The Potential of Assisted Natural Regeneration for the Health of Urban Forests

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Abstract

Urban forest patches (UFPs) are small, naturalized areas that persist in the built environment. Previously regarded as self-sustaining "wild" areas, UFPs are gaining attention as valuable resources that can deliver important ecoservices such as air cooling and cleaning, stormwater filtering and absorption, and even associated public health and education benefits. UFPs, however, face challenges that hinder their ability to spontaneously regenerate and consequently threaten their longevity. Preserving UFPs and securing the services they provide necessitates identifying appropriate management methods to establish the next generation of the forest's trees. Most additions to the urban forest are planted, but in natural areas that approach is expensive, carries an environmental impact and may compromise existing ecosystems. Identifying means to encourage the forest to regrow itself, or naturally regenerate, may be a viable and more appropriate solution.

My research evaluated the viability of Assisted Natural Regeneration (ANR), a restoration approach established in large scale, rural projects, as a management method for small scale, urban forests. ANR engages local community members to offset barriers to regeneration, thus allowing the forest to spontaneously regenerate. In a 2.2-acre forest patch in Washington, D.C., I recruited a team of community volunteers and we collectively deployed ANR by applying site treatments and providing monthly maintenance over two growing seasons to canopy gaps and edges. Our site treatments included clearing, soil disturbance, mulching, and tree planting. For maintenance, each

month of the growing season, we clipped non-tree material to below 4” and tagged seedlings for protection and identification.

The site treatments did not significantly differ in their effect on the regeneration of native seedlings (in either count or diversity), but of 48 2x2 meter plots, 85% demonstrated regeneration, for a total of 428 surviving seedlings. Compared with a control site where no maintenance or treatments were applied, the ANR plots recruited an average 2.6 seedlings/m^2 versus 0.125 seedlings/m^2 in the control plots (ANOVA, F= 9.44, p=.0032, n=60). There was no significant difference in native seedling diversity between the ANR plots and the control plots.

I compared our ANR technique with a traditional planting to evaluate the two methods in terms of social, economic, and environmental costs and gains. The ANR plots yielded more spontaneous regeneration, recruiting an average 2.6 seedlings/m^2 versus 1.8 seedlings/m^2. The cost per seedling using ANR (absent planted trees) was about $.06; it was $43.22 in the planted area. The ANR plots engaged more than 41 volunteer participants with over 500 volunteer hours, but there was no community participation in the planted area. The ANR plots (excluding those planted with trees) required no watering, but the planted area used 383.3 gallons/m for the trees in the planted area. Planting carries an inherent carbon footprint for transportation and maintenance, but greenhouse gas emissions can be avoided with ANR depending on volunteer locations and transportation decisions. Cumulatively, the data showed that ANR had fewer financial and environmental costs and greater community engagement than traditional planting.

Frontispiece

Langdon Park, Washington, D.C. 2023

Author's Biographical Sketch

My family planned to take a sabbatical in Italy in March 2020. When the pandemic thwarted that plan, we were fortunate to be able to relocate to the mountains of North Carolina instead. Hikes and trees and clean air were outsized luxuries during that time of cloistered and fearful living. Returning to Washington, D.C., I realized that I wanted to be a part of bringing nature access and environmental health to my urban community. Through my classes at Harvard Extension School, I connected with local practitioners and joined a team of volunteer stewards at a forest patch in my neighborhood park. My research is born out of falling in love with the trees that bring fresh air to my community and the desire to see them thrive for future generations.

Dedication

This is dedicated to my mentors and friends, native plant specialist and lifelong learner Mary Pat Rowan, and tireless tree advocate, both in the field and on the stand, Delores Bushong.

Also for my kids, these trees are for your future.

Acknowledgments

The more than 1,000 new native trees growing in Langdon Park are a credit to the hundreds of hours dedicated by community volunteers who care for the forest. I am so thankful to them for their partnership and hard work. This research was graciously informed by Nancy Sonti at the US Forest Service and generously supported by the entire team at Casey Trees. It would not have been possible without the support of dedicated individuals serving in the District government at DOEE (James Woodworth), DDOT (Robert Corletta and Earl Eutsler), DGS (Tyrone Tolliver) and DPR (Peter Nohrden and Brent Sisco). And last, but not least, I am so thankful to my family: my parents for their generous help with childcare, my children for learning about the trees right alongside me, and my incredible husband who has enthusiastically made this endeavor possible.

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Chapter I

Introduction

As cities around the world experience a changing climate, many are looking to trees to mitigate impacts. The urban forest includes city trees such as street trees and landscaped plantings as well as forested areas ranging from small, naturalized groves to larger forests in urban parks. Forested areas in cities offer unique benefits ranging from lower air temperatures (Zhou et al., 2018) and cleaner waterways (Phillips et al., 2019) to improved health (Wolf et al., 2020) and better learning outcomes (Sivarajah et al., 2018). Like most ecosystems in urban environments, however, city forests face significant challenges, including social pressures such as development and pollution, and ecological threats such as invasive species and disease. Identifying solutions to maximize forest services in cities involves addressing challenges in both the ecological and sociological contexts (Johnson et al., 2020).

Urban forest patches (UFPs) are small, forested areas in cities that have, until recently, been largely overlooked. As cities seek to increase their tree canopy cover and maximize tree benefits, however, UFPs are receiving increased interest. These are self-organizing and spontaneously regenerating ecosystems that interact dynamically with their urban context (Johnson et al., 2021). They are the spaces in cities where small segments of forest manage to persist between, behind or alongside the built environment. Their existence is always in jeopardy with the threat of development, but they also are at risk of failing because of limited natural regeneration (Doroski et al., 2021) and heightened vulnerability along edges and in canopy gaps.

Urban forestry research and best practices tend to clump city trees together categorically or focus specifically on either street trees or large forests (Morzillo et al., 2022). There are no established or recommended practices specific to the unique conditions and contexts of UFPs. In traditional urban forestry, planting is the standard practice to increase specimens or canopy. Large scale plantings can effectively address gaps in city forests (Simmons et al., 2016; Johnson & Handel, 2016), but the approach is costly, carries a carbon footprint, requires watering and ongoing maintenance, and can result in inconsistent survival rates (Piana et al., 2020; Bauer & Reynolds, 2017). Planted trees also introduce potentially nonnative or invasive species to forested areas with unforeseeable ecosystem impacts.

An approach called Assisted Natural Regeneration (ANR), borrowed from tropical climates, is a potentially more appropriate means to improve UFP health. Practiced primarily on degraded farmland, ANR engages local participants in the removal of barriers that prevent spontaneous regeneration (Lohbeck et al., 2021). ANR is flexible, inexpensive, and has demonstrated success in diverse contexts (FAO, 2022). Although untested in urban environments, ANR's dual focus on social and environmental threats suggests it may be suitable for UFPs.

The particulars of ANR are context-driven, reflecting both the social circumstances and the barriers to regeneration. In UFPs threatened by invasive species, a community-powered approach focused on removing invasive competition may improve forest health with less cost and fewer resources than traditional planting. Evidence suggests site treatments may be able to compound that effect by mitigating soil barriers to regeneration (Piana et al., 2020; Francisco et al., 2022; Johnson & Handel, 2016). With site treatments and community-provided maintenance and monitoring, UFPs may be relieved of the barriers that prevent regeneration such that native tree seedlings are able to establish, and the understory can be restored.

At Langdon Park in Washington, D.C., a 2.2-acre urban forest patch is the focus of a public-private management partnership. When a section of forest was illegally cleared, the city replanted the area with 25 young trees. Over the following growing season, hundreds of seedlings sprouted around the planted area (Figure 1). Community members wondered what caused the regeneration when so few trees were sprouting in other canopy gaps in the forest patch and wanted to know if they could replicate the phenomenon elsewhere and assist the forest in its own recovery.

Figure 1. Volunteer seedlings among planted area at Langdon Park.

Orange flagging tape indicates seedlings tagged by community volunteers in the previously cleared and planted area.

Research Significance & Objectives

Building on the questions posed at Langdon Park and existing UFP and ANR research, my thesis research evaluated a community stewardship model of UFP management focused on promoting natural regeneration using site treatments and ongoing maintenance. This research is relevant to communities interested in stewarding their UFPs, nonprofits and governments seeking ways to meaningfully engage citizens in UFP management, and the broader urban forestry community as it explores how to manage urban forest patches for future succession.

My research objectives were:

- To assess if community stewards practicing ANR can promote native seedling regeneration in UFPs
- To identify a site-treatment that maximizes regeneration rates while minimizing the maintenance required
- To compare the ecological and sociological impacts of traditional planting techniques with community-driven ANR

Background

Urban forest patches (UFPs) are small, naturalized areas that interact dynamically with their social and ecological settings (Johnson et al., 2020). As drivers in those contexts, UFPs provide a variety of services. Environmentally, they provide habitat and increase biodiversity (Morzillo et al., 2022). They also mitigate heat (Zhou et al., 2018) and precipitation extremes (Safford, et al., 2013), capture carbon (Morreale et al., 2021), absorb stormwater (Phillips et al., 2019) and reduce water and air pollution (Cavanaugh et al., 2009). Those benefits have economic value, particularly as cities experience more extreme weather events and need to address flooding and dangerously high temperatures (Johnson et al., 2020). Sociologically, forest patches carry a range of benefits as a touch point for urban dwellers to connect with nature (Sonti et al., 2020), from mental health to decreased obesity and improved immune function, as well as social connection (Wolf et al., 2020).

Simultaneously, the urban environment reciprocally influences the health and trajectory of UFPs. Impacts include ecological and environmental threats such as invasive plants and pests, pathogens, climate change, and air, water and soil pollution. Social threats include development, mismanagement or neglect, and low public perception. Compared with larger woods, their high edge to interior ratio makes them especially vulnerable to pressures (Doroski et al., 2021). UFP health and longevity necessitates anthropogenic intervention that addresses both social and ecological contexts to offset the challenges of the urban environment.

Management goals for Urban Forest Patches differ from those for large forests or the freestanding street trees of traditional urban forestry. A review of UFP management in four major east coast cities indicates preference for native-dominated, structurally complex forests consisting of diverse-aged species (Morzillo et al., 2022). Inventories of urban forests, however, indicate many forests are dominated by mature trees and lack diversity and complexity in their understories (Doroski et al., 2021), posing a challenge to healthy forest succession. Management approaches to improve succession outcomes include: planting and seed additions, invasive species control, and soil amendments or disturbance. Assisted or spontaneous regeneration is critical to all approaches aimed at a long-lasting, healthy forest.

Assisted Natural Regeneration

Natural regeneration is the process by which seedlings emerge from the ecological memory of the existing or former forest and eventually replace plants that have died (Burley et al., 2004). This is a spontaneous phenomenon in a healthy forest that occurs in tandem with existing wildlife and biodiversity and functions to regenerate individual plants adapted to the local climate and soil (FAO, 2019). It is an essential element of forest succession, akin to births for any population's longevity.

When forests, or formerly forested areas, are not spontaneously regenerating, humans may be able to promote the process with Assisted Natural Regeneration (ANR). ANR is a comprehensive term that refers to any initiatives designed to remove barriers to spontaneous regeneration (Shono et al, 2007). Such barriers might include pests or disease, invasive species, climate change and fire, grazing, or soil degradation or compaction. Significantly, ANR is only applied in areas where succession would likely occur naturally, absent the presence of barriers (FAO, 2020).

ANR initiatives are highly context-specific, both ecologically and sociologically. Interventions vary depending on site characteristics such as seed bank composition, soil conditions and wildlife presence. They also must be tailored to address relevant barriers, i.e. fencing to protect against deer foraging or weeding to remove invasive vines. ANR also takes into consideration land usage and ownership, engaging local land knowledge and emphasizing community priorities, such as timber production or fire abatement.

ANR was first formally practiced in the 1970s in the Philippines and has since been established as an inexpensive means to successfully encourage and enhance natural regeneration around the world (Asia- FAO, 2019; Australia- Uebel et al., 2017; Brazil-

Chazdon, 2016). The United Nations' (FAO, 2019) instructional manual on ANR reports strong outcomes ecologically alongside meaningful community engagement and low financial cost. Despite these benefits, the UN postulates ANR is often overlooked because of financial disincentives, practitioners' lack of awareness, and insufficient government or institutional support. In their review of natural regeneration studies, Lohbeck et al. (2021) concur and suggest scalability requires further context-specific research.

Although ANR is practiced around the world, its range of application has not been explored. In the United States, Abella et al. (2020) studied ANR in the Mojave Desert and found mixed results when applied to shrub seedlings in arid environments. Internationally, ANR studies have typically focused on tropical regions with abandoned agricultural land or degraded rural forests (FAO, 2019; Uebel et al., 2017; Chazdon, 2016). Neither domestic nor international studies have evaluated ANR in urban settings. However, many of the same factors that lend to ANR's success in tropical forests can be found in cities: degraded environments, existing seedbanks, disconnected communities, and limited funds.

The United Nations' practical guide (FAO, 2019) suggests basic procedures that may translate well to urban forest patches. First, they recommend marking existing seedlings and clearing nearby non-woody plants. Next, they suggest suppressing weeds or invasive species throughout the target area and then installing appropriate protective barriers to allow the seedlings time to establish. Where needed, they advise supplementing natural seedling recruitment with seed additions or plantings. They conclude that maintenance should continue, perhaps in perpetuity, unless the threat to regeneration ceases.

Socially, the UN guide (2019) discusses the importance of community understanding and participation for project success. Focused on restoring agricultural land in Southeast Asia, the guide emphasizes the local land knowledge held by farmers and the importance of their buy-in for success. Although city residents may not have equivalent ecological knowledge, their awareness of local history, usage and politics could inform ANR practices. The guide also emphasizes the importance of support from local government, a relevant factor for urban settings as well.

Regeneration Approaches

Though not formally identified as ANR, numerous domestic studies explore how to promote forest succession in urban settings. The primary approaches include planting initiatives, invasive species removal, and soil modification. Notably, these studies are strictly ecological and do not include the sociological considerations recommended for ANR.

Planting

Planting initiatives can encourage improved forest health in urban settings. Two long term studies (Simmons et al., 2016; Johnson & Handel, 2016) demonstrated that removing invasives and planting natives can offset barriers to UFP regeneration and result in improved forest diversity and structure.

Johnson et al. (2016) studied the long-term outcomes associated with planting initiatives in forested natural areas in New York City parks. In the 1980s and 1990s, forested areas that were invaded by nonnative woody species were targeted for restoration. The areas were cleared manually, mechanically, and chemically, then planted with native seedlings. In 2009, Johnson et al. studied the composition of the treated forested areas and compared them with untreated areas. They observed the treated forests had fewer invasive species, more native recruitment, and better structure and complexity than the untreated control plots (Johnson et al., 2016).

In another long-term study of the same region, Simmons et al. (2016) studied the effects of planting, chemical clearing, and mechanical maintenance. The research area was chemically cleared in its entirety, but not all areas were planted, and some that were planted also received additional maintenance in which invasive species were mechanically removed three times over the following decade. Twenty years after the plantings, Simmons et al. (2016) evaluated the health of forests with the following treatments: chemically cleared, but not planted; chemically cleared and planted; chemically cleared, planted, and mechanically maintained. They found that the cleared and planted areas had higher species diversity and more native saplings than the control, but the cleared, planted and maintained areas, even more so. In contrast, the areas that had only been cleared had higher rates of exotics. Their research indicates that planting natives encourages healthy forest succession, but that ongoing maintenance improves that effect.

These studies suggest planting can improve long-term health for urban forests. For many jurisdictions, however, planting projects can cost upward of $75,000/acre (Piana et al., 2021), and are not financially viable. In their review of UFP management strategies, Piana et al. (2021) point out the significant limiting factor of cost and suggest, “a fundamental question in urban forest management is what alternatives to planting can be most effective at establishing desired forest structure and composition?” (p.6).

Additionally, planting initiatives can have unforeseen consequences. Wang et al. (2013) pose various questions about restoration plantings in China. Specifically, how long are trees evaluated for their appropriateness before being introduced into environments? Given that many plantings focus on pioneer species, short term studies of 3-4 years may indicate canopy successes, but fail to capture ecosystem impacts such as biodiversity loss or biological invasions. Additionally, they point out that planting programs typically include a small range of species, the consequences of which may not be evident for years to come. The unforeseeable impacts of adding nonnative or even nonindigenous species to a forest may undermine the benefits of improved canopy cover.

Invasive Removal

Invasive species removal alone may be a viable approach to promote healthy native plant communities. To examine the role of invasive species on forest succession, Bauer and Reynolds (2017) compared the effects of *Euonymus fortunei* on regeneration from seeds and establishment of seedlings. They found that native seedlings were able to survive with *Euonymous* present, but seeds failed to establish, indicating that invasives may have a limiting effect on recruitment of natives from seed.

Standish et al. (2001) explored the mechanism by which the invasive ground cover *Tradescanti* limits recruitment from seed in New Zealand. They observed that shade tolerant species could germinate under the ground cover, but their survival rates after 20 months decreased exponentially with *Tradescantia* biomass and decreased light. To examine the role of seed abundance in regeneration rates, they inventoried seed bank and seed rain composition and concluded seed abundance would not protect a species in a threatened area. Instead, they suggest the intervention needs to limit the invasive species, perhaps by planting shade trees.

The New York studies (Johnson et al., 2016; Simmons et al., 2016) both indicate removing invasives has beneficial impacts on forest health. However, Simmons et al. (2016) pointed out that absent ongoing maintenance, invasive presence may increase after clearing, likely because of soil disturbance. In other words, invasive removal in UFPs should be viewed as an ongoing maintenance requirement rather than a one-time event.

Site Modification

Beyond invasive removal, additional site modifications offer possible means to encourage healthy forest succession. In their review of literature on plant establishment in urban environments, Piana et al. (2019) suggested that a confluence of factors (in addition to invasive species) limit early establishment, including altered growing conditions due to soil compaction (Sullivan et al., 2009) and woody debris removal. Site modifications may offer opportunities to offset the impacts of these barriers.

Soil compaction limits natural regeneration from the seed bank. Disruptions that expose seeds to light, warmth or moisture are necessary for seeds to germinate. Doroski et al. (2021) found that the buried seed banks of urban forests varied significantly, with larger forests and small connected patches more closely resembling traditional forests than isolated, small patches which included more invasive seeds. Consequently, disturbing soil to activate regeneration will have divergent results depending on the composition of the seedbank. Doroski et al. (2021) suggest understanding seedbank content is critical in forest management directed at encouraging a native dominant community.

Soil amendments also appear to have diverse effects on regeneration. Research in landscape agriculture as well as forestry indicates mulch applications can improve woody growth and deter herbaceous growth, possibly offering a means to encourage tree growth while inhibiting invasive species (Hartman et al., 1992; Francisco et al., 2022). The UN's ANR guide (FAO, 2019) recommends surrounding seedlings with a 3 cm thick ring of mulch consisting of weeds cut from the site. Francisco et al. (2022) compared the effects of mulch on tree, grass, and herbaceous regeneration three years after planting native trees in a 4-ha area in Brazil. For their treatments, they chemically treated grass and then either raked it out or allowed it to stay in place (mulch treatment). Eight months later, they observed different impacts based on mulch height and dispersal syndrome of the regenerating plants. Overall, however, only 13% of mulched plots included exotic grasses versus 67% of the untreated plots. Similarly, mulched plots demonstrated higher native seedling abundance (80.9%) and species richness (87.5%) compared with the control plots.

Woody mulch has been studied extensively to establish its benefit for retaining moisture in soil broadly (van Donk et al., 2011). Breton et al. (2016) looked at woody mulch specifically with regeneration of trees and shrubs and found the mulched treatments included greater regeneration rates, but their study took place on a degraded slope in the Alps. Sun et al. (2021) studied the impact of mulch on soil chemistry in an urban forest and found it can beneficially increase organic N and C in urban soils.

However, the direct impact of woody mulch applications on urban forest patch regeneration has not been assessed.

Identifying affordable alternatives to planting is critical for promoting UFP succession and ensuring forest longevity. Based on the existing literature on city forest management (Table 1), a successful approach will require ongoing invasive species removal (Simmons et al., 2016), but site treatments may improve growing conditions and limit required management. In UFPs with native dominant seedbanks, ANR consisting of site treatments and ongoing management may be adequate to encourage regeneration and support forest succession. The ideal site treatment would yield maximum native seedling diversity and count, but minimize the time needed for invasive species removal.

Table 1. Literature review of UFP intervention potentials and limitations (by author).

Intervention	Potential	Limitations	Study
Planting	Shown to improve long term forest outcomes	Expensive May not extend forest composition	Simmons et al., 2016; Johnson & Handel, 2016
Invasive Removal	Shown to improve regeneration	Needs to be ongoing or may encourage additional invasives	Bauer & Reynolds, 2017; Standish et al, 2001; Simmons et al., 2020
Site Treatments	Mulching and soil disruption may increase regeneration	Regeneration results reflect seedbank	Francisco et al., 2022; Doroski et al., 2021; Hartman et al., 1992; Sun et al., 2021

Social Context

The management approaches listed above focus on improving the ecological environment of UFPs. Just as significant, however, is their social context. Where there is an urban forest, there may be diverse opinions about the value of nature and the significance of invasive species, multiple landowners or users, and divergent perspectives about responsibility (Gaertner et al, 2017). Depending on the valuation of that forest, it may receive management and protection, or it may be neglected or even cleared for development.

Most communities only recently began considering their UFPs and are still working out what role they hold in their specific urban contexts. Beyond abstract community value, jurisdictions are also in the early stages of determining who, if anyone, is responsible for managing UFPs. Based on their assessment of value, cities may or may not decide to dedicate funding and staffing to care for and maintain UFPs. These are unique, organic processes that reflect specifics of time, space and culture (Morzillo et al., 2022).

While cities do the important work of identifying their UFPs and determining how best to care for them, invasive species continue to overwhelm and native species fail to regenerate (Piana et al., 2019). Identifying viable community-driven approaches or urban ANR techniques may provide an important bridge in care until more formal management plans can be established and employed.

Community Stewardship

Given the lack of dedicated budgets or funding available for most urban forest patches, volunteer forest management can expand impact while keeping costs low (Hauer et al., 2018). This is especially significant in smaller forest patches that may be overlooked for formal management but require the most maintenance given the abundance of edge to core typical of UFPs (Doroski et al., 2021). Community volunteers can provide an affordable manpower alternative to meet the hands-on management needs required to steward UFPs.

In addition to building capacity, community engagement also lends to project success because it increases social support. McKinley et al. (2017) argue that for conservation efforts to be successful they must consider the social context of the project, incorporating relevant politics, cultural factors, social meaning, and community input. Scoggins et al. (2022) go further to argue that the long-term viability of restoration projects depends on community engagement and buy-in.

Beyond encouraging forest health, research also indicates volunteers personally benefit from their participation. Based on surveys of forest volunteers in Baltimore, Sonti et al. (2020) demonstrated that environmental stewardship increases appreciation and use of natural areas. Patrick et al.'s (2018) literature review concurred and found evidence of increased mental and social health for environmental volunteers. Research on volunteering broadly provides a long history of evidence that volunteers receive reciprocal benefits from their participation, including an improved sense of well-being, health and happiness (Borgonovi, 2008; Thoits & Hewitt, 2001; Morrow-Howell et al., 2003).

Community engagement in UFP care offers a potential remedy to the absence of funding and planning presently available. Additionally, it can increase community support of conservation efforts and improve their longevity. Simultaneously, volunteers will likely experience a variety of personal co-benefits. Community engagement in the deployment and management of UFP regeneration efforts based on site treatments may result in not only new native seedlings, but also a long-lasting project with strong community satisfaction and support.

Ward 5 Forest Patches

The District of Columbia includes eight distinct wards, of which Ward 5 includes the most industrialized zones and is among the wards most impacted by the heat island effect (DOEE, 2022). It also includes numerous wooded areas, the larger of which, such as the National Arboretum and the Fort Circle Parks are managed by the National Park Service. Multiple UFPs in Ward 5, however, are on public land owned by the District of Columbia. The city currently lacks a management plan for these areas, but pending legislation may establish a new Office of Natural Area Conservation to steward District-owned naturalized areas such as UFPs. Two UFPs in Ward 5 have been instrumental in the development of that legislation: Langdon Park UFP and Queen's Chapel UFP.

Until recently, the urban forest patch at Langdon Park in Washington, D.C. was archetypal: unfunded, unmanaged, and in canopy gaps and along the edges, overrun by invasive species and failing to regenerate native trees. The dedication of community members to the forest patch, however, has brought attention to the park which now benefits from resources provided by various nonprofit organizations and government agencies. An article featuring the community-agency-nonprofit collaboration was recently published in *City and the Environment* (Woodridge et al., 2023). The city's Urban Forestry Advisory Council regularly reports on practices at the Langdon Park

Forest Patch and the forest stewards train volunteers around the city to engage with their own local forest patches.

In 2021 in Langdon Park, a landowner adjacent to the park illegally cleared a segment of the forest abutting their property. When community members asked the city for remediation, they responded by planting 25 young trees to close the canopy in the cleared area, a segment about 100 m^2. Soon after, the area began to demonstrate atypical natural regeneration and after three growing seasons, 333 new seedlings representing 10 species were recorded. The volunteer seedlings indicate the potential for greater regeneration throughout the forest patch.

Stewards working in the park also observed natural regeneration occurring in areas where they have removed invasive species and "liberated" trees bent over by vines. Dominant invasive species at Langdon Park include kudzu (*Pueraria montana)*, porcelain berry (*Ampelopsis brevipedunculata)*, English ivy (*Hedera helix)*, wineberry *(Rubus phoenicolasius)*, and Amur bush honeysuckle (*Lonicera maackii)*. The stewards primarily work along the edges of the forest, and they mark seedlings and small trees with flagging tape to better identify them and prevent them from inadvertently being cleared with invasives.

Queen's Chapel Forest Patch is a 5-acre UFP two blocks south of Langdon Park (Figure 2). It sits on land under the jurisdiction of two different city agencies and lacks any dedicated management. In 2023, the city proposed clearing part of the forest to develop it as a fire station. Residents and community leaders protested the plan on the grounds of environmental and social impacts and successfully prevented the project proceeding. They have since formed Friends of QCFP and are seeking ways to activate the forest for community access and optimal health. The forest is bisected by utility lines under which a right of way was mowed historically, but it has not been maintained during this study. Below the lines and in adjacent areas, the forest suffers a large canopy gap inundated by invasive species.

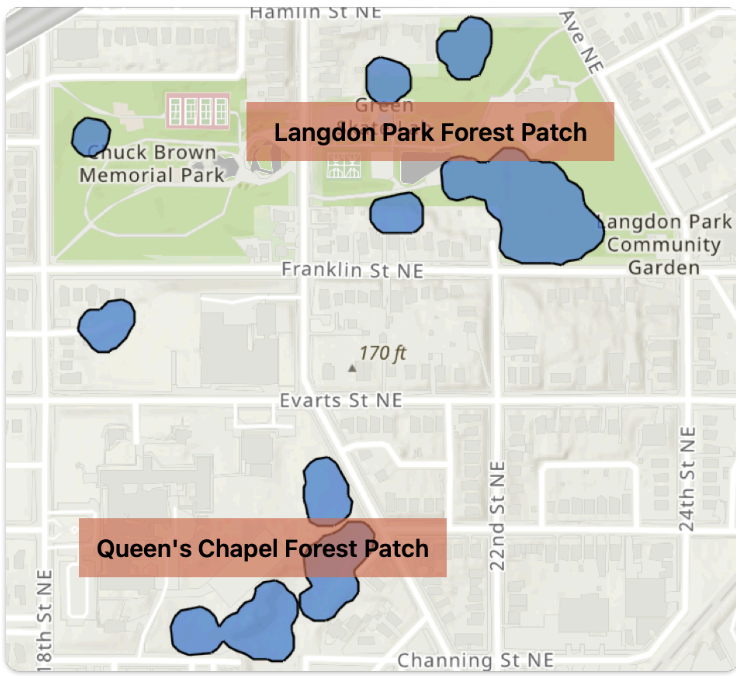

Figure 2. Ward 5 research locations.

Langdon Park Forest Patch to the north is bisected by a buried stream; Queen's Chapel Forest Patch to the south is on a slope and bisected by utility lines. (Baker et al., 2023, adapted by author).

The District of Columbia lacks an integrated management plan for its forested areas–properties that are locally, federally, and privately held. While the region navigates the various stakeholders needed to agree upon a holistic plan, the research at Langdon Park and Queen's Chapel Forest Patch could identify a viable option for community members to foster the health of their local forests. Specifically, can ANR consisting of community stewardship and low-cost site treatments be applied to encourage early establishment in an urban forest patch?

Research Questions, Hypotheses, and Specific Aims

My research assessed the viability of ANR practices, including community stewardship and site treatments, to mitigate social and ecological barriers to UFP succession. My main question was: Does a community-managed site-treatment approach improve UFP outcomes socially and ecologically? To evaluate that question, I explored three secondary questions.

First, does ANR in an urban forest patch effectively encourage natural recruitment of native tree seedlings? My hypothesis was that community applied ANR practices would result in native seedling recruitment in urban forest patches. To analyze this hypothesis, I explored the results as three sub-hypotheses:

1a. ANR results in native seedling recruitment across variations in space within a forest patch.

1b. ANR results in native seedling recruitment across variations in percent canopy cover.

1c. ANR results in native seedling recruitment across variations in percent vine cover.

Second, do site treatments improve native recruitment outcomes and/or reduce the amount of maintenance time required? I assessed four site treatments including: clearing (plain), clearing with soil disturbance (soil), clearing, soil disturbance and mulching (mulch), and tree planting (tree). My hypothesis was that mulch treatments would achieve the desired outcome of maximum seedling count and diversity and minimum management time required. To analyze this hypothesis, I explored the results as three distinct sub-hypotheses:

1a. Mulch treatments require the least amount of management time compared with the plain, soil, and tree treatments.

1b. Mulch treatments yield the most native tree seedlings after two growing seasons compared with the other treated plots.

1c. Mulch treatments yield the most native tree seedling diversity after two growing seasons compared with the other treated plots.

Third, how does ANR compare with the alternative of commercial planting in an urban forest patch? I hypothesized that community-driven ANR efforts perform better than commercial planting techniques across social-environmental measures. Again, I explored the results with multiple sub-hypotheses:

2a. ANR efforts cost less in labor and materials than traditional planting approaches.

2b. ANR efforts use less water and generate fewer greenhouse gas emissions than traditional planting approaches.

2c. ANR efforts better engage the community than traditional planting approaches.

2d. ANR efforts yield greater native seedling recruitment than traditional planting approaches.

Specific Aims

To address these questions and hypotheses, I:

1. Compared factors of Langdon Park UFP's spontaneous regeneration with existing literature to establish potential variables that contributed to the atypical regeneration there.
2. Established site treatments to explore potential variables influencing successful growth and survival of native tree seedlings.
3. Identified four research areas consisting of canopy gaps or edge areas within Langdon Park UFP and delineated 12 research plots within each.
4. Cleared the research areas and applied the treatments in the dormant season.
5. Recruited and trained community volunteers to maintain plots and collect data.
6. During the growing season for two years, oversaw monthly maintenance sessions with volunteers to remove non-tree species from the plots and identify seedlings.
7. At end of second growing season, inventoried each plot for native tree seedlings.
8. Installed and inventoried 12 additional plots at Queens Chapel Forest.
9. Collected canopy gap data for plots at Langdon Park and Queen's Chapel using a forest densiometer.
10. Calculated costs associated with traditional plantings as provided by nonprofit Casey Trees.
11. Compared the costs and benefits of traditional planting techniques with community driven ANR efforts.

Chapter II

Methods

To evaluate the effects of ANR on seedling recruitment, I established research plots in degraded areas of Langdon Park Forest Patch in Washington, D.C. Along with a group of community volunteers, I applied treatments and monitored and maintained the plots over two growing seasons. I compared the outcomes of our efforts with a traditional planting in the park to assess the effectiveness and costs and benefits of ANR in an urban forest patch.

Efficacy of ANR on Seedling Recruitment

To assess the effect of ANR on seedling recruitment, I partnered with city agencies and the National Forest Service to identify four 100 m^2 degraded areas within Langdon Park Forest Patch to conduct research (Figure 3). The forest patch sits on both slopes of a (now buried) stream valley. The forest is bisected by mowed turf, roadways and paths, a dog park, an outdoor pool, and a baseball field. A nature path was added to the forest patch concurrent with the initiation of this study. Research areas were clearly marked with signage (funded and provided by Casey Trees) inviting community members to observe, but not disturb growing trees (Figure 4). Occasional evidence during the research period indicated animal disturbance (either wildlife or dogs off leash), but there were no significant signs of human interference.

Figure 3. Research areas at Langdon Park.

Area #1 was planted in 2021. Areas #2-5 were installed in 2022 for ANR research.

Figure 4. Research study signage provided by Casey Trees.

Before clearing and treating the areas, we inventoried each area for existing trees and recorded dominant ground cover. We performed our initial inventory in the winter, but across all research areas, none had identifiable seedlings present at the beginning of the study. Area #2 is an edge section along the north slope, part of which was formerly mowed, and all of which was covered in kudzu (*Pueraria montana var. lobata)* when it was identified as a location for the research project (Table 2). Area #3 is an internal canopy gap on the south slope that included one existing young Northern red oak (*Quercus rubra*) but was otherwise inundated with invasive species including English Ivy *(Hedera helix L.)*, Wineberry (*Rubus phoenicolasius*), Multiflora rose (*Rosa multiflora)* and Porcelain berry (*Ampelopsis brevipedunculata*). Area #4 is a low-lying basin along the south slope that was artificially created to direct stormwater away from the nearby swimming pool. The northern slope of the basin includes backfill and was formerly mowed; the remainder is invaded forest edge. The entirety was inundated by Porcelain berry and lacked any trees when it was identified as a research site. Area #5 is a level section of forest edge at the bottom of the hill that was formerly the outfield of a baseball field, but the forest has encroached, and the outfield is no longer mowed. The area had the most species diversity including perennials such as Beggarticks (*Bidens*) and Goldenrods (*Asteraceae)*, nonnative vines including English Ivy and Porcelain berry, and a few small trees including Northern catalpa (*Catalpa speciosa)* and invasive Princess Tree (*Paulownia tomentosa*) (Table 2).

Working with a local nonprofit, Casey Trees, the research areas were cleared to the ground in early 2022, removing all non-tree species present. Volunteers cleared manually (pulling and clipping) and Casey Trees staff used small equipment, such as weedwhackers.

Within each area, 12 2x2 m plots were delineated with a minimum 1-m buffer between plots. Plots were formed using a frame made from PVC piping (Figure 5). Corners were permanently marked with 12” metal stakes and outlined with orange polyester string. I assigned each plot an identification code using the research area number (#2-#5) and a specific letter designation (e.g., 2-C).

Table 2. Research area descriptions.

	Exposure	Topography	Location	Dominant Cover	Existing Trees
Area #2	Southern	Slope	Edge	Kudzu (*Pueraria montana)*	None
Area #3	Northern	Slope	Internal	Diverse	1 Red Oak (*Quercus alba)*
Area #4	Northern	Basin	Edge	Porcelain berry (*Ampelopsis brevipedunculata)*	None
Area #5	Northern	Flat	Edge	Diverse	Catalpa (*Catalpa speciosa)* & Princess Tree (*Paulownia tomentosa)*

Figure 5. PVC piping for plot delineation.

I selected four site treatments:

- Plain- after initial clearing, the site was not modified
- Soil- turn over top 4” layer of soil using shovels and rakes
- Mulch- turn over top 4” layer of soil using shovels and rakes, then add 2” mulch layer
- Tree- plant a 5’ native tree (species selected to reflect existing forest composition) in center of plot according to standard city planting protocol

The treatments were assigned by pulling pieces of paper labeled with letters A to L out of a bag to ensure their random assignment. For each research area, the first four letters withdrawn from the bag were assigned the Plain treatment, the next four were assigned the Soil treatment, and so on. See Figure 6 as an example of treatment assignment. This procedure resulted in three plots of each treatment per research area.

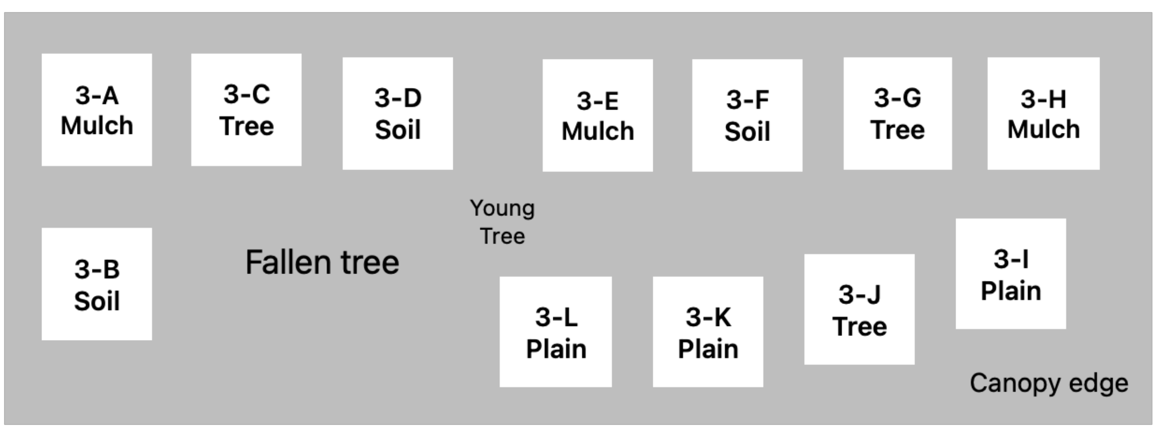

Figure 6. Research area #3 plot map reflecting existing natural elements.

Under my supervision, site treatments were applied in March 2022 by community volunteers that I trained to ensure treatment homogeneity, except for the tree plantings, which were installed by Casey Trees field staff. I surveyed the plots following the treatments to ensure integrity across areas.

Maintenance and Seedling Data Collection

During the spring of 2022, I recruited a group of volunteers from the community to assist with the research. Volunteers received onsite training and were asked to provide their own materials (gloves and pruners). The team collected data and provided monthly maintenance from April to October on each plot, typically during the first week of the month (weather dependent). As the workload varied month to month, this effort often extended beyond one day, but never more than a week.

For each plot, a volunteer first inventoried and recorded any plants growing in the plot using common names. They then cleared all non-tree species using hand tools (cutting, not pulling) and marked seedlings with flagging tape by creating a loop and feeding through two tails, allowing the seedling to grow unimpeded (Figure 7). They recorded the maintenance time needed (based on a watch or cell phone) and counted the seedlings of each native tree species present in the 2x2 m plot. Species were identified to the species with the assistance of a native plant specialist on our team and the plant identification app, PictureThis, which we found to be very accurate with seedling identification compared with other similar applications. Species identification was relevant to the research as we wanted to observe germination patterns but was primarily added as a step to educate volunteers in seedling identification. Data were collected using the Survey123 app (Esri, n.d.).

Following the first growing season, volunteers and staff from Casey Trees cleared the areas between the research plots using hand tools in the winter of 2022-2023. The plots were also restaked using 3-foot surveyor stakes and thicker nylon cord to provide better visibility and durability during the growing season (Figure 8).

Figure 7. Seedling tagged with flagging tape.

Figure 8. Site design improvements from year 1 to year 2

To improve volunteer experience and retention, the volunteer recruitment and training process was enhanced for the 2023 growing season. Volunteers were recruited using neighborhood listservs, social media, and flyers posted in the community. Prospective volunteers signed-up with a short Google form and then were invited to participate in a 2-step training process. First, everyone attended (or later viewed) an online training session to become acquainted with the research goals and the practical methods of the work. Then, prior to beginning work, everyone received brief hands-on training in the field. Volunteers never worked without me nearby so they could always ask questions for clarification. Volunteer work sessions were scheduled for two-hr periods on the first Monday, Friday and Saturday of each month, with reminders sent out using Google Calendar. Volunteer attendance was at-will and self-scheduled.

Plot management and data collection were also improved for the second growing season. First, rather than inventorying specific non-tree species present, an effort that was time-demanding and not comprehensive, volunteers estimated percent cover in ranges (0%, 1-25%, 26-50%, 51-75%, 76-100%). Categories included: bare ground, mulch, herbaceous cover <4", herbaceous cover >4", vines, leaf litter, and tree canopy. Vines referred specifically to nonnative species including Porcelain berry, Kudzu, Wineberry, and English Ivy. Additionally, instead of clearing to the ground around seedlings, volunteers cleared all non-tree species to 2-4" height (as marked on the corner stakes of each plot with a permanent marker). For this second growing season, shearers as well as clippers were recommended to do the maintenance, but volunteers were able to use either. Also, rather than using personal timing devices, volunteers each received a handheld stopwatch. They only measured their work time for maintenance and tree tagging (not species identification), to specifically measure the time needed to maintain an area and protect new seedlings. After recording maintenance time, tree species were counted and identified, again using PictureThis, but over time many volunteers were able to make accurate identifications independently. Our team's native plant specialist provided confirmation for identifications. Data were recorded by volunteers using printed questionnaires which proved easier to use in the field than electronic devices.

For our final data collection in October of 2023, I confirmed species and data counts personally as those measures were to be used for statistical analysis.

To examine the role of canopy cover in seedling recruitment, in October 2023 I recorded canopy openness at the center and corners of each plot using a Spherical Densiometer (Forestry Suppliers Spherical Crown Densiometer, Convex Model, MPN 43387), an instrument designed for measuring forest overstory density by percent canopy opening. I followed the protocol suggested by PPBio (Aparecida de Freitas et al., 2017) and collected the readings myself as the tool has high variability between users.

At the end of two years, to test the assumption that without assistance there would not have been native tree regeneration, I installed 12 additional plots at Queen's Chapel Forest Patch (QCFP). Langdon Park Forest Patch could not serve as a control because of the heavy presence of volunteers in the forest, particularly in the degraded areas. Queen's Chapel Forest Patch, however, received no maintenance during the research period, included no walking trails and was generally void of direct human impact. QCFP is approximately two blocks away from LPFP and the canopy gap selected there for comparison closely resembles the research areas at Langdon Park. Portions were previously mowed, but it was populated by Porcelain berry, Wineberry, Multiflora rose, perennials, and a few young Northern catalpa at the time of sampling. In the twelve plots there, I collected the same data as we collected at LPFN, including: ground cover by percentage, tree seedling species and count, and canopy cover. No maintenance was performed on these plots, so timing was not recorded.

Data Analysis

To evaluate the impact of ANR on forest patch seedling recruitment, the treated and maintained plots in Langdon Park were compared with the untreated and unmaintained plots in QCFP. One-way ANOVAs were performed using VassarStats.net to evaluate differences in native tree seedling count and native tree seedling diversity from October 2023 (the end of the research period).

Two-way ANOVAs were performed using VassarStats.net to evaluate the effect of the four treatments across the four research areas in LPFP. Dependent variables included final native tree seedling count, final native tree seedling diversity, and mean maintenance time during the second growing season. Final seedling measures were from October 2023 and mean maintenance time for each plot was calculated from the seven months of April to October 2023.

To evaluate the significance of the measured environmental factors on count and diversity, statistical analysis was also applied to canopy cover and vine cover. Vine cover was recorded each month in quartile categories and paired with the change in seedlings from the month prior (i.e., June’s observed vine cover was paired with the change in seedlings from May to June). The means were calculated per category for each month, excluding April because the delta April to May data indicated many of the seedlings counted in April never leafed out in the spring. The vine cover categories were translated to the mean of each category (i.e., #1 was translated to 13% as the mean of 1-25%) for analysis. A rank ordinal test was performed with the percentage cover and the mean seedlings change per month.

A regression was performed to assess the effect of canopy cover on seedling recruitment, measured as both diversity and count. The percent canopy cover was transformed with an arcsin and 1 was added to each seedling count to eliminate zeros from the regression. The tests were applied to the October 2023 data: all plots (Langdon Park experimental plots and Queen's Chapel Forest Patch), Langdon Park experimental plots only, and all plots excluding those with kudzu.

ANR Compared with Traditional Planting

For Hypothesis 2, comparing ANR in an urban forest patch with traditional planting techniques, data from the experimental research areas (#2-5) were compared with data from Area #1 (Figure 3), which was planted by Casey Trees in March 2021, and data from Queen's Chapel Forest Patch, serving as a control. Community volunteers tend portions of the planted area, but they had left the northwest quadrant (46 m^2) untouched to illustrate succession absent maintenance. The northwest quadrant was inventoried for native seedlings in its entirety in October 2023 to serve as the data source representing outcomes for traditional planting techniques when applied in an urban forest patch.

The data were evaluated to compare the socio-environmental costs and benefits (Table 3) of a traditional planting technique versus a community-driven ANR approach in an urban forest patch.

Table 3. Variables evaluated for analysis of conventional planting techniques versus community-driven regeneration efforts.

Categories	Variables
Financial	Labor and Materials
Environmental	Water and Greenhouse Gas Emissions
Social	Hours Community Participation
Successional Significance	Seedling Richness and Count

Financial data for Area #1 were provided by Casey Trees. Their per tree cost estimate included staff salary and benefits, tree stock, planting supplies, travel, water, equipment and vehicle maintenance. There is an additional cost for two years of watering following each planting. Financial data for ANR were based on expenses required for the treatments and maintenance, not those required for the research design (plots, stakes and other materials).

Environmental data were divided into two categories: water and greenhouse gas emissions. Water data were derived from Casey Trees' self-reported water allowance per tree, both on their farm and for two years after planting. Trees in the planted area (Area #1) and the Tree treatments received the same watering regimen, although the trees in Area #1 were two years younger.

Emissions data were calculated based on transportation data provided by Casey Trees and ANR volunteers. For Casey Trees usage, distances traveled were sourced from googlemaps.com and fuel economy was assumed based on vehicle category (DOE, 2020). Greenhouse gas emissions were calculated solely for CO_2, because of the limited vehicle information available. Emissions were calculated following the Climate Registry's suggested protocol for Direct Emissions from Mobile Combustion, using

Method B based on distance traveled (2019). Emissions factors were found in the Climate Registry's Table 2-1 (2022).

For ANR-associated emissions, distances traveled were calculated based on volunteers' self-reported neighborhoods. Absent specific vehicle data, emissions were calculated by multiplying distances traveled by the EPA's average CO_2 emissions per mile for passenger vehicles (EPA, 2023). Because volunteers worked across treatments, the emissions data for transportation was presumed comparable for the treated plots, excluding the Tree treatment plots for which the associated tree emissions as calculated above were also included.

Volunteer engagement, both in terms of number of individuals and hours worked, served as a proxy for social impact. There was no volunteer engagement in the northwest quadrant of Area #1 or in Queens Chapel Forest Patch. In the experimental areas (#2-5), volunteer participants cleared the plots and installed the treatments. Their time was recorded cumulatively for the work, rather than by treatment. For maintenance, time was recorded monthly for each treatment and summed for a cumulative annual time measure.

For successional significance, seedling diversity and count as recorded in October 2023 were compared across the different research areas. Data for Area #1 represented three seasons of growth since the initial planting in March 2021. Data for the experimental plots represented only two seasons of growth since the original clearing in February 2022. Data for Queen's Chapel Forest Patch was simply a measure of existing seedlings but lacked a baseline.

Across all measures, data were translated to cost (or benefit) per m^2 or per seedling, depending on the relevance. Cost per m^2 was calculated by summing total expenses for two years of maintenance and dividing by the number of m^2 treated, resulting in a cost/m^2 for each category. Similarly, cost per seedling was calculated by summing total expenses for two years of maintenance and dividing by the number of seedlings recorded in the corresponding treated area, resulting in a cost/seedling for each category. ANR data were subdivided by treatment and evaluated independently for comparison purposes.

Chapter III

Results

I first present the results related to seedling recruitment and diversity in the ANR plots and the effects of the different maintenance treatments. This is followed by comparison of ANR and traditional tree planting in urban forest patches.

ANR Seedling Recruitment

In 2021, the Langdon Park Forest Patch research areas lacked any identifiable native tree seedlings and few to no young trees. After two years of ANR treatments and maintenance, seedlings were recorded in 85% of the 48 2x2m plots for a total of 428 tree seedlings (approximately 2.5 seedlings/m^2) representing 16 native species (Table 4). One research area (#2) demonstrated greater recruitment than the others, whereas the other three were similar in both seedling mean density and species diversity (Table 4)

In the Queen's Chapel Forest Patch, where no treatments or maintenance was applied during the research period, six tree seedlings representing three native species were identified across 12 plots (0.125 seedling/m^2). Therefore, the experimental ANR plots demonstrated improved native seedling recruitment (ANOVA, $F= 9.44$, $p=.0032$, $n=60$), but not improved species diversity ($p=.167$).

Table 4. Seedling count and diversity by research area and treatment.

	Seedling Count/M2	Total Species Diversity
Research Area		
Area #2	5.17	12
Area #3	1.42	9
Area #4	1.31	9
Area #5	1.06	8
Treatment		
Plain	1.79	8
Soil	2.77	9
Mulch	2.96	10
Tree	2.27	11

Seedling count and diversity increased from zero across all treatments and research areas after two years of maintenance.

Treatment and Area Effect

Two-way ANOVAs were performed to evaluate the effects of treatment and research area on native seedling count and diversity. There was no interactive effect between treatment and area on count (F=1.05, p=.424, n=48) or diversity (F=1.37, p=.242, n=48). Although the soil and mulch had higher mean values for seedling counts than the plain and tree treatments, these were not significantly different (Table 4); there was no relationship independently between treatment and seedling count (ANOVA, F=1.14, p=.348, n=48) or diversity (ANOVA, F=.94, p=.433, n=48). There were, however, significant relationships between research area and seedling count (ANOVA, F=19.52, p<.0001, n=48) and research area and diversity (ANOVA, f=.94, p=.433, n=48), with Area #2 having greater values than the other research areas.

Treatments were also combined into mulching (mulch and tree treatments) and non-mulching (plain and soil treatments) and evaluated with a 2-way ANOVA with research areas. The results mirror those for the differentiated treatments. For seedling count, there was no interaction effect ($p=.960$) nor an effect of the treatment ($p=.563$), but there was a significant relationship with the research area ($F=17.69$, $p<.0001$, $n=48$). Similarly, for diversity, there was no interaction effect ($p=.804$) and no simple effect for treatment ($p=.392$), but a relationship with research area ($F=5.53$, $p=.0028$, $n=48$).

A two-way ANOVA examining the effects of research area and treatment on mean required maintenance showed no significant relationships, either interacting or simple (ANOVA, $F=.91$, $p=.529$, $n=48$).

Environmental Factors and Succession

The rank ordinal test showed there was no relationship between monthly vine cover and seedling recruitment ($p=.39$, $n=22$, $t=-.29$). The canopy cover regressions also showed no relationship between percent canopy cover and seedling recruitment (all plots: $n=60$, $p=.47$; experimental plots only: $n=48$, $p=.07$; all except Kudzu: $n=48$, $p=.28$). Similarly, there was no relationship between canopy cover and diversity ($n=60$, $p=.48$). It is noteworthy that neither canopy cover nor vine cover explained the higher seedling density in research area (#2).

Results Comparing ANR and Traditional Planting

The ANR data showed lower financial and environmental costs per meter and per seedling than the traditional planting approach, but greater seedling recruitment and community participation.

Financial Costs

Casey Trees reported the cost of a planted tree as $350. Summer watering cost approximately $21/tree annually. With a typical commitment of two years of watering, the total cost of planting and maintaining a tree was $392.

Costs in the research plots were minimal. As labor was performed by community volunteers who provided their own tools, there were no labor or equipment costs (Table 5). The Department of Transportation's Urban Forest Division contributed the mulch from trees they had chipped. The incurred expenses were the trees themselves (and associated watering) and flagging tape (at about one roll per month or $0.58 per plot). Excluding the Tree plots, the treated plots cost only $0.14 per m^2 to maintain for the two-year period. Translated to cost per seedling, the seedlings in those plots each cost less $0.10 per tree (Table 5).

Table 5. Planting and treatment financial costs.

	Planted Area	Experimental Plots				Queen's Chapel UFP
		Plain	Soil	Mulch	Tree	
Cost/Area (Dollars/M2)	$50.58	$0.14	$0.14	$0.14	$98.14	0
Cost/Seedling (Dollars/Seedling)	$46.12	$0.08	$0.05	$0.05	$43.22	0

In the Queen's Chapel Forest Patch, there were no associated costs as no treatments were applied and no maintenance was performed during the research period (Table 5).

Environmental Costs

The sustainability costs involved with the treatments and maintenance included watering and greenhouse gas emissions associated with the transportation of materials and labor.

Casey Trees reported they typically give a tree 525 gallons per year off a drip line on the farm and an additional 175 gallons of water each summer for two years once they are transplanted. Trees planted in Area #1 were approximately five years old. Trees planted in the research areas were approximately three years old. Both were watered for two summers after planting. Area #1 required 384 gallons of water/m^2; the planted experimental plots required 481 gallons of water/m^2 (Table 6). Although the trees were younger in the research plots, they were planted at one tree per 4 m^2 compared with the trees in Area #1 which were planted at one tree per 8 m^2, thus requiring more water per m^2. Similarly, the water used per new seedling was higher in the research plots because the regeneration rates were slightly lower per m^2, but the water used per m^2 was higher. The research plots without trees required no watering.

Emissions from Casey Trees' planted trees are derived from their delivery and maintenance. A diesel semi-trailer transported 210 trees 72 miles from the Casey Trees farm in Virginia to their city location. Trees were then delivered to their specific planting location using a Chevy 2500 with a trailer. Staff traveled two miles roundtrip to Langdon Park to service the trees about seven times per year for the first two years. Each planted tree at Langdon Park was associated with .0066 MT CO_2. Distributed among the seedlings around the planted area, associated emissions were .003 MT CO_2 per seedling Table 6).

Based on the self-reported neighborhoods of volunteers and their assumed travel distances, the average emissions per seedling of the ANR plots without trees was .0002 MT CO_2 (Table 6). For experimental plots with trees, it was .0004 MT CO_2/seedling.

Table 6. Planting and treatment associated environmental costs.

	Planted Area	Experimental Plots				Queen's Chapel UFP
		Plain	Soil	Mulch	Tree	
Water/Area (Gallons/m^2)	383.87	0	0	0	481.25	0
Water/Seedling (Gallons/Seedling)	350.00	0	0	0	211.93	0
Emissions/Area (CO2e/m^2)	0.003	0.0006	0.0006	0.0006	0.009	0
Emissions/Seedling (CO2e/Seedling)	0.003	0.0003	0.0002	0.0002	0.0004	0

Community Engagement

No volunteers participated in maintenance in the northwest quadrant of Area #1 or the Queen's Chapel Forest Patch, but volunteers contributed hundreds of hours in the ANR plots (Table 7). In the experimental areas, 21 volunteers contributed to installation and 20 additional individuals participated in maintenance for a total of 41 community participants. Clearing and installation required 95 volunteer hours or 5,460 minutes across treatments, with an average of 29 minutes per m^2. Annual maintenance in 2023 totaled 2,715 minutes across the 48 plots with an average 14 minutes/m^2.

Table 7. Community engagement in planted, ANR and control plots.

	Planted Area	Experimental Plots	Queen's Chapel UFP
Total Participants (Individuals)	0	41	0
Total Set-up Time (minutes)	0	5,460	0
Average Set-up Time (minutes/m^2)	0	29.08	0
Total Maintenance Time 2023 (minutes)	0	2,715	0
Avg Maintenance Time 2023 (minutes/m^2/year)	0	14.14	0

Successional Significance

The experimental plots, across all treatments, recruited more seeds per m^2 on average (2.55) than the planted, but not maintained area (1.8, Area #1) and the untreated, unmaintained area (0.19, Queen's Chapel Forest Patch) (Table 8). Diversity was similar among the four treatments and the tree planted area (8-11 native species summed across all plots), but the Queen's Chapel Forest Patch saw the lowest recorded diversity (three species) (Table 8).

Table 8. Seedlings recorded in planted, ANR and control areas.

	Planted Area	Experimental Plots					Queen's Chapel UFP
		Plain	Soil	Mulch	Tree	Mean	
Seedlings/Area (seedlings/m^2)	1.8	2.1	2.8	3.0	2.3	2.6	0.19
Diversity (species)	10	8	8	10	11	9.3	3

Chapter IV

Discussion

The results at Langdon Park indicate the potential for Assisted Natural Regeneration to promote succession in urban forest patches. Compared with the typical urban forestry approach of planting, ANR is less expensive, has potentially fewer environmental costs, better engages the community, and results in successful seedling recruitment.

Assisted Natural Regeneration Potential

At Langdon Park, volunteer forest stewards began removing vines and tagging seedlings for protection long before they heard the term Assisted Natural Regeneration (ANR). They realized that although most of the forest edge was inundated by invasive species, a steady practice of marking and protecting seedlings allowed some young trees to grow in areas where they were not otherwise thriving. When they saw the unexpected number of seedlings around Casey Trees' planting, they thought something may have happened during the planting that catalyzed recruitment. This study was born in the hope that we could isolate the catalyzing event and pair it with the stewards' "tree rescue" practice to increase recruitment and improve successional outcomes.

Looking at the Casey Trees' planting and existing literature, potential recruitment catalyses included: clearing, soil disturbance, mulching, and tree planting. The results of the experimental plots indicate that clearing may have been the catalysis in the planted area, because neither soil disturbance, mulching, nor tree planting increased recruitment results compared with clearing alone. All research areas were originally cleared to the ground and all areas demonstrated improved seedling recruitment compared with their baseline. This finding was substantiated by the minimal recruitment recorded in Queen's Chapel Forest Patch where no clearing took place.

Enhanced Effect of Maintenance

In agreement with Simmons et al. (2016), the results in the experimental plots demonstrated that ongoing maintenance improves outcomes for native seedling recruitment. The planted area (Area #1) and Queen's Chapel Forest Patch, neither of which received ongoing maintenance, recruited 1.8 and 0.19 seedlings/m2, respectively, whereas the experimental plots showed mean values of 2.5/m2 (Table 4). Further, the vine cover data demonstrated no relationship with seedling change from one month to the next, indicating that the maintenance performed controlled the vine growth sufficiently to prevent a retarding effect on seedling recruitment.

Consequently, the research at Langdon Park and Queens Chapel Forest Patch indicate that initial clearing paired with ongoing maintenance can increase native recruitment in canopy gaps and along compromised edges of urban forest patches.

Area Variability

The experimental plots also point out, however, the variability of outcomes based on environmental factors. Canopy cover was unrelated to seedling recruitment, but the significantly different outcomes in Area #2 compared with the other research areas suggests unmeasured variables drove recruitment there. Characteristics unique to Area #2 that may be drivers for the higher recruitment include: southern exposure, higher and more consistent moisture, kudzu invasion, soil chemistry, and a more recent history of mowing prior to being dominated by vines.

Another meaningful variable that may be present, but was not measured, between Queen’s Chapel Forest Patch and Langdon Park Forest Patch is deer presence. In Langdon Park, deer were documented on occasion during the research period and two planted trees showed signs of deer rubbing in the second year (Figure 9), but the deer presence seems to be relatively low, probably because of a perimeter of major roadways. In contrast, deer can access Queen’s Chapel Forest Patch via a nearby rail line that could serve as a wildlife corridor. Neighbors report they only occasionally see deer there, but that does not rule out a regular presence.

Figure 9. Deer rubbing on planted tree at Langdon Park.

ANR Applicability

The outcomes at Langton Park imply that ANR may be a viable means to encourage native seedling recruitment in invaded forest patches. The variability in outcomes between research areas, however, demonstrates that environmental factors can sway those outcomes significantly.

Although tested only in one forest patch in Washington, D.C., the results suggest a variety of applications (Table 9). The combination of clearing and ongoing maintenance demonstrated success in areas with a range of invasive species, including: kudzu, Porcelain berry, Multiflora rose, Wineberry, English ivy and Honeysuckle vine. They also encouraged recruitment on edges and interiors, slopes and low-lying areas, and northern and southern exposures. In terms of site history, the approach was successful in areas that had previously been mowed, included backfill, and were recently forested.

Table 9. Seedling recruitment across various site characteristics.

	Exposure	Site History	Invasive Species	Forest Location	Terrain	Seedlings /m^2
Area #2	Southern	Previously Mowed	Kudzu	Edge	Slope	5.17
Area #3	Northern	Recently Forested	Wineberry, Porcelain berry, Multiflora rose, Honeysuckle Vine, English Ivy	Interior	Slope	1.42
Area #4	Northern	Includes Backfill	Porcelain berry English Ivy	Edge	Basin	1.31
Area #5	Northern	Previously Mowed	Porcelain berry English Ivy	Edge	Level	1.06

As these areas are all part of one forest, however, they include a variety of similar characteristics that may have contributed to recruitment. All research areas likely have comparable seed banks and similar wildlife influencing seed dispersal. Langdon Park is recorded on pre-Civil War maps and the stand still includes healthy mature trees, suggesting a viable seed bank. The plots also likely experienced comparable herbivory, which in the case of Langdon Park, means relatively low deer threat. These are auspicious factors that are not ubiquitous in city forests (Doroski et al., 2021).

The findings at Langdon Park indicate that where there is a healthy seedbank and limited or controlled deer impact, initial clearing and ongoing maintenance can encourage native seedling recruitment and promote forest succession.

Limitations and Further Research

The data at Langdon Park support the use of ANR in urban forest patches. Broad application of ANR, however, requires further research into the generalizability of the approach and the best optimal maintenance schedule.

As noted in the literature about ANR in tropical environments (FAO, 2019; Uebel et al., 2017; Chazdon, 2016), the extent of applicability and the mechanics of ANR vary depending on environmental and social contexts. Environmentally, Langdon Park has a variety of favorable factors: healthy seed bank, mature trees nearby, moisture, and minimal deer browsing. Previous research and my results indicate its largest environmental threat to seedling recruitment is invasive species' competition. With ANR controlling that competition, tree seedlings can establish. Within each forest, the mechanics of ANR will need to respond to the particular threats to succession.

Social threats vary as well. In Langdon Park, there are relatively few social threats to the forest. As part of the city's park system, the forest patch is unlikely to be sold and cleared for development. Even within the park itself, it probably would not be developed for recreational amenities because of the city's canopy goals and tree protection laws. In contrast, Queen's Chapel Forest Patch is not part of the park system, lacks any formal protection, and if not for community organizing, would have been developed as a fire station. The mechanics of ANR—weeding, enclosures, seedling protection, etc.—do not prevent development the same way they prevent species competition or deer browsing. The social practice of ANR and the visual results, however, may enhance public perception of forest patches and improve succession outcomes by decreasing the likelihood of development.

Further research on ANR in urban forest patches in different contexts, both socially and environmentally, could clarify the generalizability of the findings at Langdon Park. Additionally, testing the optimum level of maintenance frequency against seedling recruitment would be helpful for clarifying best practices of ANR in urban forest patches comparable to Langdon Park. Further research could also build on Doroski et al.'s (2021) research on the correlation between forest patch size and seedbank composition to identify if there is a size threshold for application. Longer term research can move beyond recruitment to evaluate ANR impacts on establishment and eventual succession and canopy gains.

ANR and Traditional Planting

The District of Columbia aims to achieve 40% canopy cover by 2032 (DOEE, 2019). This is the driving metric for much of the city's forestry legislation and practices, emphasizing protecting large specimens and planting upward of 10,000 new trees annually (Buscaino, 2022). Natural regeneration, which is slow to produce canopy, does not readily align with the city's stated priorities. The research at Langdon Park, however, indicates that in urban natural areas, ANR may be the most appropriate practice for promoting native tree recruitment and forest health.

Traditional Planting Purposes

Although approaches vary for best practices in urban tree planting, the general process is relatively standardized. A tree grows at a farm and then is transported to its destination city where a hole is dug for the tree to spend the rest of its life. Maintenance includes initial watering (two years on average in D.C.), mulching around the base of the tree, and mowing under the canopy, sometimes for the lifetime of the tree. This method achieves growth into the canopy quickly and ensures tree longevity by preventing competition from adjacent plant species. It is a successful means to increase a city's canopy cover.

The 2021 planting in the forest patch at Langdon Park is somewhat unique, because it was installed with a different goal in mind: to close a canopy gap in a natural area. The trees were planted more tightly than they would typically be in a yard or along a street, and they were mulched, but have not been mowed. The altered planting and maintenance choices were designed to help the canopy gap close, and the forest reestablish. The establishment and growth of most of the planted trees and the abundance of native seedling recruitment over the following years indicate the forest is moving in a healthy direction.

Although the planting at Langdon Park is proving successful, the ongoing research there explores if there is a more suitable approach to achieving the unique goals of urban forestry in natural areas. Comparing Assisted Natural Regeneration with traditional planting indicates the former may be better suited environmentally and socially and include fewer costs.

Forest Health

At Langdon Park, the planted area and the experimental plots both demonstrated improved native seedling recruitment, a foundational step towards forest regeneration. Natural recruitment ensures species continuity in the stand which offers appropriate food and habitat to local wildlife and resistance to local pests and disease. Natural recruitment also promotes forest health because it provides genetic diversity in the next generation of trees and by nature's design places the "right tree in the right place."

Although planting (absent mowing) appears to successfully promote native recruitment, it also introduces novel species into the environment. The planting at Langdon Park includes six species that are novel to the park, two of which are only marginally native to the area. Although none of these species are noted invasives, introducing new species to existing ecosystems always poses the risk of unforeseen consequences. Further, their head start on the native seedlings growing around them ensures a substantial period until the younger trees reach maturity in the stand.

Environmental Measures

Beyond impacting species composition, planting carries other environmental consequences. The transportation of staff, equipment and tree stock all carry a carbon footprint. Additionally, transplanted trees need to be watered regularly for at least the first two years, requiring about 350 gallons of water per tree.

In contrast, ANR can conceivably generate zero emissions and require no watering. If ANR does not include tree planting, it does not include watering. If volunteers or staff are local, as are many who work at Langdon Park, they can walk to participate. A handful of Langdon's volunteers live relatively far away and drive to the site. Their associated emissions demonstrate how transportation needs can meaningfully alter the carbon footprint of a project. Ideally, participants would take public transportation or live close enough that they could walk or bike to the site to minimize emissions.

Financial Measures

While both options successfully encourage seedling recruitment, planting is not always a viable option because of the limiting factor of cost. Many municipalities lack budgets for tree planting. Others, like the District, prioritize planting projects along roadways and in un-treed areas, over compromised forested areas with canopy gaps or invaded edges.

ANR can be a nearly free enterprise. By following the steps at Langdon Park and engaging volunteers using their own equipment, the only expense is flagging tape. As paid work, a year of ANR maintenance at DC's minimum wage ($17.50/hour) would cost $104.15/m^2, plus the price of equipment and transportation. In other words, twice the price of planting alone. Further research to identify the optimum frequency of maintenance could reduce that cost. Notably, if professionalized, the expense of ANR is almost entirely dedicated to paying wages. Depending on a local government's priorities, redirecting costs from materials to jobs may be a valuable benefit of ANR over planting.

Social Measures

In the District of Columbia, through the work of Casey Trees, volunteers are often involved in tree planting. The project at Langdon Park, however, was accomplished by professional staff. Self-appointed volunteer stewards have taken care of portions of the planted area because of their own interest and commitment, but by design, plantings typically do not engage volunteers in any ongoing maintenance. In contrast, ANR is a labor-intensive, ongoing maintenance approach that is often volunteer dependent.

At Langdon Park, the labor-intensive, on-going nature of the volunteer work afforded a variety of benefits to participants. Volunteers made social connections, developed skills like tree identification, and participated in physical activity outdoors. They regularly commented about how much they loved being in the woods and appreciated having a reason to be out working. Beyond their personal benefits, many participants reported stewarding their own property differently because of the work. Others have participated in advocacy work and are pursuing further education in the field. The community advocacy that ultimately stymied the fire station development at Queen's Chapel Forest Patch was born out of volunteers' engagement in stewardship at Langdon Park. Although anecdotal, these outcomes illustrate how ANR can have compounding environmental benefits and positive outcomes for individual participants.

Figure 10. Graduate student records documentary footage while volunteers learn seedling identification.

ANR Applications

The outcomes at Langdon Park in Washington, D.C. suggest that the practice of ANR which has been widely applied in other settings, may be suitable for urban environments. The flexibility of the approach offers a breadth of potential applications.

ANR can be applied by informal groups interested in stewarding local natural resources. The equipment (tagging tape, gloves and pruners) is inexpensive and with plant identification apps such as PictureThis, there is no special knowledge or training required.

Similarly, municipalities with limited dedicated funds can easily train and deploy interested volunteers to perform ANR. Local government involvement is critical when working on city properties as individuals should never work on public land without explicit permission. Additionally, at larger scales, more training and oversight is important to prevent individuals from deviating from the established practice.

For well-funded municipalities or private landowners, ANR can be a professional service akin to regular landscaping maintenance such as mulching or mowing. Staff should be trained in plant identification and equipped with tools such as apps and plant manuals to ensure seedlings are tagged and not removed. Depending on the project scale, ANR could be a full-time maintenance position. Casey Trees' model of staff working alongside volunteers could be deployed with ANR to achieve some of the social benefits achieved by volunteer based ANR programs.

The ecological context and degree of degradation in a forest will determine the maintenance demands and longevity. In Langdon Park, volunteers began stewarding a small section in 2020 by clearing Porcelain berry and tagging young trees. Those trees, mostly fast-growing tulips and sycamores, are now 3-4 meters tall, and the area only requires semi-annual maintenance to retard the invasive presence. In less conducive contexts (poor soil, limited seedbank, persistent invasive presence), retarding the invasive species and establishing seedlings may take longer. In canopy gaps, successful regeneration may reach a point that maintenance can cease. On edges, however, ARN should be viewed as regular maintenance, though scheduled less frequently, even once regeneration is established because of the constant encroachment of invasives on the forest perimeter in the city.

Figure 11. A tulip tree (*Liriodendron tulipifera*) liberated in 2020 provides canopy cover in 2023.

Conclusions

Forested areas in cities are a unique element of the urban forest with distinct characteristics, services, and challenges. Canopy gaps and invaded spaces along the edges cannot be treated with the traditional plant, mulch, and mow approach applied in more classically urban settings, because it prevents regeneration. Identifying means to address these compromised areas, however, is critical to the longevity of these important ecosystems that cool and clean the air, filter and absorb stormwater, provide habitat and food for wildlife, sequester carbon, and improve community outcomes. The research at Langdon Park suggests ANR is a promising option to promote the seedling recruitment needed for the longevity of urban forests.

ANR uniquely addresses the social and environmental threats that can imperil urban forest patches. By engaging community participants, ANR can improve public perception of natural resources and promote advocacy to deter the threat of development. By removing environmental barriers to regeneration, ANR can create space for forests to regrow from their own seedbank. Using minimal resources and inherently flexible in nature, ANR is widely applicable and easily deployed. While application possibilities require further research, ANR is a promising option for stewarding urban forest patches.

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