (50,000–74,999), high (75,000–99,999), very high (≥100,000). Median for Sacramento County: 65,720 (U.S. Census Bureau, 2013).

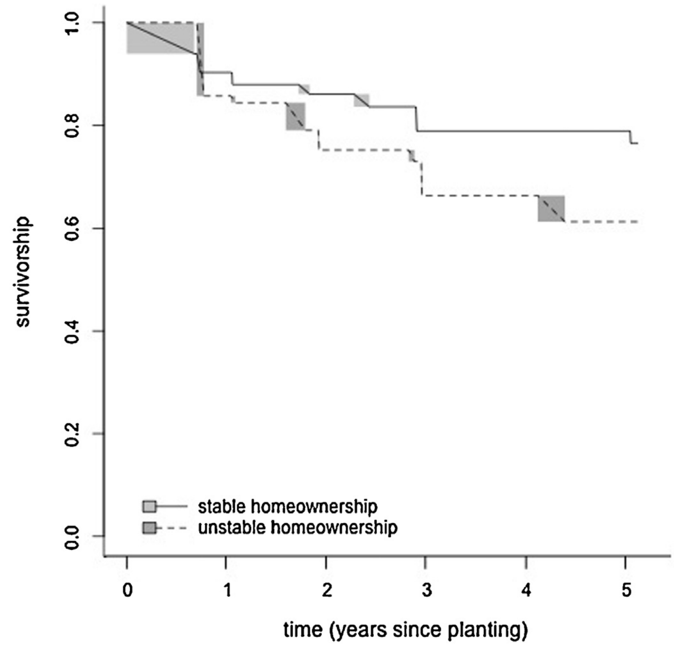

Fig. 3. Shade tree survivorship, comparing trees located on properties with stable vs. unstable homeownership over the five-year study period. Survivorship was assessed from Kaplan–Meier survival analysis with Turnbull (1976) estimator for censored observations. A weighted logrank test (Fay & Shaw, 2010) shows significant difference (n = 370, p = 0.0019). The gray rectangles indicate the range of possible values given censoring.

Table 4
Association between maintenance rating observed in 2008 and property stability (years 2007–2008 only, for trees included in model 2–5, n = 291). Maintenance categories with the same letter were significantly different with Pearson's Chi-squared (p < 0.01).

Maintenance rating	Property stability	
	Stable (%)	Unstable (%)
Good[ab]	93.9	6.1
Adequate[a]	80.0	20.0
Poor[b]	82.1	17.9

4. Discussion

Our observed tree losses in Sacramento were higher than urban tree mortality projections used in previous studies for this area (Hildebrandt & Sarkovich, 1998; McPherson et al., 1998) and for other cities (McPherson & Simpson, 2001; McPherson et al., 2008; Morani et al., 2011). While we found 6.6% annual mortality for young trees during the establishment phase, McPherson and Simpson (2001) assumed 3% mortality during the first five years after planting for urban forests across CA, and McPherson et al. (2008) assumed 1–5% mortality in the first five years for Los Angeles, CA. Our observed mortality rates are closer to the high mortality scenario considered by Morani et al. (2011) in New York City, NY, which assumed 4–8% mortality for the smallest size class (0–7 cm, roughly similar to our 0–5 years post-planting age class). Additionally, we distinguished between failure to plant rates and post-planting mortality. This is a major distinction for tree give-away programs, which are a component of million tree initiatives, yet planting rates are overlooked in the literature. The single biggest source of tree loss in our study was failure to plant: 15.1% of trees distributed were not planted (Fig. 2). To the best of our knowledge, ours is the first study reporting planting rates, as well as longitudinal survival data throughout the establishment phase.

It is possible that our planting and survival rates were low due to the recent economic recession and foreclosure crisis. Sacramento had the fifth-highest foreclosure rate in the U.S. in 2007 (Realty Trac, 2008). In repossessed bank-owned properties, lawn care typically becomes the responsibility of the bank or lending agency. However, our survivability rates (proportion surviving out of number delivered) are consistent with previously collected SMUD data, indicating that the outcomes we observed may actually be relatively typical for this program, despite the recession. An internal SMUD report (M. Sarkovich, pers. comm.) found 54% survivability five years after tree distribution (1996–2001). Using SMUD terminology, our five-year survivability was 59%. SMUD's recent projections of shade tree energy savings assume 50–57% survivability at 30 years and 69–72% at five years (M. Sarkovich, pers. comm.). Population projections in urban greening should use more realistic mortality data based on field studies. Both our study and the SMUD report indicate that survival projections for tree give-away programs – and perhaps for tree planting programs more generally – are overly optimistic. This finding has implications for urban forest management. Indeed, the issue of accounting for tree losses in the million tree campaigns has already been discussed in blogs and newspaper articles (Foderaro, 2011; Marritz, 2012; Miller, 2010). Realistic expectations of young tree mortality are also important to plan for population cycles of tree planting, death, removal and replacement in urban forest ecosystems (Richards, 1979).

With respect to the causes of tree losses in the Shade Tree Program, we found strong evidence that stewardship actions are among the most critical determinants of young tree planting and survival. While stewardship has a variety of definitions in the literature and among practitioners (Romolini et al., 2012), we use stewardship broadly to encompass the sense of responsibility for trees as it manifests in maintenance actions. For example, STF gives customers a "Shade Tree Planting and Tree Stewardship Guide" during the site visit. We interpret the homeowner stability metric as an indicator of consistent tree care by the individual(s) who requested the shade trees. This is supported by the significant association found between homeowner stability and maintenance: for trees with "good" maintenance, 94% were found on stable properties, compared to only 6% on unstable properties (Table 4). Properties with renters, foreclosure, and/or a change in residential ownership likely experienced inconsistent landscape maintenance, with some properties experiencing long gaps in tree care. Trees were more likely to be planted (Table 2) and more likely to survive (Table 3 and Fig. 3) on owner-occupied properties that had the same homeowner during the study period. Our maintenance rating, while admittedly based on a brief field inspection, nonetheless ranked as an important variable. Most customers did not adhere to recommended practices (Appendix D). Front yards may have higher survival because they serve as a showcase to the neighborhood (Larson et al., 2009; Larsen & Harlan, 2006), and potentially receive greater care than backyards. Anecdotally, we also observed some vacant and foreclosed properties with maintained front yards, but unmaintained and overgrown back yards. The higher survival for properties with only a few trees delivered fits with STF speculation that shade tree customers receiving many trees may invest less time per tree. Our finding that stewardship issues dominate during the establishment phase concurs with previous research on street trees in New York City, NY (Boyce, 2010).

In response to our results, several changes have been made in the Shade Tree Program. STF staff are trying to address the maintenance problem by enhancing communication with residents. Outreach strategies have been expanded to include mailed and emailed seasonal "tree care tips", which remind customers about tree maintenance. STF also recently implemented systematic phone calls after the site visit; such follow-up communication was previously more sporadic. During these phone calls, staff reiterate planting and maintenance recommendations, and learn whether residents need assistance with the physical labor of planting. STF may implement further changes, including tailored outreach for rental properties and planting a higher proportion of drought-tolerant species. Residents themselves may not carry out maintenance, therefore STF is also considering how to convey recommended practices to landscapers. We suggest that other urban forest monitoring projects should use a composite maintenance rating, tailored to their programs' educational materials and maintenance guidelines, in order to evaluate adherence to recommended practices and potential effects on tree survival. Additionally, other tree give-away programs may consider increased communication with residents after tree delivery.

Along with the tree care indicators described above, biophysical factors were also important in the CIT model for five-year tree survival (Table 3). We did not conduct species-specific analysis of survival outcomes due to insufficient sample size per species. By including functional groups for urban forest management, we were able to include species-related information that is useful to practitioners. We observed higher survival for species with low water use demand, and higher survival for trees planted during the rainy season. Although neither of these factors was statistically significant with weighted logrank tests, the importance of these variables in CIT indicates that species selection and seasonal patterns may be related to young tree survival in this area with summer drought. Although STF recommends watering all species during the establishment years, drought tolerant species may be more able to withstand irrigation neglect. We also observed that trees with larger mature size died more often (Table 3), the reverse of what SMUD's models assume (M. Sarkovich, pers. comm.). However, this variable was not highly ranked in variable importance, and water use demand may be the more ecologically meaningful way to group species for mortality risk.

The risk of death for species with higher water use demand may have been exacerbated by lower-than-normal precipitation during our study. Normal annual rainfall in Sacramento is 50 cm, but rainy season precipitation was 60% of normal in 2006/7, 74% in 2007/8, 83% in 2008/9, 98% in 2009/10, 125% in 2010/11, and 67% in 2011/12 (NOAA, 2014). The species used in the Shade Tree Program were selected by a technical advisory committee, and can perform well with appropriate irrigation, but our results show that tree care is not reliable. Furthermore, given the potential for more drought due to climate change, and the challenges of water resource management in this region (Delta Stewardship Council, 2013), it may be prudent for this program to plant more drought-tolerant trees. The interplay between species selections, maintenance actions, and regional climate could be included in future monitoring evaluations.

We also found that time since delivery (i.e., number of days between tree delivery and 2008 field date) was the second-most important variable for first-year survival (Table 1), but was less highly ranked in other models. This finding emphasizes the relevance of the exact time since planting in newly planted trees, especially in the first year. Trees in urban forestry programs are often planted during a range of months (e.g., all year-round, or spring and fall seasons only), while field work is often limited to summer. High mortality for young trees means that a difference of several months in the time elapsed since planting can impact survival calculations. Hence we do not refer to raw proportions of trees alive (Appendices B and C) as "survival rates" – they lack the precision of the survival analysis over the entire study period (Fig. 2) and are presented for descriptive purposes in interpreting CIT results. As the decades pass after planting, precise calculations by day may become less critical in assessing survival.

In terms of neighborhood socioeconomic characteristics, income and educational attainment were important in some of our models. While educational attainment was significantly associated with tree planting status (Table 2), with higher planting rates in areas with higher educational achievement, income did not show a consistent pattern for five-year survival outcomes (Table 3). However, our insights into these patterns are limited by our use of neighborhood-scale data, rather than household surveys. We collected these socioeconomic data at the Census tract scale because frequent changes in homeownership made interviews and surveys with every household participating in our study impractical. Additionally, income and housing value during our study period were likely affected by the foreclosure crisis in Sacramento (Immergluck & Smith, 2006), therefore other studies may find different relationships between tree mortality and neighborhood-scale socioeconomic patterns. Although income, housing value, and educational attainment were not ranked as the most important variables in our study, they deserve further analysis in future urban tree mortality research, particularly at the household scale.

Our findings are most relevant to urban tree give-away programs in which residents are responsible for tree care. Give-aways are an increasingly important segment of urban greening campaigns because of the opportunity to increase canopy on private properties. It is possible that survival rates would be different for programs in other climates and socio-economic contexts; data for give-away programs in other cities has not yet been reported. There are also factors potentially related to urban tree survival that we were not able to include, such as household values and cultural influences, neighborhood norms, and soil conditions. Future urban forestry research across different age and size classes, and different land uses, may detect other important risk factors for tree death. Additionally, most other urban tree mortality studies focus on street trees, not yard trees. As more longitudinal urban tree survival data becomes available, researchers can improve population projection models that are specific to geographic regions, species functional groups, planting site types, and program characteristics.

5. Conclusion

In summary, our results showed that tree care and climate-appropriate species selection influenced urban tree survival during the establishment phase in Sacramento, with stable homeownership as the most important variable. Our findings are consistent with arboricultural practices, which emphasize tree maintenance and species selection (Harris et al., 2004), and with previous research emphasizing the role of stewardship for young tree survival (Boyce, 2010; Lu et al., 2010). While human factors are essential to understanding urban tree death, urban forests are not divorced from biological influences (Ramage, Roman, & Dukes, 2012). To sustainably manage the urban forest (Clark, Matheny, Cross, & Wake, 1997), with planting programs that achieve the desired ecosystem services, it is essential to collect long-term field data to both improve the accuracy of projected environmental benefits and identify major impediments to tree survival.

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Appendix A. Sacramento shade tree species classified by water use demand in California's Central Valley (L = low, M = medium, H = high; Costello & Jones, 2014) and expected mature tree size [S = small (<7.6 m height), M = medium (7.7–13.7 m), L = large (>13.7 m)].

Species	Water use demand	Mature size	Percent of planted trees (*n* = 370)
Acer buergerianum	M	M	7.6
Acer campestre	M	M	1.1
Acer rubrum[a]	H	L	15.1
Acer truncatum	M	M	3.2
Betulanigra	H	L	1.6
Betulaplatyphylla japonica	H	M	3.8
Carpinus betulus	M	M	0.3
Celtis australis	M	L	0.3
Cercis canadensis	M	S	5.4
Crataegus phaenopyrum	M	S	0.8
Koelreuteria bipinnata	M	M	0.3
Koelreuteria paniculata	M	M	1.1
Lagerstroemia indica	L	S	17.0
Malus sp.	M	S	0.5
Nyssa sylvatica	M	M	1.6
Pistacia chinensis	L	M	6.5
Platanus racemosa	M	L	0.3
Platanus × acerifolia	M	L	2.7
Pyrus calleryana[b]	M	M	17.8
Quercus castaneafolia[c]	M	L	0.5
Quercus coccinea	M	L	0.8
Quercus douglasii[d]	L	L	0.3
Quercus lobata	L	L	1.4
Quercus macrocarpa	M	L	0.5
Quercus robur	M	L	0.5
Quercus rubra	M	L	3.8
Quercus shumardii	M	L	0.3
Tilia americana	M	L	0.3
Tilia cordata	M	M	1.4
Zelkova serrate	M	L	3.2

[a] *A. rubrum* includes columnar cultivar. This species was classified as high in the previous version of WUCOLS, and in STF species lists, and medium in the current version of WUCOLS (Costello & Jones, 2014).

[b] *P. calleryana* includes 'Capital', 'Chanticleer', and 'Redspire' cultivars.

[c] *Q. castaneafolia* is not listed in WUCOLS. Our classification was based on local expertise at STF (L. Leineke, pers. comm.) and the University of California, Berkeley (J.R. McBride, pers. obs.).

[d] *Q. douglasii* was categorized as very low in WUCOLS, but low by STF.

Appendix B. Percent of trees alive in the first year of field observation (2008) out of the total planted, for the most important variables identified from CIT (model 0–1). These results do not take into account the varied planting dates and field observation dates, and are presented for descriptive purposes only to aid in interpretation of CIT results (Table 1).

Explanatory variable	% alive 2007–2008
Homeowner stability	
Stable (*n* = 289)	91.7
Unstable (*n* = 81)	74.1

Appendix B (*Continued*)

Explanatory variable	% alive 2007–2008
Days since planting	
182–370 days (n = 192)	91.1
371–634 days (n = 178)	84.3
Neighborhood income[a]	
Low (n = 85)	85.9
Middle (n = 136)	88.2
High (n = 106)	88.7
Very high (n = 43)	88.4
Neighborhood educational attainment[b]	
Low (n = 126)	82.5
Middle (n = 65)	89.2
High (n = 87)	90.8
Very high (n = 92)	91.3
Mature tree size	
Small (n = 88)	92.0
Medium (n = 165)	89.1
Large (n = 117)	82.9
All trees (n = 370)	87.8

[a] Median family income, in 2011 inflation-adjusted US dollars: low (<50,000), middle (50,000–74,999), high (75,000–99,999), very high (≥100,000). Median for Sacramento County: 65,720 (U.S. Census Bureau, 2013).

[b] Percent of population with bachelor's degree or higher: low (<20%), middle (20–29%), high (30–39%), and very high (≥40%). Median for Sacramento County: 27.7% (U.S. Census Bureau, 2013).

Appendix C. Percent of trees observed alive in the fifth year (2012) that were alive during the first year of field observation (2008), for the most important variables identified from CIT (model 2–5). This table omits right censored trees with unknown status 2012, and trees lacking maintenance data 2008. These rates do not take into account the varied planting dates and field observation dates, and are presented for descriptive purposes only to aid in interpretation of CIT results (Table 1).

Explanatory variable	% alive 2008–2012
Homeowner stability	
Stable (n = 176)	86.4
Unstable (n = 115)	72.2
Yard side	
Front (n = 128)	85.9
Back (n = 163)	76.7
Number of trees delivered	
1–3 (n = 139)	83.5
4–6 (n = 94)	80.9
>6 (n = 58)	74.1
Maintenance rating	
Good (n = 66)	89.4
Adequate (n = 150)	80.7
Poor (n = 75)	73.3
All trees (n = 291)	80.8

Appendix D. Residential planting and maintenance practices observed in summer 2008 and included in CIT model 2–5 (n = 291). This table includes only trees alive in 2008, and omits both right censored trees and trees for which maintenance 2008 could not be observed. Field records about irrigation, mulch, nursery stakes, structural stakes, and trunk wounds were used in the maintenance rating (results in Appendix C). Tree care practices that adhere to Shade Tree Program instructions are marked *.

Tree care practice	% trees
Planting location	
Correct*	74.6
Incorrect	25.4
Irrigation	
Absent	14.1
Present*	85.9
Mulch	
Present*	38.5
Absent	61.5
Nursery stake	
Present	37.5
Absent*	62.5
Structural stakes	
Present*	77.7
Absent	22.3
Trunk wound	
Present	7.2
Absent*	92.8

References

Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy*, *70*(3), 295–310.

Boyce, S. (2010). It takes a stewardship village: Effect of volunteer tree stewardship on urban street tree mortality rates. *Cities and the Environment*, *3*. Article 3.

Brieman, L. (2001). Random forests. *Machine Learning*, *45*, 5–32.

Brieman, L., Friedman, J. H., Olshen, R. A., & Stone, C. G. (1984). *Classification and regression trees*. Belmont, CA: Wadsworth International Group.

Clark, J. R., Matheny, N. P., Cross, G., & Wake, V. (1997). A model of urban forest sustainability. *Journal of Arboriculture*, *23*(1), 17–30.

Costello, L. S., & Jones, K. S. (2014). University of California (UC) Cooperative Extension (2000). In *Water use classification of landscape species: WUCOLS IV*. University of California Cooperative Extension. Retrieved from ucanr.edu/sites/WUCOLS.

Craul, P. J. (1999). *Urban soils: Applications and practices*. New York, NY: John Wiley & Sons.

Cutler, D. R., Edwards, T. C., Beard, K. H., Cutler, A., Hess, K. T., Gibson, J., et al. (2007). Random forests for classification in ecology. *Ecology*, *88*(11), 2783–2792.

Delta Stewardship Council. (2013). *The Delta Plan: Ensuring a reliable water supply for California, a healthy Delta ecosystem, and a place of enduring value*. Retrieved from www.deltacouncil.ca.gov

Donovan, G. H., & Butry, D. T. (2010). Trees in the city: Valuing street trees in Portland, Oregon. *Landscape & Urban Planning*, *94*(2), 77–83.

Fay, M. P., & Shaw, P. A. (2010). Exact and asymptotic weighted logrank tests for interval censored data: The interval R package. *Journal of Statistical Software*, *36*(2), 1–34.

Foderaro, L. W. (2011). As city plants trees, some say a million are too many (2011, October 18). *New York Times*.

Gomez, G., Calle, M. L., Oller, R., & Langohr, K. (2009). Tutorial on methods for interval-censored data and their implementation in R. *Statistical Modeling*, *9*(4), 259–297.

Harris, R. W., Clark, J. R., & Matheny, N. P. (2004). *Arboriculture: Integrated management of landscape trees, shrubs, and vines* (4th ed.). New Jersey: Prentice Hall.

Hauer, R. J., Miller, R. W., & Ouimet, D. M. (1994). Street tree decline and construction damage. *Journal of Arboriculture*, *20*(2), 94–97.

Hildebrandt, E. W., & Sarkovich, M. (1998). Assessing the cost-effectiveness of SMUD's shade tree program. *Atmospheric Environment*, *32*(1), 85–94.

Hothorn, T., Hornik, K., & Zeileis, A. (2006). Unbiased recursive partitioning: A conditional inference framework. *Journal of Computational & Graphical Statistics*, *15*(3), 651–674.

Immergluck, D., & Smith, G. (2006). The external costs of foreclosure: The impact of single-family mortgage foreclosured on property values. *Housing & Policy Debate*, *17*(1), 57–59.

Jewell, N. P. (2004). *Statistics for epidemiology*. Boca Raton, FL: Chapman & Hall/CRC.

Konijnendijk, C. C., Ricard, R. M., Kenney, A., & Randrup, T. B. (2006). Defining urban forestry – A comparative perspective of North America and Europe. *Urban Forestry& Urban Greening*, *4*(3–4), 93–103.

Kuo, F. E. (2003). The role of arboriculture in a healthy social ecology. *Journal of Arboriculture*, *29*(3), 148–155.

Larson, K. L., Casagrande, D., Harlan, S. L., & Yabiku, S. T. (2009). Residents' yard choices and rationales in a desert city: Social priorities, ecological impacts, and decision tradeoffs. *Environmental Management*, *44*(5), 921–937.

Larsen, L., & Harlan, S. L. (2006). Desert dreamscapes: Residential landscape preference and behavior. *Landscape & Urban Planning*, *78*(1–2), 85–100.

Lawrence, A. B., Escobedo, F. J., Staudhammer, C. L., & Zipperer, W. (2012). Analyzing growth and mortality in a subtropical urban forest ecosystem. *Landscape & Urban Planning*, *104*(1), 85–94.

Leibowitz, R. (2012). Urban tree growth and longevity: An international meeting and research symposium white paper. *Arboriculture & Urban Forestry*, *38*(5), 237–241.

Lines, E. R., Coomes, D. A., & Purves, D. W. (2010). Influences of forest structure, climate and species composition on tree mortality across the eastern US. *PLoS ONE*, *5*(10), e13212.

Lu, J. W. T., Svendsen, E. S., Campbell, L. K., Greenfeld, J., Branden, J., King, K. L., et al. (2010). Biological, social, and urban design factors affecting young street tree mortality in New York City. *Cities and the Environment*, *3*. Article 1.

Marritz, L. (2012). A million trees? Only if we can keep them around (2012, April 18). *Next City*,. Message posted to http://nextcity.org/daily/entry/a-million-trees-only-if-we-can-keep-them-around
McPherson, E. G., Scott, K. I., & Simpson, J. R. (1998). Estimating cost effectiveness of residential yard trees for improving air quality in Sacramento, California, using existing models. *Atmospheric Environment*, *32*(1), 75–84.
McPherson, E. G., & Simpson, J. R. (2001). *Effects of California's urban forests on energy use and potential savings from large-scale tree planting*. USDA Forest Service, Pacific Southwest Research Center.
McPherson, E. G., & Simpson, J. R. (2003). Potential energy savings in buildings by an urban tree planting programme in California. *Urban Forestry & Urban Greening*, *2*(2), 73–86.
McPherson, E. G., Simpson, J. R., Xiao, Q., & Wu, C. (2008). *Los Angeles 1-Million tree canopy cover assessment*. USDA Forest Service, Pacific Southwest Research Station. GTR-207.
Miller, C. (2010). Shady dealings: Or the problem with planting trees in Los Angeles (2011, March 9). *KCET*,. Message posted to http://www.kcet.org/updaily/socal_focus/commentary/31213-los-angeles-million-trees-villaraigosa.html
Morani, A., Nowak, D. J., Hirabayashi, S., & Calfapietra, C. (2011). How to select the best tree planting locations to enhance air pollution removal in the Million Trees NYC initiative. *Environmental Pollution*, *159*(5), 1040–1047.
NOAA. (2014). *Annual climatological summary, 2006–2012*. Station: Sacramento 5 ESE, CA US: National Climate Data Center. Retrieved from www.ncdc.noaa.gov
Nielsen, C. N., Bühler, O., & Kristoffersen, P. (2007). Soil water dynamics and growth of street and park trees. *Arboriculture & Urban Forestry*, *33*(4), 231–245.
Nowak, D. J. (1986). *Silvics of an urban tree species: Norway maple (Acer platanoides L.)* (M.S. thesis). Syracuse, NY: State University of New York, College of Environmental Science and Forestry., 148 pp.
Nowak, D. J., Kuroda, M., & Crane, D. E. (2004). Tree mortality rates and tree population projections in Baltimore, Maryland, USA. *Urban Forestry & Urban Greening*, *2*(3), 139–147.
Nowak, D. J., McBride, J. R., & Beatty, R. A. (1990). Newly planted street tree growth and mortality. *Journal of Arboriculture*, *16*(5), 124–129.
Pataki, D. E., Alberti, M., Cadenasso, M. L., Felson, A. J., McDonnell, M. J., Pincetl, S., et al. (2013). Urban greening needs better data. *Nature*, *502*(7473), 624.
Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., et al. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*, *9*(1), 27–36.
Pickett, S. T. A., Burch, W. R., Dalton, S. E., Foresman, T. W., Grove, J. M., & Rowntree, R. (1997). A conceptual framework for the study of human ecosystems in urban areas. *Urban Ecosystems*, *1*(4), 185–199.
Poland, T. M., & McCullough, D. G. (2006). Emerald ash borer: Invasion of the urban forest and the threat to North America's ash resource. *Journal of Forestry*, *104*(3), 118–124.
R Core Team. (2013). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. www.r-project.org
Ramage, B. S., Roman, L. A., & Dukes, J. S. (2012). Relationships between urban tree communities and the biomes in which they reside. *Applied Vegetation Science*, *16*(1), 8–20.
RealtyTrac. (2008). *Detroit, Stockton, Las Vegas post highest 2007 metro foreclosure rates (February 13, 2008)*. Retrieved from http://www.realtytrac.com/content/press-releases/detroit-stockton-las-vegas-post-highest-2007-metro-foreclosure-rates-3691
Richards, N. A. (1979). Modeling survival and subsequent replacement needs in a street tree population. *Journal of Arboriculture*, *5*(11), 251–255.
Roman, L. A., & Scatena, F. N. (2011). Street tree survival rates: Meta-analysis of previous studies and application to a field survey in Philadelphia, PA, USA. *Urban Forestry & Urban Greening*, *10*(4), 269–274.
Romolini, M., Brinkley, W., & Wolf, K. L. (2012). *What is urban environmental stewardship? Constructing a practitioner-derived framework*. USDA Forest Service, Pacific Northwest Research Station, Research Note PNW-RN-566.
Sheil, D. F., Burslem, R. P., & Alder, D. (1995). The interpretation and misinterpretation of mortality rate measures. *Journal of Ecology*, *83*(2), 331–333.
Silvera Seamans, G. (2013). Mainstreaming the environmental benefits of street trees. *Urban Forestry & Urban Greening*, *12*(1), 2–11.
Sklar, F., & Ames, R. G. (1985). Staying alive: Street tree survival in the inner-city. *Journal of Urban Affairs*, *7*, 55–66.
Southworth, M. (2005). Designing the walkable city. *Journal of Urban Planning and Development*, *December*, 246–257.
Staudhammer, C., Escobedo, F., Lawrence, A., Duryea, M., Smith, P., & Merritt, M. (2011). Rapid assessment of change and hurricane impacts to Houston's urban forest structure. *Arboriculture & Urban Forestry*, *37*(2), 60–66.
Strobl, C., Boulesteix, A., Kneib, T., Augustin, T., & Zeilis, A. (2008). Conditional variable importance for random forests. *BMC Bioinformatics*, *9*, 307.
Strobl, C., Hothorn, T., & Zeileis, A. (2009). Party on! A new, conditional variable-importance measure for random forests available in the party pacakge. *R Journal*, *1*, 14–17.
Turnbull, B. W. (1976). The empirical distribution function with arbitrarily grouped, censored and truncated data. *Journal of the Royal Statistical Society B*, *38*, 290–295.
Turner, C., & Mitchell, M. (2013). Planting the spaces in between: New York Restoration Project's Tree Giveaway Program. *Cities and the Environment*, *6*(1). Article 4.
U.S. Census Bureau. (2013). *American Community Survey 5-year estimates. Tables DP02, DP03, and DP04. Generated January. 28, 2013 by L.A. Roman using American FactFinderfactfinder2.census.gov*.
Xiao, Q. F., & McPherson, E. G. (2002). Rainfall interception by Santa Monica's municipal urban forest. *Urban Ecosystems*, *6*(3), 291–302.
Young, R. F. (2013). Mainstreaming urban ecosystem services: A national survey of municipal foresters. *Urban Ecosystems*, *16*(4), 703–722.
Young, R. F., & McPherson, E. G. (2013). Governing metropolitan green infrastructure in the United States. *Landscape & Urban Planning*, *109*(1), 67–75.