Leominster Stakeholder Report
HERO 2025




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1 Introduction

The northeast of the United States is experiencing increased frequency and severity of extreme heat (Winter et al., 2019) and severe weather (Henny et al., 2023) that is exacerbated by financial and social challenges (Nordgren et al., 2016). Cities are especially vulnerable to climate change due to their high population density and grey infrastructure (Bulkeley and Tuts, 2013). Urban trees can increase resilience by providing cooling services as well as absorbing excess runoff (Spangler et al., 2019). Urban forests reduced heat by 8 - 12 degrees Celsius in central Europe (Schwaab et al., 2021) and they have also been hypothesized to improve stormwater management during severe weather (Berland et al., 2017)

Urban trees must survive long enough to reach maturity to provide key ecosystem services effectively (Roman, 2016). Tree planting programs heavily favor tree planting as a goal in and of itself with little support for stewardship and monitoring (Eisenman et al., 2021). Reviews of tree planting programs show there is a wide variety of types of programs as well as measures of success as tree planting is often separate from standard urban forestry management (Eisenman et al., 2021). Hilbert et al. (2019) performed a review of 56 survivorship studies and found that annual mortality was highly variable but was much higher (6.8%) during establishment (0-5 years after planting) than post-establishment (3.3%) (5 or more years post planting). Annual mortality factors in the number of years that a tree has been planted for and it is useful for comparing across cohorts and when conducting repeat surveys (Hilbert et al., 2019)

Urban tree monitoring is essential for urban forestry programs to support tree planting programs (Roman et al., 2013). Monitoring allows for urban forestry programs to manage risk, plan future planting, and adjust management regimes by assessing health of tree species and other factors such as land use and site type that impact survivorship (Roman et al., 2013; Ko et al., 2015). Surveys of tree planting in Massachusetts have been used to model ecosystem services (Moody et al., 2021) and identify ineffective stewardship regimes (Breger et al., 2019). Urban tree monitoring can be variable but generally studies assess a variety of health and site characteristics that are important to be kept consistent to allow for comparison over time (Roman et al., 2020). There is a lack of analysis of residential trees and repeat surveys with only 3 residential survivorship studies and 18 repeat surveys conducted in the literature (Hilbert et al., 2019). There are continued large scale investments in tree planting programs like Million Trees LA but without monitoring and follow up, these programs' long-term success will be poorly understood (Pincetl et al., 2013; Eisenman et al., 2021).

Socioeconomic variables play an important role in urban tree planting programs success as the urban forest is a socioecologic system (Roman et al., 2018; Vogt, 2024). Residents often prefer trees for aesthetic reasons, not for the heat mitigation or stormwater runoff control (Conway, 2016). Many residents don't want trees because of the additional maintenance as well as concerns around green gentrification (Reidman et al., 2022; Planas-Carbonell et al., 2023; Smart et al. *in review*). Geron et al. (2023) found that when residents participated in the tree planting program beyond passively receiving a tree either through negotiating with foresters or communicating about the program to friends and family, their trees had higher survivorship and more care (watering). Most studies on resident preferences have been conducted during the establishment phase. More information is needed on how resident preferences and actions change over time as trees mature in the post-establishment phase.

Massachusetts is one of the only states in the country to offer a state government funded TPI. This is known as the Greening the Gateway Cities (GGC) program that is administered by the Department of Conservation and Recreation (DCR). The program started in 2014 with the goal of increasing canopy cover by 5% in priority neighborhoods in Gateway Cities throughout Massachusetts. Gateway cities have seen history of industrialization, decades of divestment and changing demographics impact tree canopy cover (Healy et al., 2022). Their pilot cities included Chelsea, Fall River, and Holyoke. "Gateway Cities" are defined by the state of Massachusetts as potential gateway to regional socioeconomic success when given support to foster post-industrial recovery. They categorically require populations of around 30,00-250,000 people, with median household income and education attainment lower than the Massachusetts average (Mass General Laws ch. 23A §3A). There are 26 Gateway Cities in all of Massachusetts and the DCR conducts plantings in 23. Beginning in Leominster in 2016, the GGC program has planted over 3,500 trees across the city, well surpassing the original goal of 2,400 trees. Some other key dates include the non-profit organization Growing Places joining as an official Community Partner in 2019 as well as the planting zone for the city being expanded in 2024.

Figure 1.1: Timeline of the GGC Program in Leominster Massachusetts.

Research Objectives

The study objectives for this year's report were to (1) measure the survivorship and growth of Greening the Gateway Cities (GGC) program trees, and (2) explore resident perceptions of tree planting and evaluate program coordination among key actors. Key questions for research in Leominster this summer were:

1. What is the current health and survivorship of planted trees?
2. How do survival and growth differ by species?
3. How do Leominster residents perceive trees on their property and in their neighborhoods?
4. How is tree planting coordinated among DCR, city officials, and community partners?

2 Study Area

Leominster is a mid-sized city in Central Massachusetts just north of Worcester with a population of 44,209. The median household income and education attainment for the city is lower than the Massachusetts average, contributing to its designation as a Gateway City. Moreover, the city has a sizable Hispanic and Latino community, at 17.1% compared to the state's average of 13.5%. The city's socioeconomic status makes it an important location for tree initiatives like the GGC program to focus planting efforts in historically excluded neighborhoods.

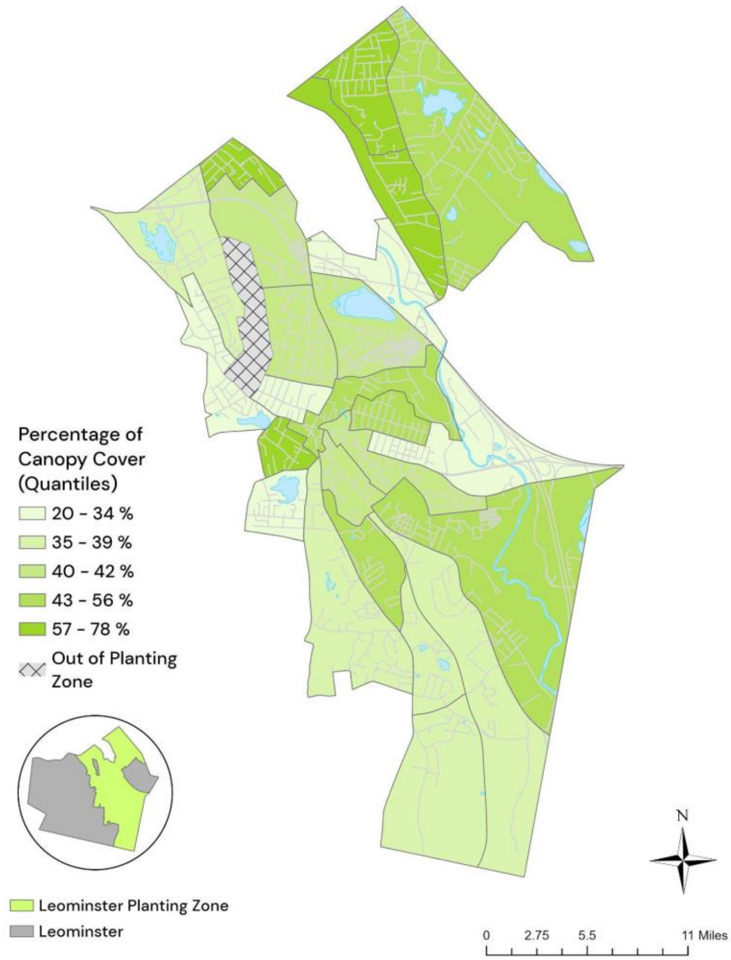

Figure 2.1: Tree canopy cover of Leominster planting zone using American Forests tree canopy data aggregated at the census block group level (American Forests, 2022).

While some areas in Leominster have a higher percentage of canopy cover, there remain numerous neighborhoods within the city that lack trees, namely around the downtown area. This points towards the importance of tree planting initiatives like the GGC program to increase tree cover and vegetation in urban centers and environmental justice communities. Focusing on specific zones designed by the State and DCR can help Massachusetts cities best allocate resources towards tree planting.

Social Demographics	**Leominster**	***Massachusetts***
White	73.3%	79.0%
Hispanic or Latino	17.1%	13.5%
Mixed Race	12.0%	2.8%
Black or African American	5.4%	9.6%
Asian	3.0%	7.9%
Population	44,209	7,136,171
Population Density	1,519 per sq. mile	901 per sq. mile
Median Household Income	$81,556	$101,341
Education (persons age 25+ with Bachelor's degree or higher)	32.3%	46.6%
Speak a language other than English at home	24.4%	24.8%

Table 2.2: Socioeconomic and racial demographic data comparing the city of Leominster to Massachusetts

Leominster has numerous social demographics that fall below the mean and/or median for Massachusetts, including median household income ($81,556) and education (32.3%). These criteria contribute to Leominster's designation as a Massachusetts Gateway City as well as the importance of tree planting initiatives in underprivileged communities. Further focusing planting efforts in environmental justice neighborhoods can help promote environmental justice by cooling neighborhoods during intense periods of heat and providing other valuable environmental services.

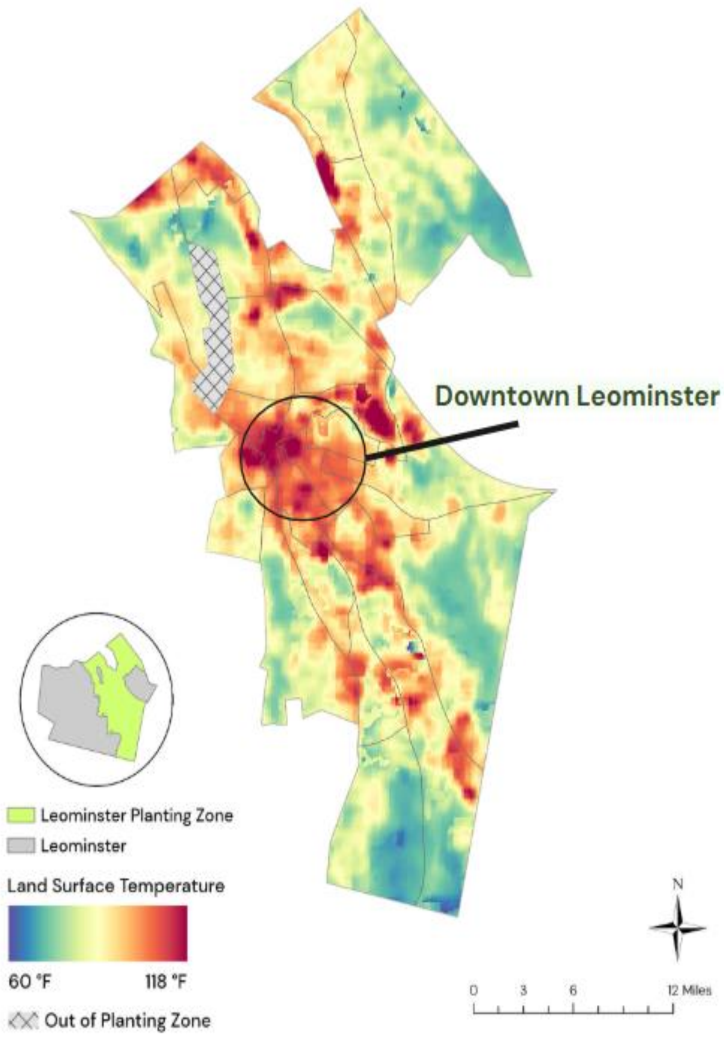

Figure 2.3: Average land surface temperature in June 2025, gathered in Leominster MA planting zone. Imagery gathered from Landsat 8, Level II, Collection II Imagery at a 30m spatial resolution.

An important motivation for tree planting initiatives is to reduce the impact of the heat island effect, as described in Oke (1982). Trees are known to help cool urban landscapes which absorb lots of heat during summer months. In Leominster, the built-up downtown area has a higher LST score than the rest of the city, indicating a need to plant more trees in built-up environments. Our results show that the temperature difference in areas below the city's mean canopy cover is around 10.4 °F.

3 Methods

We spent three weeks in the field between May to June 2025 surveying trees in Leominster. Trees were selected using a mixed sampling strategy and data was collected using the Field Maps mobile application.

Quantitative Methods

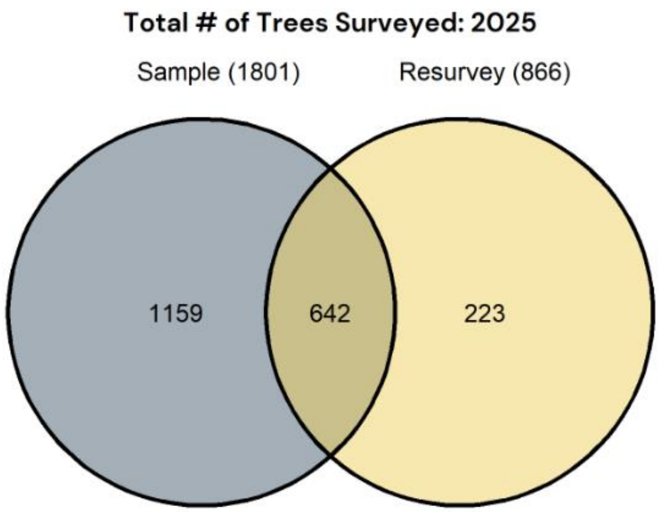

Figure 3.1: Distribution of samples including resurveyed trees.

Of the 2,025 trees we surveyed in Leominster, 1801 were a part of our random sample which included all 658 public street trees. We also resurveyed trees that had been surveyed by the HERO program in 2019, of which there were 866. There was some overlap between the two categories, with 642 trees being in both our random sample as well as the resurvey.

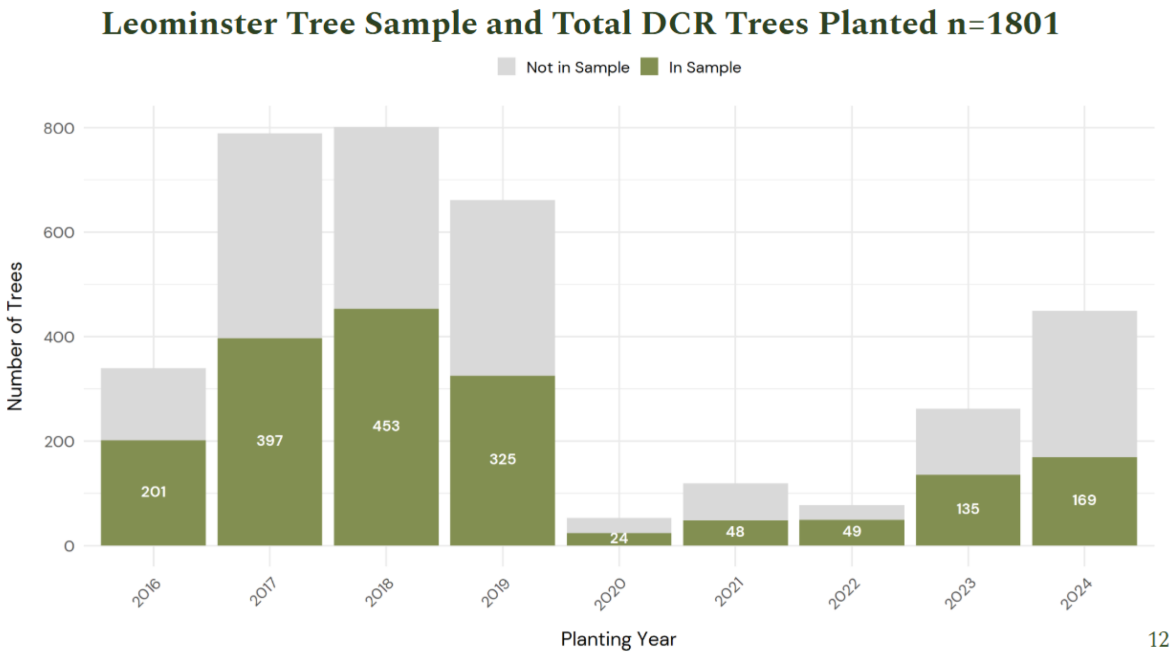

Figure 3.2: Number of GGC program trees planted in Leominster by year.

The majority of GGC program trees in Leominster were planted between 2016 to 2019. Unfortunately, there was a steep decline in planting during the 2020 Covid-19 pandemic which resulted in a much lower number of trees being planted. However, the program has begun to restore its yearly planting efforts with the number of trees increasing every year.

Fields	Description	
Property Type	The type of property based on how it is used by humans (ex. Residential)*	Location
Site Type	A tree's immediate location (where applicable)(ex. sidewalk cutout)	
Mortality	Alive, standing dead, stump, or removed	
DBH	Diameter at breast height (54in)	Structure
Tree Height	Height of tree from base of trunk to highest point	
Crown Width	Horizontal width of crown, measured from one edge to the other	
Crown Vigor	Assessment of crown health, considering fullness and leaf discoloration	Health
Condition	Holistic assessment of tree health, including trunk, branch, and crown	
Basal Sprouts	Growths coming from the low base of the trunk or the roots (yes/no)*	
Bark Damage	Punctured, peeled, or cracked bark (major/minor/none)	
Branch Damage	Lost, broken, discolored, or leafless branches (major/minor/none)	

Table 3.1: Data fields populated in ArcMaps. Fields were created using Roman et al. (2020).

While in the field, we gathered data on 11 different variables adapted from Roman et al. (2020). Each variable falls roughly into one of three categories, namely its location, structure, and health. In the case where we could not gain full access to a tree given its location and/or other barriers, we gathered as much data as was reasonably possible from a distance.

Parent Class	Property Type	Site Type (if applicable)
Street Trees	Street	Sidewalk Cutout
		Sidewalk Planting Strip
		Other Street Tree
Residential	Single-Family Home	*Front Yard*
		Backyard
		Side Yard
	Multi-Family Home (≤ 8 units)	*Front Yard*
		Backyard
		Side Yard
	Residential Complex (> 8 units)	NA
Formal Greenspace	Maintained Greenspace	NA
	Natural Area	NA
Institutional	Institutional	NA
Commercial	Business	NA
	Mixed Use	NA
Vacant	Vacant	NA
Other	Other	NA

Table 3.2: Newly revised property type and site type categories.

One important variable was the location of the tree. The criteria for a tree's location were modified from Roman et al. (2020) to differentiate settings with varying stewardship regimes as much as possible while simultaneously reducing the number of classes to alleviate confusion and overlap. Namely, land use became property type, a concise, parcel-based descriptor which includes a 'road' property type to distinguish trees adjacent to other land uses from those located on them. Additionally, site type became an optional secondary descriptor used only when it enhances analytical value (e.g., yard trees, street trees).

Figure 3.3: Examples of the different property types. From left to right; “Residential”, “Commercial”, “Street Tree”.

Within the property type variable, trees could be classified in numerous ways, including residential, commercial, or street. Some trees could be classified further by site type; for example, those on residential properties could then be marked as being in the front yard, backyard, or side yard. The majority of the trees surveyed in Leominster were residential, a difference from other Massachusetts Gateway Cities where previous HERO teams have surveyed more street trees.

Figure 3.4: Examples of different survivorship types. From left to right; “Alive”, “Standing Dead”, ‘Stump”, “Removed”, “Unknown”.

Alongside property type, another key variable was survivorship, or the overall status of the tree. While most of the trees surveyed were alive, there were many cases where trees had been removed for health reasons or other human drivers (e.g. construction). Additionally, some trees were categorized as unknown when we could not gain access to the property or if there had been a previous error in data entry.

Figure 3.5: London Planes (Platanus × acerifolia) decreasing in vigor. From left to right; “[1] 90% to 100%”, “[2] 75% to 90%”, “[3] 50% to 75%”, “[4] 50% or less”.

Canopy vigor was another important variable for determining the health status of surveyed trees. Canopy vigor considers the health of a tree’s branches and leaves and ranges from vigor class 1 to vigor class 4, each varying in the amount of canopy intact. Moreover, a tree’s vigor score could be impacted by leaf discoloration, pests, and/or diseases that could impact its category.

Figure 3.6: Examples of different stages in condition. From left to right; “good”, “fair”, “poor”.

While vigor only considers a tree’s canopy, condition is a holistic assessment of a tree’s health, including its canopy, branches, and trunk. While most trees that were classified as a vigor class 1 were also marked as in good condition, there were some cases in which a tree with a healthy canopy had major bark damage which could reduce its score. On top of bark damage, a tree’s condition could also be impacted by branch damage as well as the presence of basal sprouts at its base.

Qualitative methods

We conducted interviews in Leominster to understand GGC perceptions and program partnerships among participants in the program. Our interview data analysis also characterizes the partnerships and community roles of the program stakeholders: residents/tree recipients, Growing Places, the DCR, and the city of Leominster. Growing Places is a local non-profit and the community partner of the Leominster GGC program.

The key interview questions focus on two main groups: residents and tree recipients and the actors in charge of operating the program, which are the DCR, Growing Places, and the city of Leominster. For residents and recipients, the key interview questions are on their perceptions of the program and what impacts their tree stewardship methods. The DCR, Growing Place, and city of Leominster key interview questions are on how their partnerships and roles affect how the GGC is run.

We interviewed 32 residents and recipients. 21 of those interviews were scheduled through a DCR provided list of tree recipients and their contact information. We called 363 recipients from that list whose properties fit in the tree sample. The other 11 interviews were not scheduled and conducted in the field through convenience sampling. There was one group Growing Places interview done with three different employees. The same was done with city employees. In that interview employees from the Recreation Department, Conservation Commission, and Planning Department. There was also one interview conducted with a Leominster DCR forester.

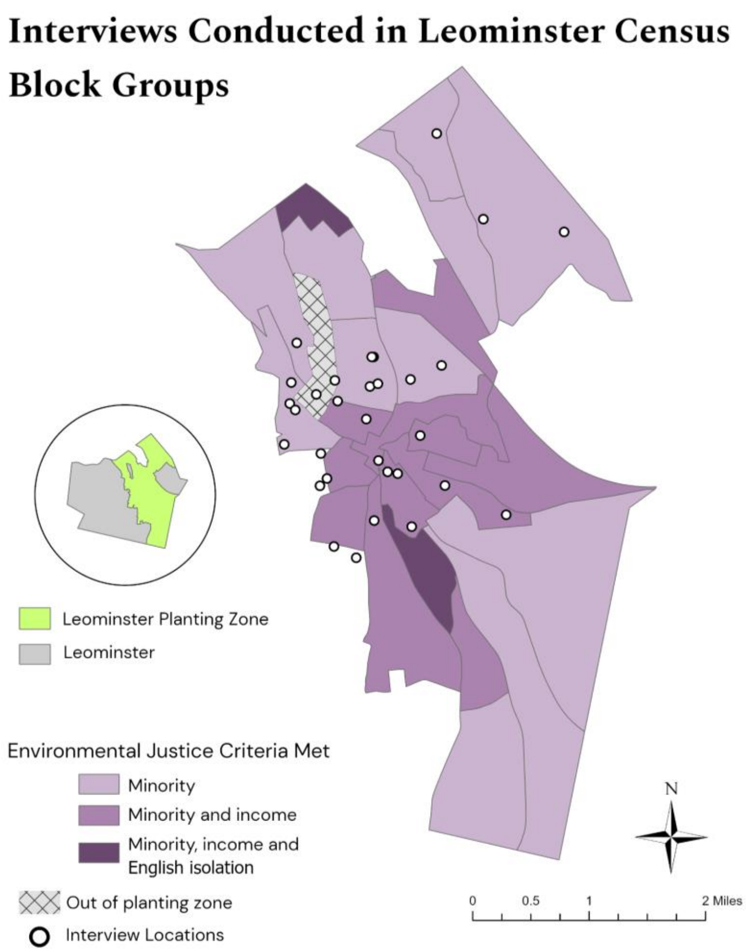

Figure 3.7: Location of interviews and census block groups that meet the environmental justice criteria in the Leominster planting zone

The majority of the interviews were conducted in state designated environmental justice areas which are delineated using U.S. census block group boundaries. However, in the two block groups that meet all three environmental justice criteria: minority, income, and English isolation, no interviews were conducted. These two block groups are identified as difficult areas to collect interview data.

Demographics	Leominster	Interviewees
Population	44,209	32
Median Age	41.8	60
Bachelor's Degree	32.3%	50%
Percent Renters	37.1%	9.7%
Percent White	73.3%	62.5%
Percent Hispanic	17.10%	12.5%
Median Household Income	$81,556	$125,000
English Only Household	75.6%	78.1%

Interviewee Male to Female Ratio: 53% Female

Table 3.3: Interviewee demographics compared to Leominster's demographics

The interviewees tended to be older, a higher percentage of homeowners, and more affluent compared to the whole city. Although the interviewee demographics were lower than the city's percent renters, it is important that some renters were interviewed. Renters and landlords are identified as hard to reach demographics in both Leominster and Worcester. Compared to past HERO interviewee demographics, this year's interviewee demographics more closely resemble its city. For example, the percentage of white interviewees (62.5%) is somewhat close to the city's percentage (73.3%).

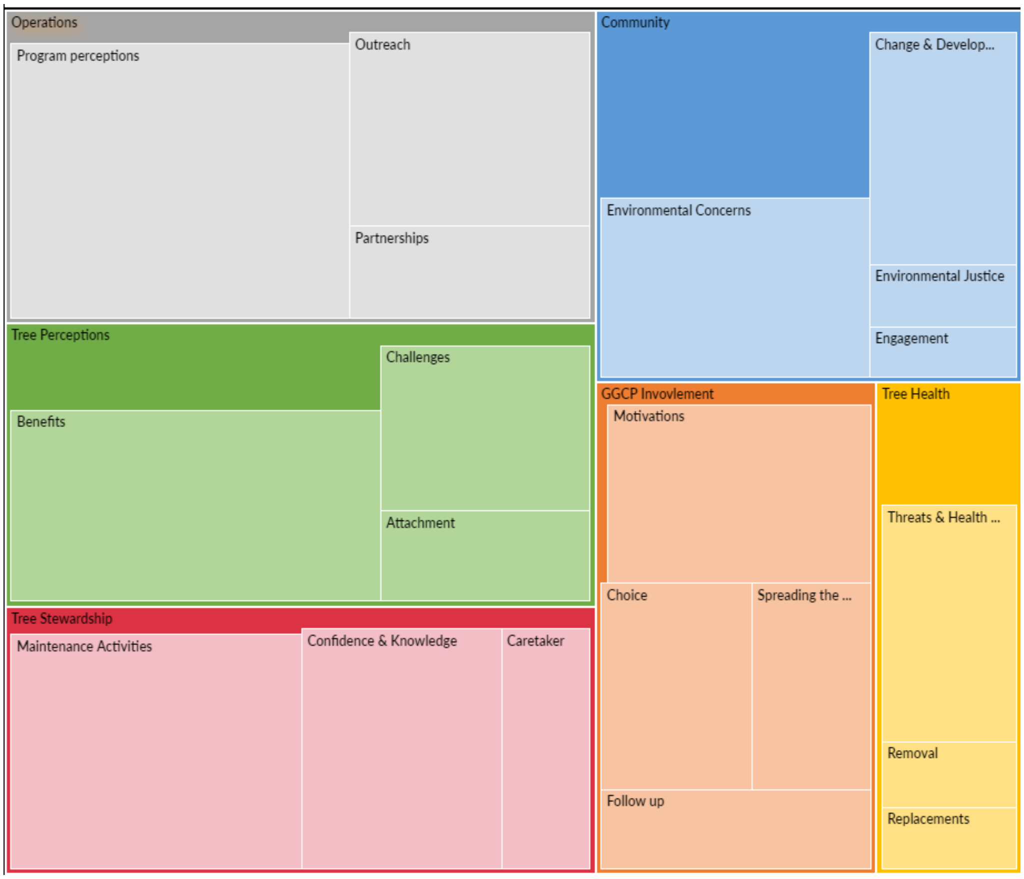

Figure 3.8: The parent and child codes used when coding the Leominster interviews

To better understand and quantify the interview data, we sorted the transcripts into codes, or general themes. The first codes created were the parent codes that emphasize the broader interview themes (operations, community, tree stewardship, GGC involvement, and tree health). We then broke them down into sub codes, or child codes that focus on a specific aspect of its parent code. For example, the parent code tree health is defined as any time the respondent mentions tree health, survivorship, or vitality in the interview. The child codes were used when threats/health concerns, removal, or replacements were mentioned in relation to tree health.

4 Results

We organized our results into primary and sub-themes to organize and quantify tree survivorship and perceptions surrounding Leominster tree planting.

Tree Survey

The tree survey is the representative sample of 1801 trees introduced in the methods sections. This section represents the overall health and survivorship of trees in Leominster.

	Establishment Avg. Annual Survivorship *(1 - 5 years after planting)*	**Post-Establishment** Avg. Annual Survivorship *(6+ years after planting)*
National Median*	93.2%	96.7%
Leominster	96.1% (2020-2024)	95.8% (2016-2019)

Table 4.1*:* Table showing the average annual survivorship rate of the national median (Hilbert et al.) and Leominster in the establishment and post-establishment phases.

Annual Survivorship is the percent of trees that survive each year after planting. The survivorship rates are split into the establishment phase, which is one to five years after planting, and the post-establishment phase, six or more years after planting. In the establishment phase, Leominster's annual survivorship is greater than the national median. In the post-establishment, Leominster is in par with the national median at less than 1% difference.

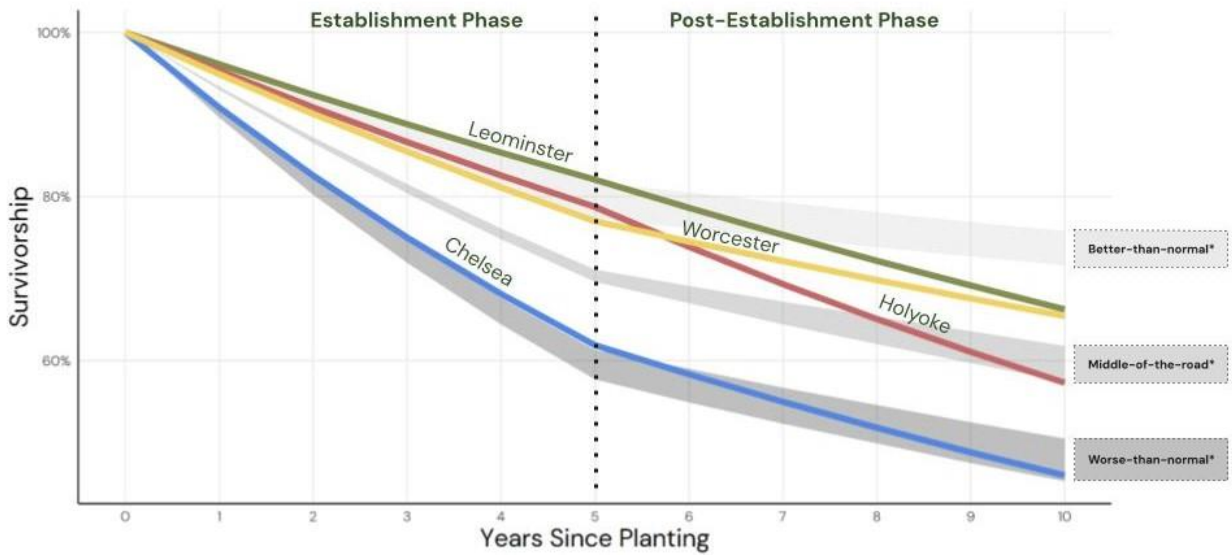

Figure 4.1: Graph showing the average annual survivorship of Leominster, Worcester, Chelsea, and Holyoke, compared to Better-than-normal, middle-of-the-road, and worse-than-normal quartiles (Hilbert et al.). The Y axis represents the percent survivorship and the X axis spans the years since planting (0-10). The graph is split into establishment phase and post-establishment phase.

This graph shows cities where repeat surveys have taken place: Leominster, Holyoke, Worcester, and Chelsea. There are quartiles based on global tree initiatives (Hilbert et al.) that are shown as better-than-normal, middle-of-the-road, and worse-than-normal. Leominster has the highest results in both phases, while Chelsea has the lowest of all. Chelsea's low rates could be attributed to the density of the city. Worcester is different from the other resurvey cities as it is not assessing the survivorship of environmental justice areas. Worcester's survivorship rate is based on tree planting after the Asian Longhorned Beetle outbreak.

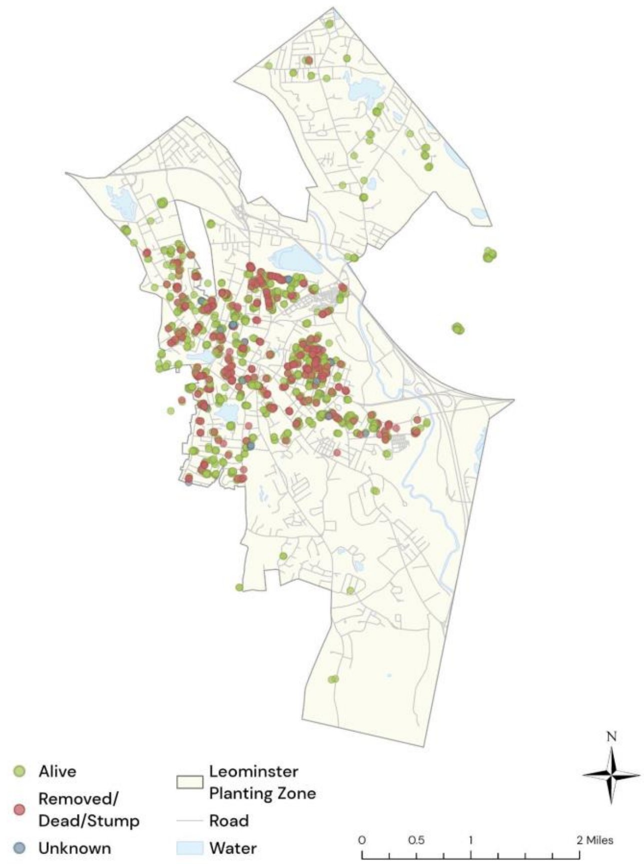

Figure 4.2: Map showing the survivorship of tree samples (1,801) in the Leominster Planting Zone with road and water layers. Survivorship is categorized by green points for alive trees, red points for removed/dead/stump trees, and blue points for unknown trees.

This map shows the tree sample and their survivorship through different colored points. There is a large cluster in the middle of the planting zone because of the initial planting zone that was recently expanded in 2024. There are fewer dead tree points outside of the initial planting zone which is most likely due to their recent planting date. Higher rates of survivorship in the establishment phase can explain the majority of alive trees in the expanded planting zone.

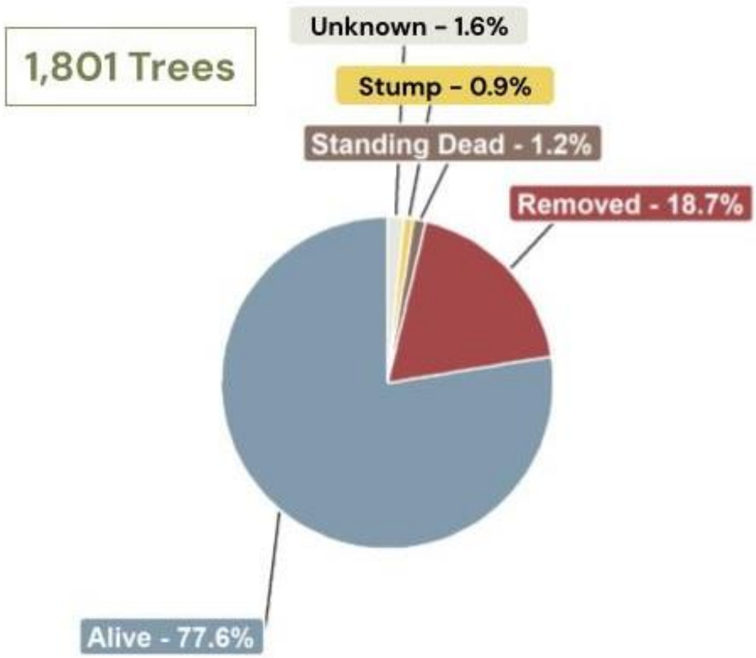

Figure 4.3: Chart showing survivorship breakdown of tree sample (1,801). Blue represents alive trees, red for removed trees, brown for standing dead trees, yellow for stumps, and gray for unknown trees.

77.6% of trees in the sample were alive, with a combined 20.8% of removed, standing dead, or stump trees. Unknown trees take up 1.6% of survivorship.

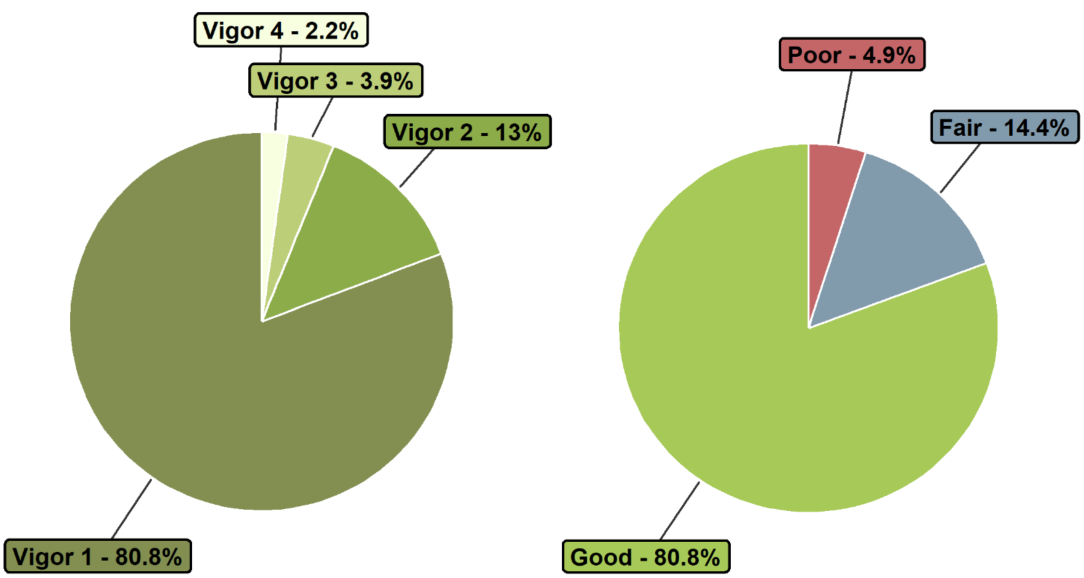

Figure 4.4: Chart showing the breakdown of vigor and condition from the tree sample.

Vigor and condition charts exclude dead trees. 80.8% have a vigor of 1 and a good condition. For condition, 14.4% are fair and 4.9% are poor. This correlates with the 13% vigor 2, 3.9% vigor 3, and 2.2% vigor 4.

Figure 4.5: Photos showing 7 trees from the resurvey sample that were removed and replaced by a parking lot.

Survivorship is influenced by biophysical, human-related, or the combination of both factors. Humans can make tree removal decisions independent of tree health or safety concerns. Survivorship statistics can be influenced by sites where trees were removed for reasons other than tree health, often being aesthetics, construction, renovation, and new ownership. When in the field, it isn't always feasible to be certain that trees were healthy, unhealthy, or dead at removal. Some sites can be confirmed by aerial imagery, but most cannot be confirmed without resident input.

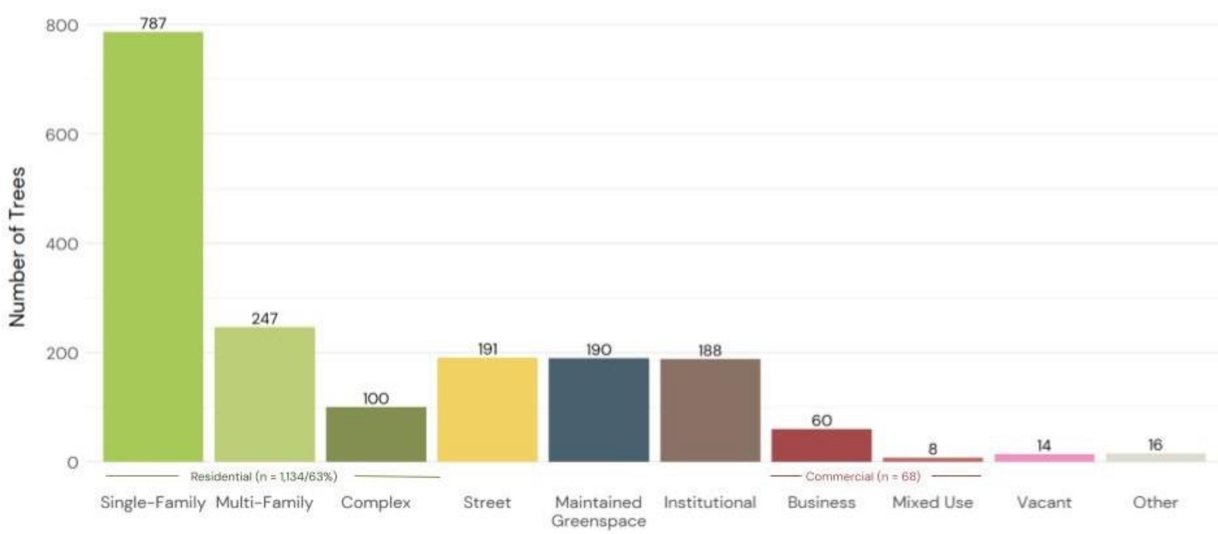

Figure 4.6: Chart showing number of trees by property type from the tree sample.

For tree count by property type, there is the further breakdown of commercial and residential categories. Residential has the largest count of trees, especially in single-family residences.

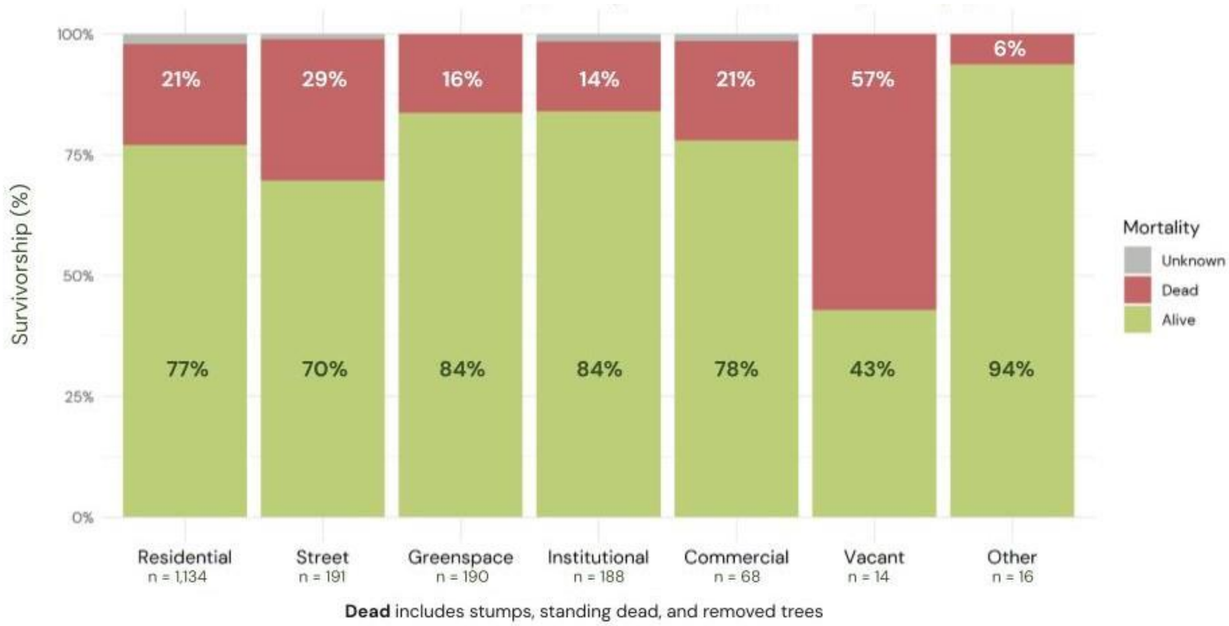

Figure 4.7: Chart showing breakdown of survivorship by property type.

Survivorship by property type shows the highest rates in greenspace and institutional sites at 84%. Residential is still higher at 77% alive. Street trees are on the lower end at 70%.

	Preferred Urban Canopy Trees	**Secondary** Consideration	Use **Sparingly**	**Unlisted**
% of Sample	46.6%	25.5%	18.4%	9.5%
Examples	Oaks, Tulip Tree, River Birch, Honey Locust, American Elm, London Plane	Maples, Firs, American Hornbeam, European Beech, Fastigiata	Serviceberry, Crabapple, Dogwoods, Cherry Trees, Japanese Tree Lilac	Sycamore, Western Red Cedar, Hybrids (Oak Hybrid), Broad genera (Elm)

Table 4.2: Table with columns of DCR/GGC tree categories with rows of example species and the percentage of each category in the tree sample.

With this list of program trees, preferred and secondary trees are often shade and canopy trees. The sparingly category is often fruit-bearing or flowering trees. The percentages of the sample show that the DCR is successful in focusing on planting preferred and secondary species.

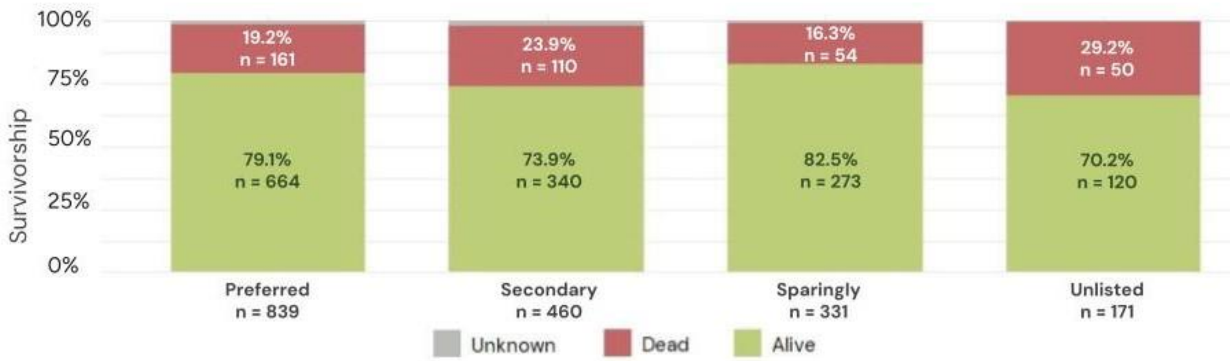

Figure 4.8: Chart showing the percentage of survivorship by DCR/GGC tree categories.

The use sparingly category has the highest survivorship at 82.5%, most likely because ornamental trees could receive more maintenance for aesthetic reasons. Both preferred and secondary are still doing well with high survivorships. Unlisted trees have the lowest survivorship at 70.2%.

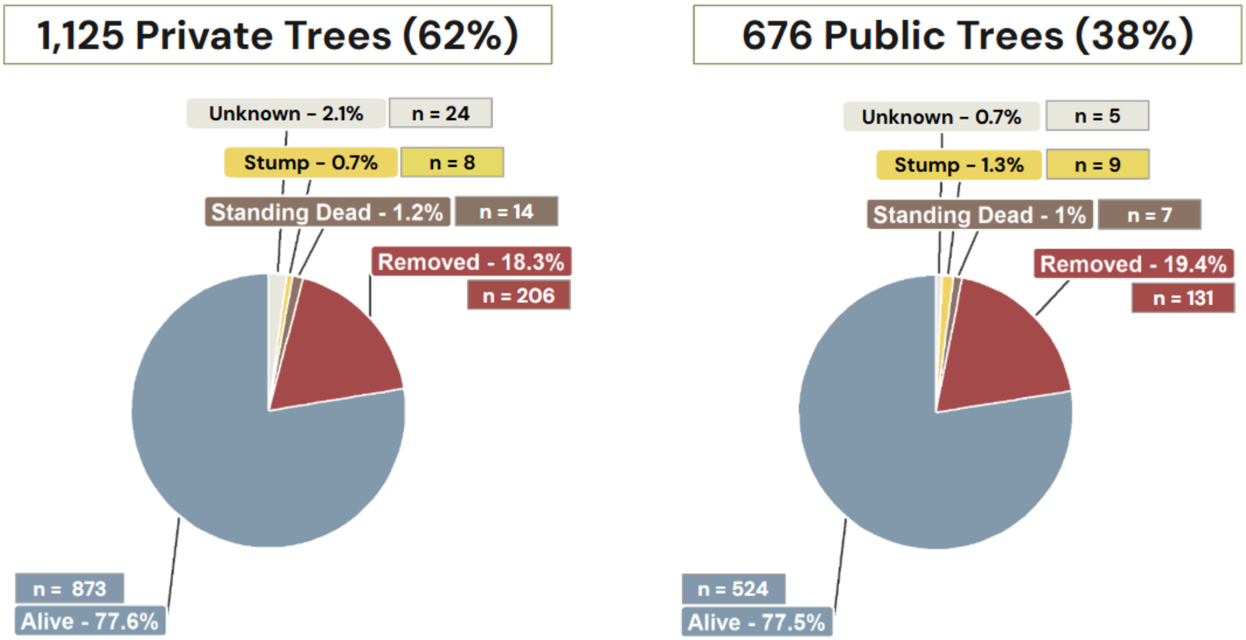

Figure 4.9: Pie charts showing the distribution of survivorship among private trees compared to public trees.

Figure 4.9 shows the proportion of living trees, which is roughly the same between public and private trees. The proportion of removed trees and stumps is slightly higher among the public trees. The proportion of standing dead trees and trees with unknown mortality are slightly higher among the private trees. Unknown mortality occurs more frequently at private residences than public locations due to fences or not being allowed onto private property. There are less standing dead trees and more stumps among public trees, presumably because standing dead public trees are cut down quicker than those at private residences because they are seen more often by more people (fig 4.9).

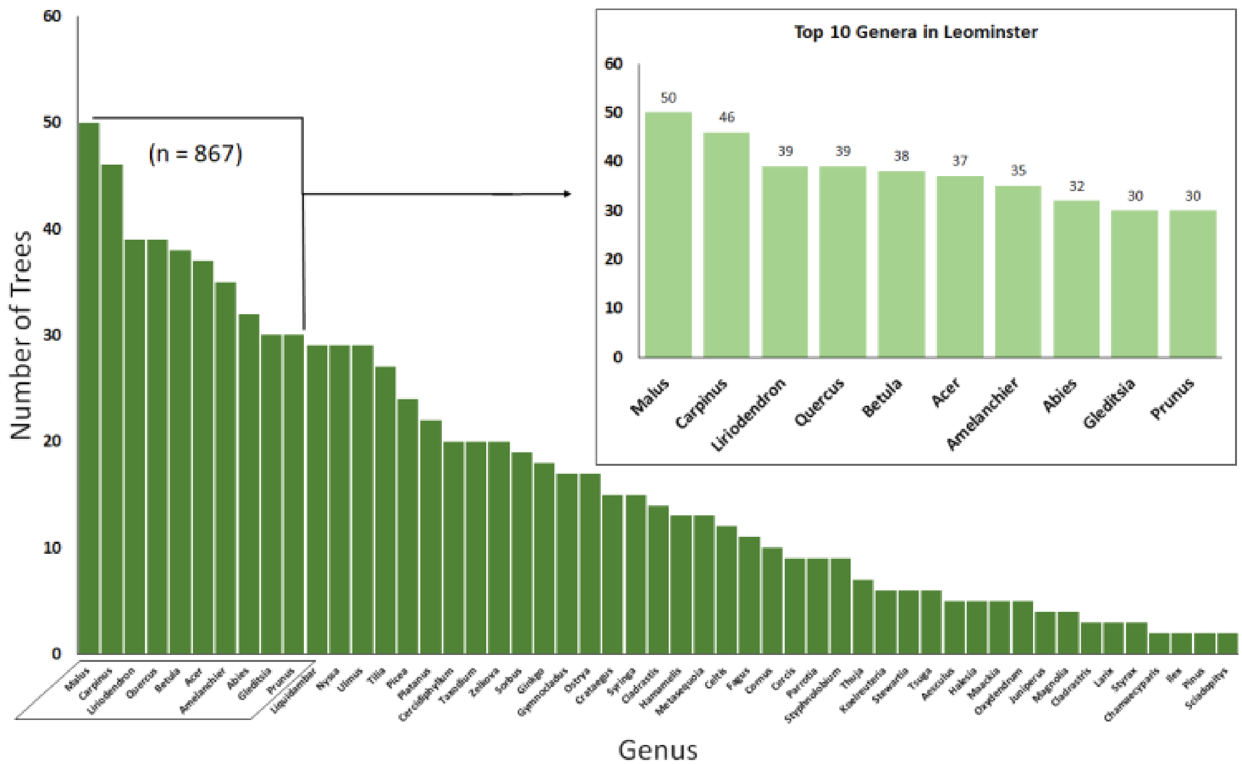

Figure 4.10: The 2019 distribution of tree genera planted in Leominster

Figure 4.10 shows the distribution of the most planted genera in Leominster and can be helpful when compared to those most planted now. The five most planted genera now, in order, are quercus, carpinus, amelanchier, liriodendron, and liquidambar (table 4.4). Most of these five were in the ten most-planted during 2019, except for liquidambar which was the 11th most planted (fig 4.10, table 4.4). Notably, the order of most-planted has changed. The genus with the most individuals in 2019 is malus (crabapples) with 50 trees (fig 4.10). The genus with the most individuals in 2025 is quercus (oaks) with 113 trees, nearly tripling the Leominster GGC program quercus trees in six years (table 4.4).

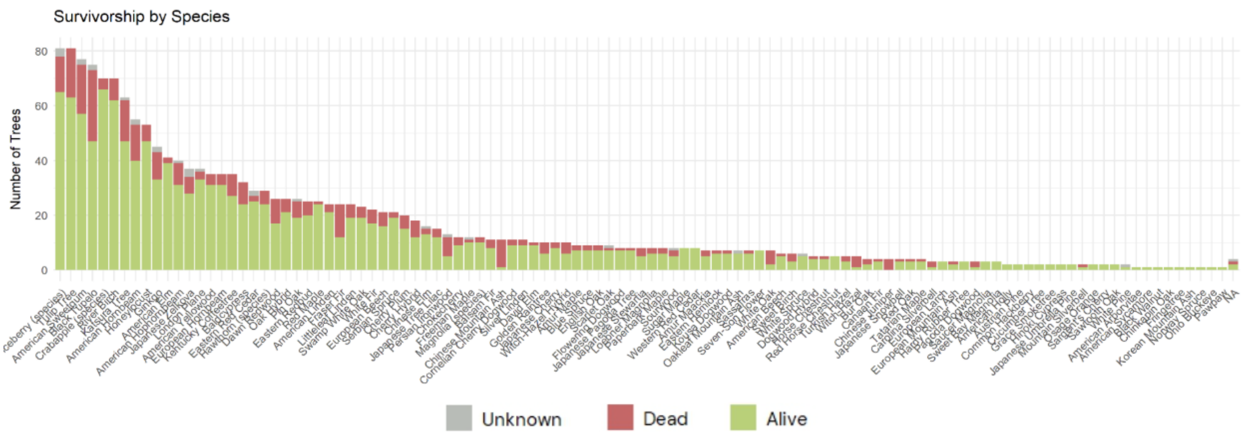

Figure 4.11: The 2025 distribution and survivorship of tree species planted in Leominster

The survivorship of all tree species shows the wide variation of trees that the GGC program has planted in Leominster (fig 4.11). There is no lack of diversity in Leominster's species selection, but the distribution has potential to be more evenly spread. Survivorship of trees with low total tree counts should be considered carefully, as they do not have an adequate sized sample to have an accurate survivorship rating. For example, the pawpaw species, found on the far right in fig 4.12, has 100% survivorship, but only one tree was planted (fig 4.11).

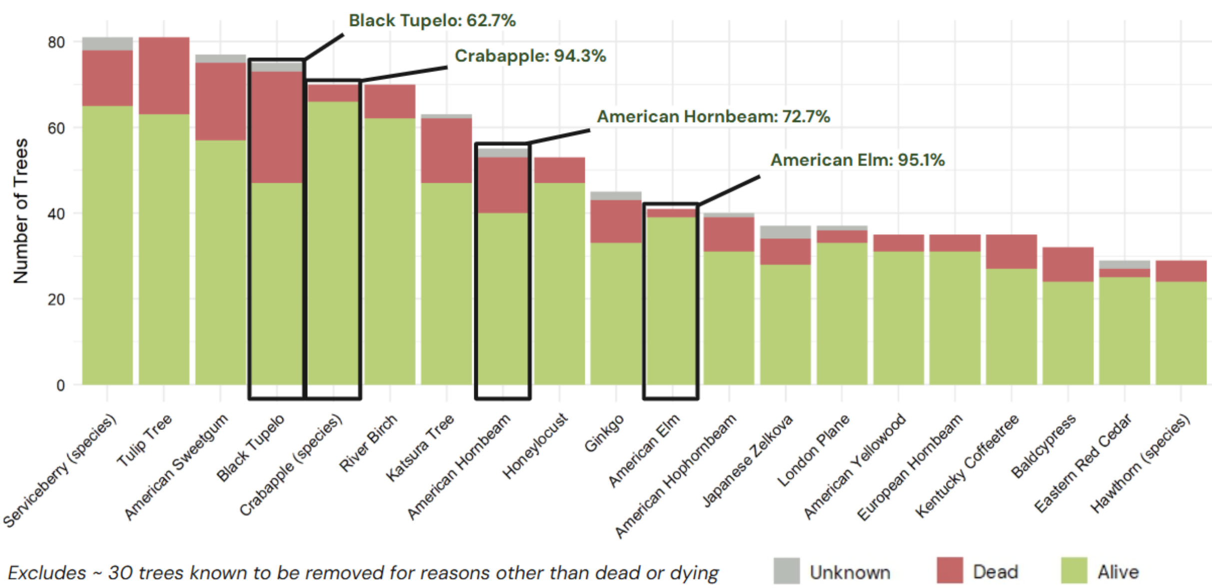

Figure 4.12: Survivorship of species with more than 28 individuals planted. The y-axis is the number of trees and the x-axis has the species names. The two species with the lowest and highest tree survivorships are pointed out. We excluded 30 trees from this analysis that we were able to confirm were removed for reasons other than dead or dying to not skew survivorship towards or away from any species.

Figure 4.12 shows the top 20 most-planted tree species by the GGC program in Leominster. We can see the distribution of species planted up to this point, with serviceberries and tulip trees being the most planted with 81 individuals each (fig 4.12). In addition to distribution, we also see the survivorship performance of each species in figure 4.12. The highlighted species point out the range of survivorship statistics we see here, with the two best species survivorships belonging to the American Elm (*Ulmus americana*) at 95.1% and the Crabapple (*Malus sylvestris*) at 94.3% (fig 4.12). The species with the lowest survivorship was the Black Tupelo (*Nyssa sylvatica*) at 62.7% and the American Hornbeam (*Carpinus caroliniana)* at 72.7% (fig 4.12).

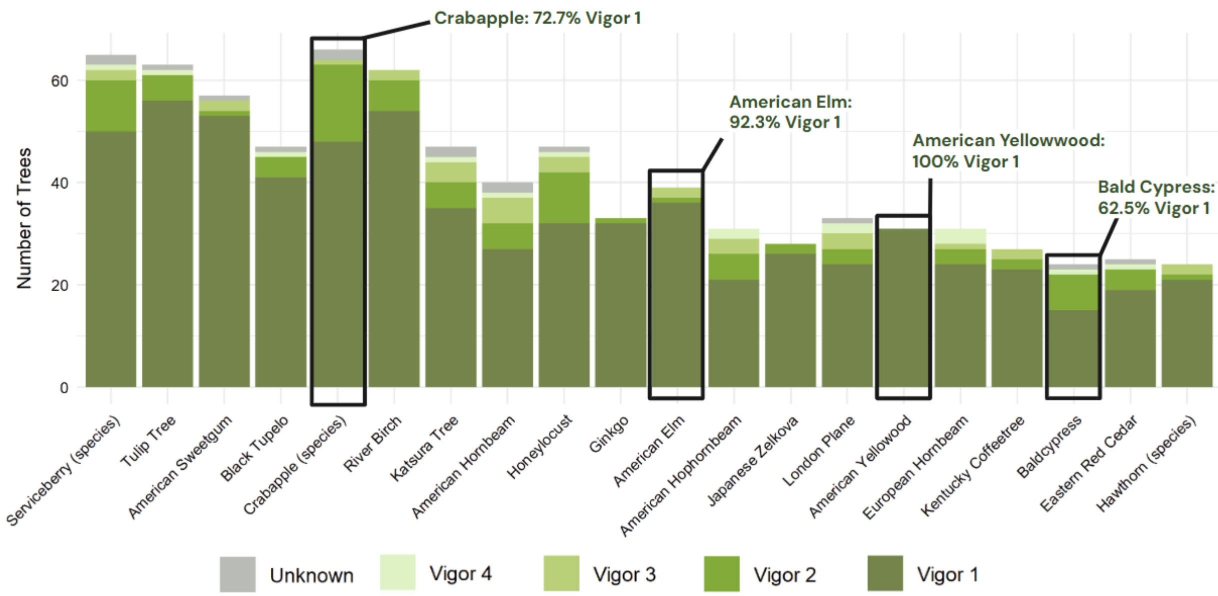

Figure 4.13: Distribution of vigor ratings among species with more than 28 individuals planted. Dead trees are excluded from this graph. The species on the x-axis are ordered by those most-planted in Leominster. Species of interest are pointed out.

After determining the survivorship of the most planted species, we wanted to look at the canopy health of those living trees. Most trees show a majority of vigor 1 trees, which is great. We noticed in the field in Leominster that many of the crabapples were not looking in the best health. Looking at fig 4.13, we can see that Crabapples (*Malus sylvestris*) have a relatively lower proportion of vigor 1 trees (72.7%) (fig 1.13). A notable consideration is that many of the crabapples in Leominster are street trees, and thus receive more human-caused harm, such as being hit by a car. The Bald Cypress (*Taxodium distichum)* has the lowest proportion of vigor 1 trees out of the 20 most-planted species with only 62.5% (fig 4.13). The highest proportion of vigor one trees belongs to the American Yellowwood (*Cladrastis kentukea)* at 100% followed by the American Elm (*Ulmus americana*) at 92.3% (fig 1.13).

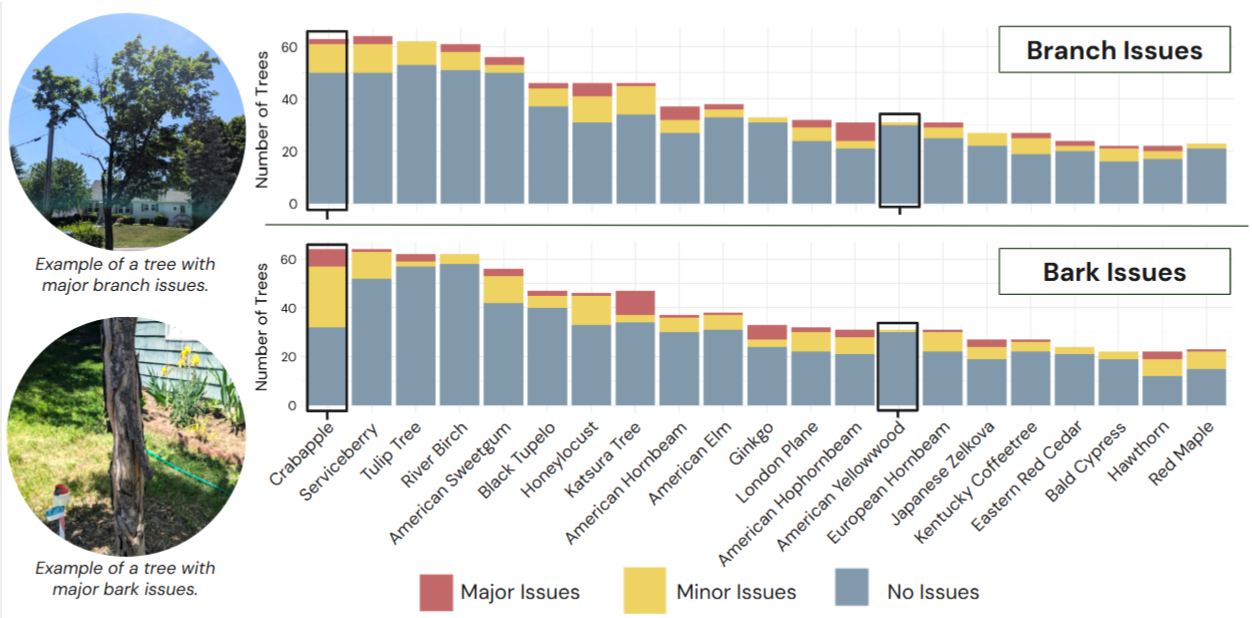

Figure 4.14: Distribution of health issues among species with more than 22 individuals planted. Dead trees are excluded from this graph. The top bar graph shows the distribution of branch issues and the bottom graph shows the distribution of bark issues. On the left are example photos of major issues. Species of particular interest are outlined.

In figure 4.14, we are seeing health issues– branch and bark damage– rather than a categorical health of the canopy in figure 4.13. Similarly to how the majority of living trees had a vigor of 1, most of the trees have no health issues. Although the graphs are different, they are showing similarities between health issues and canopy issues in the same species. For example, 100% of the living American Yellowwood (*Cladrastis kentukea)* trees had a vigor of 1 (fig 4.13) and they also have very few branch or bark issues (fig 4.14). On the other hand, we saw that Crabapples (*Malus sylvestris*) had a relatively low proportion of vigor 1 trees (fig 4.13) and that they have a high proportion of branch and bark issues (fig 4.14).

These examples show that health issues can be indicative of vigor. For example, if a branch is not leafing out due to branch damage, it will likely receive a lower vigor score. We are unable to discern whether these health issues are characteristics of the species or if they were a result of human interference. Some species may have a more brittle structure and receive more damage to their branches and bark– or it may be that tree recipients hit the bark with a weedwhacker or hung a tire swing on a branch.

To summarize the tree survey in Leominster, we see that overall, 77.6% of trees were still alive. We see that 18.7% of trees were removed and we found that trees are removed for various reasons. Some trees are removed because of the tree dying, safety concerns, or to make space for development. We are unable to determine the reasons for removal in the field unless a resident tells us. We see better-than-normal annual survivorship during the establishment phase when compared to the national median, which could be attributed to the professional DCR planting and public tree stewardship. Leominster has middle-of-the-road annual survivorship during the post-establishment phase.

80.8% of the living trees had a vigor rating of 1 and a condition rating of good. Leominster has a higher proportion of private trees compared to other Massachusetts Gateway Cities– and compared to most tree planting initiatives in the US– making it an especially interesting and important study site. We see that private trees (77%) have a slightly better overall survivorship than street trees do (70%). Species with the highest survivorship include the American Elm (Ulmus americana) at 95.1% and the Crabapple (Malus sylvestris) at 94.3%. The property types with the highest survivorship are maintained greenspace (84%) and institutional (84%). This is likely attributed to these property types having more routine maintenance and/or professional landscapers.

Resurvey

The resurvey is the sample of 866 trees introduced in the methods sections that was previously surveyed by HERO in 2019. While this sample is smaller, this section is intended to show growth metrics and health changes that can only be shown with resurvey data. Overtime, we can see many interesting and complex situations, such as those pointed out in figure 4.15, including a tree that shrunk over the years.

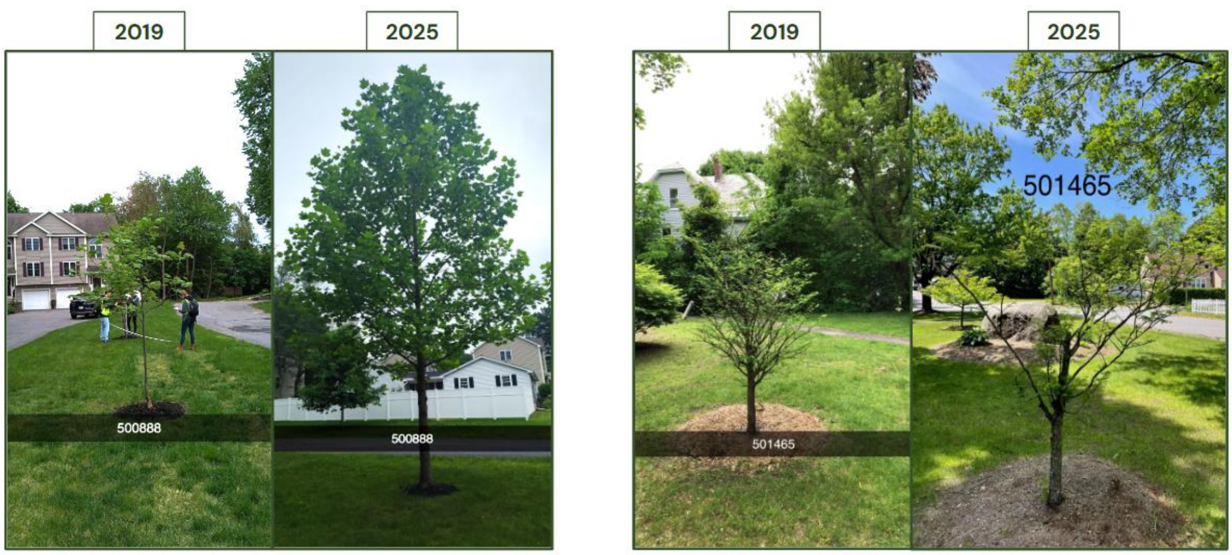

Figure 4.15: Photo examples of trees surveyed by HERO in both 2019 and 2025. The set of photos on the left is a Tulip Tree (*Liriodendron tulipifera*) at a residence that grew 20.5 ft in height from 2019-2025. The set of photos on the left is a Dawn Redwood (*Metasequoia glyptostroboides*) in a Leominster pocket park that shrunk 3.5 ft in height from 2019-2025.

	Vigor 2019			
	1	2	3	4
Dead Trees	95	18	7	14
Total Trees	614	99	28	33
Mortality (2019-2025)	15.5%	18.2%	25%	42.4%
Annual Mortality	2.6%	3%	4.2%	7.1%

Table 4.3: Table showing mortality statistics from 2019-2025 and vigor ratings from 2019.

In table 4.3, we explored how vigor ratings in 2019 affected survivorship in 2025. In other words, this table looks at the trees that have been removed since 2019 and tells us how healthy they were when last surveyed. We see an intuitive relationship in mortality– as vigor score raises, rate of mortality raises. 42.4% of trees recorded as vigor 4 in 2019 were removed while only 15.5% of trees recorded as vigor 1 trees in 2019 were removed. These proportions suggest good things, but since there are far more vigor 1 trees than any other vigor rating. There were 95 trees that were healthy in 2019 that were removed. It is possible some of these trees could have decreased in health over the six years, but as noted earlier, we know that some trees are removed for reasons unrelated to health. We established earlier that health issues can be indicative of vigor– table 4.3 also shows that vigor can be indicative of the probability of future mortality. Figure 4.16 shows a bald cypress that decreased from vigor 1 in 2019 to figure 4 in 2025 with branch issues. Using our logic here, it is possible we may see this tree be removed in the coming years due to its poor vigor rating.

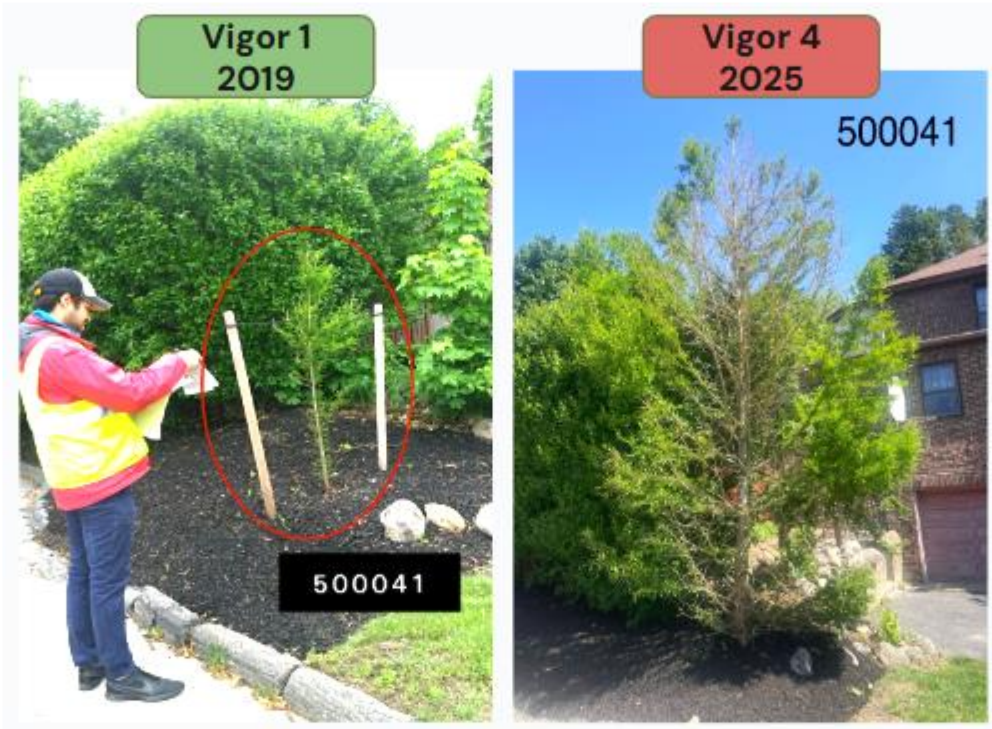

Figure 4.16: Photo example of a bald cypress that decreased from vigor 1 in 2019 to vigor 4 in 2025.

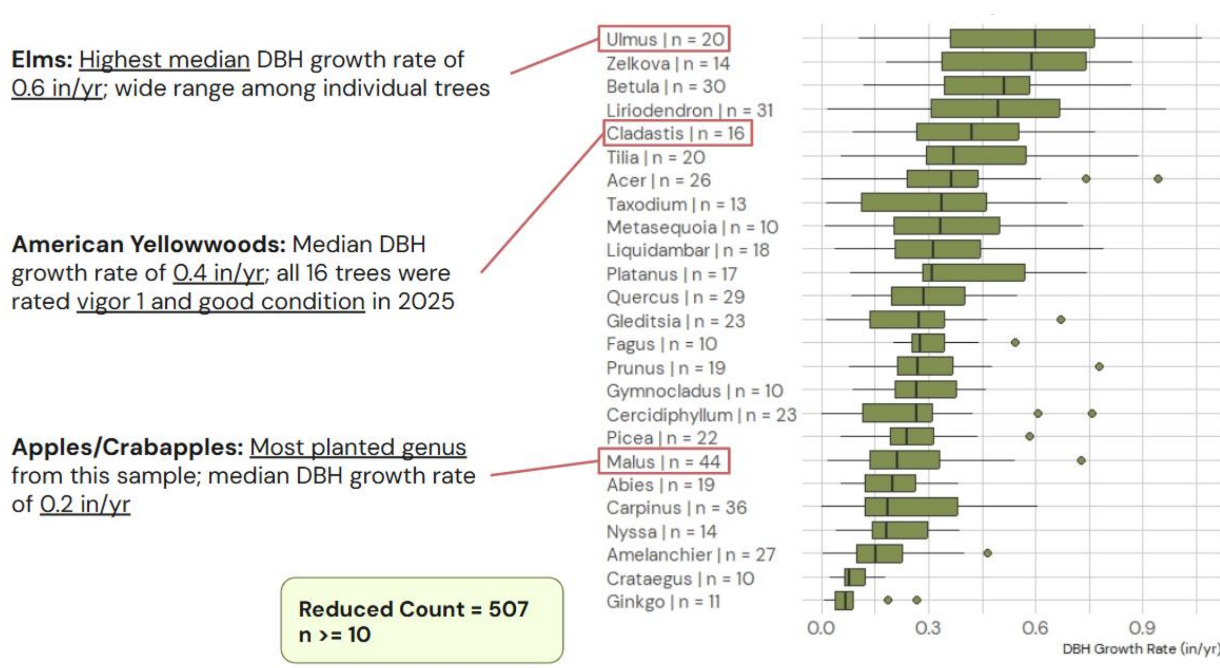

Figure 4.17: Growth rate of diameter at breast height (DBH) by genera with more than 10 individual trees that were alive in 2019 and in 2025. Count is reduced further to exclude individuals with a missing DBH measurement. Ordered by median growth rate. Genera of interest are pointed out.

Another advantage of resurvey data is that we can calculate growth rates of these trees. We calculated the growth rates for all genera with over 10 living trees by DBH (fig 4.17), height (fig 4.18), and canopy width (fig 4.18).

The fastest growing genus by DBH is Ulmus (Elms) with a median growth rate of 0.6 inches per year. Negative DBH growth rates were excluded for clarity and accuracy. The fastest growing genus by height is Liriodendron (Tulip Trees) with a median growth rate of 1.9 feet per year. There are negative growth rates included in this metric because they can be due to natural branch breakage or resident pruning. Height metrics need to be considered more carefully because the height measuring methods have changed since 2019. The fastest growing genus by canopy width is Betula (River Birch) with a median growth rate of 1.7 feet per year. There are negative growth rates included in canopy width for the same breakage and pruning reasons. Figures 4.17-19 show the median growth rate, but also the range of growth rates among individual trees. For example, the genus Acer experiences a very wide range of growth rates from approximately -0.3 feet per year to nearly 4 feet per year, while the genus Fagus has a very narrow, thus consistent, growth rates. Gingko trees show to be the slowest growing genus by all metrics, but this could speak to its structural integrity.

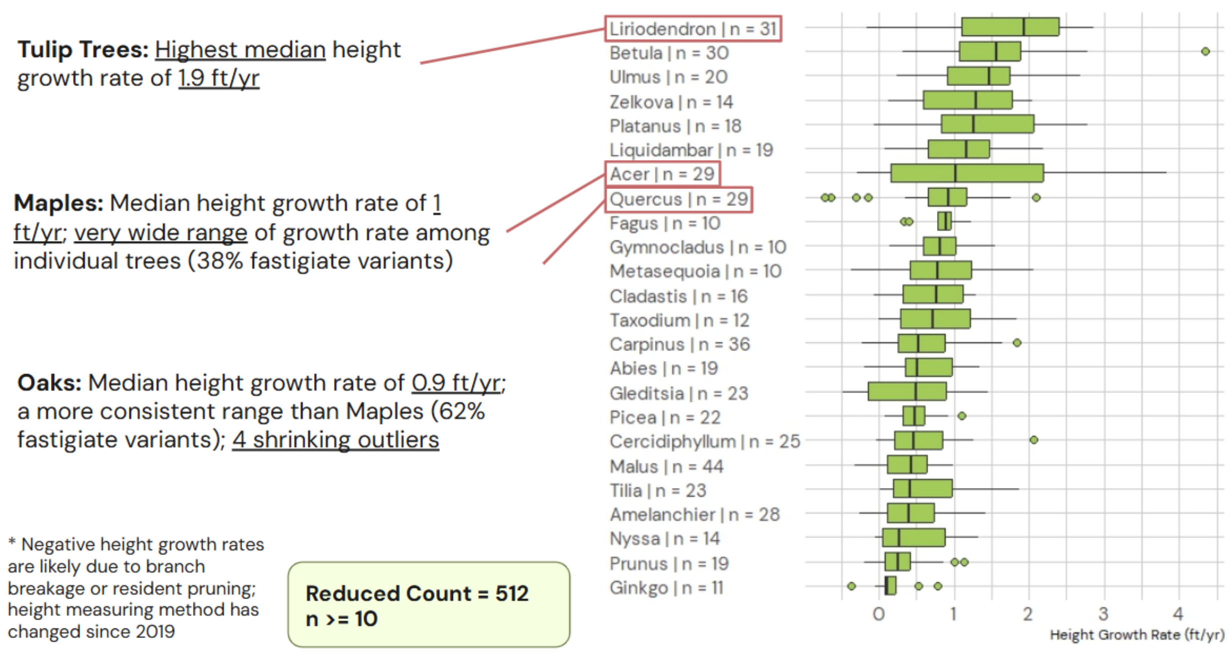

Figure 4.18: Growth rate of tree height by genera with more than 10 individual trees that were alive in 2019 and in 2025. Count is reduced further to exclude individuals with a missing height measurement. Ordered by median growth rate. Genera of interest are pointed out. HERO height measuring methods were different in 2019.

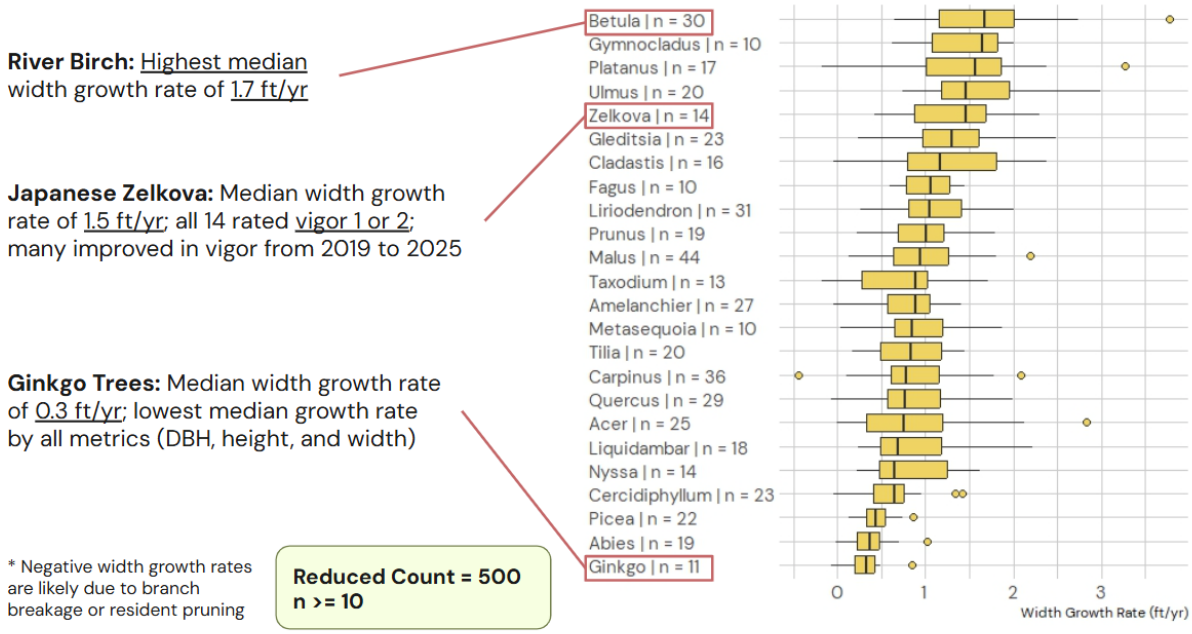

Figure 4.19: Growth rate of tree canopy width by genera with more than 10 individual trees that were alive in 2019 and in 2025. Count is reduced further to exclude individuals with a missing width measurement. Ordered by median growth rate. Genera of interest are pointed out.

	Genus #1	Genus #2	Genus #3	Genus #4	Genus #5
DBH Growth Rate	Ulmus (0.6 in/yr)	Zelkova (0.59 in/yr)	Betula (0.5 in/yr)	Liriodendron (0.5 in/yr)	Cladrastis (0.42 in/yr)
Height Growth Rate	Liriodendron (1.93 ft/yr)	Betula (1.57 ft/yr)	Ulmus (1.48 ft/yr)	Zelkova (1.29 ft/yr)	Platanus (1.26 ft/yr)
Canopy Width Growth Rate	Betula (1.67 ft/yr)	Gymnocladus (1.65 ft/yr)	Platanus (1.57 ft/yr)	Ulmus (1.47 ft/yr)	Zelkova (1.46 ft/yr)
Survivorship (total > 30)	Malus (94.3%)	Ulmus (91%)	Platanus (89.5%)	Gleditsia (88.7%)	Cladrastis (88.6%)
Most Planted	Quercus (113)	Carpinus (93)	Amelanchier (81)	Liriodendron (81)	Liquidambar (80)

Table 4.4: Table showing the top five genera for DBH growth rate, height growth rate, canopy width growth rate, survivorship, and most planted. Boxes are colored by genus that show up three or more times in this table. Used in consideration for making top species list.

In order to choose the highest performing species of Leominster (fig 4.20), we took an index thinking approach to consider field observations and other nuances in addition to the data and figures. The key criteria for choosing the highest performing species was high growth rates by genus (fig 4.17-19), high survivorship by species (fig 4.12), vigor by species (fig 4.13), health issues by species (fig 4.14), past planting numbers by species (fig 4.12). To combine some of these ideas into a visual, we created table 4.4 that shows the top five genera for a few of these criteria. For example, Ulmus (Elms)-- in purple in table 4.4– were chosen for their high growth rates, high survivorship, and relatively low planting numbers (fig 4.20). Liriodendron (Tulip Trees)-- in orange in table 4.4– were not chosen, despite their high growth rates, because they are heavily planted.

American Yellowwood (Cladrastis kentukea): *#1 for vigor 1, low health issues, relatively underplanted (~40)*

American Elm (Ulmus americana): *# 1 for survivorship by species, high proportion of vigor 1, relatively underplanted (~40)*

London Plane (Platanus x acerifolia): *High survivorship, high growth rate, relatively underplanted (~40)*

River Birch (Betula nigra): *High survivorship, high growth rates, high proportion of vigor 1, low health issues*

Figure 4.20: Examples of Leominster's most high performing tree species. Key criteria in choosing these trees was high growth rates, high survivorship, a high proportion of vigor 1 trees, a low proportion of health issues, and past GGC program planting numbers in Leominster.

The top performing species we identified were the American Yellowwood (*Cladrastis kentukae)*, American Elm (*Ulmus americana*), London Plane (*Platanus x acerfolia*), and River Birch (*Betula nigra)*.

Black Tupelo (Nyssa sylvatica): *Low survivorship, lowest proportion of vigor 1, highly planted (~70)*

Serviceberry (Amelanchier): *Low proportion of vigor 1, high health issues, highly planted (~80)*

Crabapples (Malus sylvestris): *Low growth rates, low proportion of vigor 1, high health issues, highly planted (~70)*

Figure 4.21: Examples of Leominster's less-than-normal performing tree species. Key criteria in choosing these trees was past GGC program planting numbers in Leominster, survivorship, a low proportion of vigor 1 trees, a higher proportion of health issues, and low growth rates.

While choosing top performing species, we also identified some species that should be planted with caution in the future of the GGC program in Leominster. The key criteria used to determine these trees past planting numbers (table 4.4), survivorship (fig 4.12), vigor (fig 4.13), health issues (fig 4.14), and growth rates (fig 4.17-19). The trees identified in this category were the Black Tupelo (*Nyssa sylvatica)*, the Serviceberry (*Amelanchier)*, and the Crabapple (*Malus sylvestria).* Black Tupelo is the species we advise most caution with, because it has the lowest survivorship and has been heavily planted before. We have already identified that crabapples have excellent survivorship and are resilient street trees, but we want to point this out to avoid any over planting of crabapples because of this. We want to acknowledge that these trees have their ecosystem services and it is still beneficial to plant these trees rather than no trees.

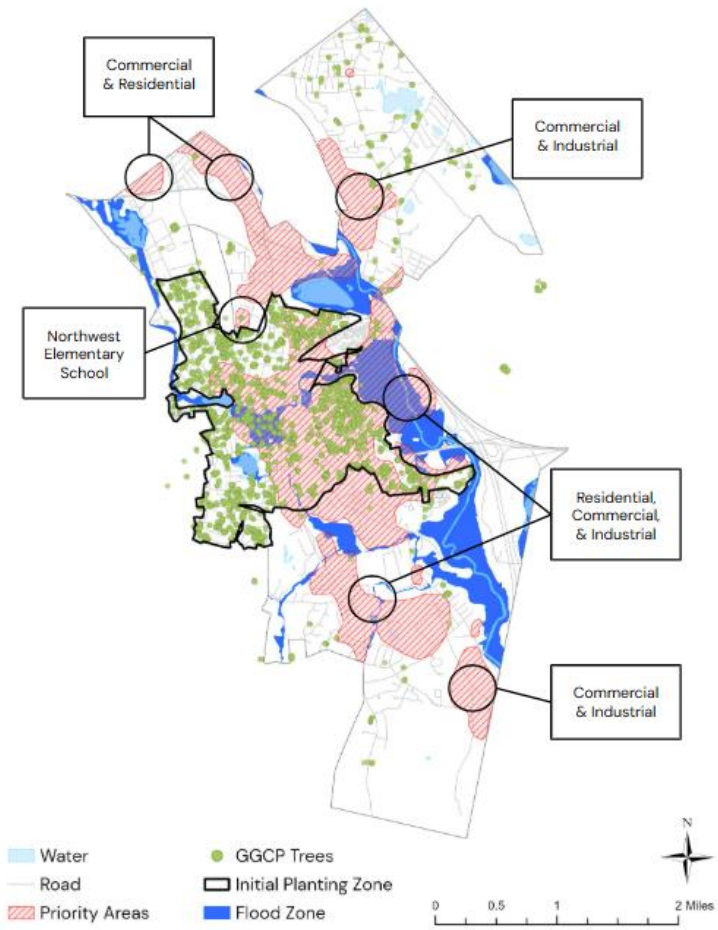

Figure 4.22: The Leominster planting zone with some priority areas identified for future tree planting. Priority areas are the intersection of high land surface temperature and low canopy cover. All GGC program trees are marked by a point in green with the old planting zone outlined to convey the spatial distribution.

In figure 4.22, we identify both broad and specific areas to prioritize for future planting in Leominster. The priority areas are where temperatures are high and tree cover is low, thus where there are more trees needed. The flood zone is included for extra tree planting considerations, as trees have the ability to help mitigate flood, but their health can also be put at risk by floods. With the recent expansion of the planting zone and the clustered previous plantings, there are plenty of priority area locations to target in the future. One of these includes the Northwest elementary school, which is right in the hot spot of a priority area and an example of a property type that the GGC program has had success planting on in the past.

Resident survey

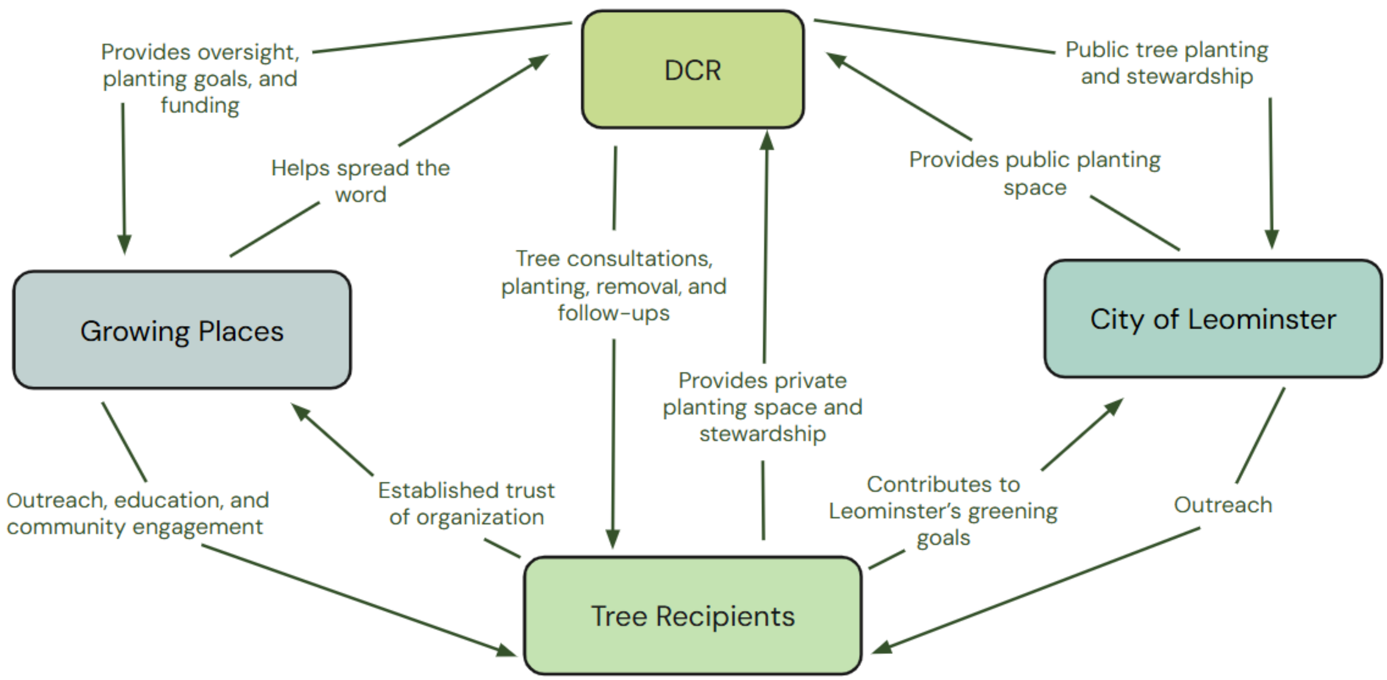

Figure 4.23: Flow chart representing the GGC program stakeholder roles and how they support and interact with each other

The stakeholders involved with GGC all support each other and have different roles within the program. The DCR provides Growing Places with oversight, planting and canvassing goals, and funding for GGC outreach. In turn, Growing Places assists the DCR in running the program by spreading the word about it to Leominster residents. The city of Leominster gives the DCR access to public planting space, while the DCR plants public trees and are stewards of those trees. Growing Places' role with tree recipients involves outreach, education, and community engagement. They focus on direct outreach, such as canvassing and flyers. Because the GGC is a highly trusted program in Leominster, Growing Places' involvement aids in building more trust for their organization. The city of Leominster also does outreach to recipients, but it is more indirect compared to Growing Places. The city's outreach is mainly online and through social media. By participating in the GGC program, tree recipients are supporting the city because it contributes to Leominster's overall greening goals. Tree recipients also give the DCR private planting space and stewardship of GGC trees. The DCR provides residents with tree consultations to decide what species of trees to plant where, removal services, and follow-ups if requested. The different connections of support that a stakeholder provides to the others helps the GGC program efficiently and successfully run.

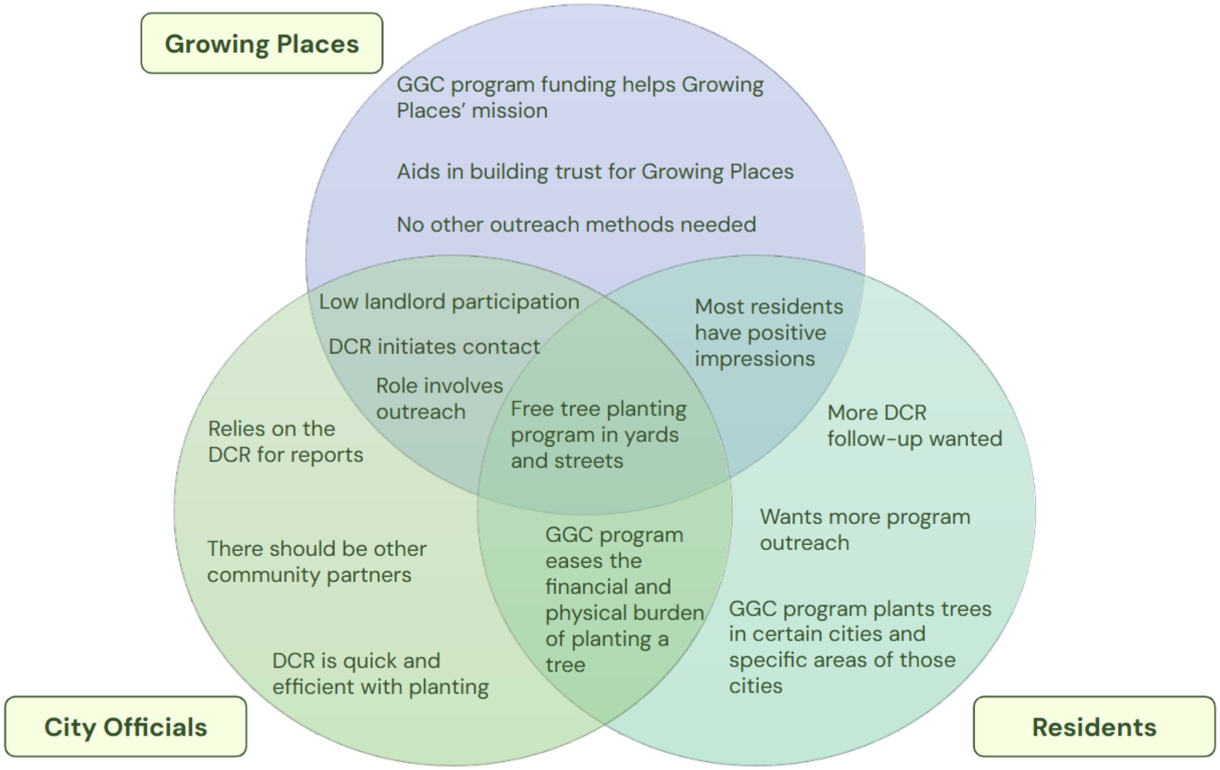

Figure 4.24: Venn diagram representing growing places, city officials, and resident's perceptions of the GGC program and the DCR

The Venn diagram of figure 4.24 compares GGC and DCR perceptions from city officials, residents, and Growing Places. The only common perception found between residents, city officials, and Growing Places was the general knowledge of the GGC program ~~is~~. All three stakeholders knew that the GGC program is a free tree planting program in yards and streets of Leominster. There were also several positive perceptions found between the three stakeholders. City officials noted that the DCR was very quick and efficient with planting, and they heard very little negative feedback from recipients. Overall, residents have very positive perceptions of the program. From the interview data, 93.5% of the interviewees had positive perceptions of GGC. Growing Places also noticed these impressions while canvassing around the city. When asked about their thoughts on the GGC, one resident emphasized their experience.

> *"It's been a positive experience all around, not just because we got free trees, but because of everything we learned in the process of getting, growing and caring for those trees."*

Finally, both residents and city officials explained that the GGC program eases the financial and physical burden of planting a tree. There were also a couple program concerns that stakeholders brought up. City officials and Growing Places both stated that they noticed low landlord participation in the program and were unsure of how they could encourage more participation from that group. Residents noted that they wanted more program outreach (n=8) and more DCR follow-up (n=9). A couple residents wanted “a hotline waiting call.” Although there were some concerns, it is important to emphasize that the majority of the DCR and program perceptions across all three stakeholders were positive.

Leominster residents were first asked how they first heard about the Greening the Gateway Cities program. This question was open ended and in total, we received 5 different responses show in Figure 25. The top three forms of outreach methods residents mentioned were receiving a flyer (52%), speaking with the Department of Conservation and Recreation (DCR) during door to door canvassing (26%), and advertisement or signage posted online or in town (16%). Based on our survey responses, Leominster residents were typically more responsive to more personalized forms of advertisement of the Greening the Gateway Cities program like flyers being delivered to homes or meeting DCR officials through canvassing efforts. Some noted how they appreciated the involvement of foresters from the outreach phase all the way to the planting phase.

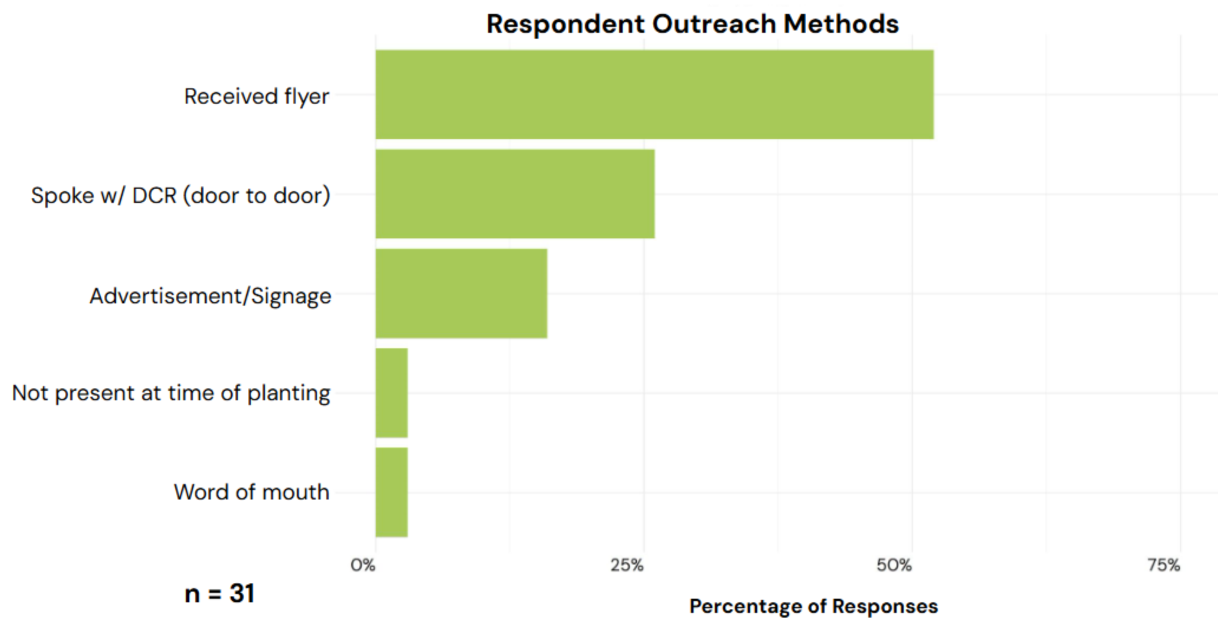

Figure 4.25: Horizontal bar chart depicting Leominster tree recipient~~s~~ responses to a survey question asking how they heard about the Greening the Gateway Cities program.

Residents of Leominster were also asked about the benefits of having trees on or around their property. The surveyed residents listed 12 different benefits of having trees on or around their property listed in Figure 4.26. The top 3 listed benefits for Leominster residents were added shade and cooling (69%), added aesthetics and beauty (69%), and habitat provisioning (47%).

Many residents indicated in their survey that added shade and cooling was an important benefit due to rising temperatures as a result of climate change. Additionally, another notable benefit was improved air quality, residents indicated this being a benefit also due to climate change effects like greenhouse gas emissions. Another theme of the benefits was added value and attachment to their property. Many residents noted that the free trees would beautify and contribute to their properties' value over time. Some residents also personified and showed close attachment to their gifted trees as well.

> *"First of all, I think it sets a good example to show people. Strategically, planted trees can truly improve a property. […] my house and my property will continue to just look more and more beautiful."*

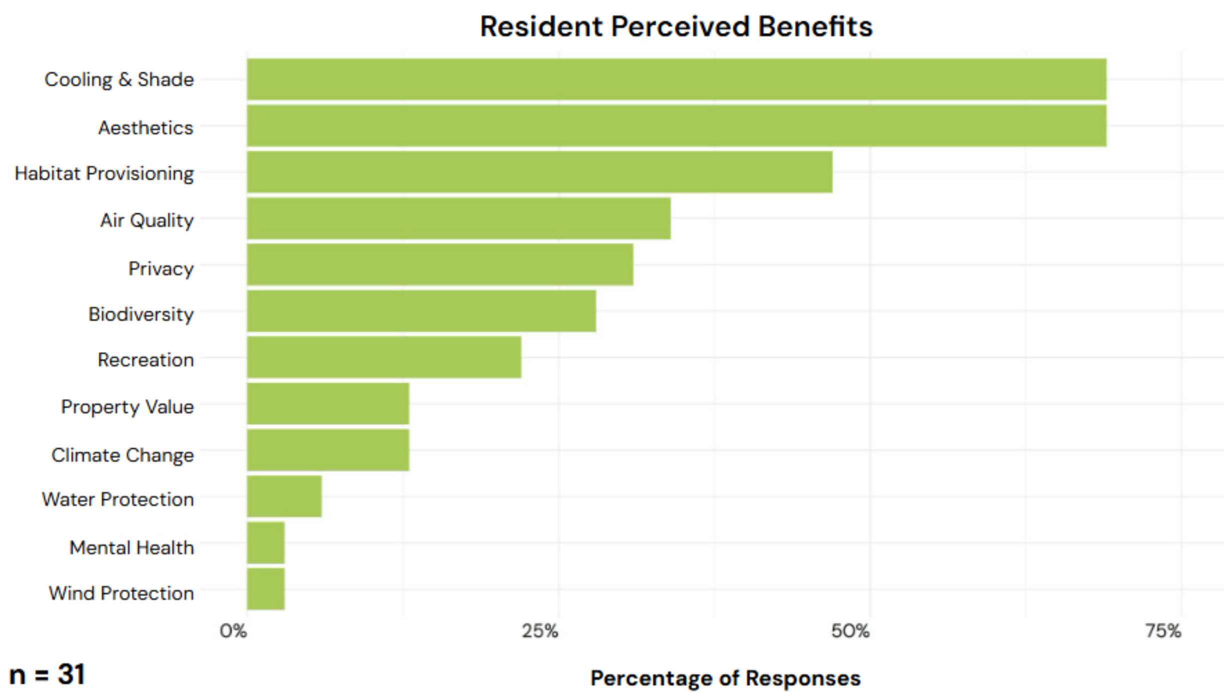

Figure 4.26: Horizontal bar graph displaying Leominster tree recipient~~s~~ responses to a survey question asking about the benefits of having trees on or around their property.

Residents of Leominster were asked about any challenges or ecosystem disservices from the trees on or around on their property. Residents had less challenges with trees than benefits overall. In total, interviewed residents listed 11 different challenges with trees on or around their property. The top three challenges for residents with trees on or around their property was maintenance (44%), physical obstacles (34%), and property damage (25%). Some residents noted that they felt some pressure with maintenance, and that they weren't completely confident in how to properly care for a tree as it was a living thing.

"It is a living thing [...] and keeping a good, consistent watering schedule and knowing when to water it or feed it and giving it the best care that it needs does take time, effort, and learning."

With physical obstacles, residents expressed frustration with trees getting in the way of landscaping practices typically because they couldn't get close enough without damaging their trees. As per property damage many residents noted that more mature trees were much more susceptible to storm damage causing branches to fall damaging their property. Others noted that trees were growing too large and in some cases touching their roof or home which created fear of possible damage in the future.

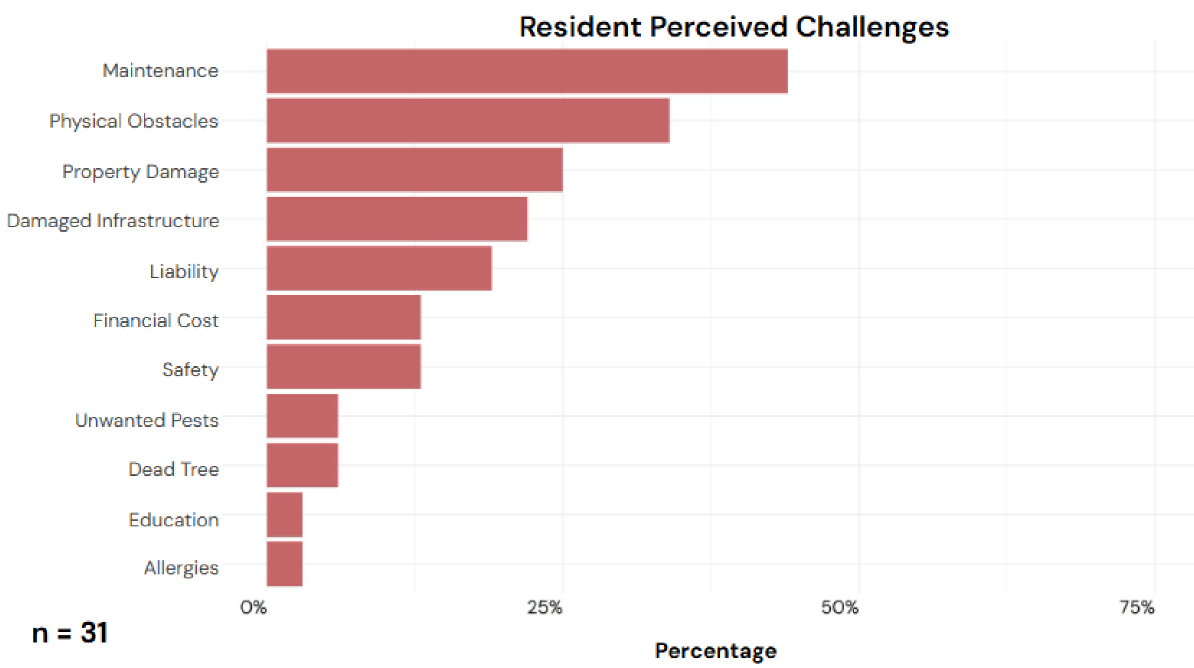

Figure 4.27: Horizontal bar chart displaying Leominster tree recipient~~s~~ responses to a survey question asking about the challenges or ecosystem disservices provided by Greening the Gateway Cities program tree on their property.

Leominster residents were also asked to share their maintenance practices for trees on their property. In total, our residents listed 9 different maintenance activities, the top 3 being watering (75%), mulching (53%), and pruning at (47%). While 75% of our residents reported watering about 25% of our sample did not report watering at all and some even said that trees did not need outside watering asides from the water nature already provides in the form of rain. Another notable statistic is that only 19% of our surveyed residents participated in all of the top 3 maintenance activities being watering, pruning, and mulching.

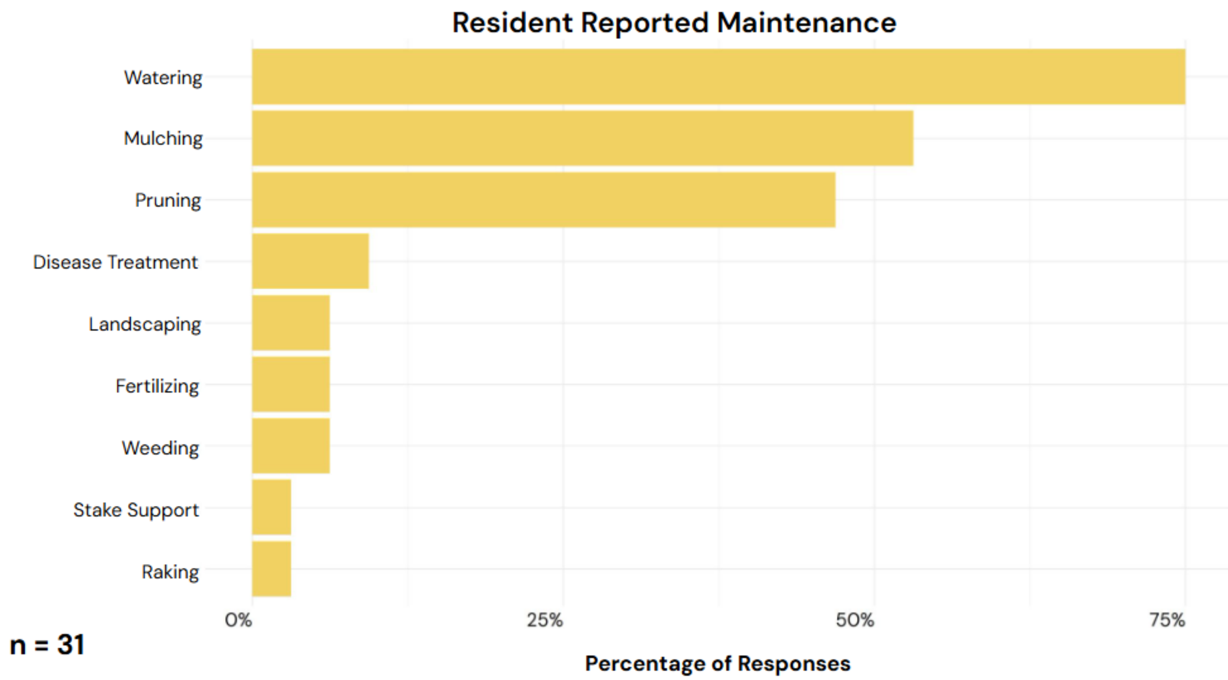

Figure 4.28: Horizontal bar chart displaying Leominster tree recipient responses to a survey question asking about their maintenance activities being performed on their Greening the Gateway Cities program trees.

Within our survey we asked questions asking if residents have done any of the following: (a) communicated the Greening the Gateway Cities to others; or (b) requested either a specific tree type or specific planting location. From these questions we classified residents into 4 different roles, these roles were used from a previous paper, Geron et al., 2023. From the Geron et al. framework, we classified residents into one of the following roles. Policy Actor: Communicated to friends, family, or neighbors about the GGC program and negotiated their planted tree species and planting location. Communicator: Communicated with friends, family, or neighbors about the GGC program. Negotiator: Negotiated for a specific tree species and specific planting location. Passive Recipient: Did not communicate about the program or negotiate for specific tree species or location. The distribution of residents in these roles from our 2025 survey of Leominster was Policy Actor (42%), Communicator (32%), Negotiator (10%), and Passive Recipient (16%). This distribution differs from the Geron et al. paper from the 2019 survey of Leominster, as in 2019 the passive recipient distribution was about 28% and the distribution of communicators was just 7%. What we've found is that as time has gone on and the GGC program has developed in Leominster is that more and more residents are becoming more engaged in the program. More residents overall have been communicating about the program as well. However, it is important to note that our 2025 survey is likely biased towards more actively engaged residents due to the fact that a more engaged resident is more likely to agree to an interview.

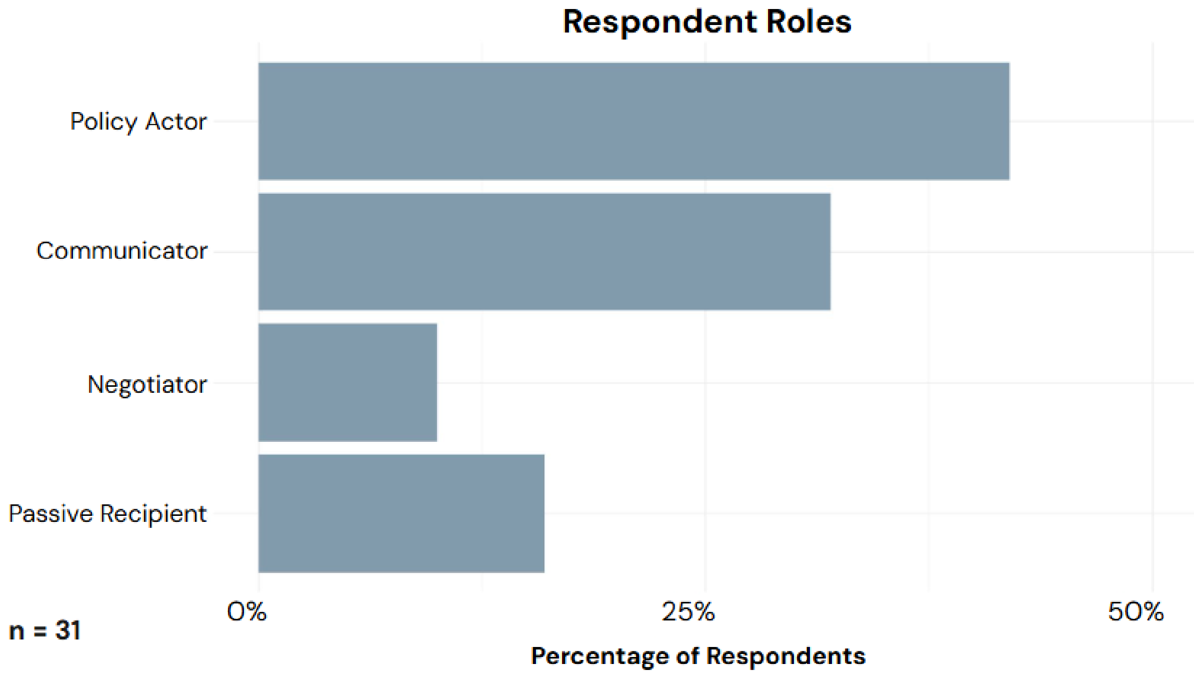

Figure 4.29: Horizontal bar chart displaying the distribution of resident roles in Leominster from our survey respondents. Residents classified by their answers to survey questions, framework largely based on Geron et al. (2023).

While looking at resident roles, we looked into the overall survivorship of residents' trees based on resident role type. What we can observe from figure 4.30 is that our more engaged residents who have communicated or shown more interest in the program overall have a much higher survivorship. When looking at our passive recipient survivorship, we see a large difference in survivorship in which about 46% of passive recipient trees have been marked as removed, standing dead, or stump. Similar to Geron et al. we found that passive recipients perform poorest in tree stewardship while more engaged residents perform better. This is likely due to the fact that our engaged residents care far more about their trees.

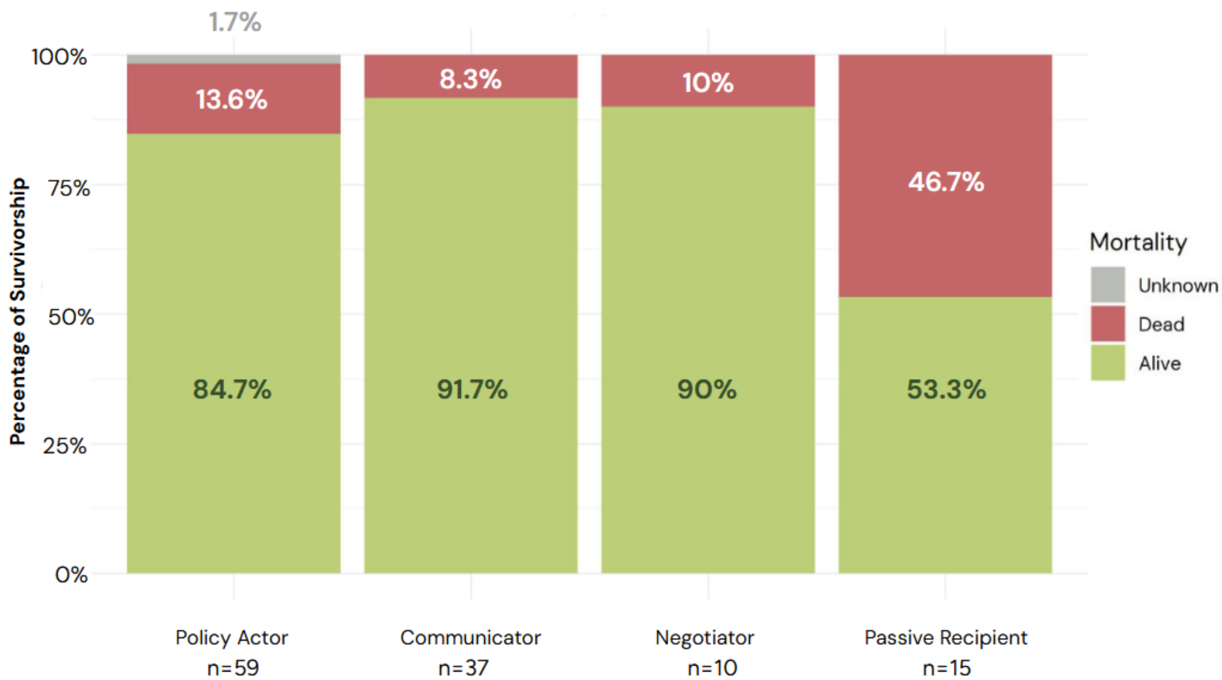

Figure 4.30: Stacked bar chart displaying the difference in survivorship of private Greening the Gateway Cities trees by resident role type. Residents classified by their answers to survey questions, framework largely based on Geron et al. (2023).

To understand resident role type survivorship further, we explored our residents top 3 reported maintenance activities (Watering, Pruning, and Mulching) and sorted them by resident role type. In figure 4.31, we see that overall the policy actors in our survey performed at a rate 100% reported. We also see that 62% of policy actors reported mulching and 38% reported pruning. When looking at our other roles, we see that 70% of communicators reported watering, 50% reported mulching, and 50% reported pruning. With our negotiators, we see a similar distribution of 67% reporting watering, 67% reporting mulching, and 33% reporting pruning. For passive recipients, we see a very different distribution. Only 40% of passive recipients reported watering, 40% reported mulching, but 80% reported pruning.

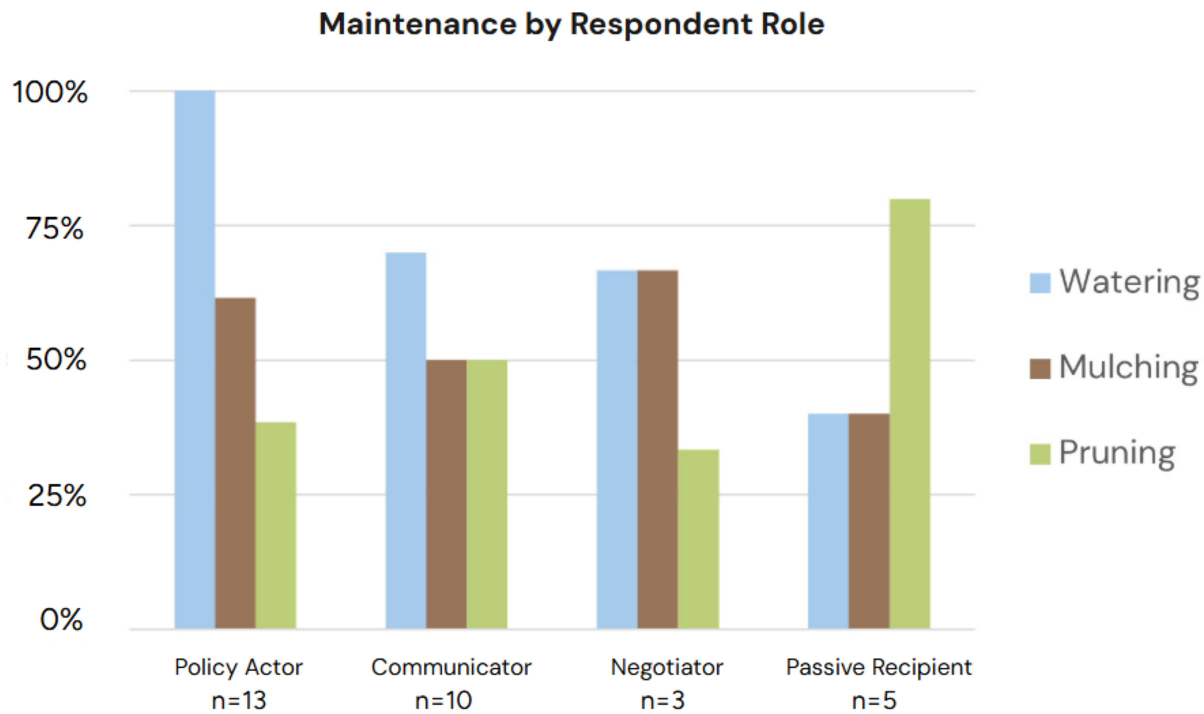

Figure 4.31: Clustered bar chart displaying resident reported maintenance activities on their Greening the Gateway Cities trees separated by resident role type. Residents classified by their answers to survey questions, framework largely developed by Geron et al. (2023).

5 Discussion

Biophysical

The annual survivorship in Leominster for the establishment phase (96.1%) and the post establishment phase (95.5%) were higher or the same as the national median percentage. We also found that resident trees (77%) have higher survivorship than street trees (70%). The majority of the trees surveyed were doing well. 80.8% of the trees exhibited a positive health status, which includes condition and vigor. In terms of tree health, we found that bark and branch damage often lead to a low canopy vigor. Also, a poor 2019 vigor is indicative of 2025 mortality. The higher performing species in Leominster are American Elms, American Yellowwoods, London Planes, and River Birches. Species with the highest survivorship that have n>28 are American Elms and Crabapples. The species with the highest vigor that have n>28 are American Yellowwoods and American Elms. Black Tupelos, Serviceberries, and Crabapples were identified as the species to plant with caution.

We recognize that different tree species are more suitable for certain places than others. For example, River Birches (*Betula nigra)* exhibit high growth rate in height and canopy width making it ideal for areas deprived of shade. On the other hand, Crabapple trees (*Malus sylvestria)* do not provide much shade or greening, but they are a resilient street tree that can tolerate Massachusetts winters, salt from the roads, and extra human interference. The index-like framework used in table 4.4 is a basic analysis of species/genus success in Leominster but is limited by Leominster's planting inventory and the goals set to achieve by the index (i.e., increasing shade vs. mitigating flood vs. beautifying neighborhoods). Further explorations of spatial and temporal patterns that lead to greater or lesser success under this framework will benefit future endeavors to increase urban tree success and vitality

Social

From the interviews, we found that the perceptions of the GGC program are generally positive from all stakeholders. Residents cited numerous benefits from having trees, namely aesthetics, shade/cooling, and habitat provisioning. On the other hand, city officials and community partners noted that programs like the GGC program alleviate the operating costs of tree planting initiatives within the city and make it easier for residents to participate. While residents noted more tree planting benefits than challenges, some challenges that were identified are maintenance/upkeep, physical/tree obstacles, and property damage from falling trees and/or limbs. Another challenge that was identified is a need for more DCR outreach and follow-up once trees have been planted in the ground, as some residents showed a lack of knowledge surrounding tree maintenance.

Our Leominster interviews from 2025 showed that residents most valued cooling and shade (69%), added aesthetics and beauty to their property (69%), and habitat provisioning (47%). Some residents noted that because of climate change and rising temperatures, they believed their trees would help mitigate heating effects on their property. Similarly, in the 2019 survey of Leominster residents also listed shade and added beauty as a top benefit and also energy efficiency. Our 2025 results showed that our top 3 challenges were maintenance (44%), physical obstacles (34%), and property damage (25%). Similarly, in 2019, residents noted maintenance as a top challenge, but differently they noted that a lack of follow-up and time and effort being put into their trees was a challenge as well. What we've seen over time is that residents still hold similar values with their benefits, but ultimately challenges have changed over time likely due to better DCR involvement.

The impact of individual maintenance and involvement in the GGC program is shown in our findings that the different recipient roles (policy actor, communicator, negotiator, and passive recipient) affected tree stewardship and survivorship. While policy actors, communicators, and negotiators showed higher percentages of survivorship, passive recipients only saw a 53.3% survivorship. This may be due to passive recipients having less overall interest in the program and less likely to maintain GGC program trees. For example, passive recipients were found to have lower levels of watering when compared to other roles, likely influencing the survivorship of trees on their property.

Lastly, landlords were identified as a hard to reach group by the DCR, which is reflected in the lower number of landlords we were able to interview. This is further compounded by our interviews with the city government and the community partner who both recognized that landlords have low engagement with the GGC program. The lack of landlord participation in tree planting initiatives is an opportunity for further research and the development of new outreach methods.

7 References

American Forests. (2022). Tree Equity Score Methodology. https://www.treeequityscore.org/methodology/

Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., & Hopton, M. E. (2017). The role of trees in urban stormwater management. *Landscape and urban planning*, *162*, 167-177.

Breger, B. S., Eisenman, T. S., Kremer, M. E., Roman, L. A., Martin, D. G., & Rogan, J. (2019). Urban tree survival and stewardship in a state-managed planting initiative: A case study in Holyoke, Massachusetts. *Urban Forestry & Urban Greening*, *43*, 126382.

Bulkeley, H., & Tuts, R. (2013). Understanding urban vulnerability, adaptation and resilience in the context of climate change. *Local environment*, *18*(6), 646-662.

Conway, T. M. (2016). Tending their urban forest: Residents' motivations for tree planting and removal. *Urban forestry & urban greening*, *17*, 23-32.

Eisenman, T. S., Flanders, T., Harper, R. W., Hauer, R. J., & Lieberknecht, K. (2021). Traits of a bloom: a nationwide survey of US urban tree planting initiatives (TPIs). *Urban Forestry & Urban Greening*, *61*, 127006.

Healy, M., Rogan, J., Roman, L. A., Nix, S., Martin, D. G., & Geron, N. (2022). Historical urban tree canopy cover change in two post-industrial cities. *Environmental Management*, *70*(1), 16-34.

Henny, L., Thorncroft, C. D., & Bosart, L. F. (2023). Changes in seasonal large-scale extreme precipitation in the mid-Atlantic and Northeast United States, 1979–2019. *Journal of Climate*, *36*(4), 1017-1042.

Hilbert, D. R., Roman, L. A., Koeser, A. K., Vogt, J., & van Doorn, N. S. (2019). Urban tree mortality: A literature review. *Arboriculture & Urban Forestry: 45 (5): 167-200.*, *45*(5), 167-200.

Ko, Y., Lee, J. H., McPherson, E. G., & Roman, L. A. (2015). Factors affecting long-term mortality of residential shade trees: Evidence from Sacramento, California. *Urban Forestry & Urban Greening*, *14*(3), 500-507.

Moody, R., Geron, N., Healy, M., Rogan, J., & Martin, D. (2021). Modeling the spatial distribution of the current and future ecosystem services of urban tree planting in Chicopee and Fall River, Massachusetts. *Urban Forestry & Urban Greening*, *66*, 127403.

Nordgren, J., Stults, M., & Meerow, S. (2016). Supporting local climate change adaptation: Where we are and where we need to go. *Environmental Science & Policy*, *66*, 344-352.

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly journal of the royal meteorological society*, *108*(455), 1-24.

Pincetl, S., Gillespie, T., Pataki, D. E., Saatchi, S., & Saphores, J. D. (2013). Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. *GeoJournal*, *78*(3), 475-493.

Planas-Carbonell, A., Anguelovski, I., Oscilowicz, E., Pérez-del-Pulgar, C., & Shokry, G. (2023). From greening the climate-adaptive city to green climate gentrification? Civic perceptions of short-lived benefits and exclusionary protection in Boston, Philadelphia, Amsterdam and Barcelona. *Urban climate*, *48*, 101295.

Riedman, E., Roman, L. A., Pearsall, H., Maslin, M., Ifill, T., & Dentice, D. (2022). Why don’t people plant trees? Uncovering barriers to participation in urban tree planting initiatives. *Urban Forestry & Urban Greening*, *73*, 127597.

Roman, L. A., McPherson, E. G., Scharenbroch, B. C., & Bartens, J. (2013). Identifying common practices and challenges for local urban tree monitoring programs across the United States. *Arboriculture & Urban Forestry. 39 (6): 292-299.*, *39*(6), 292-299.

Roman, L. A., van Doorn, N. S., McPherson, E. G., Scharenbroch, B. C., Henning, J. G., Östberg, J. P., ... & Vogt, J. (2020). Urban tree monitoring: a field guide. *Gen. Tech. Rep. NRS-194. Madison, WI: US Department of Agriculture, Forest Service, Northern Research Station. 48 p.*, *194*, 1-48.

Roman, L. A., Pearsall, H., Eisenman, T. S., Conway, T. M., Fahey, R. T., Landry, S., ... & Staudhammer, C. (2018). Human and biophysical legacies shape contemporary urban forests: A literature synthesis. *Urban Forestry & Urban Greening*, *31*, 157-168.

Schwaab, J., Meier, R., Mussetti, G., Seneviratne, S., Bürgi, C., & Davin, E. L. (2021). The role of urban trees in reducing land surface temperatures in European cities. *Nature communications*, *12*(1), 6763.

Spangler, K. R., Manjourides, J., Lynch, A. H., & Wellenius, G. A. (2019). Characterizing spatial variability of climate-relevant hazards and vulnerabilities in the New England Region of the United States. *GeoHealth*, *3*(4), 104-120.

Winter, J. M., Bowen, F. L., Partridge, T. F., & Chipman, J. W. (2019). Future extreme event risk in the rural Northeastern United States. *Annals of the American Association of Geographers*, *109*(4), 1110-1130.

Vogt, J. (2024). A Comprehensive Framework for Understanding Urban Forests as Social-Ecological Systems. *Arboriculture & Urban Forestry (AUF)*, *50*(6), 427-469.