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Factors driving natural regeneration beneath a planted urban forest

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ABSTRACT

Cities around the world are investing in urban forest plantings as a form of green infrastructure. The aim is that these plantations will develop into naturally-regenerating native forest stands. However, woody plant recruitment is often cited as the most limiting factor to creating self-sustaining urban forests. As such, there is interest in site treatments that promote recruitment of native woody species and simultaneously suppress woody non-native recruitment. We tested how three, common site treatments—compost, nurse shrubs, and tree species composition (six-species vs. two-species)—affected woody plant recruitment in 54 experimental plots beneath a large-scale tree planting within a high-traffic urban park. We identified naturally regenerating seedling and sapling species and measured their abundance six-years after the site was planted. This enabled us to examine initial recruitment dynamics (i.e. seedlings) and gain a better understanding of seedling success as they transition to the midstory (i.e. saplings). Seedling and sapling recruitment (native and total) was greater in areas with higher canopy cover. The combination of the nurse shrub treatment with compost and species composition (six-species) treatments increased seedling recruitment by 47% and 156%, respectively; however, the nurse shrub treatment by itself decreased seedling recruitment by 5% and native seedling recruitment by 35%. The compost treatment alone had no effect on the total number of recruits but resulted in 76% more non-native seedlings. The sizes of these treatment effects were strongly dependent on whether the forest plantings were in open areas, versus areas with existing tree canopy, the latter condition facilitating recruitment. Our findings therefore suggest that combinations of site treatments, paired with broad canopy tree species, may be most effective for promoting regeneration of native species resulting in more self-sustaining urban forests.

1. Introduction

Urbanization of forests and open areas is rapidly increasing around the world (Nowak et al., 2002). As cities grow denser and expand their footprint, urban trees and forests will become an increasingly important way to enhance quality of life through their provision of ecological, economic, health, social, and aesthetic services (Pataki et al., 2011). In recognition of the value of these services, many cities are investing in afforestation efforts and restoring degraded forests, with the goal of generating self-sustaining native forests (Sullivan et al., 2009; McPhearson et al., 2010; Clarkson et al., 2012; PlaNYC Reforestation Overview, 2015). Although cities are dedicating substantial resources to these projects, there is limited information on restoring, creating, and managing new urban forests so that they develop toward sustainable entities.

Large-scale tree plantings have been successful in establishing native forests in degraded tropical lands (Parrotta, 1992 Guariguata et al., 1995; Parrotta et al., 1997; Brockerhoff et al., 2008), but urban systems present a unique set of circumstances. These include frequent human-caused disturbances (Rebele, 1994; Grimm et al., 2000), modified soils (Craul, 1985; Pavao-Zuckerman, 2008), high edge-to-interior ratios, and invasion from introduced plant species (Alson and Richardson, 2006; Cadotte et al., 2017) all of which have the potential to negatively impact restoration goals (Cadenasso and Pickett, 2001). Few studies to date have examined forest development in urban areas post-planting and of those that do, most cite lack of native woody plant recruitment as one of the biggest hurdles to achieving a sustainable restoration (McClanhan and Wolfe, 1992; Robinson and Handel, 2000; Oldfield et al., 2013; Labatore et al., 2017).

Woody plant recruitment is an important component of forest development (Greene et al., 1999; Aide et al., 2000). By examining species composition of woody plants regenerating in the understory of new tree

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plantings, it is possible to infer the future species composition and the capacity of the plantings to self-perpetuate (Franklin and DeBell, 1988). However, in urban settings planted species often do not recruit, or recruit sparsely and instead local seed sources from nearby ex-situ trees fill in gaps (Robinson and Handel, 2000). This has implications for reforestation projects with the goal of steering species composition towards a "native-dominated" forest (PlaNYC Reforestation Overview, 2015; Morgenroth et al., 2016) because local seed sources are often from non-native, invasive species and not the desired planted species. These projects favor the regeneration of native or planted tree species over non-native invasive ones because invasive trees have been found to negatively impact biodiversity (Van Wilgen and Richardson, 2014), forest structure (Asner et al., 2008), and ecosystem services (Richardson et al., 2014).

Some of the factors found to limit recruitment of planted tree species in urban settings include competition at the ground level in the form of weeds or other ground cover (Rawlinson et al., 2004; Ruiz and Aide, 2006) and above-ground competition in the form of canopy cover and shade (Nakamura et al., 2005; Michalak, 2011). Degraded soils can be a barrier to regeneration in urban settings as soil nutrients, beneficial microbes such as mycorrhizae, and moisture may be limiting (White and McDonnell, 1988; Rebele, 1994; Pavao-Zuckerman, 2008; Oldfield et al., 2015; Pregitzer et al., 2016). In addition, soil compaction may limit root respiration (Craul, 1985). To ameliorate these inhospitable urban conditions land managers will often install costly and time-consuming site treatments prior to planting to create a more favorable environment for the desired planted species (Castro et al., 2002; Saebo and Ferrini, 2006; Oldfield et al., 2014; Dominguez et al., 2015). Compost amendments are one such site treatment with the potential to improve site conditions by increasing the soil's water holding capacity, nutrient availability, and microbial biomass (Cogger, 2005; Davidson et al., 2006; Oldfield et al., 2014). Nurse shrubs are another site treatment expected to improve microclimatic conditions in harsh environments by decreasing soil temperatures, increasing soil moisture, providing organic matter in the form of leaf litter, and in some cases increasing soil nitrogen through fixation (Shumway, 2000; Gomez-Aparicio et al., 2004; Castro et al., 2002). Finally, diversity or species composition of planted trees is another site treatment with the potential to enhance tree growth, alter understory light conditions, and in the case of nitrogen-fixing species, increase available nitrogen (Guariguata et al., 1995; Piotto, 2008).

Understanding the competitive and environmental barriers to woody plant recruitment, and the potential for site treatments to reduce these barriers for target natives, is vital to the successful implementation and maintenance of afforestation and reforestation sites. However, much of the existing research on site treatments and their impact on woody plant recruitment is from high-stress Mediterranean or tropical climates rather than urban areas (Guariguata et al., 1995; Gomez-Aparicio et al., 2004; Piotto, 2008; Castro et al., 2002; Dominguez et al., 2015), has conflicting results (Nakamura et al., 2005; Michalak, 2011), and/or only examined short-term dynamics (< 5 y) and hence may not capture factors that can take several years to have an effect, such as soil conditions (Rawlinson et al., 2004; Ruiz and Aide, 2006). Furthermore, urban forest site treatments are intended to improve environmental conditions such as soil temperature, moisture, and available light for woody plant recruits, but commonly these conditions are not measured, making it difficult to tease out how site treatments translate to outcomes (Oldfield et al., 2013).

To examine how site treatments impact environmental conditions and natural regeneration we explored woody plant recruitment of both planted and non-planted tree species beneath a large, experimental, urban afforestation site in New York City, USA. Specifically, we examined the abundance and composition of natural regeneration in relation to site treatments and conditions known to affect recruitment (Kostel-Hughes and Young, 1998; Prach et al., 2001; Rawlinson et al., 2004; Nakamura et al., 2005; Ruiz and Aide, 2006; Michalak, 2011). We assessed several site treatments including compost (amended with compost or not amended), planted nurse shrubs (presence or absence), and planted tree species composition (six-species or two-species) (Oldfield et al., 2015). Our study evaluated woody plant recruitment six years after the initial planting of 3–5 year-old woody saplings. By this point in the experiment, planted trees were approximately 10 years old and five of the six planted tree species were producing seeds (Oldfield et al., unpublished dataset). We assessed recruited seedlings and saplings of both the planted species, as well as non-planted species, to gain insights from a 'snap-shot' set of observations into the temporal dynamics as woody recruits shift from the seedling to sapling size classes.

Using these site treatments, coupled with measurements of environmental conditions, we asked the following questions:

i To what extent is natural regeneration occurring within establishing afforestation areas?
ii Do site treatments increase woody plant recruitment and direct species composition towards a native-dominated system, and if so, is this the result of improved environmental conditions?

2. Methods

2.1. Site description and experimental design

We conducted this study within long-term research plots established in partnership with AECOM, Inc., the Yale School of Forestry and Environmental Studies, and the New York City Department of Parks and Recreation (NYCDPR) at Kissena Corridor Park, a recently reforested 40-ha urban park in Queens, NY (40°44′ N, 73° 49′ W) (Felson et al., 2013a,b). The US Natural Resource Conservation Service (NRCS) classified the soils as the Laguardia-Ebbets complex, which are characterized as well-drained coarse sandy loam with 10% human-transported material (NRCS, 2016); a complete soil analysis of the site can be found in Oldfield et al. (2014). Average temperatures in July and January are 24.9 °C and 0.2 °C, respectively; mean annual rainfall is 109.12 cm (NOAA, 2016).

The experimental plots at Kissena Corridor Park are dubbed the New York City Afforestation Project (NY-CAP) and are part of the MillionTreesNYC initiative. Launched in 2007 by New York City, the MillionTreesNYC Initiative allocated $400 million to NYCDPR over 10 years to plant 1,000,000 trees in parklands, natural areas, and in street tree pits (PlaNYC Reforestation Overview, 2015). As part of this initiative, in the fall of 2010, 54 experimental plots were installed within Kissena Corridor Park's interior (Fig. 1). Experimental plots are divided between the east (n = 26) and west (n = 28) sides of the park. While pre-planting tree cover at Kissena Corridor Park was generally sparse, stands of *Robinia pseudoacacia* (black locust), *Rhus typhina* (staghorn sumac), *Prunus serotina* (black cherry) and a few large individuals of *Acer saccharinum* (silver maple) were present on the east side of the park prior to NY-CAP installation (Fig. 1). The presence of adjacent forest stands coupled with less human traffic distinguished the east side from the more heavily-used and less-forested west side. To account for these differences between the two areas of the park, we grouped plots on the east and on west sides separately and will hereafter refer to them as "forested" and "open" blocks respectively. Prior to planting and plot installation, Kissena Corridor Park was densely overgrown with non-native invasive herbaceous species, such as *Artemisia vulgaris* (common mugwort) as well as native old-field species like *Solidago canadensis* (Canada goldenrod) (Oldfield et al., 2014).

The NY-CAP experimental plots test how three site treatments—-compost (amended with compost or not amended), co-planting with nurse shrubs (presence or absence), and species composition (six-species or two-species)—affect afforestation efforts (Felson et al., 2013b; Oldfield et al., 2014; Oldfield et al., 2015). Replication is uneven and is outlined in Appendix A Table A1.

In 2010, each 15 × 15 m plot was planted with 56 trees 2.1-m apart