Tree Board
~Agenda~

August 18, 2026 **5:10 PM**

I. Call to Order

II. Approval of Minutes

A. Tree Board Meeting Minutes - June 16, 2026

III. Business

A. Tree City USA Application Approaching - September 2026

B. Tree Article: Building Climate Resilient Urban Forests: Impacts of Irrigation and Heat on Tree Establishment in a Legacy City

IV. Other Business

V. Adjournment

Minutes of **Tree Board** Held **June 16, 2026**

Call to Order

Meeting called to order at 5:17 PM.

Sylvia Harlow	Chair	Present
Patricia Bond	Member	Present
Sharon Duff	Member	Present
Jeanie Gay	Member	Present
Erica Grooms	Member	Present

Staff Present: Parks and Recreation Director Brent Shane; Clerk of Council Karen Powell

Approval of Minutes

Tree Board Meeting Minutes - April 21, 2026

Mrs. Harlow asked if there were any changes or corrections to the April 21, 2026, Tree Board meeting minutes. Hearing none, the minutes were approved as submitted.

Business

Tree City USA

Mr. Shane informed the board members that he will be taking over Tree City USA until the City hires a new City Planner. He said he will handle the correspondence with Wendy and the Arbor Day Foundation. He said this year the City received recognition for 15 years of being a Tree City USA and will be going into 16 years.

Summer Tree Care Article

Mr. Shane said the packet includes an article on summer tree care. He said also included in the article is a hyperlink containing more tree care articles.

Other Business

Next Meeting - August 18, 2026

Mr. Shane informed the Tree Board that the next meeting will be held on August 18, 2026.

Adjournment

Meeting adjourned at 5:19 PM.

Tree City USA Application Approaching - September 2026

Department: Community Development
Request: Staff Report

Item Background and Purpose:
Each year, the City of Moraine applies for the Tree City Status and performs various duties throughout the year to stay in compliance.

Attachments:

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Original article

Building climate resilient urban forests: Impacts of irrigation and heat on tree establishment in a legacy city

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ARTICLE INFO

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Tree planting

ABSTRACT

Climate change is causing temperatures to rise across much of the earth, and this warming is amplified in urban areas due to the urban heat island effect. One of the most effective methods of reducing urban heat is expanding the urban forest. However, rising temperatures coupled with increasing drought intensity create challenges for the establishment of newly planted trees in cities. Obstacles to urban tree establishment are exacerbated in legacy cities, which have limited financial resources to plant and manage trees. In summer 2024, we conducted a large-scale field study in Dayton, Ohio, USA to address the challenges of expanding the urban forest in a legacy city. To determine low-cost solutions for urban forest expansion, we supplied 640 newly-planted native saplings with varying levels of irrigation investments across 20 parks in Dayton. We then monitored sapling survival, growth, and health in response to our irrigation investments and surrounding impervious surfaces within a 500-m radius of each planting site as a proxy for heat. We found that the effects of both irrigation treatment and surrounding heat varied among tree species. Overall, approximately 50% of planted saplings survived to the end of the growing season, and many saplings went missing due to anthropogenic disturbance. Therefore, we recommend a tailored approach to urban forest expansion which takes species, resources available for irrigation, and surrounding imperviousness into consideration to inform sustainable urban reforestation plans.

1. Introduction

Climate change has led to rising temperatures and longer, intensified periods of drought across many parts of the world (Cook et al., 2021; Mukherjee et al., 2018). These impacts are exacerbated in cities in the form of urban heat islands, city areas which are warmer than surrounding suburban and rural areas. The urban heat island effect primarily results from localized, high concentrations of impervious surfaces (e.g., pavement, building materials) that absorb and re-radiate heat (Aleksandrowicz et al., 2017; Frank and Backe, 2022; Oke, 1982). In addition to urban heat islands, heat waves are becoming more common and intense, and the intensity of heat waves may be heightened in urban areas (Tan et al., 2010; Tripathy et al., 2023). Extreme heat has negative ramifications for human health, disproportionately impacting vulnerable populations (i.e., elderly or very young individuals). For instance, heat-related deaths have increased 53.7% during the past 20 years for adults age 65 or over, with the 2022 European heat wave responsible for over 60,000 deaths (Ballester et al., 2023; Sorensen and Hess, 2022; Watts et al., 2021). Additionally, members of vulnerable populations are less likely to take preventative measures to mitigate heat stress, such as running air conditioners more frequently, due to the cost of electricity or lack of access to air-conditioning (Sampson et al., 2013). Thus, it is crucial that city residents, especially vulnerable and sensitive groups, have access to cooling within their communities. One way to provide cooling across a city is to utilize shade provided by urban trees.

The urban forest is essential to the health and well-being of city

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residents as well as the ecological health of cities (Dwyer et al., 1992; Mullaney et al., 2015; Nowak et al., 2018). Urban trees can beautify cities and provide numerous ecosystem services, including stormwater management, carbon sequestration, and, notably, cooling via shade (Dwyer et al., 1992; Nowak et al., 2008, 2018). The many benefits trees provide make them crucial tools for mitigating the effects of urban warming. Urban trees have been estimated to reduce summer electricity usage by 1.5–5.2% (Donovan and Butry, 2009), while model simulations of current urban forest cover for the continental United States (US) show daily average temperature reductions of 3.06°C in cities due to shade from trees (Wang et al., 2018). In addition to benefitting human health, the urban forest also supports biodiversity by providing food and habitat for many species of arthropods, birds, and other wildlife (Gardiner et al., 2013; Pham et al., 2023; Riley et al., 2018; Tallamy, 2021; Turo and Gardiner, 2021). Thus, expanding urban forests is integral to combating adverse effects of climate change.

Unfortunately, many US legacy cities (also referred to as shrinking or post-industrial cities) – defined by once-booming economies whose declines have led to severe and sustained population reductions (20–60%) – lack the financial or labor resources for planting, management, and long-term care of trees that urban reforestation requires (Mallach and Brachman, 2013). Legacy cities are predominantly located in the "Rust Belt" region of the US and thus have economies that were primarily dominated by manufacturing in the early to mid-1900s (J. Max Bond Center, 2015; Mallach and Brachman, 2013; Watts et al., 2021). Since their initial booms, legacy cities have faced major population declines resulting from loss of the manufacturing industry, movement of residents to surrounding suburbs, and significant political challenges such as disproportionate investment of state and federal funds in suburban development over urban development (Hughes, 2020; Mallach and Brachman, 2013). Facing shrinking populations, economic declines, and decreasing tax revenues (Shetty and Reid, 2014), these cities are left highly vulnerable to the impacts of climate change and urban warming, as there is little to no funding available for climate change planning and mitigation (Hughes, 2020).

Despite funding limitations, many legacy cities have created reforestation plans to improve their climate resilience through greening initiatives. For example, Cleveland, Ohio has developed a Climate Action Plan which details goals for reducing greenhouse gas concentrations through various methods including tree planting, and Dayton, Ohio has begun to develop an urban forest master plan (City of Cleveland, Ohio, 2024; Department of Public Works, Division of Street Maintenance, 2025). Developing these plans is an essential first step towards expanding the urban forest, however, acting on these greening efforts brings a myriad of challenges. Newly planted trees require essential aftercare to reduce mortality. Tree planting efforts in cities often face high mortality rates due to the abundant stressors present in urban environments such as contaminated and compacted soil, extreme heat, drought, and restricted growing environments (Day and Bassuk, 1994; Jim, 2019). Mitigating these stressors and caring for trees is costly, as trees in these conditions additionally require irrigation, pruning, and pest management to establish (Roman et al., 2014a, 2016, 2021). Urban heat worsens tree stress, as pest insects tend to thrive in high temperatures in cities, further increasing costs of urban tree management (Dale et al., 2016). The high cost of tree care is another barrier to tree planting and survival in lower income communities and legacy cities at-large, as funding for tree planting and aftercare are limited by insufficient local budgets and short-term grant cycles, and a lack of buy-in from local government can place the burden of site management on local residents, contributing to abandonment and neglect (Turo and Gardiner, 2020).

Considering the growing challenges legacy cities face due to warming and disinvestment, we investigated replicable irrigation techniques requiring a range of financial and time investments. Our objective was to evaluate how different approaches to irrigation and planting site landscape context impacted the survival, growth, and health of eight species of native tree saplings in the legacy city of Dayton, Ohio. We predicted that irrigation investments with higher input costs would lead to higher sapling survival, increased growth, and improved health when compared to less costly irrigation investments due to reduced water stress in increasingly watered saplings. We also predicted that plantings in cooler areas of the city with larger amounts of surrounding greenspace and less impervious surface would have higher establishment success than warmer areas.

2. Materials and methods

2.1. Site & species selection

We partnered with the Sustainability Office in Dayton, Ohio, USA for our study, as city officials had expressed interest in exploring strategies to expand their city's urban forest. Though booming in the early 1900's, Dayton has experienced one of the largest population declines in Ohio since the 1970s, losing approximately half of its peak population, and is projected to lose 8% more of its population by 2050 (Columbus Dispatch Editorial Board, 2024; Office of Research, 2024). From the early 1900s through the 1970s, Dayton was a major manufacturing hub, with innovations including the creation of the first mechanical, then electrical, cash registers by the National Cash Register Company, as well as other advancements in the dental industry, engineering, and air travel (Wright, 2022). Since this initial boom in industry, Dayton has steadily declined in population, leading to the present existence of over 9000 vacant lots and abandoned structures in Dayton (City of Dayton Planning Commission, 2022). There have been many efforts to draw more residents back to Dayton since its initial decline, including the designation of many parks such as the sprawling Five Rivers Metroparks system, which includes over 340 miles of paved recreational trails (Five Rivers Metroparks, 2025). Despite these efforts, Dayton's population has continued to decline.

To select sites for reforestation in Dayton, Ohio, USA, we worked with the city sustainability manager to locate urban parks across the city for reforestation. The city helped to guide our selection of sites based on the current and future use of parks and other areas where they saw opportunities to expand canopy cover and the sustainability manager approved our final site selections after an iterative site evaluation process. Site canopy cover ranged from 0% to 87%, with 8 out of our 20 sites having less than 5% canopy (see "Appendix A", Table S1). Current overall canopy cover in Dayton is 22.5%, with some lower income neighborhoods having canopy as low as 5–8% (Department of Public Works, Division of Street Maintenance, 2025), which helped guide our selection. Sites were selected across a gradient of impervious surface as a proxy for urban heat. The average distance between sites was 1.20 km, with the minimum distance being 0.59 km and the maximum distance being 2.49 km. To further narrow selection among possible sites, we chose locations with a range of impervious surface within a 500 m radius of the site center, as increasing levels of surrounding imperviousness can exacerbate impacts of urban warming (Schatz and Kucharik, 2014; Ziter et al., 2019). Buffer size was selected based on previous findings that a 500-m radius is a suitable size for characterizing heating effects of impervious surfaces (Schatz and Kucharik, 2014). Our 20 sites included 19 urban parks and one vacant lot that varied in surrounding impervious surface from 7 to 65%. (Fig. 1). The city sustainability coordinator encouraged us to include the single vacant lot as it is part of a large area slated to be transformed into long-term greenspace. We assumed this vacant lot is affected by high levels of both volatile organic compounds and dense, non-aqueous phase liquids in the soil and groundwater. The majority of residential infrastructure has been removed from this area, which is near two United States Environmental Protection Agency superfund sites (Delphi/General Motors Home Avenue Plant and Behr Dayton Thermal System VOC Plume).

Due to the close proximity of our sites, it is possible that site conditions such as soil and precipitation characteristics were similar; however, we were limited in our site selection and thus were unable to

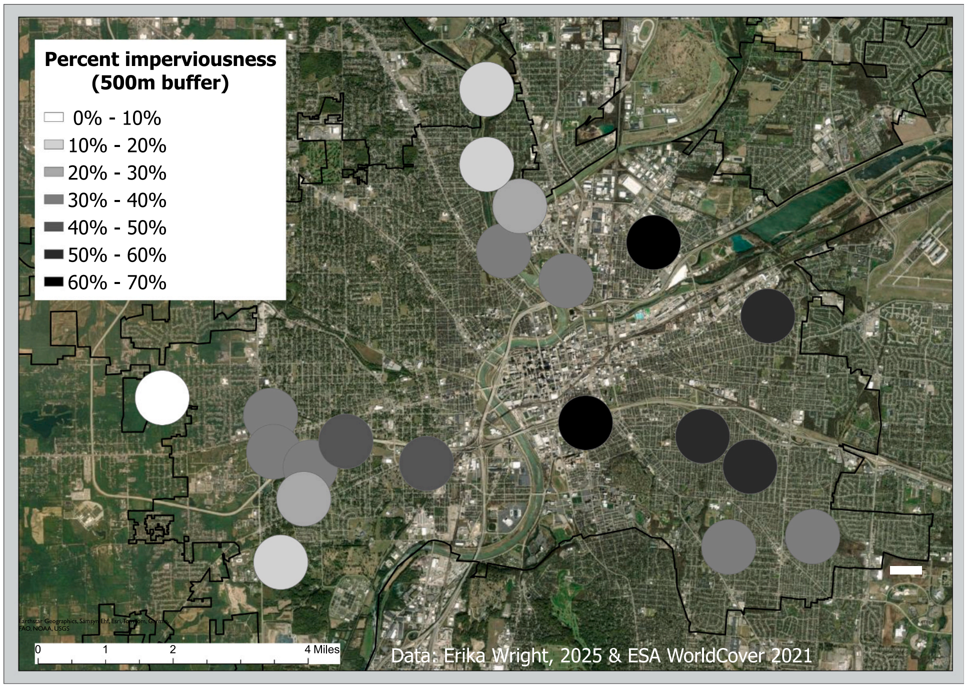

Fig. 1. Map of planting sites and imperviousness Map of tree planting sites in Dayton, Ohio, USA. Circles represent the percent of impervious surface within a 500 m radius around each tree planting location. Impervious percentages range from 7% to 65%. Darker circles represent sites with higher impervious percentage, while lighter circles represent sites with lower impervious percentage. Map was made using Arc GIS Pro software v3.2.0.

choose sites that were farther apart. The primary soil type was silt loam, while at Washington Park and Stuart-Patterson Park the primary soil type was loam (see “Appendix A,” Table S2). Drainage of soils at our sites varied from well-drained to very poorly drained; for specific soil information from each site, see “Appendix A,” Table S2. All sites are currently maintained as mown turf. We used ArcGIS Pro to calculate impervious surface percentages within a 500 m buffer around each site with the ‘built-up’ category of the 2021 European Space Agency 10 m resolution WorldCover Map (Zanaga et al., 2022), projected to NAD 1983 Ohio State Plane South (Fig. 1). At the start of data collection in May 2024, we placed one iButton temperature logger (DS1921G-F5# Thermochron 4 K, iButtonLink Technology, Whitewater, WI, USA) at each site to collect temperature data throughout our study period. However, due to many of the loggers being removed from sites (13 of 20 loggers removed by end of season), presumably to theft or weather events like strong winds, we were unable to obtain accurate site-level temperature data and used impervious surface percentage as a proxy for site-level urban heat instead. We used data from temperature loggers that either never went missing or were replaced immediately upon finding that they were missing to verify that impervious surface percentages corresponded with recorded temperatures at these sites (see “Appendix A”, Fig. S1).

We chose eight tree species native to eastern North America to establish at each site: black gum (*Nyssa sylvatica* Marshall), northern catalpa (*Catalpa speciosa* Warder ex Engelm), red maple (*Acer rubrum* L.), tulip poplar (*Liriodendron tulipifera* L.), sassafras (*Sassafras albidum* (Nutt.) Nees), white oak (*Quercus alba* L.), American sycamore (*Platanus occidentalis* L.), and honey locust (*Gleditsia triacanthos* L.). Many of these species are commonly planted in urban areas and are thus known to be hardy to stressful urban conditions, while others are well-adapted to forests in eastern North America. We obtained 1.2–1.5 m tall bare root saplings from a commercial supplier (TyTy Nursery, Georgia, USA) and planted the saplings within 1–7 days following their delivery. Saplings were stored in a walk-in cooler at 0.4°C with their roots wrapped in wet paper, hydrating gel, and plastic wrap until planting.

2.2. *Tree planting*

In early April 2024, we planted 640 saplings across the 20 sites selected throughout Dayton. At each site, 32 saplings were planted across four blocks, with each block containing eight saplings (Fig. 2). Within a block, each sapling was spaced 2.5 m apart. Between blocks, 5 m of space was left to provide a park-like esthetic to the plantings and to create ample space for mowing by park managers. The location of each sapling was measured and marked with a stake before planting to ensure consistent spacing across sites. In addition to staking each sapling, we also placed rodent guards around each sapling to protect from rodent and deer browsing, as well as mower damage (Plantra 47” SunFlex Grow Tubes with 59” Trunk Builder Stakes – Beaver Shield (10-Pack), SFXV0L-4859–0010, Plantra, Inc., Eagan, MN, USA). To retain moisture and promote weed control, we installed 29 cm mulch mats made of coconut fiber at the base of each sapling (Coco Weed Guards, 29 cm diameter, CD29A, A.M. Leonard, Piqua, OH, USA). Individual holes for each sapling were dug using a track loader with an auger attachment. Soil preparation and planting were performed by teams of 2–5 individuals who were trained on proper tree planting techniques before planting. All trees were primarily surrounded by turfgrass, with little other vegetation present at sites. Saplings did not receive supplemental water at planting due to the cooccurrence of ongoing precipitation events which culminated in Dayton receiving 12 cm of rainfall during the month of April (National Weather Service, 2024). Each block contained one of each of the eight species we selected for planting, and the location of each species was randomized within blocks. In total, each of the 20 sites had four replicates of each species.

2.3. *Irrigation treatments*

To test the effects of irrigation on sapling survival, growth, and health, we implemented four irrigation treatments that ranged in resource inputs. In our study, we define irrigation as providing supplemental water in addition to what sites naturally receive. Irrigation treatments were assigned by block during the summer of 2024. Block 1

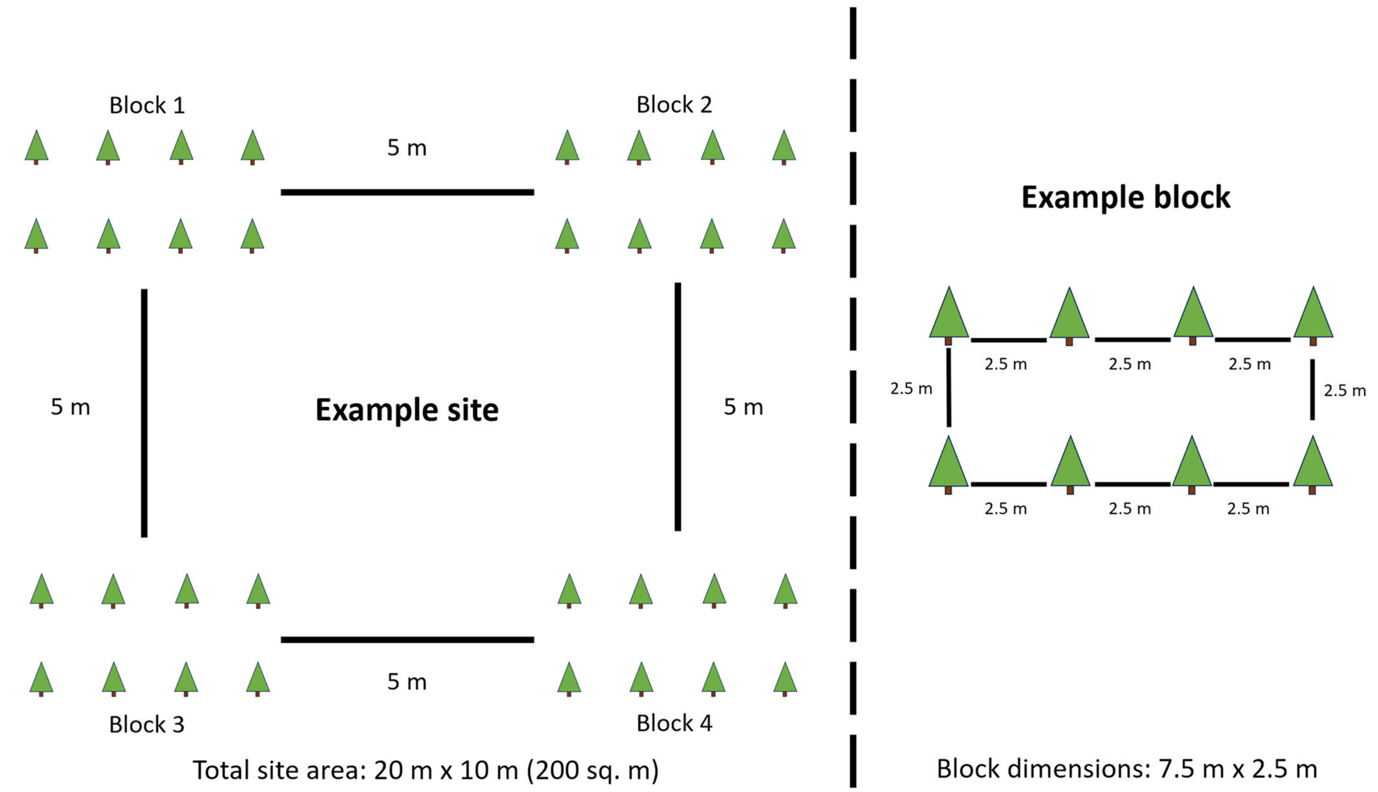

Fig. 2. Diagram of planting design Diagram of site design for tree plantings in urban parks across Dayton, Ohio. Green triangles represent individual trees planted.

served as the control (hereafter referred to as "control"), with saplings in this block receiving no supplemental watering throughout the duration of the study. Block 2 (hereafter referred to as "bi-weekly") saplings received 19 L of water every other week from May-September unless at least 2.54 cm of rainfall occurred between each scheduled watering event. Saplings in block 3 (hereafter referred to as "monthly") received 19 L of water each once per month unless at least 2.54 cm of rainfall occurred between each scheduled watering event. Finally, saplings in block 4 (hereafter referred to as "gator bag") received 75.7 L gator bags (Ike's Tree Watering Bag, 20 gal, Middlesex, North Carolina, USA) which were filled once per month regardless of rainfall amounts. Gator bags are a type of slow-release tree watering device which consists of a plastic, tarp-like bag that wraps around the base of the tree and has a compartment that can be filled with water which will slowly drip through the bag over time. Irrigation amounts were selected based on recommendations from the Ohio Department of Natural Resources, which states that saplings should receive 5 gal (19 L) of water per each inch caliper (19 L); our saplings were all under 1-inch (25.4 mm) caliper upon planting, so we provided the minimum amount of water recommended, i.e., 5 gal of water each (Siewert, 2021). We used rainfall thresholds for blocks 2 and 3 to simulate budget and time constraints faced by urban forest managers to make our study as realistic as possible. Total rainfall in Dayton from May-September 2024 was approximately 38–51 cm. Irrigation amounts were measured by filling containers of known sizes and dispensing water from those containers to the base of each tree. Gator bags were filled directly from the water source.

2.4. Data collection

While deploying irrigation treatments, we also measured sapling survival, growth, and health monthly from May-September 2024. To assess survival, saplings that had no foliage or viable buds received a 0, while saplings that had foliage or viable buds anywhere on the stem received a 1. To measure sapling growth, we measured stem diameter using digital calipers at 15.24 cm (6 in) above ground level; the initial measuring location was marked with a white paint pen and all subsequent measurements were taken at this mark. Height was measured in cm using a meter stick from ground level to the tallest point on the sapling. Finally, sapling health was measured using a crown vigor rating system with values from 1 to 5 created by the USDA Forest Service in which saplings with no foliage or viable buds received a 5, and saplings with ample green, healthy foliage received a 1 (Roman et al., 2020). All measurements were recorded once per month from May-September 2024. To avoid observer bias, the same teams of two to three individuals collected data each month, and the first author collected data every month alongside team members. Dead trees were removed from growth and health analyses, as we did not measure or rate dead trees. Missing trees were excluded from all analyses because equating dead trees with missing trees would have been inaccurate, and we could not measure or rate missing trees. In total, there were 53 missing and 304 dead trees by the end of the growing season.

2.5. Statistical analysis

To analyze sapling survival, we fit a Cox mixed effects model testing (1) effects of the interaction of irrigation (categorical) and species (categorical), (2) effects of the interaction of irrigation and imperviousness (continuous), (3) effects of the interaction of species and imperviousness, and (4) the main effects of species, irrigation, and imperviousness. Site and block nested within site were fit as random intercepts to account for a potential lack of independence. We then used type II analysis of variance (ANOVA) for hypothesis testing. When computing F ratios for the ANOVA, we summed the mean interaction sums of squares and the mean error sums of squares as the denominator for main effects. The Cox mixed effects model was run using the coxme package in R (Therneau, 2024), and we used the car package to run the ANOVA (Fox and Weisberg, 2019). To fit the Cox mixed effects model, we calculated survival times for each tree, with planting date as the "starting date" for survival. We ran pairwise comparisons for significant interaction terms, but not main effects, using estimated marginal means with the emmeans package (Lenth, 2024). We assessed our model visually using Schoenfeld plots to confirm that assumptions of hazard proportionality were met.

We fit linear mixed effects models and used type II ANOVA to quantify sapling growth at the end of the study. We analyzed final caliper and height, in separate models, as a function of 1) the interaction of irrigation and species, 2) the interaction of irrigation and imperviousness, 3) the interaction of species and imperviousness, and 4) the main effects of species, irrigation, and imperviousness. Site and block nested within site were fit as random intercepts to account for a potential lack of independence. We fit initial caliper or height as a fixed effect in each model to account for the large differences in height and caliper of the saplings at planting. F ratios were calculated as stated above. We ran pairwise comparisons for significant interaction terms, but not main effects, using estimated marginal means with the emmeans package (Lenth, 2024). Model assumptions were assessed visually using the plot() function in R to ensure assumptions were met.

To analyze the effects of irrigation on sapling health, we treated our response variable, final crown vigor, as continuous and used linear mixed effects models and ANOVA to analyze crown vigor ratings as a function of (1) the interaction of irrigation and species, (2) the interaction of irrigation and imperviousness, and (3) the interaction of species and imperviousness, and (4) the main effects of species, irrigation, and imperviousness. Site and block nested within site were fit as random intercepts to account for a potential lack of independence. We then ran a type II ANOVA on our linear mixed effects model. We ran pairwise comparisons for significant interaction terms, but not main effects, using estimated marginal means with the emmeans package (Lenth, 2024). Additionally, we analyzed the interaction of species and time on all crown vigor ratings using a linear mixed effects model and type II ANOVA. We fit a unique identifier for each tree and time as a random slope to account for repeated measures over time as well as tree-level differences in crown vigor ratings. The lme4 package in R was used for this analysis (Bates et al., 2015). Model assumptions were assessed visually using the plot() function in R to ensure assumptions were met. Data associated with this study can be found on Zenodo: https://doi.org/10.5281/zenodo.19335840.

3. Results

3.1. Survival

At the end of the growing season, overall sapling survival was 48% ± 2.06 (mean ± SE; Table 1), which excludes 53 missing trees. Sapling survival was highest for red maple at 91% ± 3.38 and lowest for black gum at 10% ± 3.52, followed by white oak at 15% ± 4.27. Sapling survival was significantly affected by tree species ($X_7^2 = 521.25$, $p < 0.001$), irrigation investment ($X_3^2 = 18.14$, $p < 0.001$), the interaction of species and irrigation investment ($X_{21}^2 = 47.82$, $p < 0.001$; Fig. 3), and the interaction of species and percent imperviousness ($X_7^2 = 19.10$, $p < 0.01$; see "Appendix A", Table S3). Significant interactions between species and irrigation indicate that irrigation investments affected species differently; for example, gator bags led to the highest survival for all species except for American sycamore and northern catalpa, for which the bi-weekly and monthly treatments led to the highest survival, respectively (Fig. 3). The significant interaction between species and percent imperviousness indicates that imperviousness affected our tree species differently, as illustrated by northern catalpa having 100% survival in 6 sites across a wide range of impervious surfaces contrasted by honey locust having 100% survival across just three sites, all of which ranged from 13% to 30% imperviousness (see "Appendix A", Table S3).

According to our pairwise comparisons, large differences existed between many species-irrigation investment combinations. Notably, survival of white oak and black gum was significantly lower than red maple survival for all irrigation investments ($|Z| > 7.60$; see "Appendix A", Table S4). Sapling survival also differed among species at differing levels of imperviousness. For black gum, every 1 unit increase in imperviousness was associated with a 0.02 unit decrease in survival, while northern catalpa was associated with a 0.01 unit decrease in survival at increasing levels of imperviousness (see "Appendix A", Table S5).

3.1.1. Growth

Saplings grew minimally in caliper during the study period, with the highest average change in caliper being 0.65 mm ± 0.20 for northern catalpa and the lowest average change being 0.056 mm ± 0.025 for black gum. Species ($X_7^2 = 54.51$, $p < 0.001$) and the interaction of species and irrigation investment ($X_{21}^2 = 48.77$, $p < 0.001$; Fig. 4) had a

Table 1

– Total end of season living trees by species and site Total numbers of living saplings at each site and for each tree species planted at the end of the data collection period in September 2024. We initially established 4 trees of each species within each site, for a total of 32 trees per location.

Site number	Black gum	Northern catalpa	Honey locust	Red maple	Sassafras	American sycamore	Tulip poplar	White oak	Total alive
1	0	0	3	2	0	1	1	0	6
2	0	3	2	3	0	0	0	0	8
3	0	2	0	0	0	0	0	0	2
4	0	1	2	4	0	2	0	0	9
5	0	3	3	4	0	3	1	1	15
6	0	1	2	3	1	2	0	0	9
7	1	4	4	4	2	3	3	2	23
8	0	3	0	4	0	2	1	0	10
9	0	3	4	4	1	4	1	1	18
10	0	2	3	4	0	4	0	0	13
11	0	4	3	4	1	4	1	1	18
12	1	4	4	0	3	3	1	0	16
13	0	2	3	4	0	4	0	0	13
14	2	4	3	2	0	1	3	2	17
15	1	3	1	4	2	3	0	0	14
16	0	2	4	4	0	2	1	1	14
17	1	3	3	4	1	3	3	0	18
18	0	4	2	3	0	4	1	1	15
19	1	4	4	4	2	4	3	1	23
20	0	4	3	4	0	3	2	0	16
Total alive	7	56	53	64	16	51	22	10	

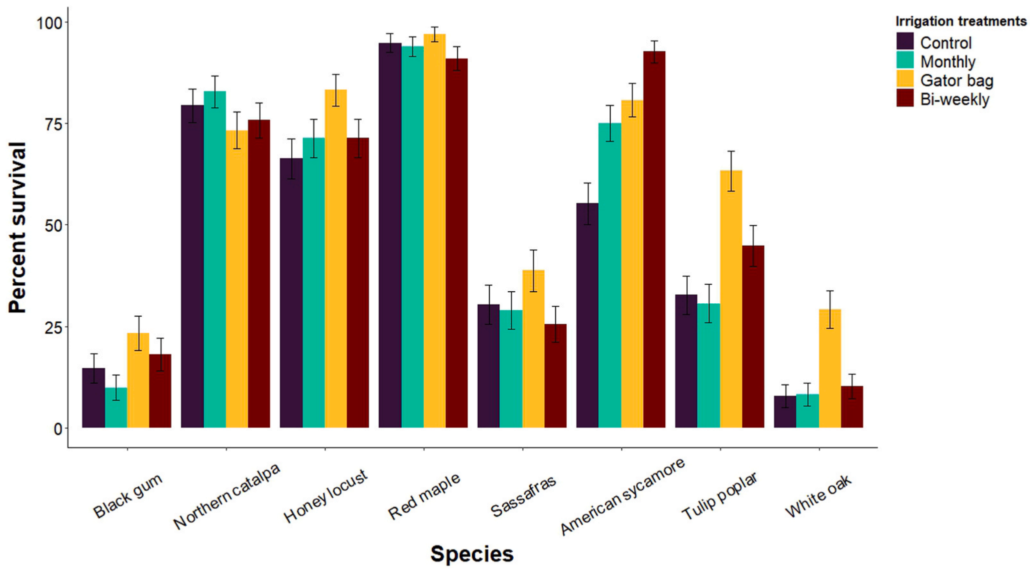

Fig. 3. Effect of irrigation and species on survival The effect of irrigation investments on sapling survival across eight tree species (irrigation*species: $X^2_{21} = 47.82$, $p < 0.001$). Percent survival indicates the percent of living saplings. Error bars indicate the standard error associated with each percent survival. Irrigation investments are ordered left to right from least (control, no irrigation) to most costly (bi-weekly irrigation).

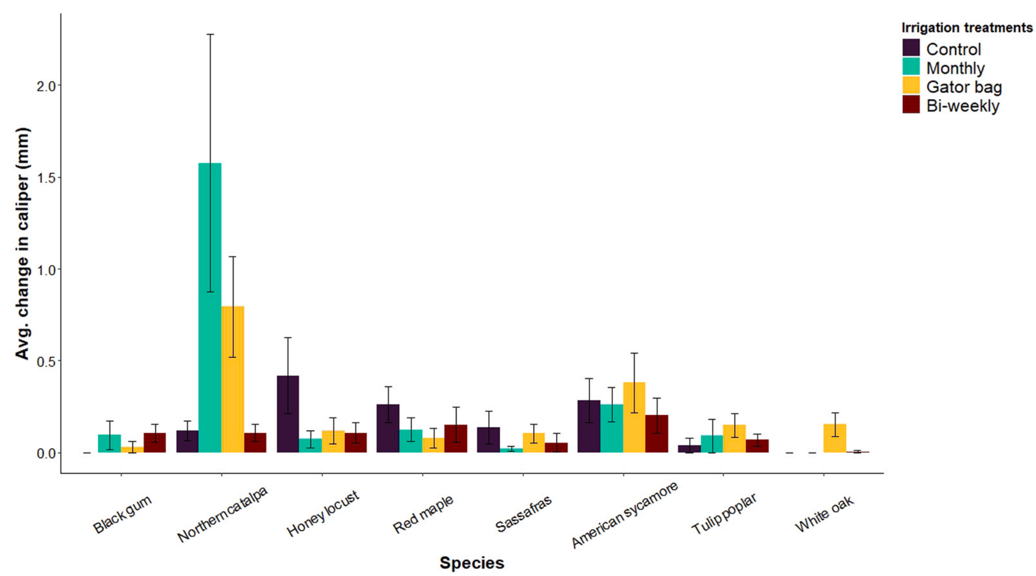

Fig. 4. Effect of irrigation and species on caliper The effect of irrigation investments on average change in caliper across eight tree species (irrigation*species: $X^2_{21} = 48.77$, $p < 0.001$). Error bars indicate the standard error associated with each average change in caliper. Irrigation investments are ordered left to right from least (control, no irrigation) to most (bi-weekly irrigation) costly.

significant effect on final caliper, as different species grew more under different irrigation methods, such as northern catalpa and sassafras. Initial caliper also significantly affected final caliper ($X^2_1 = 5340.90$, $p < 0.001$), indicating that initial sapling size strongly determined growth.

From our pairwise comparisons, there were major differences in final caliper between species at different irrigation investments. For instance, after accounting for initial caliper size, blackgum, sassafras, and tulip poplar had significantly smaller final caliper than northern catalpa for all irrigation investments ($|t| < 2.39$; see "Appendix A", Table S6). Honey locust was also significantly larger in caliper than many species for all irrigation investments, including red maple, sassafras, and American sycamore ($|t| < 2.91$, see "Appendix A", Table S6).

In contrast to caliper growth, certain sapling species grew much taller during the study period, with the largest average change in height being 4.58 cm ± 2.13 for honey locust, followed by 4.02 cm ± 1.14 for northern catalpa (Fig. 5). Initial height $X^2_1 = 1159.08$, $p < 0.001$) and species ($X^2_7 = 45.58$, $p < 0.001$; Fig. 5) had a significant effect on final height. There were no significant interaction effects on final height.

3.1.2. Health

While final average crown vigor ratings were high (higher crown vigor ratings = less healthy crowns) overall, some species such as honey locust (final average crown vigor: 2.0 ± 0.17), red maple (2.9 ± 0.14), and northern catalpa (2.9 ± 0.17) received much lower crown vigor ratings, with honey locust being the least visibly stressed species overall (Fig. 6). Sapling species ($X^2_7 = 212.77, p < 0.001$; Fig. 6 A) and irrigation investment ($X^2_3 = 30.18$, $p < 0.001$; Fig. 6B) significantly affected final

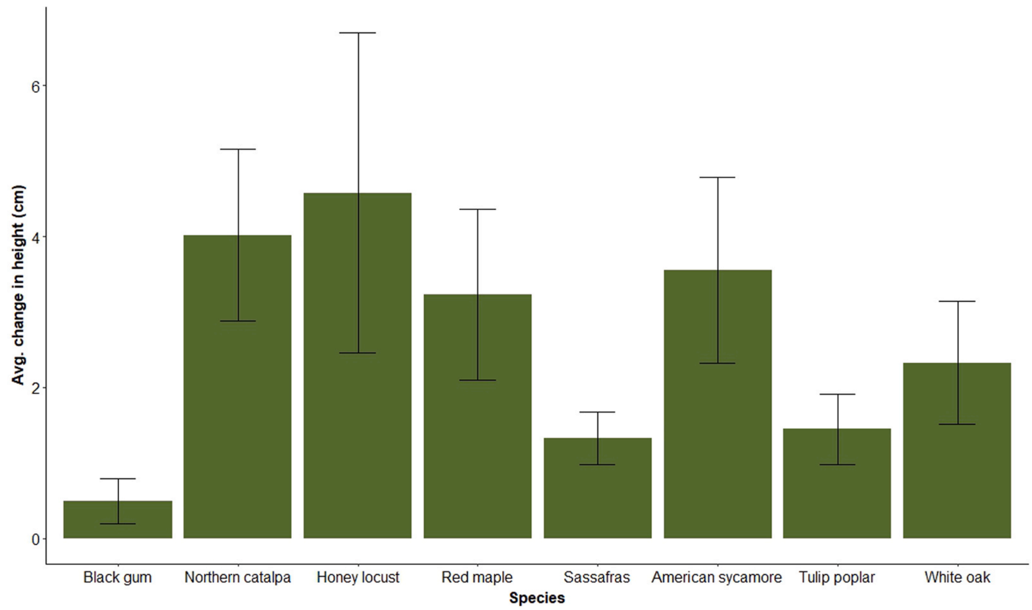

Fig. 5. Effect of species on height The average change in sapling height varied by tree species ($X^2_7 = 45.58$, $p < 0.001$). Error bars indicate the standard error associated with each average change in sapling height.

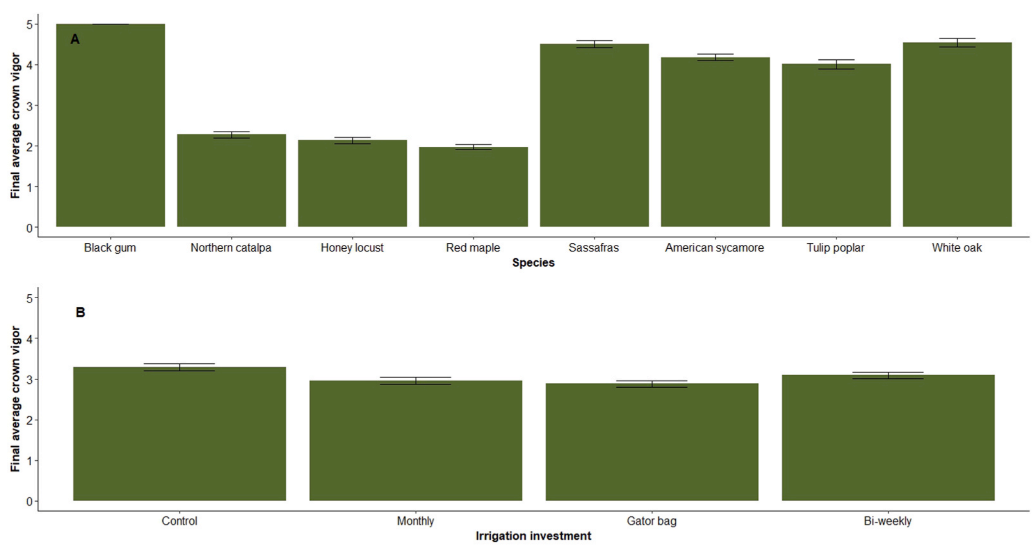

Fig. 6. Effect of species (A) and irrigation (B) on vigor The effect of (A) sapling species on final average crown vigor ($F_{7,271} = 26.97$, $p < 0.001$) and (B) irrigation investment on final average crown vigor ($F_{3,271} = 8.22$, $p < 0.001$). Error bars indicate the standard error associated with each final average crown vigor.

average crown vigor, while imperviousness did not have a significant effect. The interaction of irrigation and imperviousness had a significant effect on final crown vigor ($X^2_3 = 9.89$, $p < 0.05$, see "Appendix A", Table S7). In our model analyzing crown vigor over time, the interaction of time and species ($X^2_7 = 191.36$, $p < 0.001$; Fig. 7) and the interaction of time and irrigation investment ($X^2_3 = 14.61$, $p < 0.01$; Fig. 8) had significant effects on crown vigor ratings. Generally, crown vigor ratings increased, or became less healthy, over time for all species except for honey locust and tulip poplar, indicating that the condition of most species deteriorated throughout the growing season (Fig. 7).

4. Discussion

Urban trees require intensive aftercare and management for long-term success. However, our findings illustrate that irrigation needs differ based on tree species and the landscape context of plantings. We determined that sapling survival, growth, and health all significantly differed by species, with red maple, northern catalpa, and honey locust having greater success for all metrics measured than other species examined in the study. Species with consistently lower survival, growth, and health included white oak, black gum, and sassafras. Notably, crown vigor ratings were significantly lower for these species from planting (Fig. 7), indicating poor condition upon arrival, which illustrates the importance of planting quality nursery stock as well as potential differences in success for species planted as bare root saplings. The poor quality of white oak, black gum, and sassafras upon arrival from the nursery may have been a major driver of the low establishment success of these species when compared to more successful species like red maple and northern catalpa rather than differences in the ability of these species to withstand stress. The high crown vigor ratings for white oak, black gum, and sassafras may indicate a reduced likelihood of long-term survival for these species, as prior studies have shown that poor crown

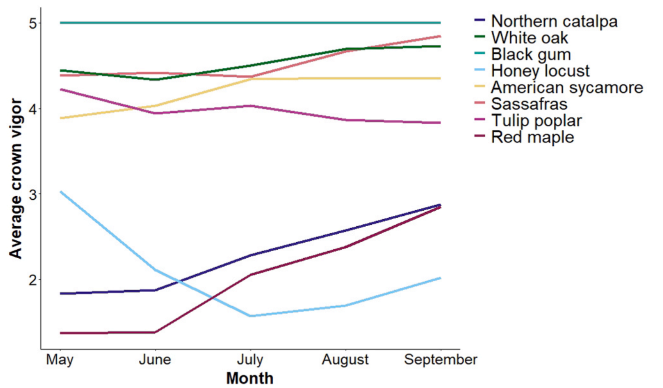

Fig. 7. Effect of time and species on vigor The interaction of species and crown vigor ratings over time was significant (time*species: $X^2_{7,271} = 195.57$, $p < 0.001$). Each species receives a different colored line indicating average monthly crown vigor.

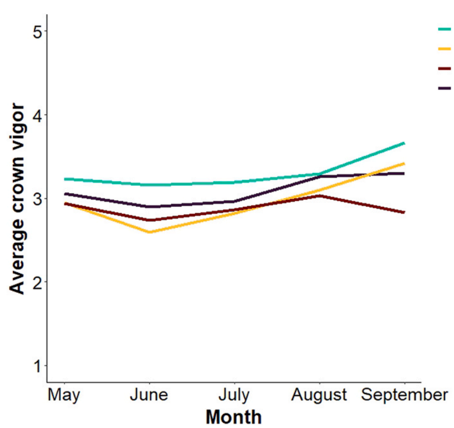

Fig. 8. Effect of time and irrigation investment on crown vigor The effect of the interaction of time and irrigation investment on crown vigor ratings over time (time*irrigation: $X^2_3 = 14.61$, $p < 0.01$). Each irrigation investment received a different colored line representing crown vigor over time (recall crown vigor runs from least to most healthy, 1–5).

health and small tree size lead to reduced survival over time; however, larger species like honey locust, catalpa, and American sycamore may be able to rebound even if crown vigor was high, according to the study (Roman et al., 2014a). Interactions between species and irrigation as well as species and the extent of impervious surfaces found in the surrounding landscape were also observed for sapling survival, growth, and health, leading to varying effects of irrigation and imperviousness on these metrics based on species (Figs. 3, 4). Our findings accord with previous studies in which imperviousness had varying effects on survival and growth of different tree species (Chen et al., 2017; McClung and Ibáñez, 2018). Because impervious surface levels within urban landscapes can serve as a proxy for heat (Schatz and Kucharik, 2014; Ziter et al., 2019), our findings indicated that saplings generally had improved survival, growth, and health when irrigated using gator bags in cooler parks, with some species, such as red maple and northern catalpa, exhibiting high survival across all levels of imperviousness. Thus, our results suggest that urban heat radiated by impervious surfaces can have a significant negative impact on sapling establishment.

High imperviousness was consistently associated with reduced survival and health at our study sites, underscoring the role of heat in tree planting outcomes. However, some species, such as red maple, northern catalpa, and honey locust did not appear affected by hot temperatures, indicating that these species could be potential planting options for cities with limited labor and financial resources for planting and managing trees, particularly in Ohio. There is strong evidence that heat and drought combine to negatively impact urban forest health by making trees more vulnerable to insect attacks (Dale and Frank, 2017; Meineke et al., 2013), reducing photosynthesis (Wang et al., 2019), and increasing water stress (Dale et al., 2016), which coincides with our findings. As cities such as Cleveland, Ohio and Dayton, Ohio develop and revise climate action and urban forest master plans (City of Cleveland, Ohio, 2024; Department of Public Works, Division of Street Maintenance, 2025), city planners and urban foresters should consider surrounding heat levels at their planting locations and choose heat and drought resistant tree species for locations with high surrounding imperviousness.

Identifying low-cost planting and management options for urban forest expansion is challenging, as planting and managing trees is costly. Our results showed that gator bags led to the highest establishment success of our irrigation treatments (Fig. 3). While filling gator bags once per month was not intensive in terms of labor, the up-front and replacement cost of gator bags was high. The gator bags used in our study cost approximately $30 USD per bag; thus, installing a gator bag on all 640 trees planted in our study would cost nearly $20,000 USD for the bags alone. Additionally, many of our gator bags were damaged by lawnmowers and other anthropogenic and environmental factors at our sites, leading to high replacement costs. For legacy cities with limited funds for post-planting tree care, gator bags could be a low to mid-cost irrigation option if protective fencing or other precautions are taken to ensure that the bags are not damaged by landscaping equipment.

Our study aimed to test different irrigation investments, but with our saplings being spread across 20 sites scattered throughout the city of Dayton, we did not have access to public water sources and instead obtained permits from the city to use water from fire hydrants near our sites to fill up a large (757 L) water bladder that we transported via truck to our sites, with the bladder requiring several refills throughout the irrigation process. This process was extremely time-consuming and challenging; thus, implementing similar irrigation regimes would require input from the city or large volunteer support to be feasible beyond the scope of a temporary research study.

Despite our irrigation efforts, survival rates were generally low across our study sites, with a final survival rate of 48% ± 2.06 overall, which is slightly lower than five-year post planting survival rates (50–60%) recorded in previous studies (Roman et al., 2014a, 2014b). While many saplings died due to environmental factors, a large number of saplings were also damaged or entirely removed due to anthropogenic disturbance at our sites. One site in particular lost 30 of the 32 trees that were initially planted due to either human-caused breakage or removal of entire stems from patrons either using or maintaining the park. These high removal rates due to anthropogenic disturbance illustrate the significant challenges associated with planting and managing urban trees, especially when planting in public areas such as parks. While there are studies that have documented the high mortality associated with urban tree plantings (Huff et al., 2020; Roman et al., 2016), it is difficult to overstate the variety of obstacles to tree establishment success in cities. Because of the disproportionate losses of newly planted, young trees compared to large, mature trees, some suggest that city resources should be allocated more heavily to tree aftercare than tree planting to ensure the success of newly planted saplings (Miller and Miller, 1991; Richards, 1979; Roman et al., 2014a). In legacy cities with reduced financial and labor resources, we support these suggestions, as our study sites also faced major losses and removal of the saplings we planted.

While our findings indicate that certain species performed better under heat and water stress, we do not recommend planting only these species. Urban forests with a mix of species have been shown to be more resilient to pest and disease outbreaks (Huff et al., 2020; Laćan and McBride, 2008), and some arthropod pest species thrive on heat and drought-stressed trees (Dale and Frank, 2017; Meineke et al., 2013; Meineke and Frank, 2018). Thus, it is essential for city managers to consider both resilience of individual trees to stressful urban conditions as well as the resilience of the urban forest as a whole. For example, in lower income neighborhoods which have lower canopy than high-income areas and higher heat, it may be beneficial to plant a larger proportion of trees that are highly resistant to heat and drought, such as red maple, northern catalpa, and honey locust in the initial stages of urban forest expansion. As these species become established, additional species that are not as resistant to urban stressors can be planted to create a diverse urban forest that will be resilient to heat and drought. Further research is needed to identify additional species with beneficial traits to increase the diversification and resilience of urban forests. However, the cost of planting trees that are more susceptible to heat and water stress may be prohibitive for low-income communities even after initial urban forest expansion.

Our findings provide specific planting and management guidelines that could realistically be applied by city managers and urban foresters in all cities, but in legacy cities in particular. While saplings in our study faced high mortality due to both environmental and anthropogenic factors, nearly half of the saplings planted survived. This illustrates that even with high levels of human disturbance and infrequent watering, saplings of some species can survive and even thrive in urban areas experiencing rising heat and drought levels. Although challenging, our irrigation regimes and planting recommendations could be implemented with support from city and local governments to grow resilient urban forests.

CRediT authorship contribution statement

Christopher B. Riley: Writing – review & editing, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Wright Erika R:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mary M. Gardiner:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Samuel F. Ward:** Writing – review & editing, Formal analysis. **Ellen Danford:** Writing – review & editing, Data curation.

Declaration of Competing Interest

The authors have no conflicts of interest to disclose.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2026.129422.

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