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Demographic trends in Claremont California's street tree population

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ABSTRACT

The aim of this study was to quantify street tree population dynamics in the city of Claremont, CA. A repeated measures survey (2000 and 2014) based on a stratified random sampling approach across size classes and for the most abundant 21 species was analyzed to calculate removal, growth, and replacement planting rates. Demographic rates were estimated using a hierarchical Bayesian framework. The community-level (all species) median growth rate was 1.41% per year (95% CI: 1.21–1.65%) with *Pinus brutia* and *Pistacia chinensis* growing significantly faster than the community-level median. The community-level median removal rate was 1.03% per year (95% CI: 0.66–1.68%), with no significant differences between species and the community-level medium. Once removed, only 7.2% (95% CI: 4.4–12.9%) were replaced annually. Presence of overhead utility lines influenced tree removal rates while age, diameter-at-breast-height, and prior tree condition influenced tree growth. Overall live aboveground biomass in sampled sites was 713.29 Mg in 2000 and increased to 877.36 Mg by 2014. Biomass gain from growth outweighed loss from removals nearly three-fold; replacement contributed 0.5% of the total biomass gain. We conclude that to increase the resilience of the street tree population will require 1) an increase in percent of full stocking or biomass stock and 2) a shift in the species palette to favor species less vulnerable to pests and expected disturbance from climate change and 3) ongoing monitoring to detect departures from baseline demographic rates.

1. Introduction

Quantifying the components of forest demography: recruitment, mortality and growth, is key to understanding future change and implications of different management regimes. The same principles apply to urban forest demography, except processes can vary. New trees, termed "recruitment" can occur from natural regeneration or plantings in new sites and old sites as "replacements". In urban forests, the term "removal rate" is used in lieu of mortality rate because humans remove trees at any time and it is often difficult to know if the tree died of biological causes or was removed for other reasons. Growth of surviving trees is important to quantify because much of the urban forest's function and value is modeled on the size of its trees (McPherson et al., 2016b). It is the combination of growth, removal and replacement plantings that drives the changes in the structure and function of the population (Fahey et al., 2013), and therefore all three demographic components need to be assessed to gain a complete perspective of the state of the urban forest.

Stability in municipal forest structure translates to predictable and sustained levels of ecosystem services. Stability minimizes the risk of catastrophic losses that would inevitably lead to disruptions in municipal budgets and ecosystem function (McPherson and Kotow, 2013). In the urban forestry context, stability has been defined as the low probability of incurring tree loss leading to disruptions in management and diminished flow of functional values and benefits from trees (Richards, 1983). Two metrics can be used to define stability in a street tree population. The first is continuity of stocking level or percent of full stocking, where full stocking is two trees per 15.2 m of street length (Wray and Prestemon, 1983). Stocking level reflects street tree density without reference to tree size. The second metric is continuity of biomass stock over time, where biomass is calculated for each tree at periodic intervals using allometric equations. Biomass incorporates differences in tree sizes and reflects the magnitude of the population's function and value. In terms of stocking level, stability occurs when replacement plantings match or exceed removals to the cohort under study. In terms of biomass stock, stability occurs when biomass from replacement plantings and growth of survivors matches or outpaces loss from removals. Just as the current urban forest is a reflection of the integrated outcome of past removals, growth, and plantings, the stability of the forest in the future is determined by the balance of these demographic components.

Previous work on demographic rates have taken a parsed approach.

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Most studies have solely looked at the survival or growth of newly planted trees (e.g., Impens and Delcarte, 1979; Ko et al., 2015; Nowak et al., 1990; Roman et al., 2014; Thompson et al., 2004) and replacement rates have not been explicitly reported in urban forestry literature. Fewer studies have considered the balance of inputs and outputs (but see Roman et al., 2014) and to our knowledge, not one has analyzed stability in terms of stocking or biomass. Ideally, demographic rates should be quantified on a species-specific level (Roman et al., 2016), but very little information exists for empirical tree growth rates. In light of the central role urban forests play in uptake of pollutants and carbon in cities (Brack, 2002; Escobedo et al., 2011; Nowak and Crane, 2002; Nowak et al., 2006) it is important to build our understanding of species-level dynamics within the population and assess temporal patterns. In this study, we demonstrate application of the demographic approach successfully used in wildland forest systems (e.g., Fahey et al., 2013; Levine et al., 2016; van Doorn et al., 2011) to assess drivers of urban forest change.

Within the urban forest landscape, street tree populations differ from remnant forest patches or afforested parks due to being of planted origin and high management intensity (Zipperer et al., 1997). Although street trees are only a small part of the urban forest, they contribute considerable ecosystem services (McPherson et al., 2016b) as well as disservices to the urban landscape (Escobedo et al., 2011; Pataki et al., 2011) and thus require municipal budget spending for their management. For example, in California, 9.1 million street trees make up approximately 5.2% of the 173.2 million trees in urban areas (McPherson et al., 2017) and contribute an estimated annual value of $1 billion in ecosystem services (McPherson et al., 2016b). Evaluating drivers of change to street tree populations can help municipalities plan management strategies.

The structure of the urban forest is typically assessed from one-time measurements described as static "snapshots in time" (McPherson and Kotow, 2013; e.g. municipal inventories, i-Tree Eco plot data, aerial imagery). These are the methodological building blocks for assessing changes in the urban forest, but unless individual trees are tracked and repeatedly measured over time, the relative contributions of removal, growth, and plantings to changes in population numbers and total biomass stock remains unknown.

Analysis of these drivers of change by way of longitudinal tracking of individual trees can be a valuable tool for predicting population stability and identifying trends. An initial estimate of removal, growth and replacement rates provides a baseline to which future measurements can be compared to evaluate changes in forest structure and value. Estimates of demographic rates form the basis of many projection tools and benefit calculators. Increased accuracy of growth and removal rates for a broader range of species will increase the usefulness of these tools. In addition, knowing how demographic rates differ by species allows managers with limited funding to identify the most vulnerable segments of the population and make more informed decisions about where to focus management efforts. For example, low removal rates can imply fewer opportunities to improve species and age diversity. Small changes in demographic rates can deeply affect future forest structure, composition and dynamics.

To help understand street tree dynamics in a maturing urban forest, we quantified species-level removal, growth, and replacement over a 14-year time interval in Claremont, CA. A sample of 762 street tree sites in Claremont, CA first measured in 2000 (McPherson et al., 2016b; Morani et al., 2011) was revisited in 2014 to collect information on tree presence (e.g., removed, replaced), structural characteristics (e.g., diameter-at-breast-height [dbh], tree height), and physical factors surrounding the site (e.g., sidewalk damage). The objectives of this study were to (1) quantify species-level removal, growth, and replacement rates, (2) evaluate the contribution of these components to changes in biomass, (3) identify determinants of growth and removal in this all-aged population, and (4) qualitatively assess the trajectory of the street tree population given the observed demographic rates.

2. Methods

2.1. Study system

The study area, Claremont, CA is situated at the eastern end of Los Angeles County and is characterized by a Mediterranean climate. In the summer months, average temperature highs reach the 30 s (C), while the winters remain mild with average lows above freezing, and highs in the upper 10 s (C) (Western Regional Climate Center, 2017). The mean annual precipitation is 591 mm with most of it occurring in the winter. In fall months, Claremont can receive strong gusts of wind (i.e. "Santa Ana Winds").

Claremont has a long urban forest tradition and has been awarded the Arbor Day Foundation's Tree City USA award for over 20 years. Claremont has a population of 34,926 (2010 United States Census) and a land area of 34.6 km^2. A 2011 municipal street tree inventory reported 19,980 street trees for tree density of 97 trees per street kilometer (McPherson et al., 2016a). In 2011 street tree sites were 74% stocked.

2.2. Data collection

In 2000, street trees from 21 of the most abundant species (in addition to a palm species we excluded from our study) were stratified by size class and randomly selected for measurement (McPherson et al., 2016b). The 21 species sampled in this study represent 63% of the total street tree population in 2000 (n = 23,554) and 64% of the street tree population in 2011 (n = 19,903). These 21 species captured 70% of the total street tree leaf area and 67% by importance value in 2000 (Appendix A in Supplementary material). A detailed description of methods of the original survey can be found in McPherson et al. (2016b). Claremont, CA was selected as a "reference city" representative of the Inland Empire climate zone (Brenzel, 1997). The sample was stratified into nine dbh classes (0–7.6, 7.6–15.2, 15.2–30.5, 30.5–45.7, 45.7–61.0, 61.0–76.2, 76.2–91.4, 91.4–106.7, and > 106.7 cm). The most recent municipal inventory at the time was used to determine the most abundant species. Although the trees were not tagged, location information was recorded in reference to the nearest residential address. Measurements included tree dimension metrics such as dbh (i.e. trunk diameter at 1.37 m), tree height, height to crown base, the average of two crown diameters, crown height and leaf area. In addition to tree dimensions, tree condition, management needs, and infrastructure were assessed (e.g., presence of utility lines and growing space). Tree age was obtained through a variety of methods including interviews with local residents and the city's urban forester and historical records such as street and home construction dates, historical planting records, and aerial and historical photos.

In 2014, we revisited 752 of the original sites. "Sites" refer to locations of the trees measured in 2000–the same trees might not be present in the second census. The main goal of the resurvey was to account for live trees in the initial survey, identify replacements, measure dbh and assess health. Trees found at the sites were recorded to species and measured for dbh, tree height, crown height, and crown width. Sidewalk damage, growing space, presence of overhead utilities, and tree condition were also assessed. For multi-stem trees, the quadratic mean of the individual diameters was used as the measure of trunk diameter.

Of the 752 sites total that were surveyed in 2000, we were unable to find 20 sites in 2014 (3% of the total), leaving only 732 sites surveyed in 2014. They could not be located due to issues with site location as recorded in 2000. Site location information was based on nearest residence address and relative location within the address which made it difficult to distinguish between similar trees planted at a single residence. In one instance, there was a typo in the address listing; in another instance the reworked landscaping made it impossible to determine the exact location of the site. When there was uncertainty,