Urban Forestry & Urban Greening 19 (2016) 95–102

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Establishment period of street trees growing in the Boston, MA metropolitan area

Alex R. Shermana [a], Brian Kanea [a,*], Wesley A. Autioc [b], J.Roger Harrisd [c], H. Dennis P. Ryan [a]

[a] Department of Environmental Conservation, 160 Holdsworth Way, Amherst, MA 01003, United States
[b] Stockbridge School of Agriculture, 205 Paige Laboratory, Amherst, MA 01003, United States
[c] Department of Horticulture, 490 West Campus Dr., Blacksburg, VA 24061, United States

ARTICLE INFO

Article history:
Received 22 April 2016
Received in revised form 1 July 2016
Accepted 11 July 2016
Available online 12 July 2016

Keywords:
Establishment period
Street tree
Urban tree growth

ABSTRACT

Slow growth following transplanting is characteristic of the establishment period, which has been studied for many years. Most of this work, however, has been conducted on trees transplanted in nurseries or favorable growing sites. In urban areas, many trees are transplanted into more challenging growing conditions, and very few studies have investigated establishment period of such trees. We analyzed ten years of transplanting records for the metropolitan Boston, MA, USA area to determine the establishment period of three species commonly planted as street trees {hedge maple [*Acer campestre* L.], London planetree [*Platanus* x *acerifolia* (Ait.) Willd.], and red oak [*Quercus rubra* L.]}. Using piecewise linear regression, we determined the "break point," the intersection of two lines fitted to a scatter plot of caliper versus years after transplanting. The break point indicates the number of years after transplanting at which growth rate increases—the establishment period. We also analyzed whether site factors affected stem caliper. Establishment period varied among species: 2.1 years, 4.0 years, and 5.9 years for red oak, London planetree, and hedge maple, respectively. Site factors variably affected stem caliper of different species. Stem caliper of London planetree and red oak increased with greater sidewalk cut-out area. Tree grates in sidewalk cut-outs adversely affected stem caliper of London planetree. Our results can help practitioners manage street trees in the northeastern United States, but more work on trees transplanted in urban areas is necessary to understand the initial post-transplant growth of street trees.

1. Introduction

Planting trees in urban environments creates unique challenges for urban foresters and arborists. Urban trees are often subject to harsh growing conditions caused by insufficient rooting space, soil compaction, unsuitable soils, construction operations, and utility trenching (Pauleit et al., 2002), yet achieving reasonable growth is critical to receiving the full benefits that such trees provide. Nearly 40 years ago, sidewalk trees in Boston, MA, USA survived, on average, only 10 years (Foster and Blaine, 1978), although recent work has demonstrated a lifespan twice as long (Roman and Scatena, 2011). Recent planting initiatives in Boston, such as Grow Boston Greener, aimed to plant 100,000 trees by 2020 and increase canopy cover from 20% to 35% (Grow Boston Greener, 2010). Unless trees survive for longer than ten or twenty years, however, obtaining intended canopy cover will be challenging.

Transplanted trees often suffer from "post-transplant stress," characterized by impaired physiological function (Struve et al., 2000) and reduced growth rate (Struve, 2009). Tree establishment, the period after which pre-transplant growth rates resume (Struve and Joly, 1992), can last for several growing seasons (Watson et al., 1986; Struve et al., 2000) depending on initial tree size and USDA hardiness zone (Gilman, 1994). Many studies that have investigated different aspects of the establishment period of transplanted trees did not consider trees growing in typically harsh urban areas (e.g., Watson et al., 1986; Struve et al., 2000; Arnold and McDonald, 2009; Struve, 2009; Gilman et al., 2013). While the establishment period of several species measured in Washington, D.C. was similar to that measured in nursery conditions (Neal and Whitlow, 1997), sample trees were mostly growing in well-designed growing spaces, atypical of most urban sites. Site factors (tree grates, urbanization level, underground obstacles, irradiation, street width, tree pit soil volume, and penetration resistance) (Jutras et al., 2010),

* Corresponding author.
E-mail address: bbkane@eco.umass.edu (B. Kanea).

http://dx.doi.org/10.1016/j.ufug.2016.07.006
1618-8667/

production method, irrigation (Koeser et al., 2014), and social factors (Jack-Scott et al., 2013; Vogt et al., 2015) also can influence post-transplant growth and mortality, which suggests that unless planting sites are well designed, the establishment period of trees in actual urban sites will likely be longer than for trees transplanted to nursery or agricultural soil.

A few studies have considered establishment of trees planted in real urban sites, but their focus has mostly been on the effects of management practices such as nitrogen fertilization (Harris et al., 2008), structural soils (Grabosky et al., 2002), nursery production method (Buckstrup and Bassuk 2000), and planting strategy (Appleyard, 2000). A survey of tree managers from various cities in Europe reported a lack of knowledge and information on tree establishment and survival in urban areas (Pauleit et al., 2002), but recent studies have considered various aspects of survival (Roman and Scatena 2011; Jack-Scott et al., 2013; Koeser et al., 2013; Koeser et al., 2014; Roman et al., 2014; Vogt et al., 2015). Quantifying the establishment period of different species, and the effects of production method, irrigation, tree size, and mulch on establishment period continues to apply only to trees transplanted to nursery soil (Gilman et al., 2010; Gilman et al., 2013).

In light of the sparse empirical data quantifying the establishment period of trees planted in urban areas, our objectives were to: 1) determine establishment periods for trees planted in actual landscape sites within a major metropolitan area and 2) assess the effect of site factors (surface area and type of sidewalk cut, soil texture and bulk density, installation of air vents in sidewalk cut-outs) on post-transplant growth rate.

2. Methods

We analyzed tree planting records from 2000 to 2008 in the densely populated Boston metropolitan area (Fig. 1) (USDA Hardiness Zone 6) to determine which species had enough individuals in a variety of age classes and planting locations to address our objectives. Three species met our criteria: hedge maple (*Acer campestre* L.), red oak (*Quercus rubra* L.), and London planetree [*Platanus* x *acerifolia* (Ait.) Willd.]. In July and August 2010, from addresses in the planting records we located individuals of each species and measured stem caliper 15 cm above ground, in accordance with the industry standard [ANSI Z.60.1-2004 (American Nursery and Landscape Association, 2004)]. In addition to stem caliper, we measured the following variables: the type [open, grass strip, and tree grate (Fig. 2)] and surface area of the sidewalk cut, and the presence/absence of an air vent (Fig. 3). From the vicinity of the dripline of each tree, we collected a soil sample from the top 15 cm of the soil profile (but below the roots of turfgrass if present) using a 2.54 cm diameter soil core (JBK Manufacturing Co., Dayton, OH). We measured the mass and volume of soil before and after drying at 105C for 48 h, sieved soil to remove coarse organic matter and rocks, and used conventional methods to calculate soil bulk density (United States Department of Agriculture, 2004). For soil samples greater and less than 40 g dry mass, we analyzed soil texture using hydrometer and pipette methods (Gee and Bauder, 1986).

Since we did not measure individual trees over time, we analyzed stem calipers of individuals within annual cohorts of trees planted in the Boston metropolitan area from 2000 to 2008. Calipers measured in July and August 2010 reflected the cumulative stem growth of each tree within each annual cohort. We present results in terms of "years after transplant": "ten years after transplant" indicated trees that had been planted in 2000, and stem caliper measured in 2010 reflected the cumulative growth for the past ten years; likewise, "two years after transplant" indicated trees planted in 2008 and caliper measured in 2010 reflected the cumulative growth for the previous two years.

To determine establishment period, it was necessary to know the caliper of trees at the time of planting (i.e., "zero years after transplant"), but planting records did not include this measurement. Records indicated that all transplanted trees were in the same caliper class (5.1–7.6 cm) and balled in burlap, so we estimated stem caliper at the time of planting by measuring trees in a local nursery that frequently supplies Boston with plant material. At the nursery in June 2010, we measured the stem caliper (as described above) of 100 balled in burlap individuals of each species in the caliper class 5.1–7.6 cm.

We used piecewise linear regression (Ryan and Porth, 2007) to analyze individual stem calipers within each species and annual cohort (2000–2008) that we measured in July and August 2010. We assumed that stem calipers of individuals of each species measured in the nursery reasonably represented the initial stem calipers (i.e., "0 years after transplant") of individuals of each species in each annual cohort of trees transplanted in Boston from 2000 to 2008. Using the nonlinear least squares (nls) procedure, we determined the "break point," the intersection of two lines fitted to a scatter plot of caliper versus years after transplanting, which indicated the number of years after transplanting at which point the growth rate increased—the establishment period. The analyzed calipers reflected the cumulative growth of individuals in each annual cohort of transplants from 2000 to 2008, not annual growth of individual trees. We used an analysis of variance (ANOVA) to compare the fits of linear and piecewise regression models and only fit piecewise models when the fit was significantly better than the linear model.

We used multiple regression to investigate whether years after transplanting, the square of years after transplanting (to account for non-linear growth trends), surface area of the sidewalk cut, soil bulk density, percent sand, and percent clay influenced stem caliper. One group of three red oaks shared the same sidewalk cut, as did a separate pair of hedge maples. In both of these cases, we divided surface area of the sidewalk cut-out by the number of trees to define the surface area per tree. We used an analysis of covariance (ANCOVA) to explore the influence of air vents (present or absent) and the type of sidewalk cut-out (open, grass strip, tree grate) on stem caliper, including years after transplanting, the square of years after transplanting, and the surface area of the sidewalk cut-out as covariates. Restrictions in sample size precluded us from including sidewalk cut-outs covered by tree grates in the ANCOVAs for hedge maple and red oak. We used Tukey's Honestly Significant Difference (HSD) test to separate means of significant main effects.

To account for variable growth rates between species, we analyzed them separately. We used boxplots to confirm that discrete data were normally distributed with homogeneous variance. We examined scatter plots of continuous variables to confirm that residuals were normally distributed with homogeneous variance. Since the assumptions of parametric analysis were not violated, we analyzed raw data and did not have to correct our models. We conducted all analyses using R Statistical Software, version 2.9.2 (The R Foundation for Statistical Computing) and declared significant results at $\alpha = 0.05$.

3. Results

Excluding trees measured in the nursery in June 2010, we measured the stem caliper of 126, 116, and 69 individual hedge maples, London planetrees, and red oaks, respectively in July and August 2010 (Table 1). With some exceptions, we measured at least five individuals of each species in each year after transplanting (Table 1). Most soils were loamy sands or sandy loams (Table 1). Mean surface area of sidewalk cut-outs in which red oaks were planted was much larger than for the other species. It was also much more vari-