Clark University Human-Environment Regional Observatory (HERO) Report June 2023 - June 2024

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Summary of Work (June 2023-June 2024)

This report describes the work conducted by the Clark University Human-Environment Regional Observatory (HERO) program, in collaboration with the Massachusetts Department of Conservation and Recreation (DCR) between June 2023 and June 2024. The report is presented in three sections: (1) work performed June-July 2023; (2) work performed August-December 2023; and (3) work performed January – June 2024.

June-July 2023: Tree survey and resident interviews in the City of Worcester, MA

The results show a high level of tree survivorship (66%) between the baseline survey and fall 2023. Mortality is due to removal of trees, especially in the backyards of residences. Interviews with residents indicate that they are positive about the DCR tree planting initiative.

August-December 2023: Tree survey within the Longhorned Beetle Regulation Zone

The results show a lower level of tree survivorship (52%) in the areas outside of Burncoat and Greendale neighborhoods. Some of the contributing factors to the lower survivorship include: (1) mortality of trees planted on properties with an n greater than 10 (in some cases 20 or more trees were planted on a property that were all removed when surveyed again in Fall 2023); and (2) high mortality of trees planted in 'natural areas' (i.e., trees planted at the rear of large properties along the property line dominated by large overstory trees).

January-June 2024: Tree canopy mapping in the City of Worcester, MA

The combination of freely available LIDAR and digital aerial photographs from 2021 allowed for the creation of a new tree canopy map for the city of Worcester. The 2012 tree canopy gap shows substantial gains in tree canopy compared to 2010 (immediate post-host tree removal). Considering the Burncoat and Greendale neighborhoods, tree canopy has increased by 15% since 2010. The increase is canopy is associated with the planting performed by the DCR and the Worcester Tree Initiative.

Additionally, during May and June 2024, the HERO team recruited seven new undergraduate students, and a team of four graduate students to start the work for the summer 2024 HERO program. Beginning May 28th, the team visited two sites with DCR Foresters – Holyoke and Chelsea MA. The goal is to re-survey trees that were planted in 2014-2015 to assess the health and status of those trees. Additionally, interviews have already begun with residents and other stakeholders in Holyoke. We expect that work to be completed by June 21. Beginning June 24th, the team will travel to Chelsea and stay in accommodations for 5 nights to allow them to conduct the tree survey and interviews efficiently.

June 2023-July 2023

June-July 2023: Tree survey and resident interviews in the City of Worcester MA

1. Introduction

With the continuous expansion of global commerce, an increasing number of invasive species have spread, and their prevalence is expected to rise (Danko et al., 2016). One such species, the Longhorned Beetle (LB), has been identified as one of the world's 100 most destructive invasive species (Simberloff and Rejmánek, 2011). The Longhorned Beetle, originally from eastern China and Korea (Culin et al., 2015), targets a number of hardwood tree species, particularly maples, genus *Acer* (USDA, n.d). As of 2007, Worcester's urban canopy was highly monotypic, with maples comprising 80% of all street trees, making it highly susceptible to the Longhorned Beetle (Palmer et al., 2014). To mitigate the spread of Longhorned Beetle, the US Department of Agriculture (USDA) establishes regulation zones, then removes the majority of host tree species (Meyerson and Mooney, 2007; NISC, 2008). This practice was enacted in Worcester following the 2008 detection of LB, resulting in the removal of 34,196 trees (Palmer et al., 2014).

This reduction in urban tree canopy led to a noticeable increase in temperature and prolonged periods of warm weather during summers (Rogan et al., 2013; Elmes et al., 2017). Tree planting initiatives can be effective in recovering tree canopy lost due to infestation related removals, though the ecosystem services provided accrue gradually as the replanted trees mature. The success of tree planting is defined by maintaining low mortality over time to maximize tree canopy cover and basal area, and correlated ecosystem services (Ko et al., 2015; McPherson et al., 2011).

The success of a tree planting program is often limited by various challenges that hinder juvenile trees from reaching maturity, such as poor nursery stock, trunk girdling due poor staking and tying techniques, damages from vandalism, construction, and vehicles, proximity to impervious surfaces, and poor irrigation (Elmes et al., 2018). Factors such as the percentage of renter occupancy, the number of trees planted on the property, and tax parcel size and value can also predict tree mortality in the early stages of development. Survival is particularly critical in the first five years of a tree's life since this is the most vulnerable period (Elmes et al., 2018).

While municipal plans prioritize ecosystem services, Conway (2016) demonstrates that residents prefer and take better care of trees they find aesthetically pleasing, contradicting municipal plans. Investments in tree stewardship by tree planting programs can enhance tree survivorship (Breger et al., 2019), and positive relationships between individuals and organizations can strengthen community-scale resilience against pest infestation (Palmer et al., 2014). Even at the juvenile stage, trees offer various benefits. Planting three trees per acre can result in substantial monetary savings in terms of energy and ecosystem services (Moody et al., 2021). Additionally, a higher tree canopy density near a house can increase the property's value (Wilkens et al., 2018).

2. Research Goals

The research goals for HERO 2023 were to assess the biophysical and social change of urban tree canopy after the private tree planting by the Department of Conservation and Recreation (DCR) and the street tree planting by the Worcester Tree Initiative (WTI). The tree planting was concentrated in the Worcester neighborhoods that suffered the most tree loss from the Longhorned Beetle in 2009. We used a mixed-methods approach that examined the biophysical and social changes to the LB regulation zone from 2008 to 2023.

The biophysical assessment of the trees assessed the growth and survivorship of trees planted between 2010 and 2012 by the DCR and WTI. We conducted field surveys of residential and street trees that were previously surveyed in 2014, 2015 and 2016 to answer following questions:

1. What is the current status of tree health and structure and what factors have the greatest impact?
2. How does the tree health and structure compare to the past HERO tree survey?

The social assessment of the neighborhood examined residents' perceptions of trees and post-LB tree planting initiatives. It consisted of interviews with residents who received DCR trees to answer the following questions:

1. How do residents perceive the role of trees and DCR tree planting on their property and in their neighborhood?
2. How do residents' past experiences and beliefs impact tree stewardship?

3. Study Area

3.1 Worcester Regulation Zone

The study area for our research comprises four neighborhoods in northern Worcester: Greendale, Burncoat, Great Brook Valley Area, and North Lincoln Street. These neighborhoods lay at the heart of the Longhorned Beetle regulation zone, a 110 square mile area encompassing all of the city of Worcester, and all or part of five surrounding towns: Holden, West Boylston, Boylston, Shrewsbury, and Auburn (Figure 2). The regulation zone was established shortly after LB was first detected in Worcester in 2008 and was expanded to collectively encompass all LB infested trees found in the Worcester area, with a buffer of varying width.

Worcester has a humid continental climate, with an average daily high of 28 °C in July and 0 °C in January. Average annual precipitation is 1220 mm, as well as 129 cm of snow per season (www.nws.noaa.gov, 2022). The Worcester area is highly susceptible to 'Nor'easter' storm events, which often produce strong winds and high amounts of precipitation, thus contributing to the natural vegetation disturbance regime. Worcester's population of 205,272 makes it the second largest city in New England after Boston, MA (US Census, 2020). Of this population, approximately 55% live in renter-occupied housing. The city has a diverse industrial history and is currently home to prominent healthcare and biotechnical industries (Elmes, 2018). Worcester's median household income is $56,746, which is substantially lower than the MA median of $89,026 (US Census, 2020).

Of the four neighborhoods in our study area, three are whiter, wealthier, and more educated than Worcester as a whole, while one, Great Brook Valley Area, is not (Table 1). Typically canopy cover is positively correlated with wealth (Schwarz, 2015), however, this is not the case across the four neighborhoods we focus on. Notably, Greendale, which has the highest median income in the study area, has the lowest canopy cover. This is due to the presence of large industrial and commercial sites in the neighborhood, such as Saint-Gobain. Conversely, the Great Brook Valley Area, despite a significantly lower median income, includes large, forested areas, giving it a canopy cover higher than all but Burncoat.

Table 1. Socioeconomic and biophysical variables of four neighborhoods within the study area

Socioeconomic Variables	Greendale	Burncoat	Great Brook Valley Area	North Lincoln Street
Percent English Limited*	2.5%	11%	27%	9.9%
Percent White***	64%	69%	21%	43%
Percent Renter**	43%	21%	96%	60%
Median Household Income*	$86,851	$72,962	$24,284	$68,932
Percent Bachelors Degrees	39%	41%	19%	33%
Total Population (2020)	7,915	6,146	3,439	5,992
Biophysical Variables	**Greendale**	**Burncoat**	**Great Brook Valley Area**	**North Lincoln Street**
Percent Tree Canopy Cover (2015)	16%	38%	32%	31%
Percent Impervious Cover	57%	32%	35%	44%
Number of Trees Planted	1,111	885	67	317
Physical Area (sq km)	3.96	4.06	1.12	2.79

*Statistical significance markers: * = $p<0.1$; ** = $p<0.05$; *** = $p<0.01$*

3.2 History of Longhorned Beetle in the Worcester Area

According to data from an inventory of city trees conducted in 2005-2007 by The Worcester Department of Public Works and Parks, on the eve of the discovery of LB in Worcester, the city's street trees were heavily skewed towards species susceptible to the pest, with 79.7% of street trees belonging to the maple genus (*Acer*) alone (Freilicher, 2008). Of these, the majority were Norway maple, comprising a staggering 60.8% of *total* street trees in the city. Neighborhood level street tree data from this period is not available. However, we know several facts about the state of the urban forest in our study area at this time. Burncoat and Greendale were home to a disproportionately high density of street trees in the city, with a species distribution in line with that of the city as a whole.

The Longhorned Beetle was detected in Worcester in August of 2008 in the Greendale neighborhood. It is suspected the pest arrived via the wooden shipping pallets of a company in the neighborhood engaged in international trade. Extensive surveying of host trees began immediately, spearheaded by the Massachusetts Department of Conservation and Recreation (DCR). It was soon found that the pest had been circulating for several years and had already dispersed beyond the Greendale neighborhood, though the highest concentration of infested trees was in Burncoat/Greendale.

The Massachusetts Asian Longhorned Beetle Cooperative Eradication Program, a collaboration between the MA DCR and USDA was established in the fall of 2008. By the end of 2008, 5,113 infested trees had been detected. Tree removals began in January of 2009, and by the end of the year 25,502 trees had been removed. Removals were most highly concentrated around the point of origin of the outbreak, Greendale and nearby Burncoat (Figure 1). Surveying and removals continued after 2009, with total removals surpassing 30,000 by 2012. For a full timeline of the Longhorned beetle outbreak in Worcester see, this DCR story map.

Across the four neighborhoods of our study area, canopy loss was at least 25%. It is estimated that Burncoat and Greendale lost 48% of their canopy (Rogan et al. 2013). The initial approach was to remove any confirmed infested tree, as well as potential host species within the travel radius of the beetle. As containment efforts progressed, foresters began using insecticide on uninfested host trees in the regulation zone to prevent infestation, and as an alternative to preemptive removal.

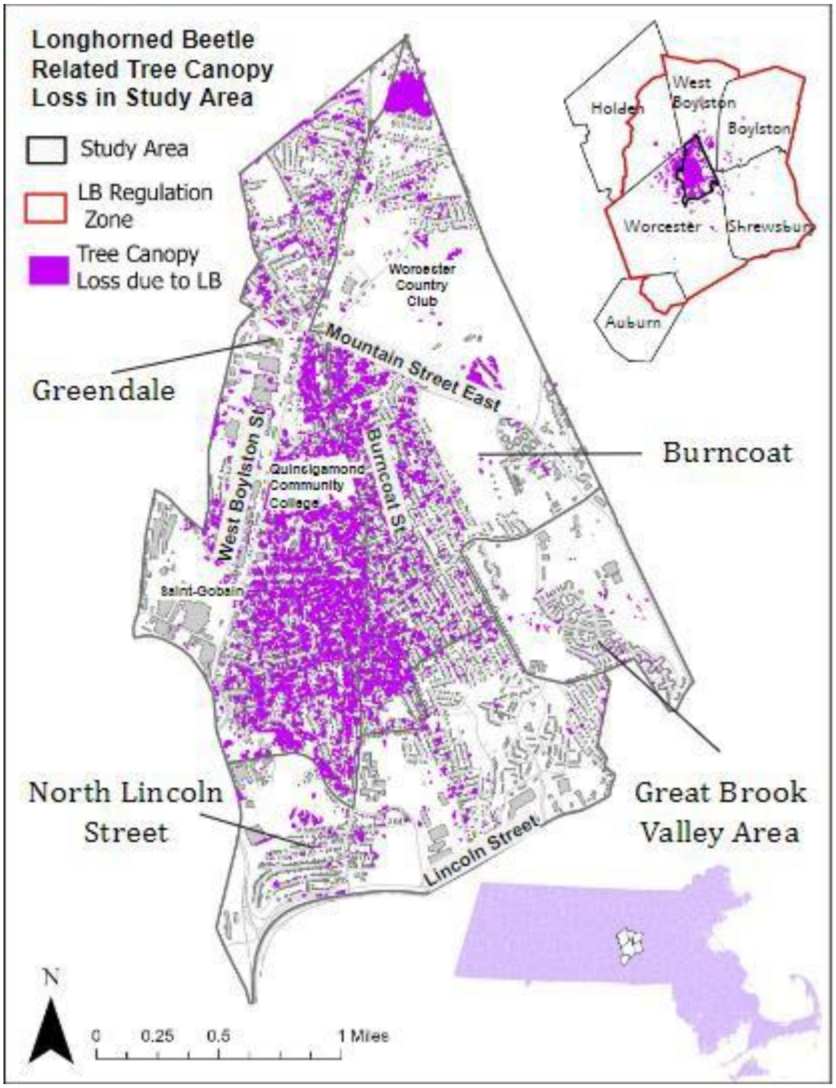

Figure 1. Tree canopy loss in study area due to the USDA host-tree removal policy 2008- 2012

3.3 Tree planting efforts

Tree replanting programs were quickly established in the wake of the removal program. The Worcester Tree Initiative (WTI) was formed in 2009 and set a goal to replant 30,000 trees in five years across the LB Regulation Zone. The DCR established its own post-LB tree planting initiative around the same time. In our study area the DCR carried out the majority of tree planting, with roughly 7,000 trees planted on private land in between 2010 and 2017, with most planted by 2012.

Our survey focuses on trees planted between 2010 and 2012 by the DCR on private land, as well as a subset of street trees planted by the WTI. The DCR tree planting program in our study area evolved over time. The agency initially contracted exclusively with Bigelow Nursery and faced limitations in terms of the species and quality of saplings available from the nursery. For this reason, arborvitae and white fir are highly over-represented in the species composition of our sample, though this would change in later years.

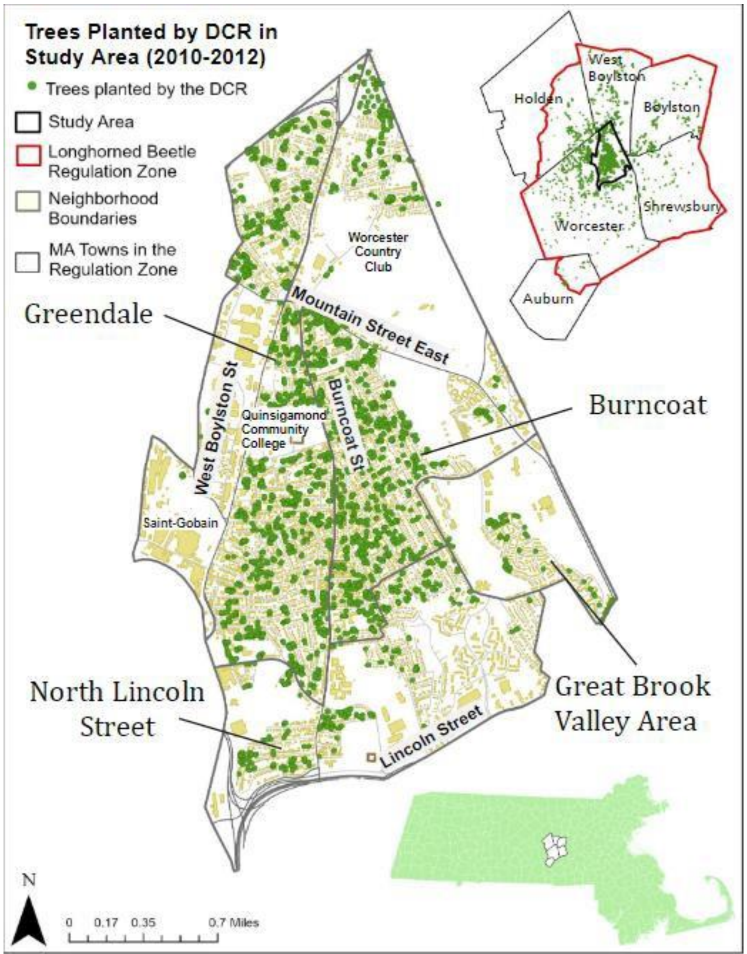

Figure 2. Trees planted by DCR in the study area 2010-2012

4. Methods

4.1 Sampling

The sampling methods we employed come from previous work. For the private tree survey, past HERO teams surveyed trees in the entire regulation zone. In 2014, after developing the entire dataset of ~17,000 trees planted by the DCR on private property, they employed a stratified sample by species, resulting in ~9,000 trees. From this, a randomized subsample of 500 trees was taken. The subsample was then clustered to create a clustered sample of ~1,600 trees. Of this, 1,054 were sampled. In 2015, the same sampling methodology was repeated, but out of the ~1,600 trees in the clustered sample, 1,516 were measured. In 2016, from the full dataset of ~17,000 points, arborvitae species were removed, and a random sample of 345 trees were selected. It is important to note that many of the residential trees were resampled in multiple years. For the street tree sample, the 2016 team took a non-probabilistic convenience sample of street trees planted and watered by the Worcester Tree Initiative (WTI) along street transects. This resulted in a sample of 539 trees. In following sections of this report, these three years of tree surveys will be treated as one survey, referred to as the baseline survey.

In our survey, we measured all of the trees from the stratified sample by species that were within our study area. This resulted in a sample size of 2,381 private trees. This included 800 trees that had been surveyed in at least one of the previous surveys. We also surveyed all of the street trees within our study area that were sampled in 2016, for a sample of 413 trees (Figure 3).

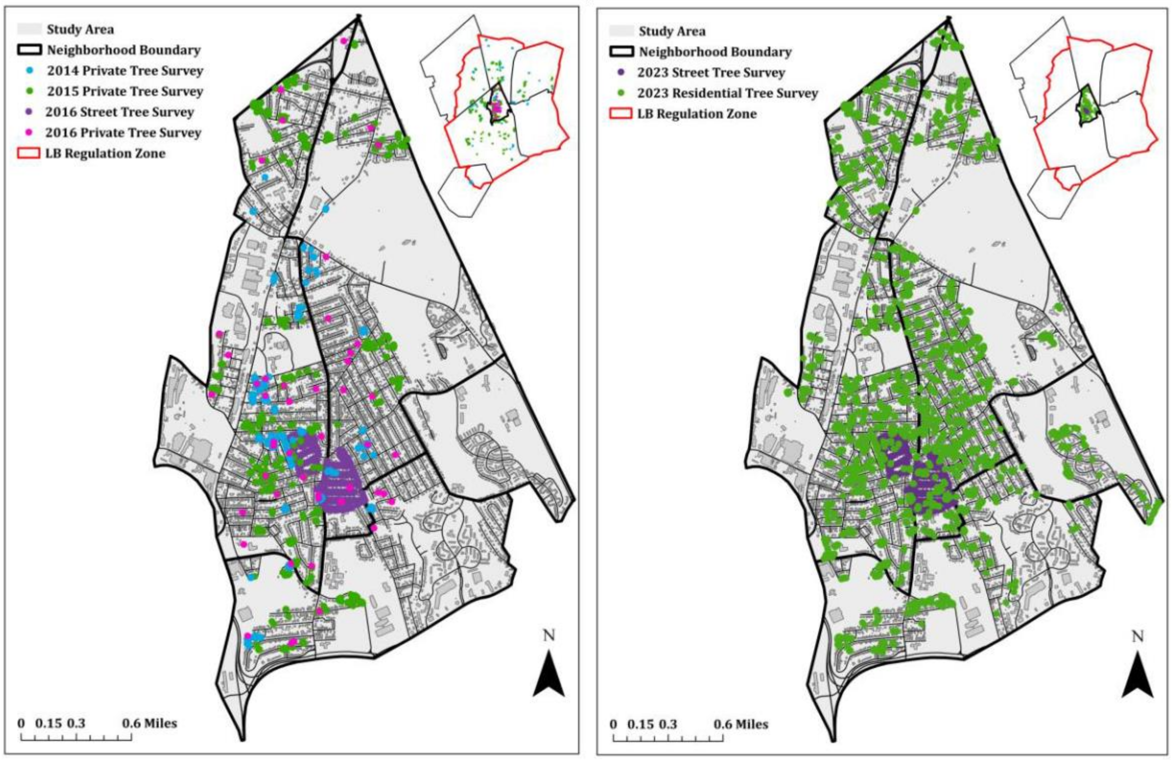

Figure 3. Comparison of tree surveys from baseline (left) to 2023 (right)

4.2 Survey Methods

Our tree survey methods roughly follow those laid out in the US Forest Service's *Urban tree monitoring: a field guide* (Roman et al., 2020). For every tree, we recorded the date and time of the site visit, as well as the initials of the survey crew. For each tree we recorded mortality status as either "alive", "standing dead", "stump", removed, or unknown. Unknown includes trees we were unable to access or were explicitly denied permission to measure (Figure 4).

Figure 4. Examples of differing tree mortality types. From left to right: alive, standing dead, stump, and removed.

For trees of mortality alive or standing dead, we measured diameter at breast height (DBH), crown width, and height. DBH was measured using a standard diameter tape, at 54 inches or the next unobstructed point. Height at which DBH was measured was recorded as well. For trees with multiple trunks, the largest and smallest trunks were recorded. DBH was measured in inches to the nearest tenth of an inch. Crown width was measured as close to the trunk as possible, from one edge of the tree crown to the opposite edge. If there was not sufficient room to measure across, crown width was measured from the trunk to the crown edge and multiplied by two. Crown width was measured in feet to the nearest quarter of a foot. Tree height was measured using the Nikon Forestry Pro II Rangefinder/Hypsometer using the two-points mode, from the base of the tree to the tip of the tree crown. Tree height was recorded in feet to the nearest tenth of a foot.

Crown vigor was assessed on a scale of 1-5. 1 being where 100%-90% of the tree canopy was foliated, 2 being where 90%-75% of the tree canopy was foliated, 3 being where 75%-50% of the tree canopy was foliated, 4 being where less than 50% of the tree canopy was foliated, and 5 being dead. (Figure 5)

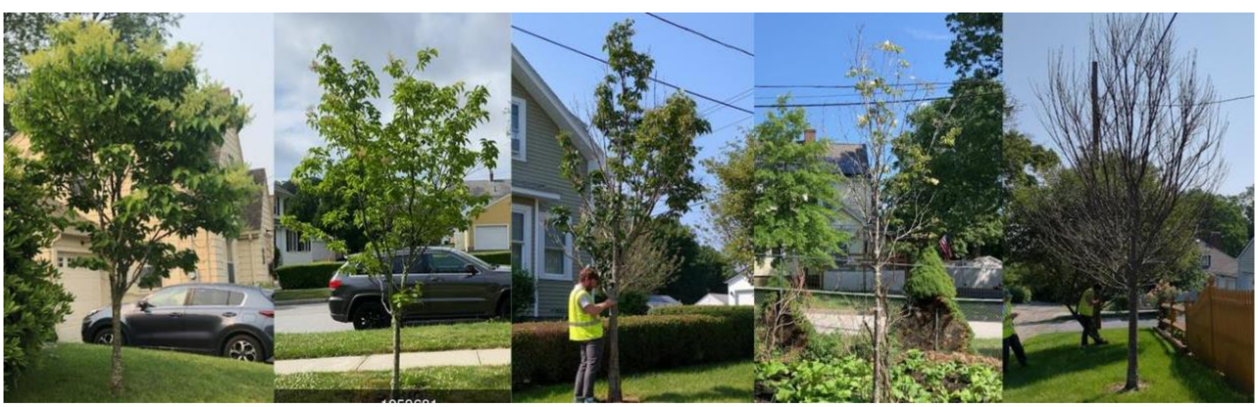
Figure 5. *Syringa reticulata* (Japanese tree lilacs) in varying stages of vigor, ranging from 1-5, left to right.

For trees of mortality "alive," condition was recorded, on a scale of "good," "fair," and "poor". This involved a complete assessment of the tree's overall health, including crown health and other characteristics, such as bark damage, rot, insect damage, or other health indicators. The presence or absence of basal sprouts on the tree was also recorded. The presence or absence of Norway maples on the property was recorded as well. Land use of where the tree was planted was recorded as one of the following: single family residence detached, single family residence attached (including duplexes and row houses), multi-family (three or more units, including triple deckers), or institutional (including schools and businesses). The site type where the tree stands was also recorded as one of the following: front yard, backyard, side yard, or maintained park. (Figure 6). Maintained park was a catch-all category for locations that were not in yards.

Figure 6. Examples of trees on multiple land use/site types. From left to right, single family detached backyard, single family attached front yard, multi-family front yard, institutional maintained park.

In addition, a photo was taken of each tree and tagged with the unique tree ID using Instagram or Snapchat. For trees that we were unable to access (eg. behind a closed fence) but were able to see, we recorded as much information as possible. All of these data were input using Esri software ArcGIS Field Maps mobile app.

4.3 Interviews

Our main objective for the social assessment was to interview neighborhood residents in the study area to understand their perceptions of their neighborhood urban forest and the post-Longhorned Beetle tree planting initiatives. The target population for these interviews was residents who had at least one tree planted on their property by the Department of Conservation and Recreation (DCR) in the years immediately following Longhorned Beetle tree removal. To identify interviewees, we employed a convenience sampling method. We first called all residents (582) in our study area who had received a tree from the DCR on their property. Researchers also attended a neighborhood monthly meeting to explain our presence and solicit interviews. We scheduled 40 interviews from this initial outreach, and conducted an additional 12 interviews with residents encountered in the field. In total, we conducted 52 interviews.

All interviewees signed a consent form and participated in a 10-40 minute interview which was audio recorded when possible. All interviewees also filled out a basic demographic questionnaire with information relating to race, gender, age, income, education level, language spoken at home, homeownership, and years lived on property. Interview topics included personal history & experience with DCR, tree stewardship, perception of trees, perception of neighborhood, and environmental concerns. The complete interview guide with all the questions can be found in Appendix A.

We then transcribed all audio-recorded interviews using a combination of manual transcription, Otter.ai, Zoom, and Panopto. Next, we used the NVIVO software to process interview transcripts. First, we assigned demographic attributes to each interview, to later assess connections between resident demographics and interview responses. We then sorted quotes from interviews into 25 codes (Figure 7). Codes were created to address the following themes: perception of tree benefits & challenges, experience with tree removal policy, experience with DCR planting, neighborhood recovery, and tree stewardship. The codes were created through an iterative process to address the central themes. Each interview was coded by two HERO researchers to ensure intercoder reliability. We then identified key themes that emerged from these codes. These themes will be the focus of analysis in the Social Assessment Results section.

Figure 7. Hierarchy chart showing 25 codes, sorted by relevance. Larger boxes represent codes with a higher number of quotes and darker colors represent codes that are pulled from a higher number of interviews. Codes ordered by relevance: Neighborhood, TP Benefits and Motivations, LB Tree Loss and Removal, Environmental Concerns, TS Activities, OD Worcester Parks, TP Emotions, TP Challenges, TS Caretaker, OD Yards, TS Other Trees and Yards, Tree Health, DCR Choice, TS Difficulties, TS Frequency, TS Consistency, DCR Positive, LB Present, DCR Number, DCR Negative, DCR Neutral, OD Other, TP Benefits, TP Motivations, LB Not Present.

5. Results

This analysis is divided into baseline, private trees, and street trees. The biophysical assessment surveyed 2,381 trees across 44 species planted by the DCR on private land and 411 street trees across 16 species planted by WTI on public land (Figure 8).

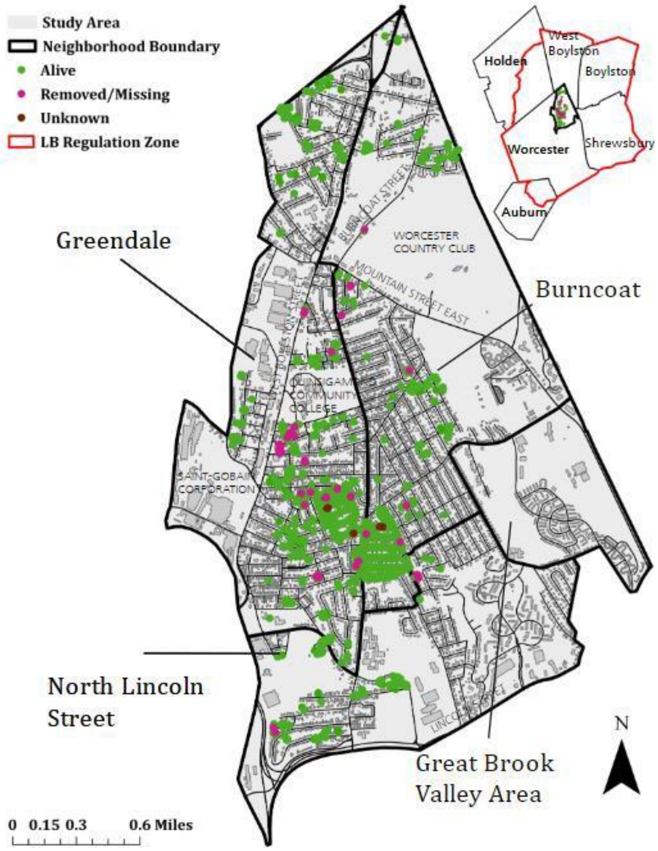

Figure 8. Map of baseline surveyed private trees in study area based on survivorship

5.1 Biophysical Assessment

5.1.1 Baseline Results

HERO surveys conducted in 2014, 2015, and 2016 found an overall survivorship of 77.1% for private trees (Figure 9). For street trees, the 2016 survey recorded 98.5% alive and 1.5% either removed, standing dead, or unknown. Of the 800 trees surveyed in the baseline, nine species enjoyed 100% survivorship: *Pyrus calleryana* (bradford pear), *Prunus avium* (cherry), *Larix* (larch), *Tilian* (linden), *Quercus coccinea* (scarlet oak), *Picea omorikaas* (serbian spruce), *Quercus bicolor* (swamp white oak), *Pinus strobus* (white pine), and *Cladrastis Kentukea* (yellowwood) (Figure 10). *Thuja occidentali*s (american arborvitae) and *Abies concolor* (white fir) were the most common species in the survey (Figure 10).

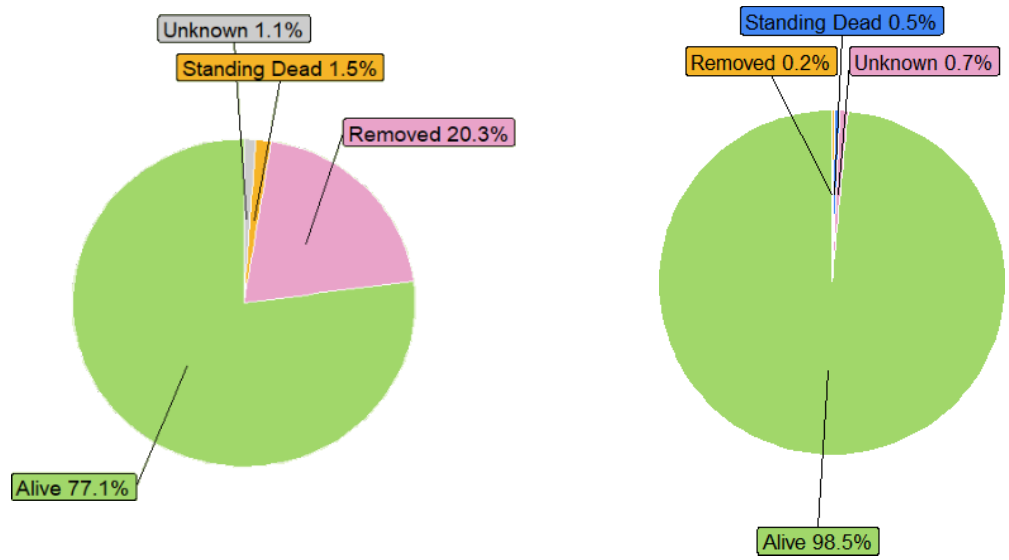

Figure 9. From left to right, pie charts showing baseline private tree survivorship and baseline street tree survivorship

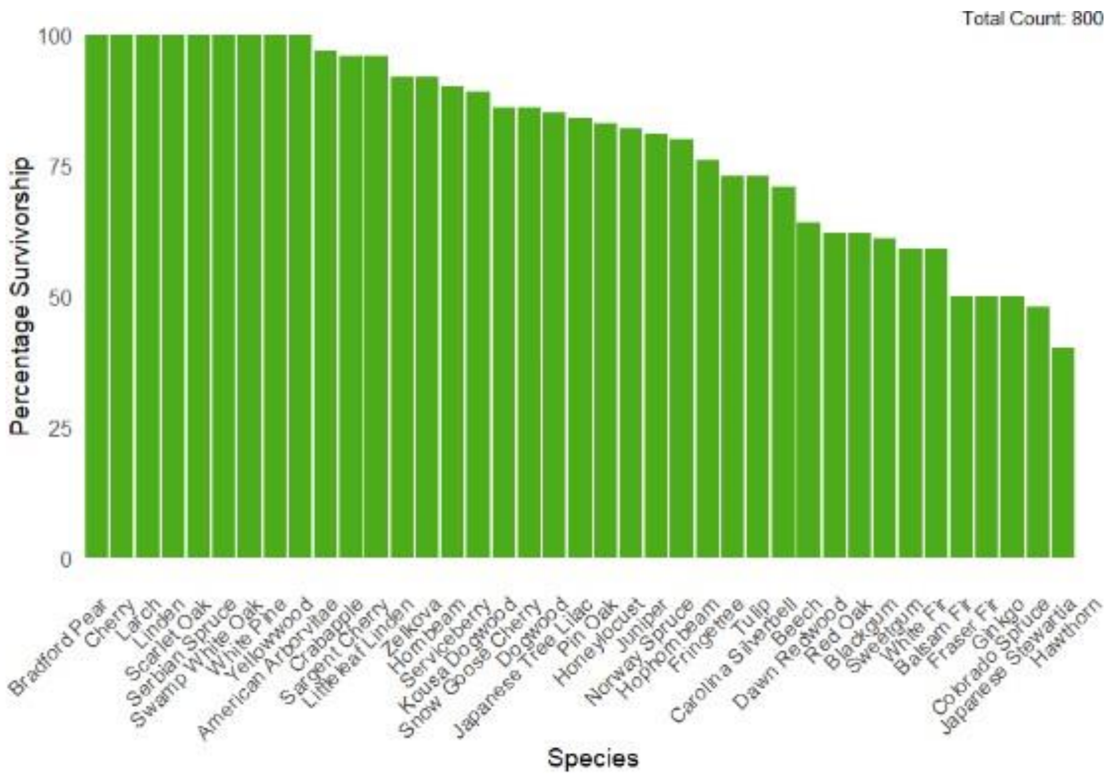

Figure 10. Bar graph of private trees species ordered by percentage of baseline survivorship

5.1.2 Private Trees

The private tree survey conducted in 2023 found no neighborhood association between dead and alive trees, rather private tree survivorship fluctuated from property to property. The survey found 66.9% of private trees to be alive and 29% to be removed (Figure 13). Figure 12 shows a map of the private trees surveyed in the study area. Of living trees 89.4% were in 'good' condition. Of the 44 species surveyed, *Thuja occidentalis* (american arborvitae) and *Abies concolor* (white fir) were the most common. Other frequently observed species surveyed were *Cornus kousa* (kousa dogwood), *Syringa reticulata* (Japanese tree lilac), *Gleditsia triacanthos* (honeylocust), *Amelanchier spp.* (serviceberry) and *Metasequoia glyptostroboides* (dawn redwood) (Figure 14). Of the reduced sample, *Tilia americana* (American basswood/linden), *Syringa reticulata* (Japanese tree lilac) and *Tilia cordata* (littleleaf linden) were the top species for survivorship (Figure 17). Shade trees did particularly well, of the top seven species, four were shade trees (Figure 17). *Abies fraseri* (fraser fir), *Ginkgo biloba* (ginkgo), and *Stewartia pseudocamellia* (Japanese stewartia) had the lowest survivorship. For the most part, low survivorship were a combination of evergreen and ornamental trees (Figures 13-18, Table 2).

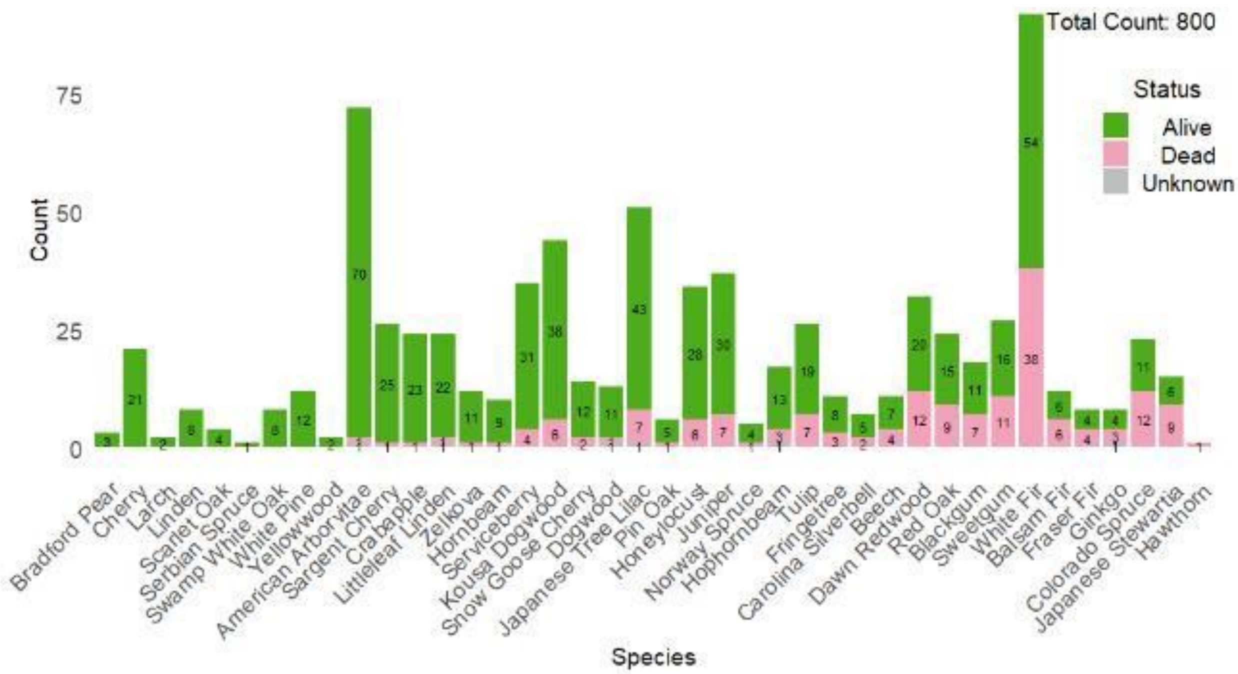

Figure 11. Private trees species ordered by percentage of baseline survivorship with count

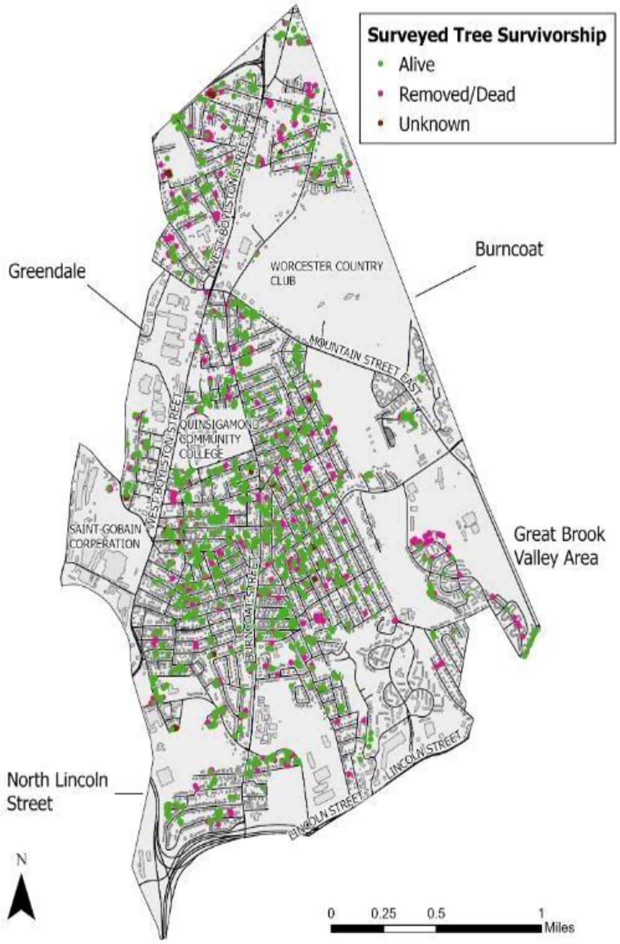

Figure 12. Map of 2023 surveyed private trees in study area based on survivorship

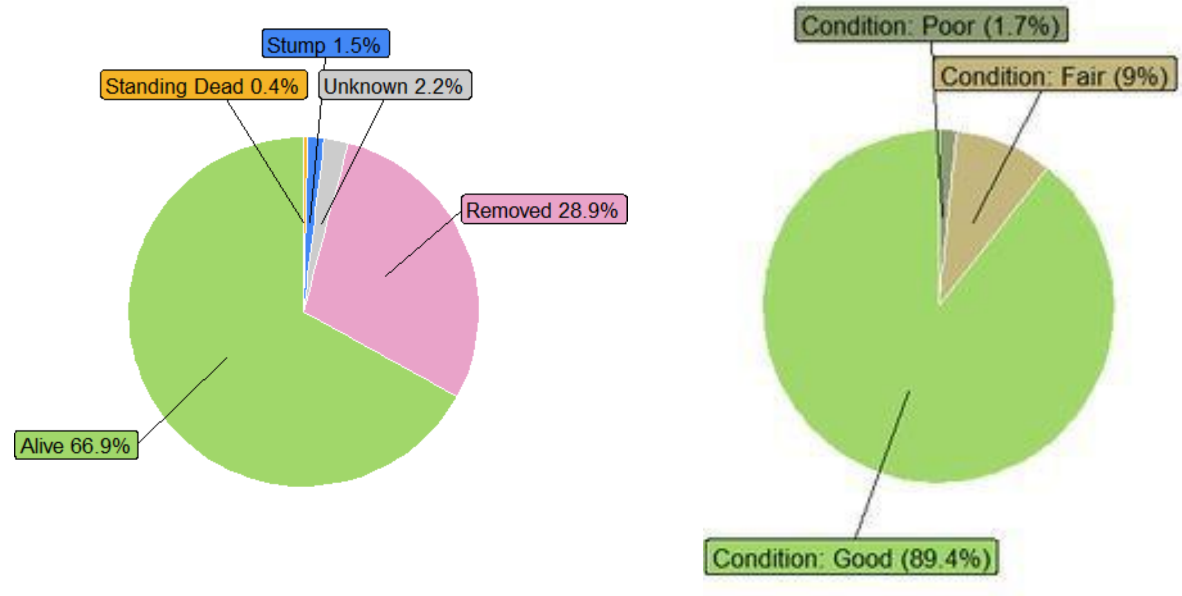

Figure 13. From left to right pie charts showing survivorship and condition of the 2023 private tree sample

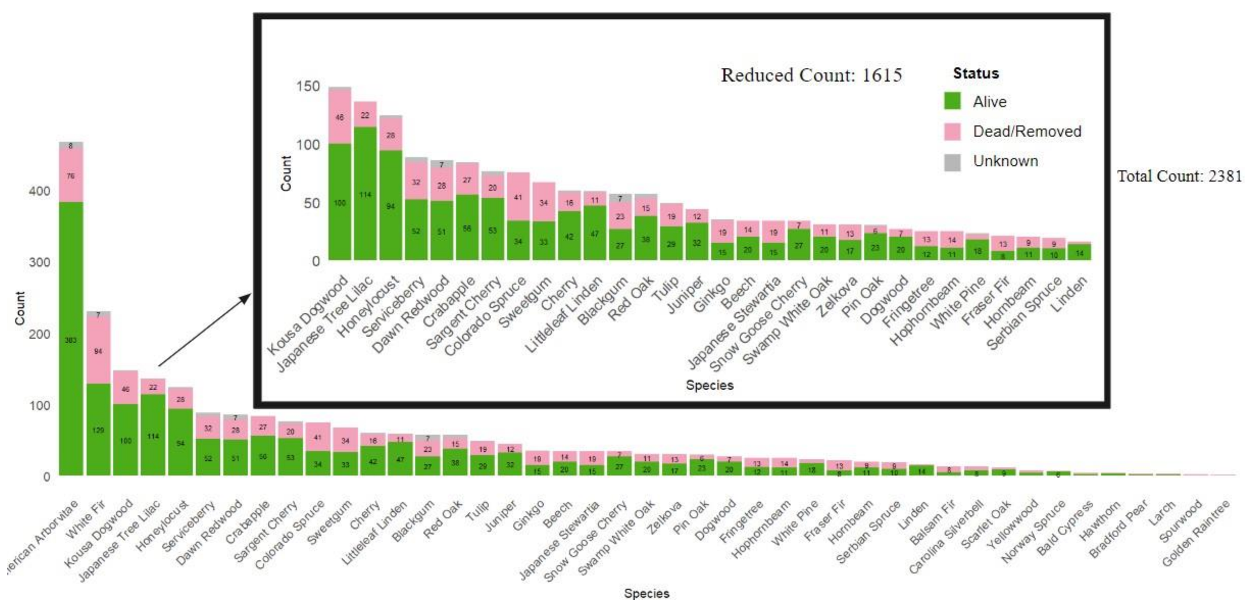

Figure 14. Bar graph of private tree species status by count. Smaller bar chart excluding white fir, American arborvitae, and those with a count less than 15

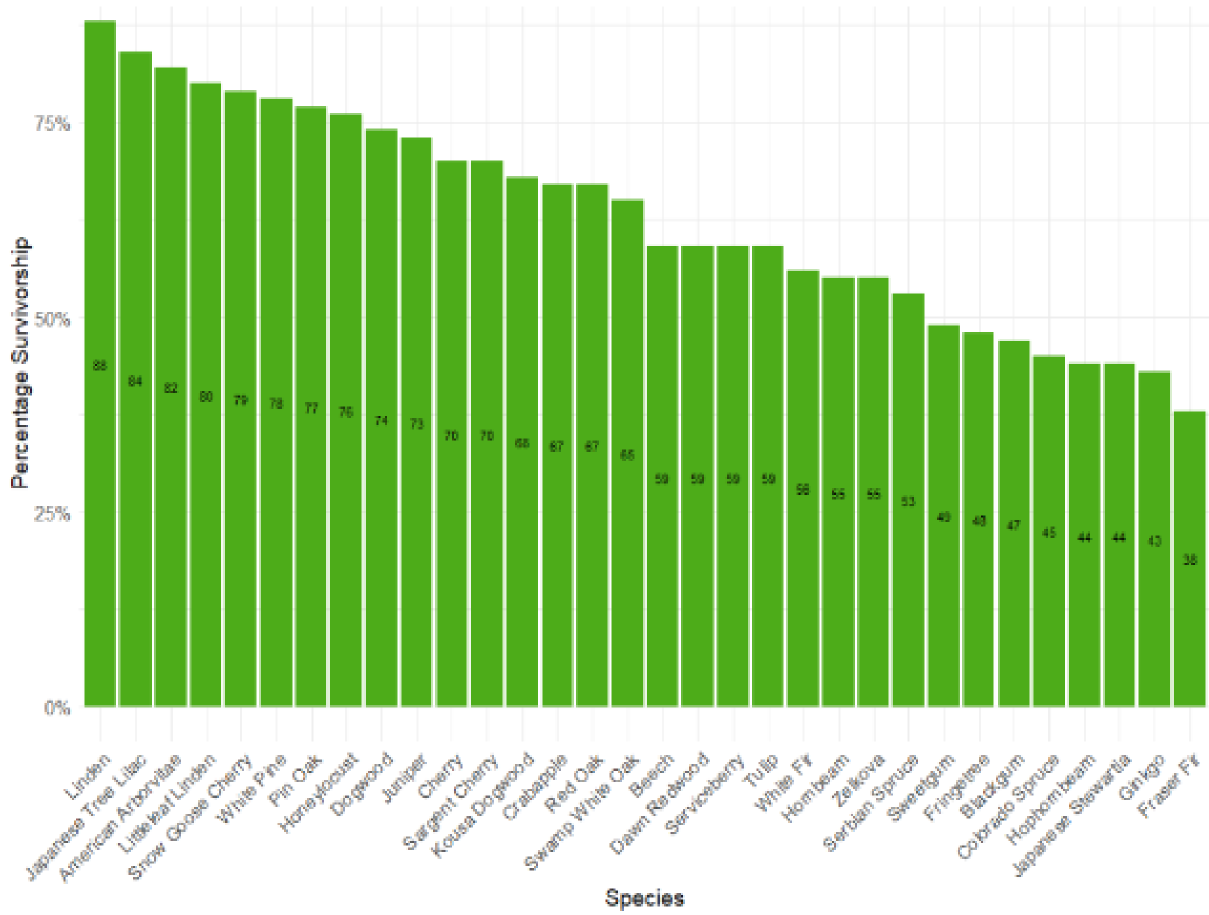

Figure 15. Bar graph of private trees survivorship percentage

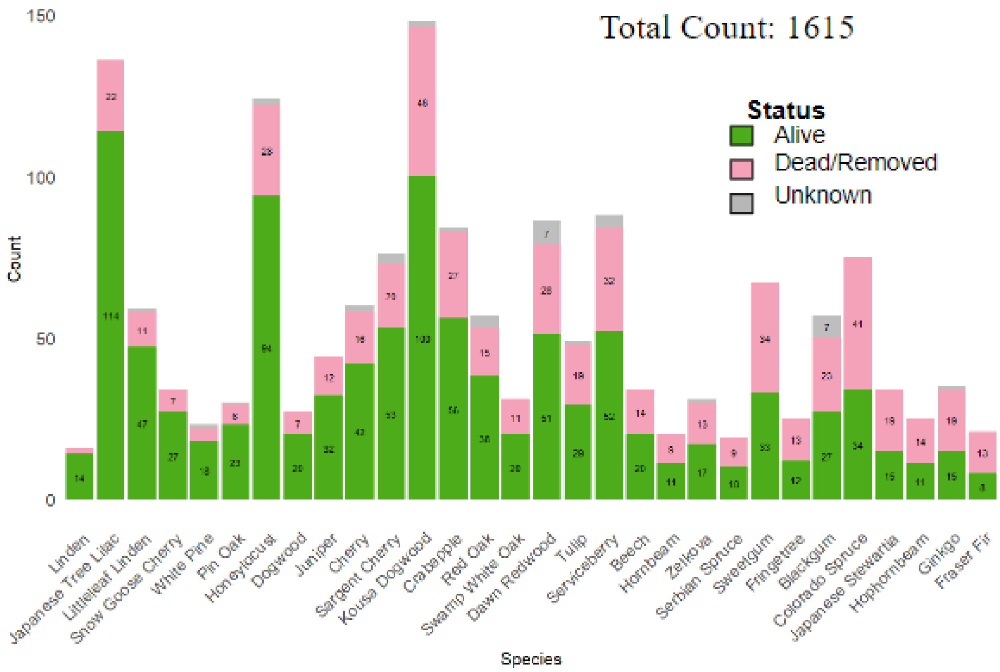

Figure 16. Bar graph of private trees survivorship percentage highlighting tree count

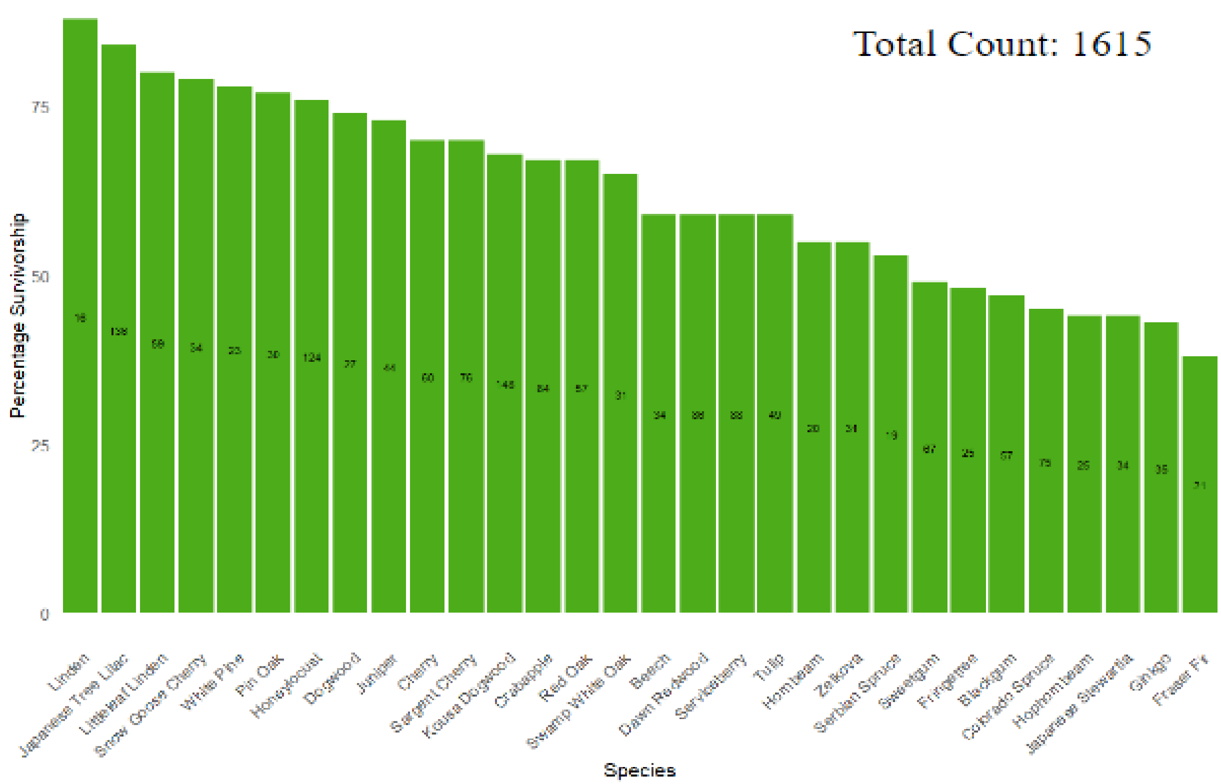

Figure 17. Bar graph of private trees survivorship percentage with reduced sample

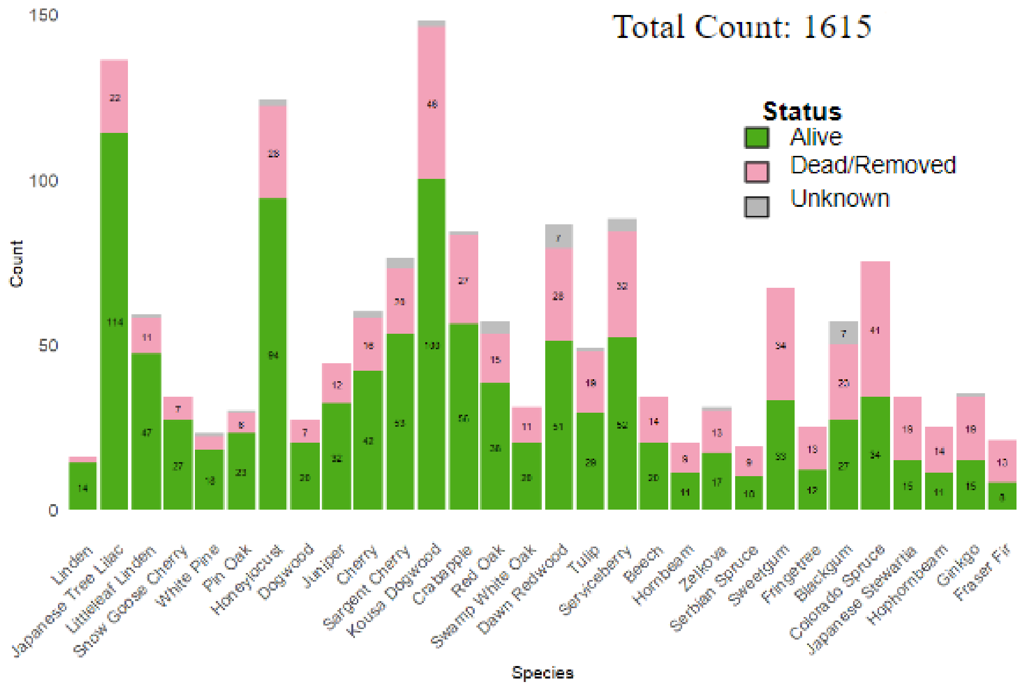

Figure 18. Bar graph of private trees survivorship percentage highlighting tree count excluding white fir, American arborvitae, and those with a count less than 15

Table 2. Table describing the top and bottom species based on survivorship excluding white fir, American arborvitae, and those with a count less than 15

Top 7 species	Survivorship	N surveyed	Bottom 7 species	Survivorship	N surveyed
Linden	88%	16	Fraser Fir	38%	21
Japanese Tree Lilac	84%	136	Ginkgo	43%	35
Littleleaf Linden	80%	59	Japanese Stewartia	44%	24
Snow Goose Cherry	79%	34	Hophornbeam	44%	44
White Pine	78%	23	Colorado Spruce	45%	75
Pin Oak	77%	30	Blackgum	47%	57
Honeylocust	76%	124	Fringetree	48%	25

5.1.2.1 Private Tree Factors

The entire sample of 2,381 private trees is used in this analysis. The most common site type for trees to be planted was the backyard with almost 60% of private trees in backyards (Figure 19).

Private trees in the front yards had the highest survivorship. The further away from the street the tree was planted, the worse the average survivorship. Despite this, living trees have high vigor regardless of site type with more than 95% of trees having a vigor of 1 or 2. The most common land use was single-family residences which had the highest survivorship amongst the site types (Figures 22-23). Of the single-family residences, 76.7% being single-family detached and 12.9% being single-family attached or duplex. Single-family residences had the highest survivorship (Figure 24). Regardless, when trees were alive, they all had low vigor values. (Figure 25). Trees were healthy when alive, or removed and dead. The three tree types we looked into are shade (deciduous hardwoods), evergreen, and ornamental. We found that shade had the lowest survivorship amongst the tree types, but when alive, had the greatest average vigor score. Ornamentals trees had the best survivorship but the worst average vigor score (Figures 26-27).

We found that *Prunus avium* (cherry), *Prunus serrulata* (snow-goose cherry), and *Prunus sargentii* (sargent cherry) had particularly high vigors. To define native trees, we used the historical range in Massachusetts from Mass Audubon. Native species include *Fagus sylvatica* (beech), *Gleditsia triacanthos* (honeylocust), and *Quercus rubra* (red oak), while non-native species include *Pyrus calleryana* (bradford pear), *Ginkgo biloba* (gingko), and *Syringa reticulata* (Japanese tree lilac). We found that slightly more non-native species were planted within the study area. Native species had better survivorship and higher vigor scores than non-natives. For drought tolerance, the majority of trees surveyed on private property are drought tolerant species (68.9%). However drought sensitive species seemed to have a higher survivorship and vigor overall.

Our analysis based on the factors of site type, land use, tree type, and native status pointed towards native trees in the front and side yards of single-family residences or duplexes having the best chance of survivorship.

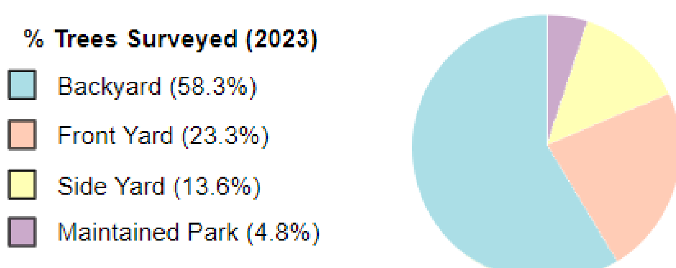

Figure 19. Pie chart of the percent of trees surveyed based on site type

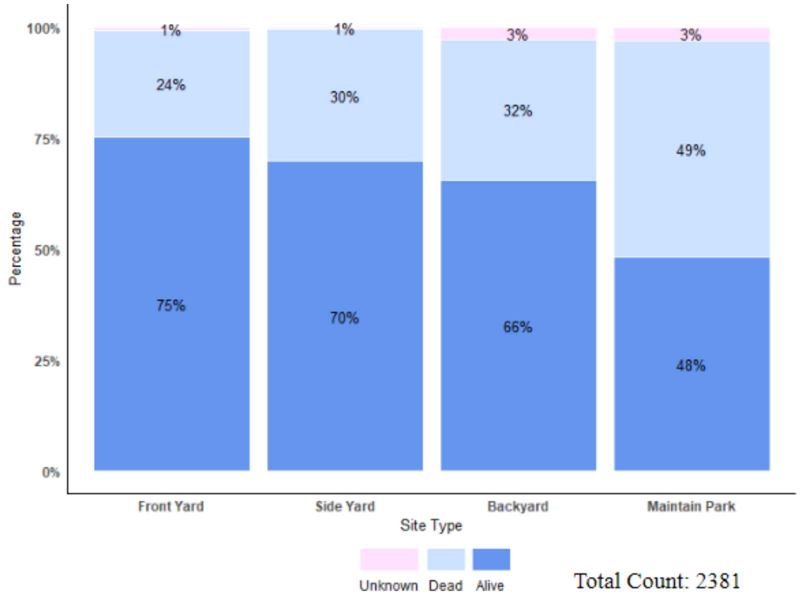

Figure 20. Bar graph of percent survivorship based on site type

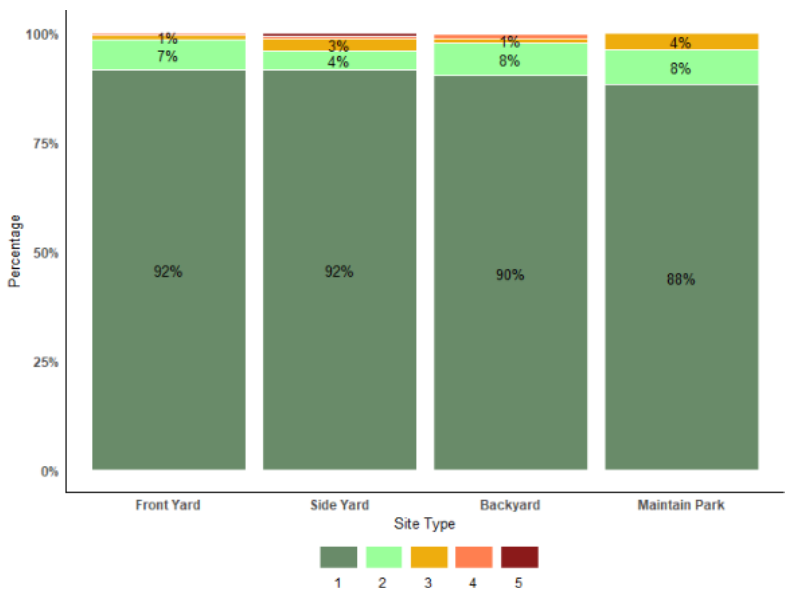

Figure 21. Bar graph of percent vigor based on site type

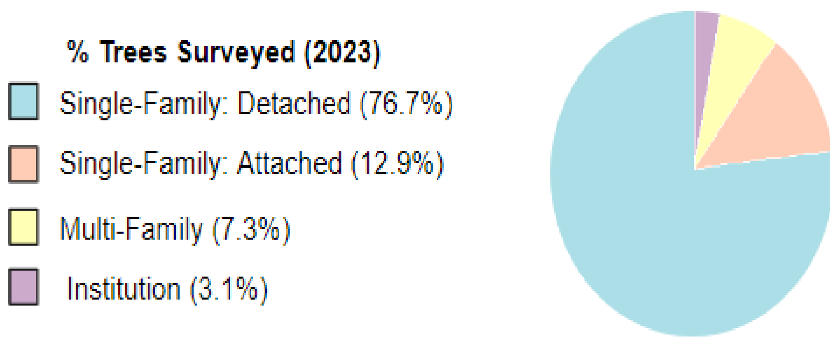

Figure 22. Pie chart of the percent of trees surveyed based on land use

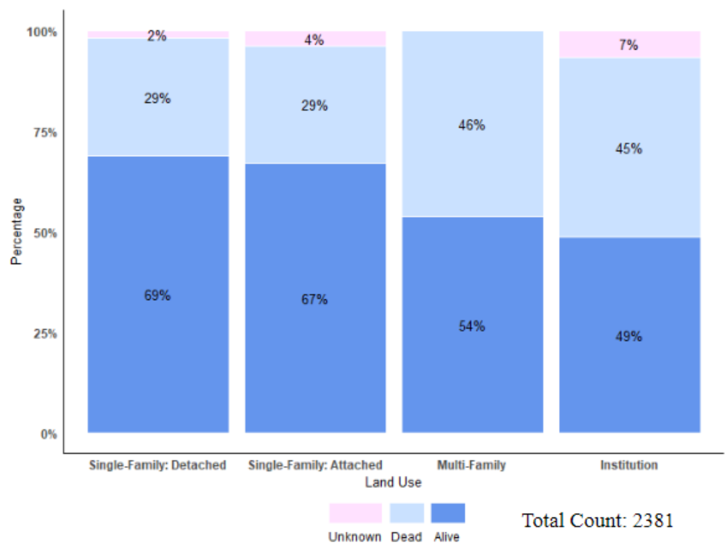

Figure 23. Bar graph of percent survivorship based on land use

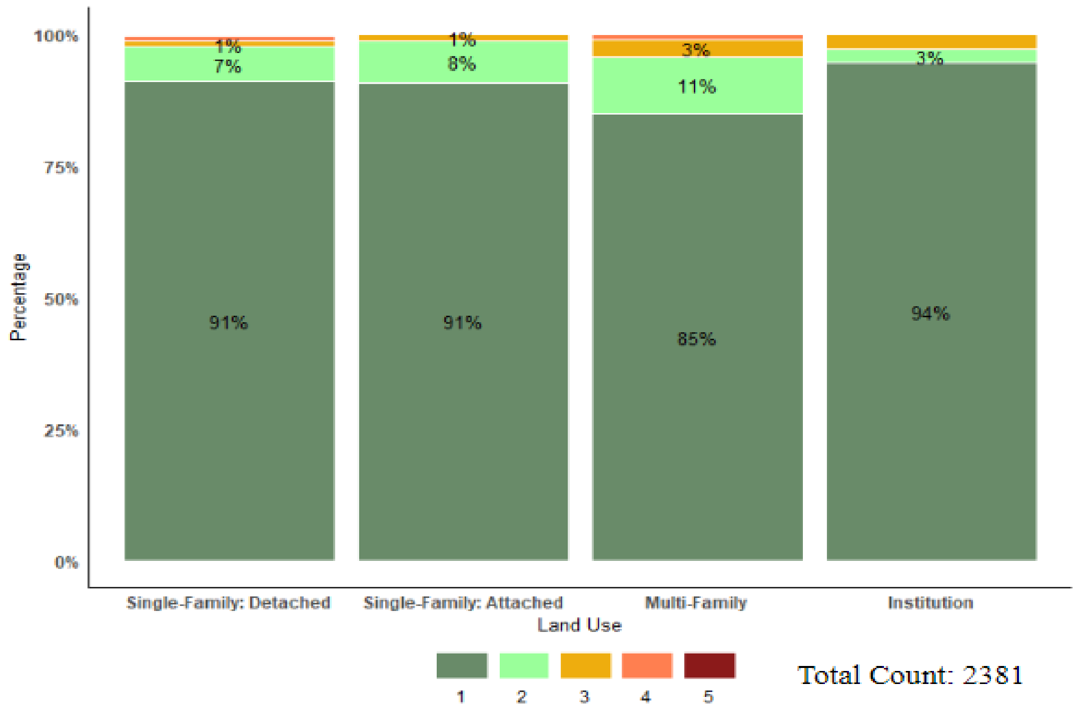

Figure 24. Bar graph of percent vigor based on land use

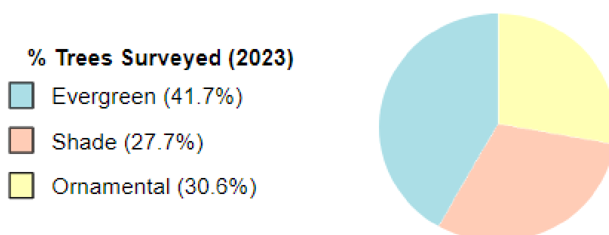

Figure 25. Pie chart of the percent of trees surveyed based on tree type

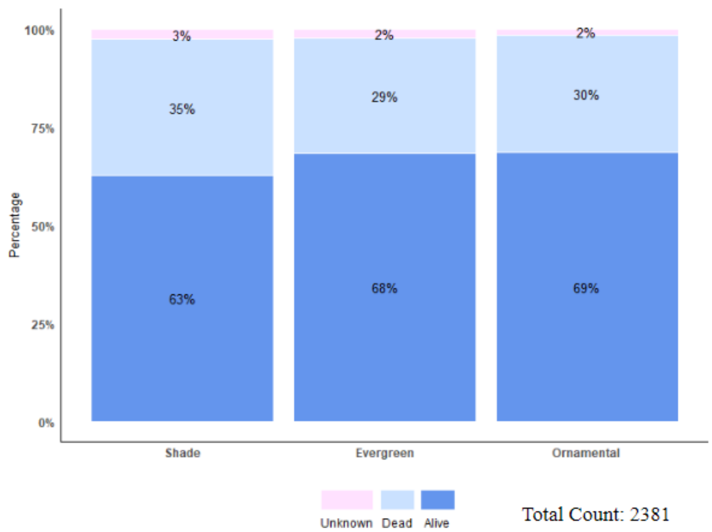

Figure 26. Bar graph of percent survivorship based on tree growth form

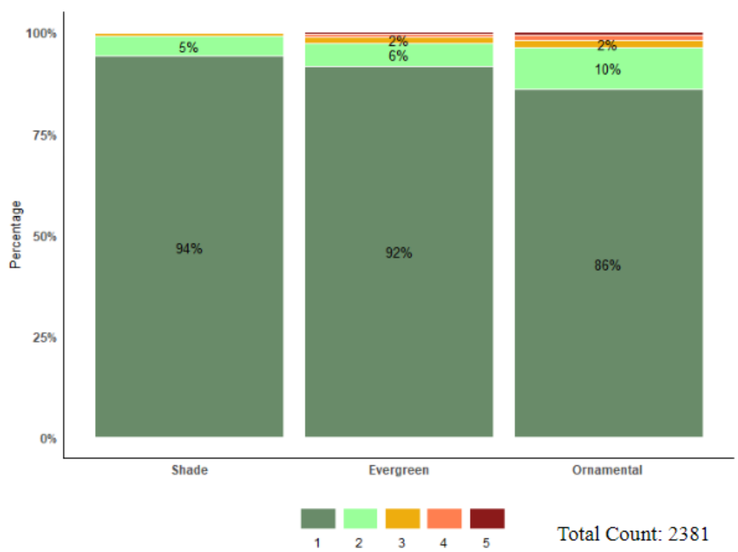

Figure 27. Bar graph of percent vigor based on tree type

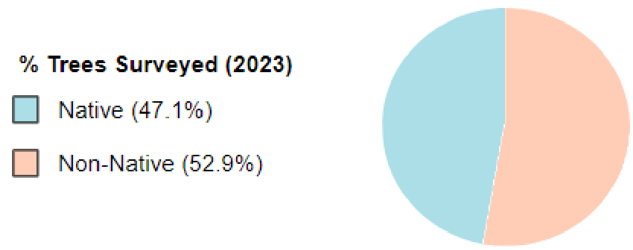

Figure 28. Pie chart of the percent of trees surveyed based on native status

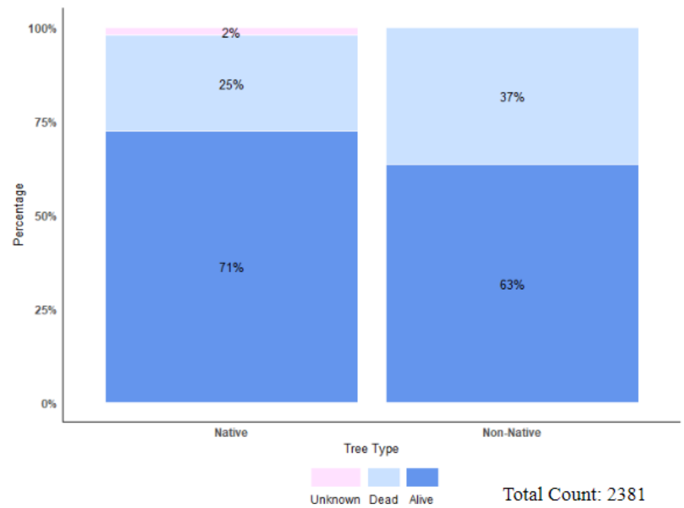

Figure 29. Bar graph of percent survivorship based on native status

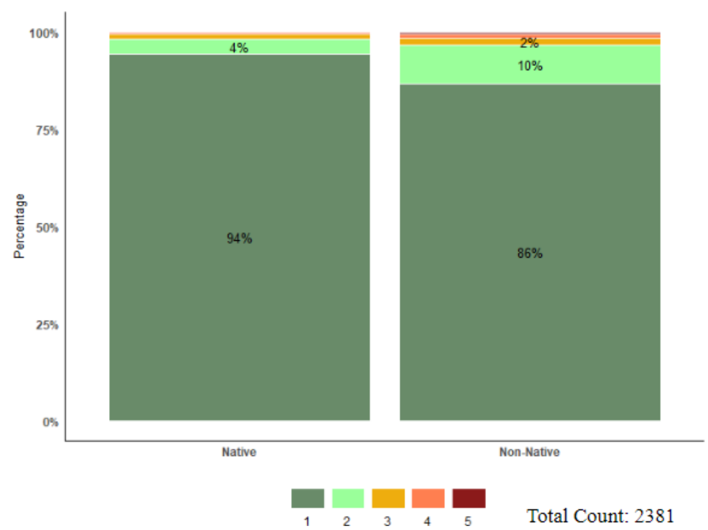

Figure 30. Bar graph of percent vigor based on native status

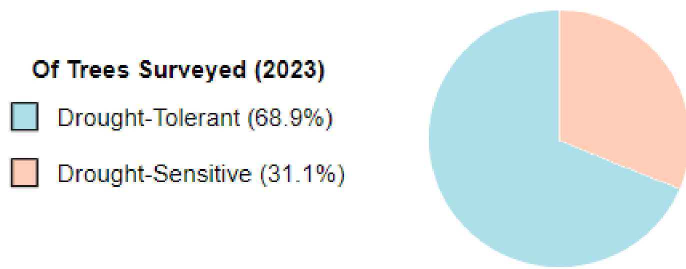

Figure 31. Pie chart of the percent of trees surveyed based on drought tolerance

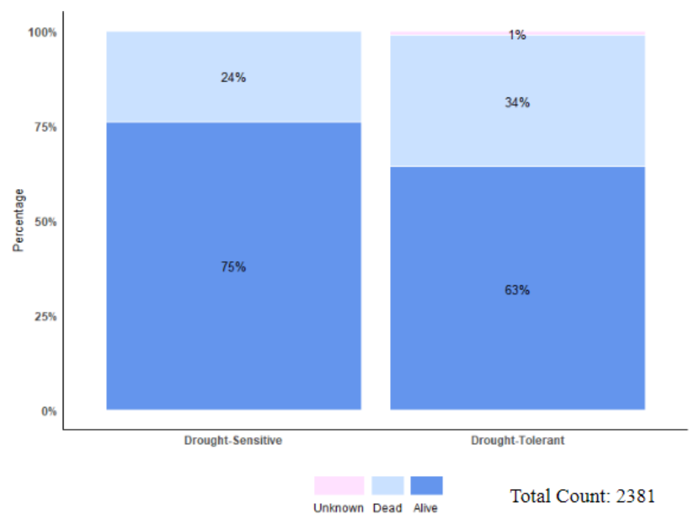

Figure 32. Bar graph of percent survivorship based on drought tolerance

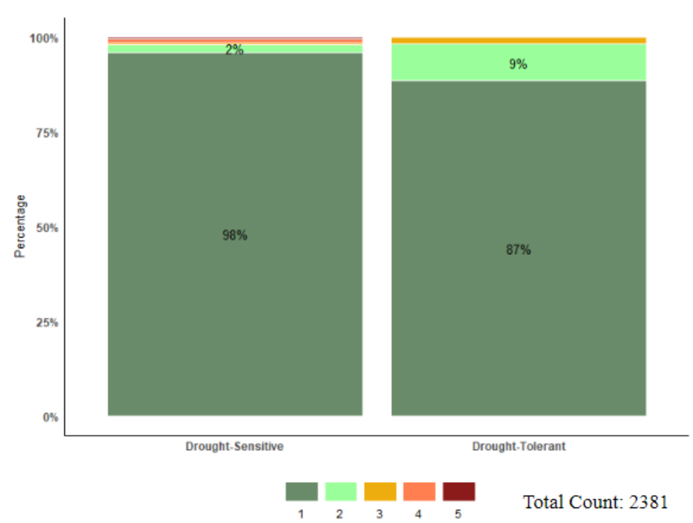

Figure 33. Bar graph of percent vigor based on drought toleranc

5.1.3 Tree Change on Private Property

We saw a lot of change from baseline and 2023 in terms of survivorship, height, DBH, and width. The species on this graph all had a minimum count of 14 in both our baseline and 2023 survey. Annual survivorship incorporates the number of years a tree has been alive and allows us to compare the baseline and 2023 surveys. We expect a lower rate of survivorship in the establishment phase of a tree, and then for the survivorship to start to increase after maturity. For most species, we see this. *Quercus rubra* (red oak) as an example, at our baseline, annual survivorship is 92% which means for the approximate 3 years since planting, 92% of the existing *Quercus rubra* (red oak) population will survive each year. In 2023, annual survivorship is 97% which means for the 12 years since planting, 97% of the existing population will survive each year.

Therefore, the difference in survivorship is about 5% (Figure 34). However, there are a few exceptions. *Prunus avium* (cherries) had unusually high survivorship for the establishment phase and so any problems with the species, either social or biophysical, lead to a decrease in annual survivorship. *Thuja occidentalis* (american arborvitae) were often planted in rows as a living fence, and when changes were made to landscaping, we often found whole rows of them removed which we think contributed to the negative value. Change analysis was also conducted for residential trees by filtering out just the trees that were surveyed in both the baseline and 2023 surveys, and comparing their change in height, width, and DBH. Negative values of change were deemed to be data collection errors and removed from the dataset. *Liriodendron tulipifera* (tulip) had the greatest growth in height, followed by *Quercus rubra* (red oak), and *Tilia cordata* (littleleaf linden) (Figure 35). *Liriodendron tulipifera* (tulip), *Quercus rubra* (red oak), and *Tilia cordata* (littleleaf linden) also had the three greatest growth in crown width as well (Figure 36). *Prunus serrulata* (snow goose cherry), had the largest increase in DBH, followed by *Liriodendron tulipifera* (tulip), and *Prunus spp.* (cherry) (Figure 37).

To summarize some of our findings, *Liriodendron tulipifera* (tulip), *Tilia cordata* (littleleaf linden), and *Tilia* (linden) performed the best out of our shade trees across several metrics. In most metrics, *Prunus serrulata* (snow-goose cherry) performed the best out of the members in the cherry genus, and *Syringa reticulata* (Japanese tree lilac) was the highest survivorship ornamental tree (Figure 38).

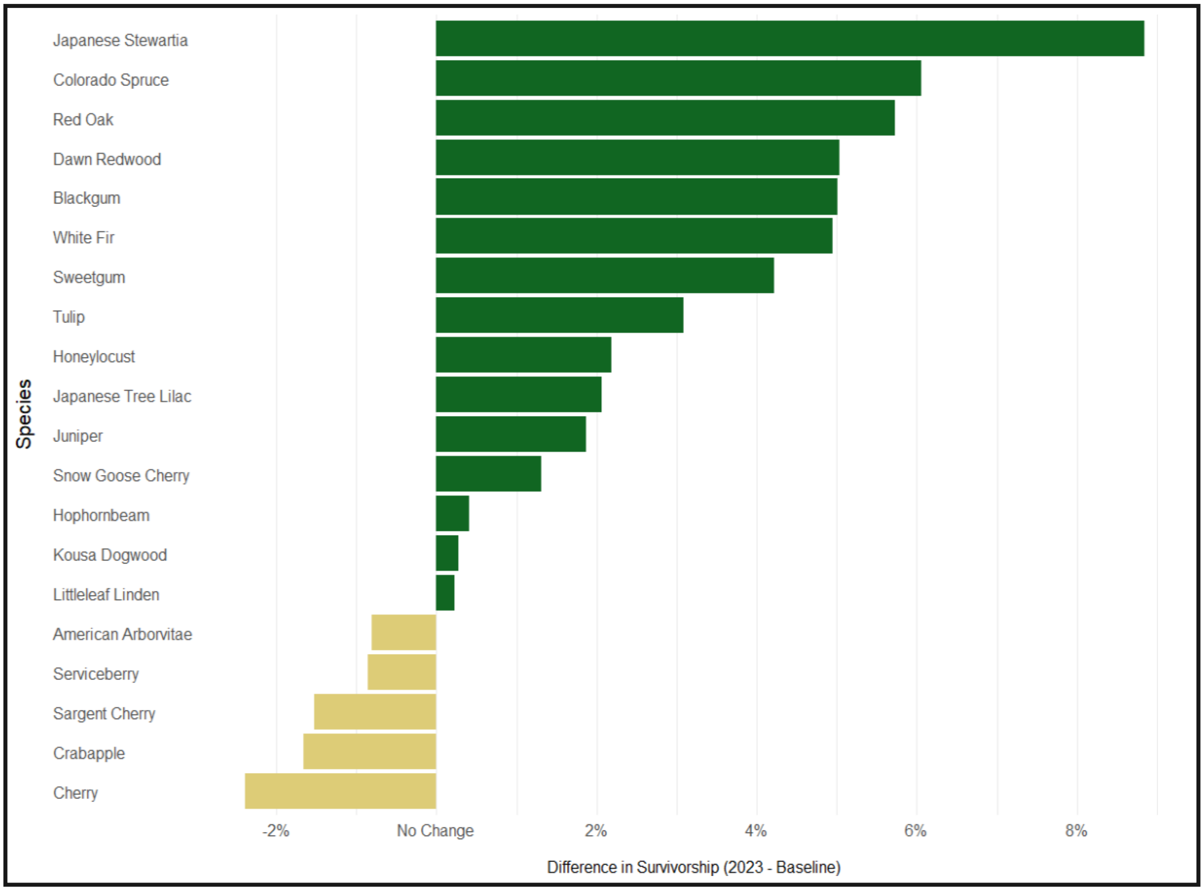

Figure 34. Dual bar graph depicting change in annual survivorship between species with count greater than or equal to 14

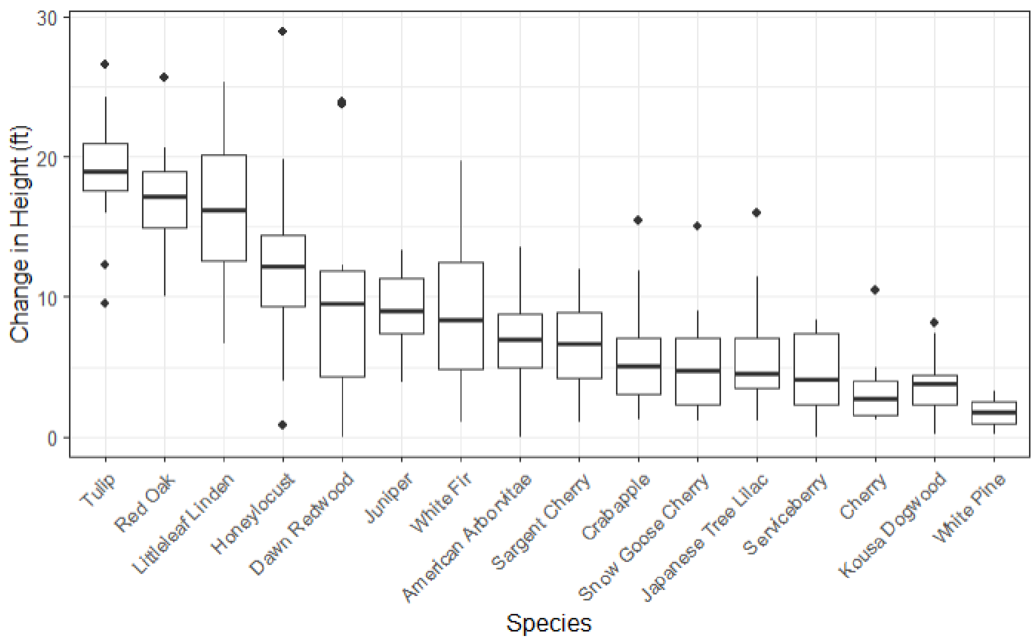

Figure 35. Box and whisker plot depicting change in height between baseline and 2023 survey, ordered by mean change

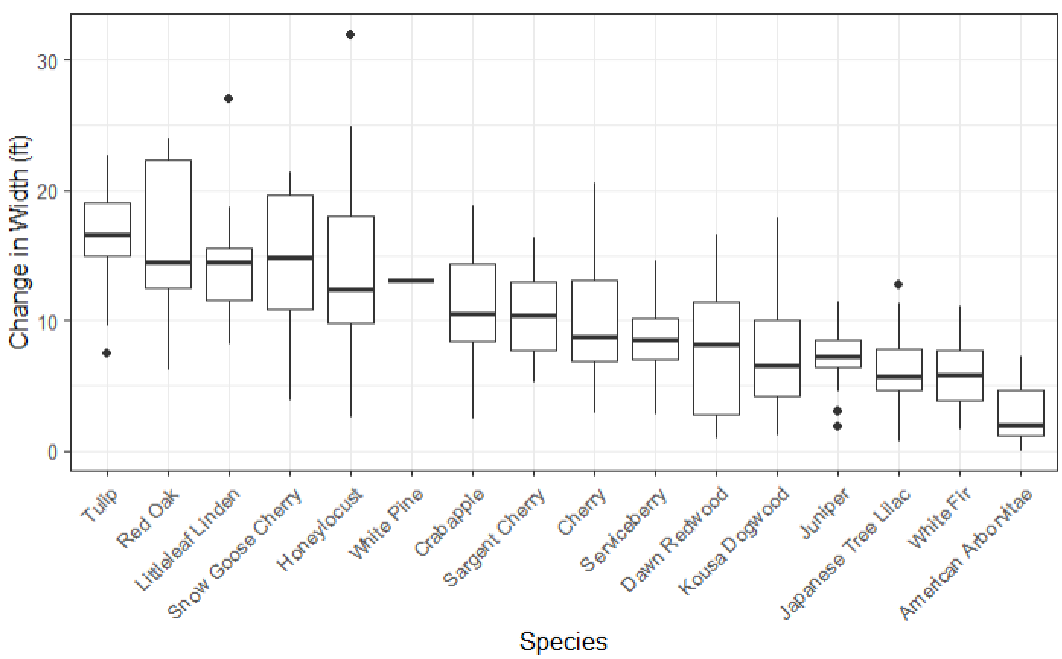

Figure 36. Box and whiskers plot depicting change in tree crown width, sorted by mean change highest to lowest

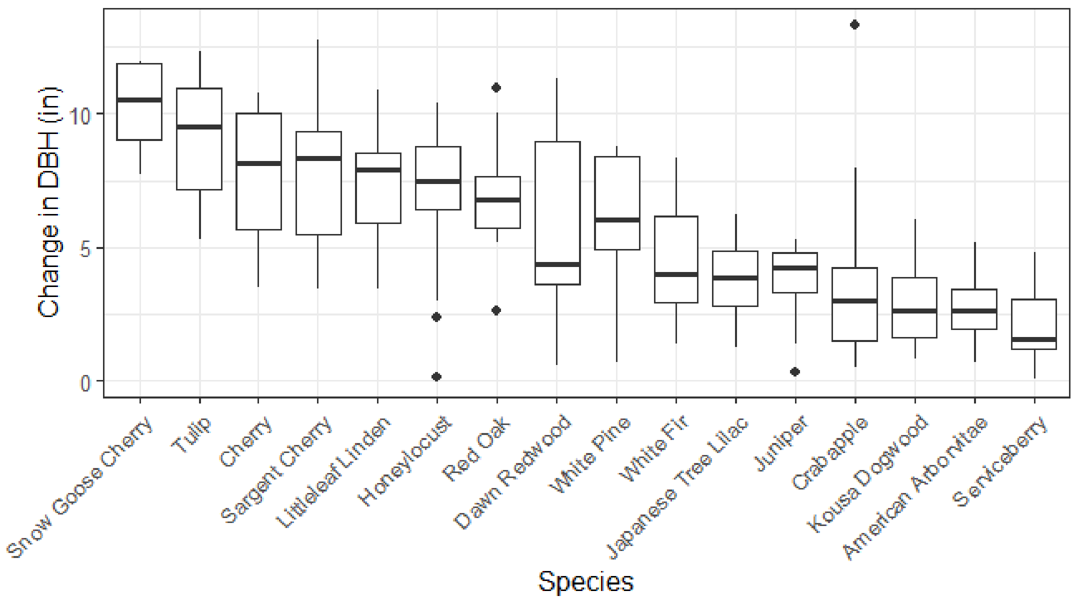

Figure 37. Box and whiskers plot depicting DBH growth from baseline to 2023 survey, ordered by mean growth

Table 3. Description of tree species structural change in terms of height, crown width, and DBH growth.

Top 5 change species	Height (ft)	Change from baseline (ft)
Tulip	35.7	18.9
Red Oak	29.0	16.8
Littleleaf Linden	29.7	16.5
Honeylocust	28.6	12.3
Dawn Redwood	24.6	11.1

Bottom 5 change species	Height (ft)	Change from baseline (ft)
White Pine	11.9	1.73
Kousa Dogwood	13.3	3.5
Cherry	16.5	3.6
Serviceberry	14.3	4.8
Japanese Tree Lilac	17.4	5.4

Top 5 change species	Crown width (ft)	Change from baseline (ft)
Tulip	25.5	16.3
Red Oak	23.6	15.8
Littleleaf Linden	22.0	14.1
Snow Goose Cherry	30.3	14.1
Honeylocust	25.7	13.6

Bottom change species	Crown width (ft)	Change from baseline (ft)
American Arborvitae	7.2	2.9
White Fir	11.7	5.8
Japanese Tree Lilac	12.6	6.3
Juniper	11.6	7.2
Kousa Dogwood	15.3	7.6

Top 5 Change species	DBH (in)	Change from baseline (ft)
Snow Goose Cherry	12.6	10.4
Tulip	10.5	9.3
Cherry	9.2	7.7
Sargent Cherry	8.8	7.6
Littleleaf Linden	8.4	7.4

Bottom 5 change species	DBH (in)	Change from Baseline (in)
Serviceberry	2.8	2.1
American Arborvitae	3.4	2.7
Kousa Dogwood	3.7	2.9
Crabapple	4.2	3.6
Juniper	4.3	3.7

5.1.4 Street Trees

Street trees overall had very high survivorship in both the baseline and 2023 survey (98.5% and 88.6%), about 22% higher than private trees (77.1% and 66.9%). The was an even distribution of survivorship across the streets we examined (Figure 38). Street trees had high vigor and condition as well (Figure 41). We hypothesize the high survivorship and good health was due to regular watering by the WTI Young Adults Foresters Program during the first few years post-planting. In addition, there are fewer street tree removals due to street trees not competing with yard amenities and landscaping changes. There was less species diversity in street trees, but a higher percentage of shade trees compared to private plantings.

We saw high survivorship in street trees overall in both our baseline and 2023 survey. In our baseline survey, street trees had a survivorship of 98.5%, and in our 2023 survey they had a survivorship of 88.6%, a difference of 9.9% (Figure 40). In 2023, the survivorship ranged from 100% with the *Pyrus calleryana* (calory pear), *Syringa reticulata* (Japanese tree lilac), and *Quercus rubra* (red oak), to 60% survivorship with *Zelkova serrata* (zelkova) (Figure 42). *Quercus palustris* (pin oak) were the most frequently planted trees by the WTI in our sample. In terms of individual species growth, *Quercus rubra* (red oak) had the greatest growth in height and width, and the second greatest growth in DBH (Figures 43-48). *Prunus avium* (cherry)species grew the least in height and width, but the most in DBH (Figures 43-48). Overall, the shade trees have the largest growth numbers for each metric, except DBH, which cherries grew the most.

We saw that overall that street tree survival and growth was higher than the private trees. In our 2023 survey, private trees had a survivorship of 66.9%, compared to street trees' survivorship of 88.6%. When analyzing the growth of species, *Quercus rubra* (red oak) grew taller by 6.05 feet, wider by 7.5 feet, and had an increase in DBH by 3.1 inches, in the street compared to private plantings. *Gleditsia triacantho*s (honeylocust) had a higher width by 7.75 feet, and a larger DBH by 2.75 inches. Generally, trees on the street grew higher in most metrics according to our survey. However, some species were more successful on private residential land than on the street. *Syringa reticulata* (Japanese tree lilacs) grew 1.4 feet wider, 3.65 feet taller and 0.5 inches in DBH on private residences when compared to plantings on streets. Similarly, *Prunus avium* (cherry) and *Cornus* (dogwood) did better on private residences than on the street (Figures 46-48, Table 4).

Figure 38. Map depicting location of alive, removed/dead, and unknown trees in our sample

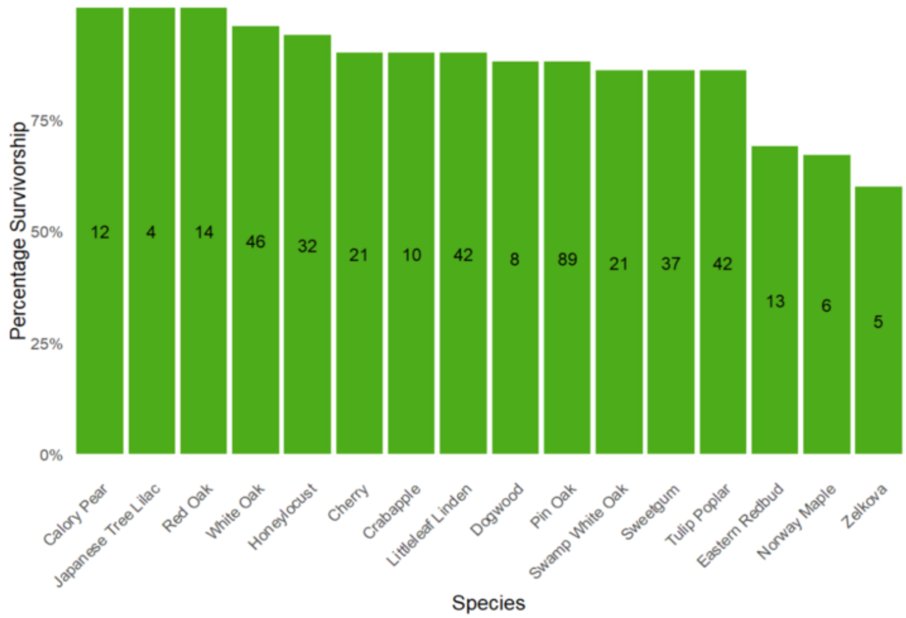

Figure 39. Bar graph depicting average survivorship per species for street trees

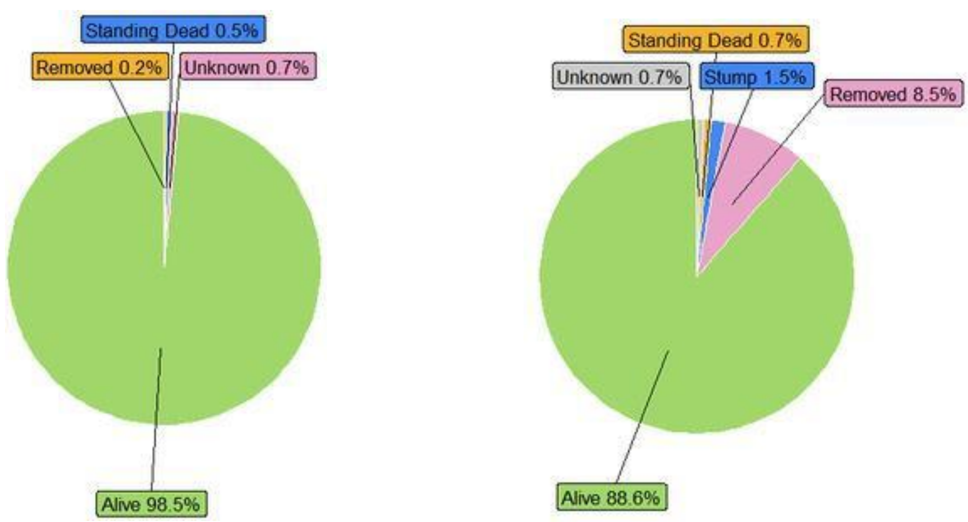

Figure 40. Set of pie charts depicting street tree survivorship from baseline and 2023 survey

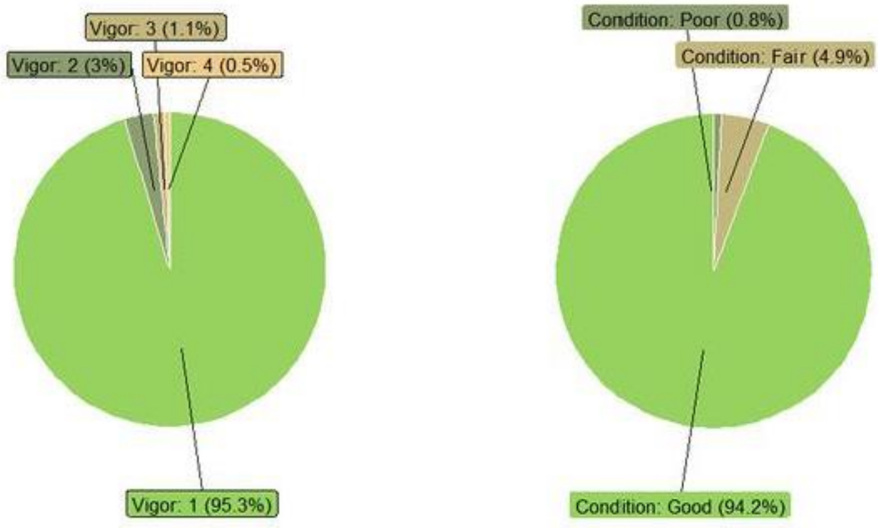

Figure 41. Set of pie charts depicting street tree vigor and condition from the 2023 survey

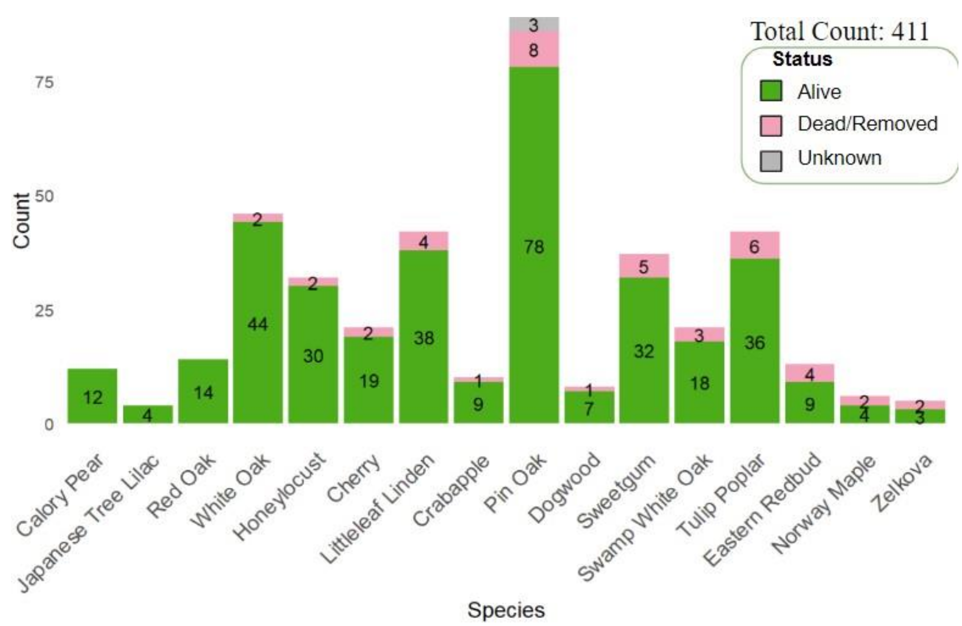

Figure 42. Bar graph depicting street trees with a count of 4 or greater, ordered by survivorship percentage

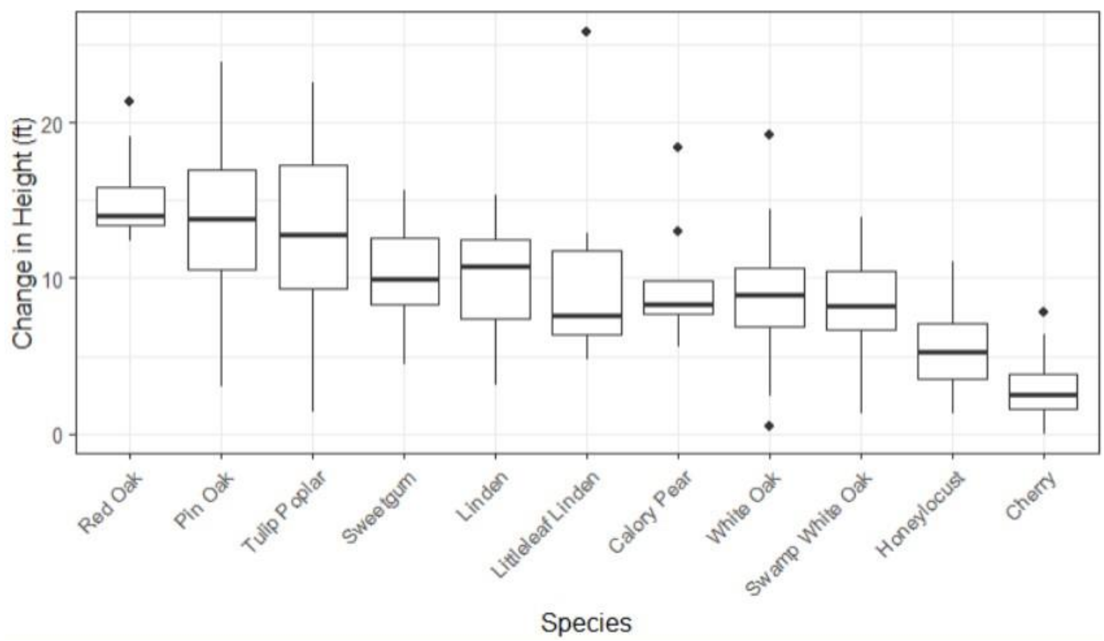

Figure 43. Box and whisker plot of change in height between baseline and 2023 by species

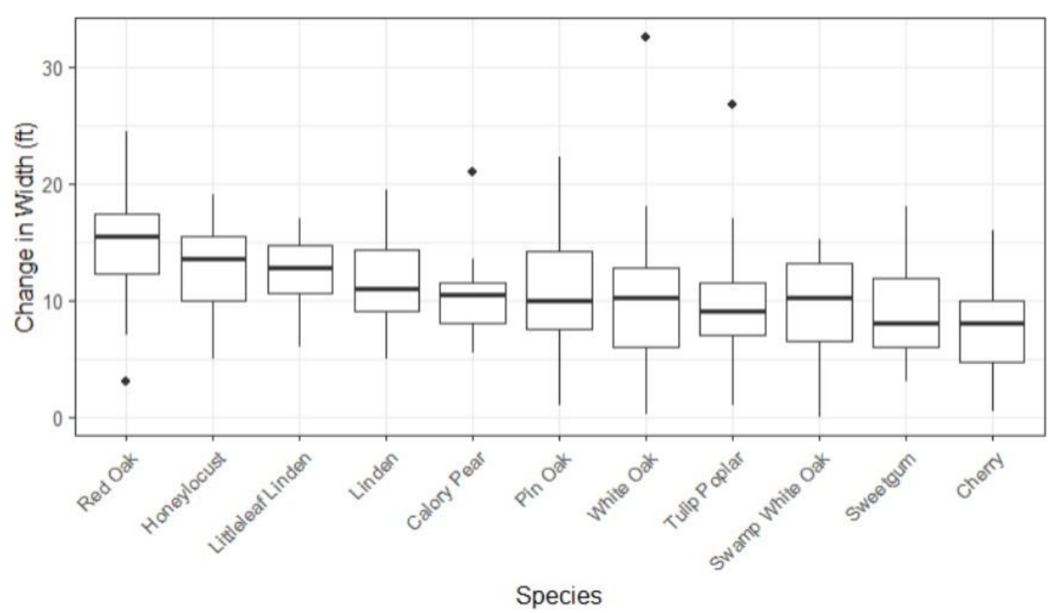

Figure 44. Box and whisker plot of change in width between baseline and 2023 surveys by species

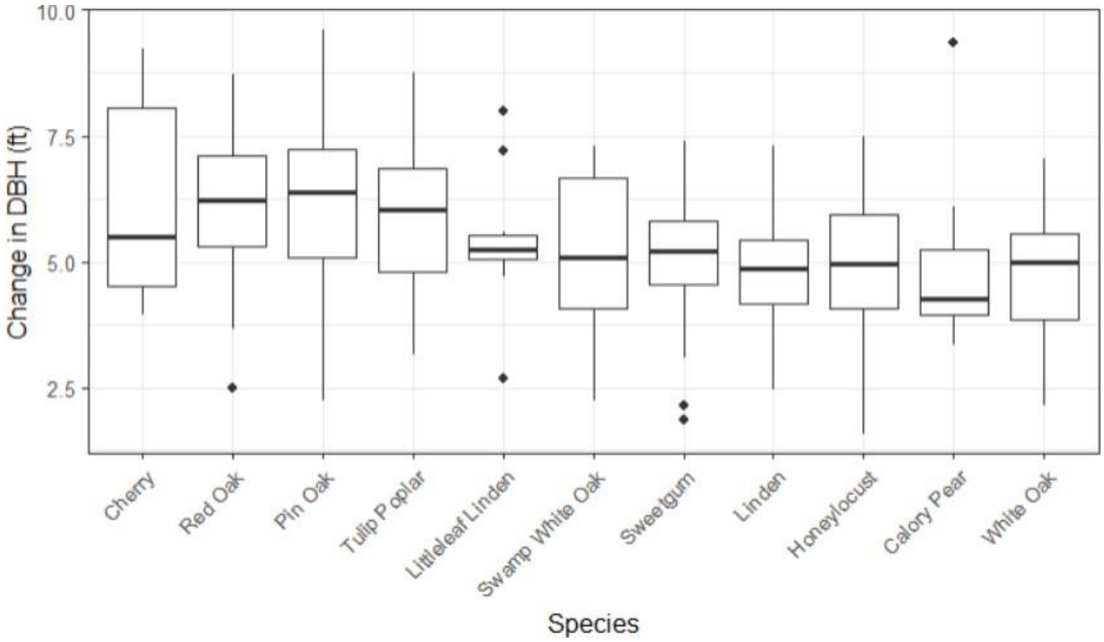

Figure 45. Box and whisker plot of change in DBH between baseline and 2023 surveys by species

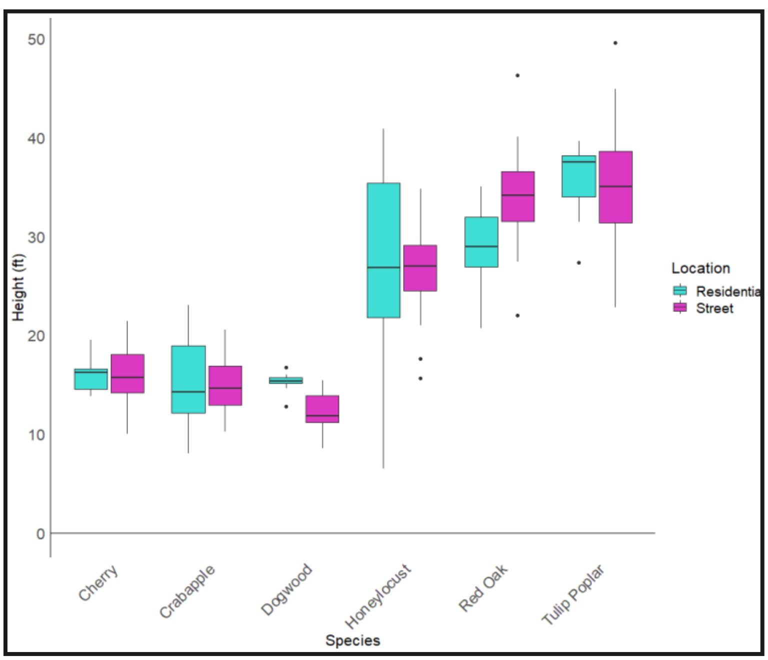

Figure 46. Box and whisker plot comparing height between street and residential plantings

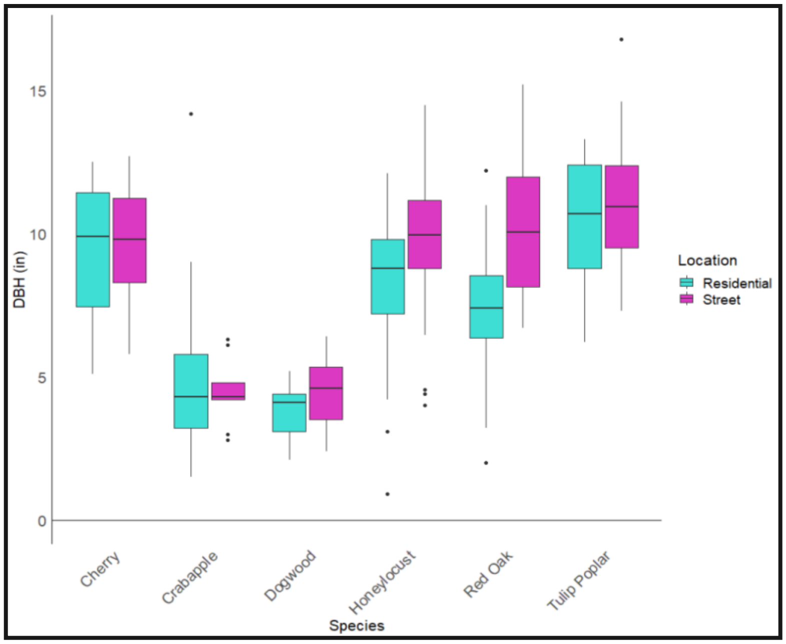

Figure 47. Box and whiskers plot comparing DBH between street and residential plantings

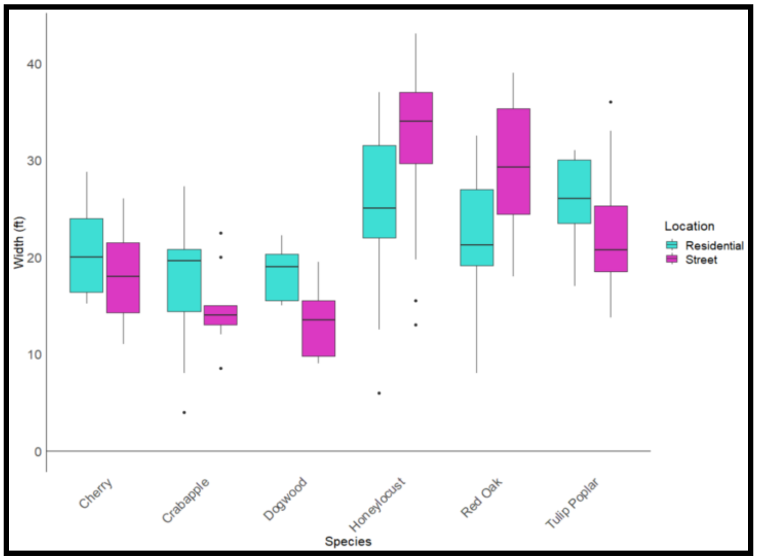

Figure 48. Box and whiskers plot comparing crown width between street and residential plantings

Table 4. Table showing the difference in median width, height, and DBH between planted street and residential trees from the 2023 survey. Negative values indicate a higher value in residential plantings.

	Width	Height	DBH
American Elm	7.5	4.9	1.3
Black Gum	10.42	13.5	6
Cherry	-0.25	-1.45	1.1
Crabapple	-1	-0.1	-0.1
Dogwood	-1.75	-2.8	1.65
Honeylocust	7.75	0.35	2.75
Japanese Tree Lilac	-1.4	-3.65	-0.5
Kousa Dogwood	-0.25	3.2	1.8
Littleleaf Linden	1.1	-2.05	1.15
Pin Oak	1	4.5	1.125
Red Oak	7.5	6.05	3.1
Serviceberry	-9.5	-4.9	0.1
Swamp White Oak	8.375	6.5	5.6
Sweetgum	0	5.55	4.5
Tulip Poplar	-3.75	-2.1	0.65
Zelkova	-2.5	-0.6	-1.9

Figure 49. A *Quercus rubra* (red oak) planted in the shade on a private property (pictured left) and next to the street (pictured right)

Figure 50. A *Gleditsia triacanthos* (honeylocust) planted on a private property (pictured left) and next to the street (pictured right)

6 Social Assessment

6.1 Sample Population

Our interviews were distributed throughout our study area (Figure 51), and our sample represents about 10% of our target population. Additionally, nearly 10% of the total private trees we surveyed were on interviewee's property. The average survivorship for these trees was 77%, which is 10% higher than average for the study area. Interviewees had an average of 6 trees per property. It is important to note that 11 interviewees did not have DCR trees planted on their property, but all interviewees had experience with trees being removed on or nearby their property during the Longhorned Beetle outbreak.

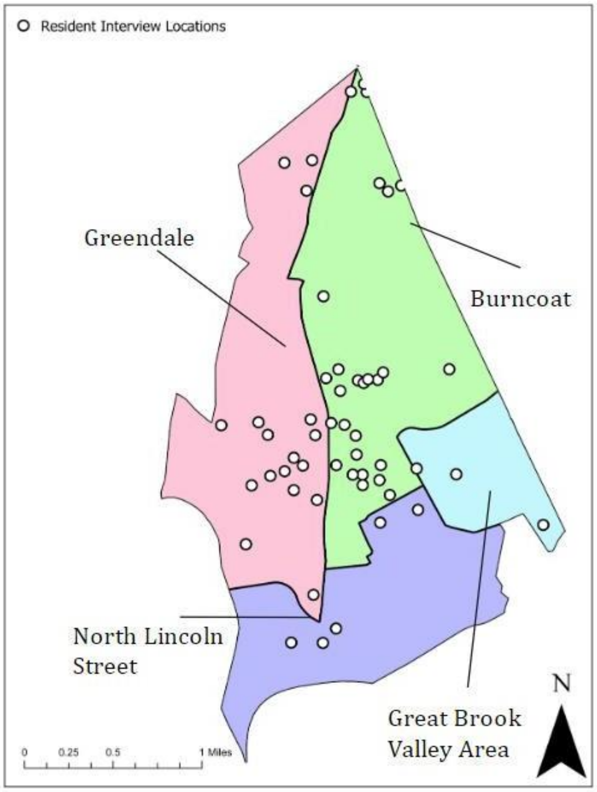

Figure 51. Distribution of resident interview locations in the study area. 27 interviews in Burncoat, 17 in Greendale, 3 in Great Brook Valley Area, and 5 in North Lincoln Street

The convenience sampling method we employed is reflected in the demographics of our interviewees. Our sample was generally whiter, older, and had received more formal education than the populations of both our study area and Worcester as a whole (Table 5).

Table 5. Key socioeconomic variables in Worcester, study area, and sample

Demographic Variables	Worcester	Study Area	Interviewees
Percent English Limited	12.10%	9.1%	5.6%
Percent White	48%	56%	92%
Percent Renter	59%	47%	2%
Median Household Income	$61,106	$72,243	>$75,000
Percent Bachelors Degrees	31%	36%	71%
Population	206,518	23,492	52
Average Age	34.6	37.5	65+

Additionally, our sample population showed a dramatic skew towards homeowners (Figure 52). The average number of years an interviewee had lived in their home was 26 years.

These demographics demonstrate that our average interviewee has lived on their property for a long time and cares deeply about their neighborhood.

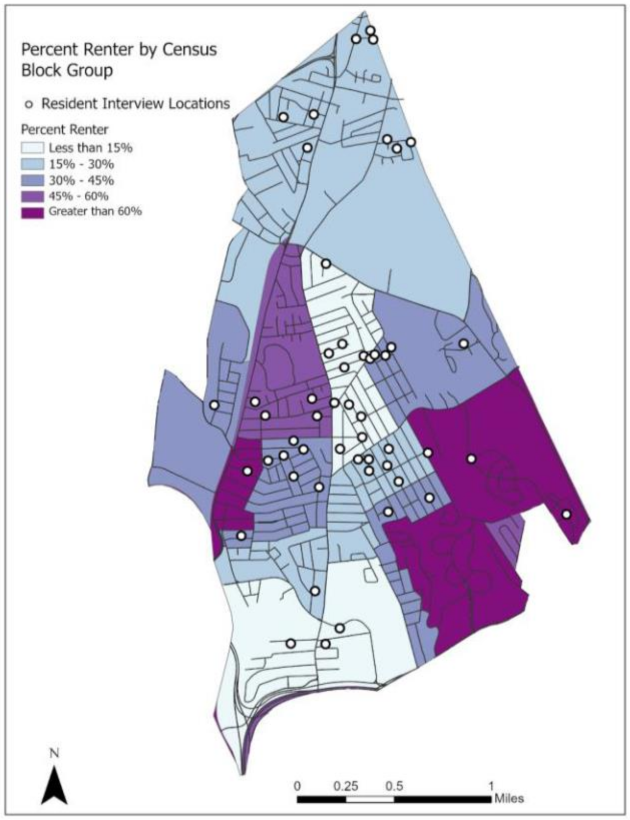

Figure 52. Interviews in study area with percent renter census block
Note. This map illustrates the skew towards homeowners in our sample.

6.2 Residents' Perceptions and Experiences

6.2.1 Perceptions of Tree Benefits

Interviewees had varying perceptions of tree benefits which were identified through a qualitative analysis of interviews (Figure 53). Residents identified 17 key benefits of having trees on their properties. The top five were shade (81%), aesthetics (65%), wildlife (40%), privacy (35%), and energy savings (29%). The most frequently reported benefit reveals that residents value canopy cover for the shade and the natural cooling effects, which could also lead to perceived and actual energy benefits. Aesthetics, or more specifically, "beautification", was brought up by many residents. This shows that beauty and design play a large role in residents' decision-making regarding tree planting. Notably, there is a potential link between the perception of energy savings and shade as key benefits, as more shaded properties might have lower energy costs due to decreased usage of air conditioning. Other benefits in order of prevalence mentioned by interviewees are listed in Figure 53.

We also looked at resident perceptions of tree benefits across different geographical scales, namely individual trees, the resident's property, and the larger neighborhood (Figure 54). At the individual tree scale, many interviewees listed ecosystem services such as shade, aesthetics, presence of wildlife (e.g. birds, squirrels), noise reduction, and cooling (from shade). At the property scale, residents reported that trees add economic and aesthetic value to their property. At the neighborhood scale, residents emphasized the importance of trees mitigating environmental concerns such as lower air quality and extreme heat. They also reported enjoying having tree lined sidewalks and streets in their neighborhood, which is both aesthetically pleasing and leads to a sense of peace. It is important to note that aesthetics are valued across individual, property and neighborhood making aesthetics an important motivation for residents to engage in tree planting.

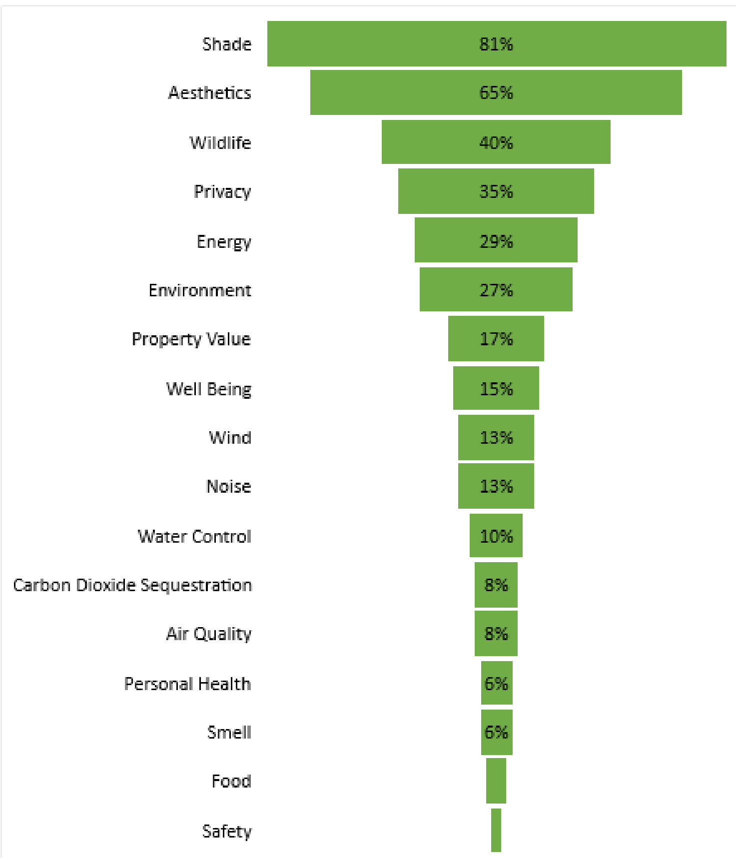

Figure 53. Resident perceptions of tree benefits. Note. Some interviewees mentioned multiple benefits, so percentages do not add to one hundred.

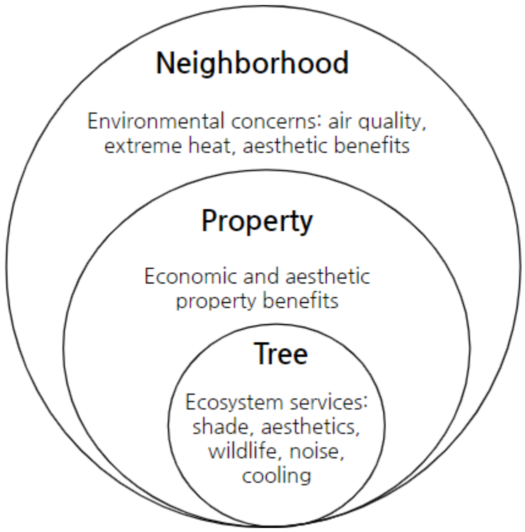

Figure 54. Tree benefits by scale

6.2.2 Perceptions of Tree Challenges

Most challenges reported by residents involved property maintenance, hazards, or space limitations caused by trees on their properties. We identified 7 categories, of which the top three were leaves/cleanup (48.1%), hazard/damage (34.6%), and wildlife/environment (32.7%). The most reported barrier was the clean up of leaves and branches caused by both trees on residents' property and those surrounding. Hazards/damage mostly involved fears around property damage during or after storms but included other safety concerns such as hazards to children and pets.

Root systems growing into gas or sewage lines was a commonly expressed concern. In the wildlife/environment category, residents were concerned about wildlife that entered homes or destroyed gardens, as well as trees obstructing sunlight in some cases. The full list of tree challenges reported by interviewees are listed in order of frequency in figure 55.

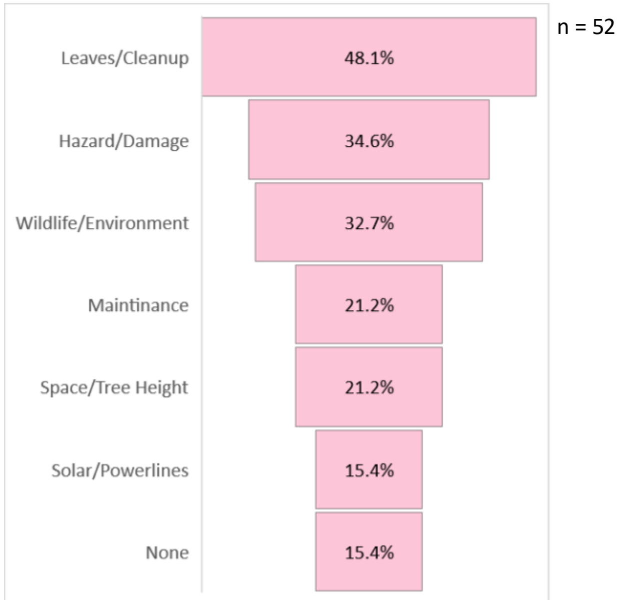

Figure 55. Resident perceptions of tree challenges

Note. Some interviewees mentioned multiple challenges, so percentages do not add to one hundred.

6.2.3 Perceptions of the Tree Removal Policy following the Longhorned Beetle

We asked residents about their perceptions of the USDA's tree removal policy following the Longhorned Beetle outbreak, a decade after its implementation. We categorized residents' perceptions as positive, neutral (including mixed perceptions), negative, and not present (the interviewee was not present in the regulation zone at the time of tree removal). A majority of residents reported positive (30.8%) or neutral (38.4%) perceptions. Residents with positive opinions of the removal policy stated that the policymakers responded appropriately to a crisis and prevented large-scale tree loss across the northeastern forests even if they were saddened by the tree loss. Those who had mixed perceptions communicated feelings of anger and sadness, but recognized the necessity of this policy and its timeliness in retrospect. 13.5% of interviewees had strong negative perceptions of the removal policy, stating that some neighborhoods were treated more unfairly than others, that the devastating impacts outweighed the potential benefits, or that financial incentive drove the execution of the removal policy rather than it being a necessary measure. Lastly, 17.3% of interviewees either were not present when this policy was implemented or had no answer.

6.2.4 Experience with the DCR Planting

Interviewees were also asked about their experience with the DCR's tree planting program. Responses were again categorized as positive, neutral (including mixed perceptions), negative, and not present (at the time the DCR trees were planted on their properties). Almost half of the interviewees (46.2%) reported positive experiences with the planting program, describing how the DCR foresters were very friendly and knowledgeable, held discussions about tree species, and involved the residents in the decision making process. One resident reported,

> *"When that program came through to reforest, that was very welcomed, very embraced, you know, they came through and they offered to plant. And… it felt like someone cared about our little neighborhood here."*

About a quarter of our interviewees (26.9%) had a neutral experience with the planting program, reporting that it was "*fine*" and that the DCR just came in and did their job. A notable percentage (17.3%) had a negative experience, citing lack of communication or too many people coming onto their properties as their source of dissatisfaction with the program. Those who were not present at the time of planting (9.6%) were often relatively new to the area. They had bought the property from previous homeowners who chose to have DCR trees on their property, and some new homeowners continued to take care of them while others removed them.

6.2.5 Perceptions of Neighborhood Recovery

To assess the role of the DCR's planting program in neighborhood recovery, we asked residents if their neighborhood felt similar to before the Longhorned Beetle outbreak. Resident opinions were split pretty evenly, with 40.4% saying that their neighborhood had recovered, and 38.5% saying that their neighborhood had not recovered. One resident expressed,

> "*It hasn't fully recovered from that… I still have memories of the Norwegian Maples creating this green canopy, you know, over the street, you could… walk through a tunnel of green… It's still a little bit bare compared to my memory of it as a kid growing up in this neighborhood.*"

The remaining 21.1% of interviewees were not present or had no answer. In order to understand how location plays into resident perceptions of neighborhood recovery, we plotted interviewees' neighborhoods on a map of the study area along with tree canopy loss (*circa* 2009) attributed to the Longhorned Beetle (Figure 56). We plotted residents who thought the neighborhood had recovered as blue points, those who thought the neighborhood hadn't recovered as orange points, and those with no answer as gray points. We observed that residents who had felt more recovery lived in the northern and more suburban sections of the study area. Those who were located in the central section of the study area, which was heavily impacted by the Longhorned Beetle, had very mixed opinions on neighborhood recovery. Though we did not interview many residents in the North Lincoln Street area, all of them felt that their neighborhood had not recovered, despite there being relatively less tree canopy loss in that location.

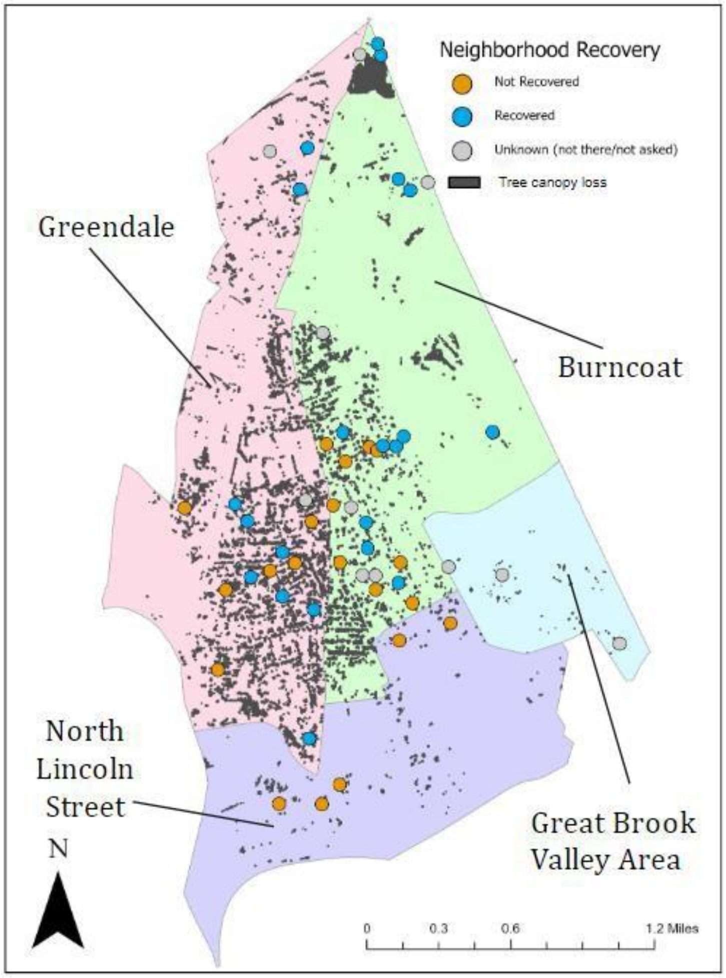

Figure 56. Residents' opinions on neighborhood recovery within study area

6.2.6 Who is Stewarding Trees

Identifying effective tree stewards could inform tree planting initiatives in a way that promotes tree retention and health. Interviewees were asked who maintains the trees on their property, if anyone. The majority of interviewees (78%) reported that their trees were stewarded by themselves or someone else in their immediate household. Other steward categories included professionals (among which are the Bartlett Tree Experts), nature (as explicitly cited by interviewees), and friends/family (Figure 57).

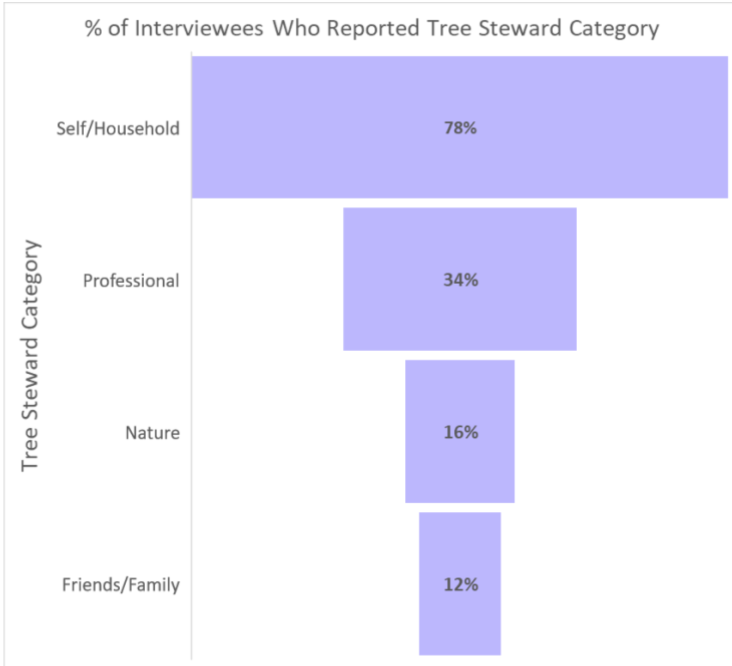

Figure 57. Commonly identified tree stewards of resident's trees
Note. Some interviewees mentioned multiple tree stewards, so percentages do not add to one hundred.

While assessing the average survivorship of trees by steward, we see that trees on properties where interviewees report caring for trees themselves have the highest average survivorship, at 82% (Table 6). Interestingly, this category has even higher survivorship than trees maintained by professionals (71%). This indicates that those who have a sense of personal connection and agency over their trees could have better tree survivorship, but this association could also be attributed to other factors, such as better attention and care towards trees that are maintained by residents. Some interviewees also said that they left their trees to be taken care of by nature, and often performed little to no maintenance (e.g. pruning branches growing too close to their house). This category has the second highest average survivorship, at 77%.

Table 6. Average survivorship by tree steward

Tree Steward	Interviewees (n)	Trees (n)	Average Survivorship
Self/Household	39	149	82%
Nature	7	23	77%
Professional	17	93	71%
Friends/Family	6	13	70%

6.2.7 Stewardship Activities

We asked residents to describe the ways they care for their trees both at the time of planting and present day while asking about watering, pruning, and mulching habits (Figure 58). We found that watering was the most frequently identified activity at the time of tree planting.
Many interviewees diligently watered their trees the first few years and gradually stopped as they said their tree "took." 39 residents stated that they regularly watered at the time of planting, while only 24 continued watering in 2023. As for current stewardship activities, pruning was the most frequent. The need for pruning grew along with the tree as branches began to encroach on buildings, driveways, power lines, neighbors' yards, etc. 34 interviewees stated that they are pruning their trees a few times a year, even in 2023, as opposed to only 27 residents who pruned their trees in the first few years of planting. Even fewer residents mulched their trees, with little difference between mulching at the time of planting (14) and in 2023 (13). Fertilizing and pest control were the least frequently identified activities. The full list of tree stewardship activities reported are listed in order of frequency in Figure 58.

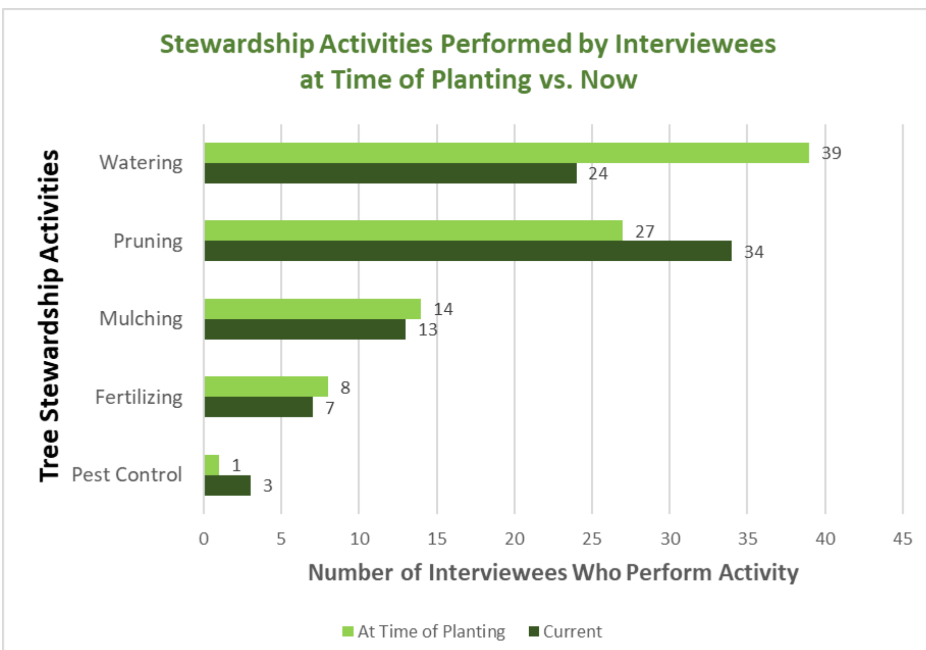

Figure 58. Stewardship activities performed by interviewees at time of planting vs. 2023

We found through this study that watering young trees in the first few years of planting resulted in notable differences in average survivorship (as assessed in 2023). As shown in Table 7, people who watered their trees during the initial stages had an average tree survivorship of 80%, while those who didn't had an average survivorship of only 66%. Overall, we found that the impact of continued watering diminishes as the trees mature. Once the trees are established, the difference in survivorship between those watered (78% average survivorship) and those not watered (77% average survivorship) is not significant.

Table 7. Average survivorship of trees watered or not watered at time of planting
Note. "At time of planting" refers to the period of up to two years following initial planting.

Watering at Time of Planting	Interviewees (n)	Average Survivorship
Not Watered	13	66%
Watered	39	80%

Watering 2023	Interviewees (n)	Average Survivorship
Not Watered	28	77%
Watered	24	78%

6.2.8 Past Experience with DCR Planting and Stewardship

As part of our analysis, we assessed how residents' past experiences and beliefs affect their tree stewardship. We compared residents' experience with the DCR planting to the average survivorship of trees on their properties (Table 8). Those who were not present at the time of planting, often newer homeowners, had the lowest average tree survivorship, at 41%. This could be explained by the tree removals due to changes in homeownership, whether it's by the seller to beautify their property or by the buyer to personalize their new homes to their liking. People with positive opinions of the planting had the highest average survivorship, at 85%. Interviewees with positive experiences also had the highest average number of trees planted on their property, at 7.79 trees. It could be that those who had more trees which were doing well on their properties, later formed more positive opinions of the DCR's planting program, so these variables could be influencing one another.

Table 8. Residents' DCR planting experience and average tree survivorship

DCR Planting Experience	Average Trees Planted on Property	Average Survivorship	Interviewees (n)
Not Present	4.75	41%	5
Negative	5	66%	9
Neutral	3.29	85%	14
Positive	7.79	82%	24

6.2.9 Common Barriers to Tree Stewardship

We asked residents to identify the difficulties they face when caring for their trees (Figure 59), which can help us understand barriers to effective tree stewardship. From their responses we identified six common barriers to tree stewardship: capability, interest, safety, pests, and city issues. 59.6% of interviewees identified capability as a major barrier, which includes physical disability or health concerns, financial strain, lack of knowledge, or time, among others. 32% of residents reported experiencing no barriers to tree stewardship. When talking about tree care one such resident stated,

"And so if I have to go out and spend $100 every couple of years on mulch and, and water these trees while I'm watering other things, I don't care. You know, so, so like I said, a labor of love."

In comparison, the other categories (interest, safety, pests, and city issues) were each reported as difficulties by less than 10% of interviewed residents.

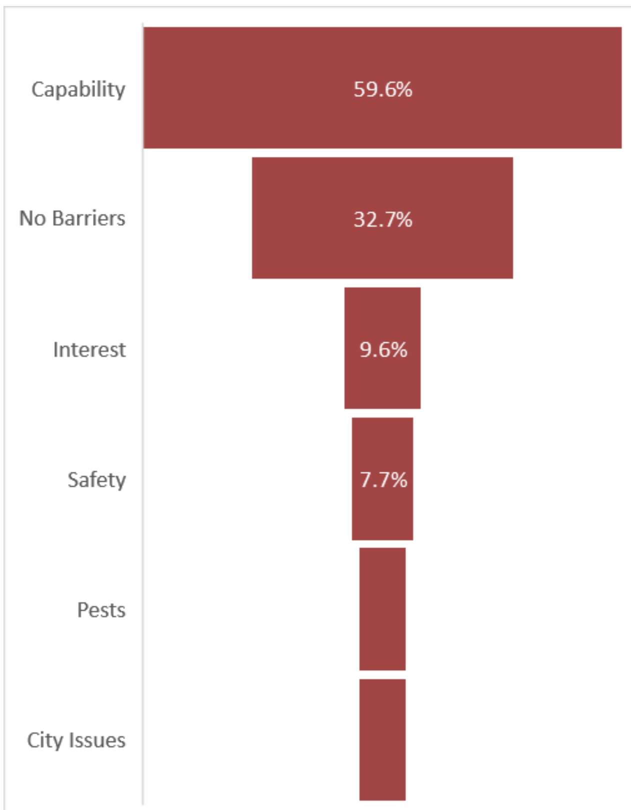

Figure 59. Common barriers to tree stewardship

Note. The percentages of each barrier/challenge does not add up to 100% as residents were asked to list all challenges they face.

7. Outcomes

7.1 Ecosystem Services

We analyzed the ecosystem services provided by the private trees within the study area using iTree Eco v6. The following parameters were used as inputs: species, DBH, total tree height, land use, distance to nearest building, and direction from nearest building. A total of 1,438 trees were included in this calculation. Only trees for which all above metrics were recorded were included in the calculation of ecosystem services, therefore our findings do not fully represent the ecosystem services provided by the entire sample. Distance from and direction to nearest building were calculated in ArcGIS Pro 3.1.2, and the building layer was sourced from MassGIS. This analysis was also run with trees sampled in the baseline survey, using the same variables, with a total of 615 trees included.

Trees in the 2023 sample provided $7,206 worth of ecosystem services annually. Of this $7,206, $4,012 was energy savings. The other annual ecosystem services and amounts are as follows: producing 12.2 pounds of oxygen to the atmosphere, sequestering 4.6 tons of carbon, removing 238 pounds of air pollution, and preventing runoff of 62,000 gallons of water. In addition to this, these trees had a combined replacement value of $678,000.

The mean value of annual ecosystem services provided by species was calculated, both in the baseline and 2023 (Table 9). Additionally, select species from the baseline and 2023 surveys were plotted by the amount of ecosystem service provided (Figures 60-63).

Table 9. Top 5 and bottom 5 species ranked by the mean value contributed in ecosystem services in 2023

Species ranked by 2023 Mean Value	Baseline Mean Value	2023 Mean Value
Tulip	$1.22	$18.12
Pin Oak	$1.85	$14.14
Zelkova	$0.80	$13.16
Linden	$0.83	$12.56
Littleleaf Linden	$0.71	$11.98
Bottom 5 Species	------	-------
Balsam Fir	$0.17	$0.91
Serviceberry	$0.76	$0.83
Kousa Dogwood	$0.27	$0.77
Dogwood	$0.21	$0.76
Fringetree	$0.23	$0.47

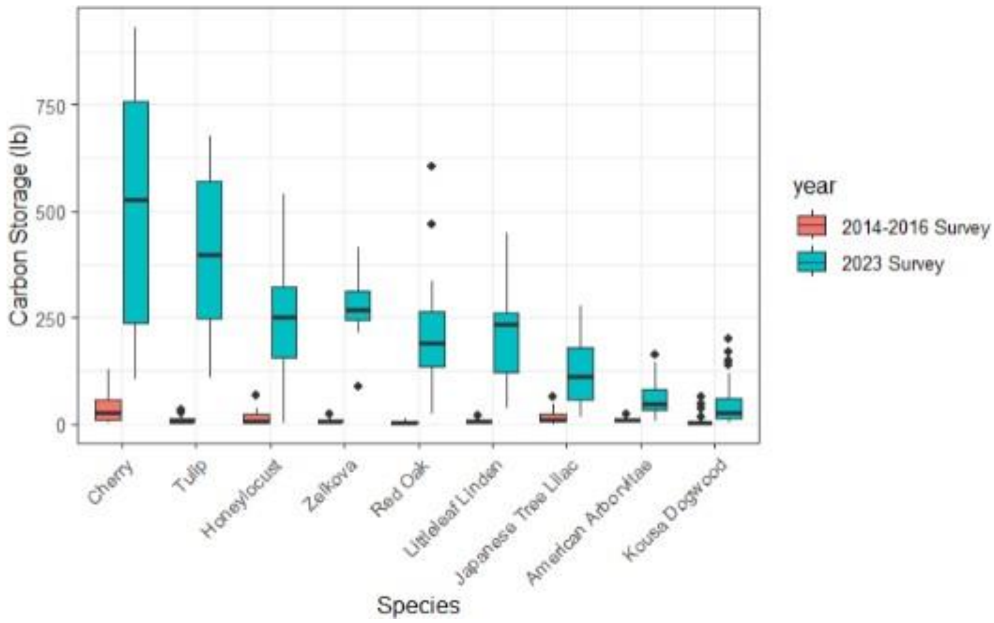

Figure 60. Carbon storage in pounds provided by various species planted by the DCR

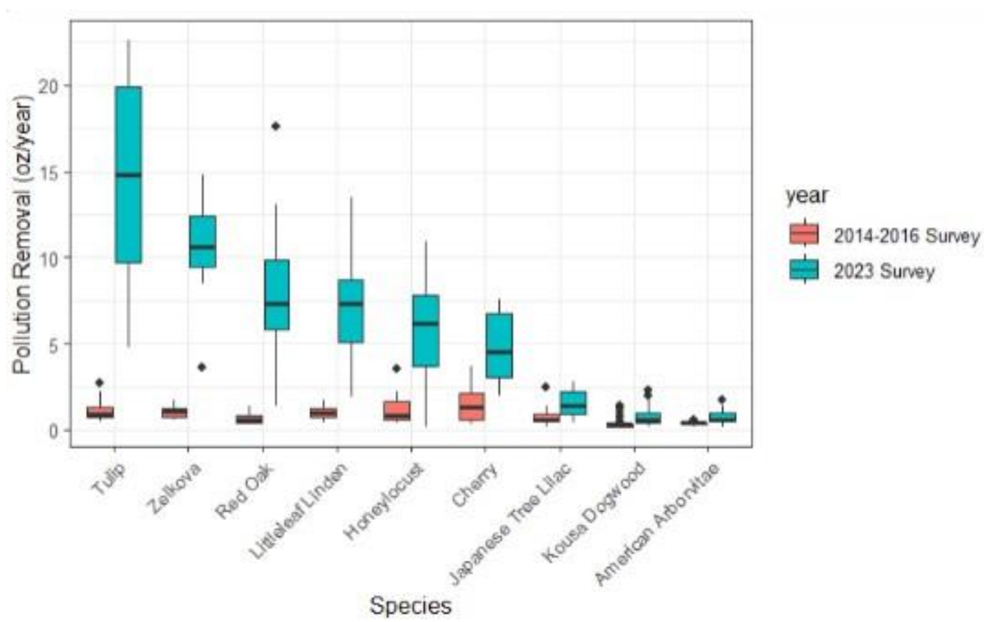

Figure 61. Pollution removal in ounces per year provided by various species planted by the DCR

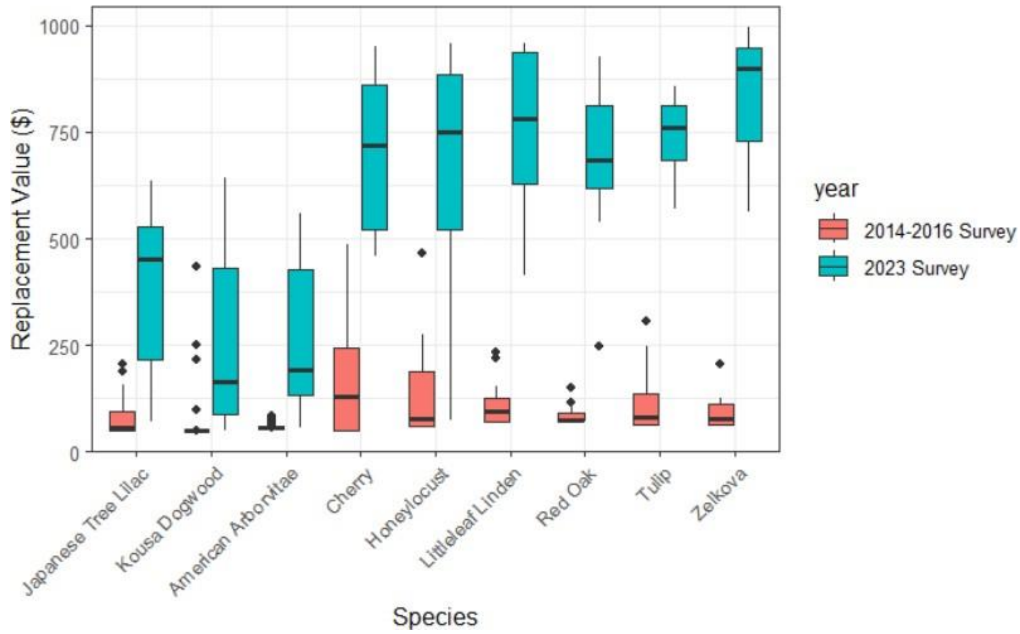

Figure 62. Replacement value of various species planted by the DCR

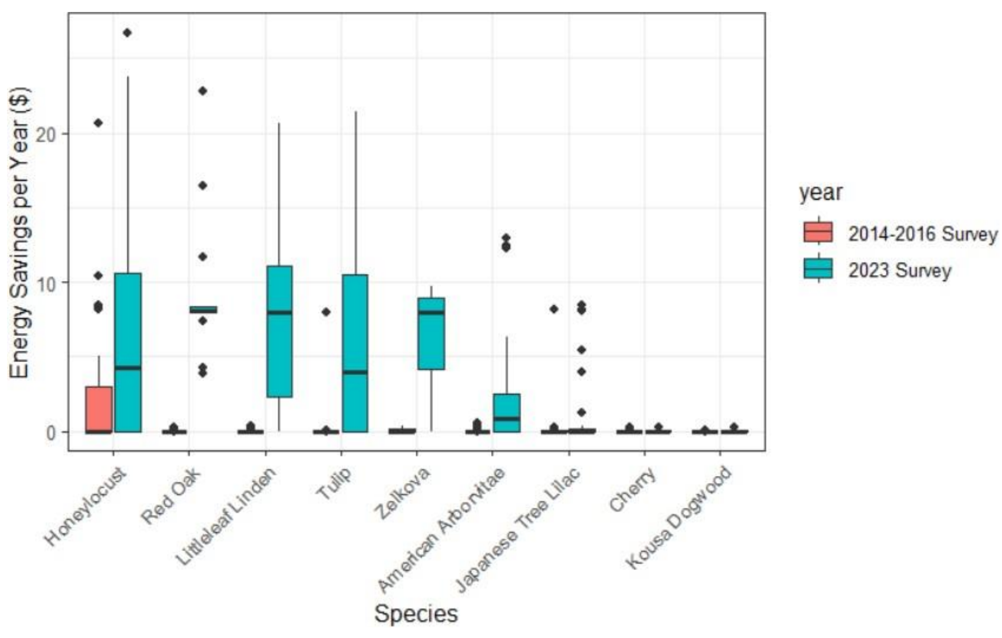

Figure 63. Energy savings per year provided by various species planted by the DCR

7.2 Tree Planting Impact on Surface Temperature

We analyzed the impact of tree cutting and planting on surface temperature. Surface temperature was collected on the thermal band of Landsat 5 for the data collected in 2007 and 2009 while Landsat 9 was used for the data collected in 2022. The Landsat 5 data was collected at a 120-meter resolution and resampled to a 30 meter resolution while the Landsat 9 data was collected at a 100 meter resolution and resampled to a 30 meter resolution. Because of the difference in temperature on a given day, the data was standardized with the use of zScores. A zScore compares each pixel to the rest of the study area. zScores of 0 represent the average temperature in the study area while a zScore of 1 represents 1 standard deviation higher than the mean and a zScore of -1 represents 1 standard deviation lower than the mean. Areas of interest were identified as areas with Norway maples which were present prior to the Longhorned Beetle, then had those cut after the discovery of the beetle, and finally had private trees planted by the DCR after the cutting. As shown in Figure 65, these areas tended to get warmer after the cutting of the trees and are now beginning to cool off as the canopy of the DCR trees develops. Figure 67 shows a series of satellite images in 2007, 2010, and 2022 where there is a presence of Norway maples followed by the cutting of the trees, and finally the canopy development of the trees planted by the DCR as well as the street trees planted by the WTI.

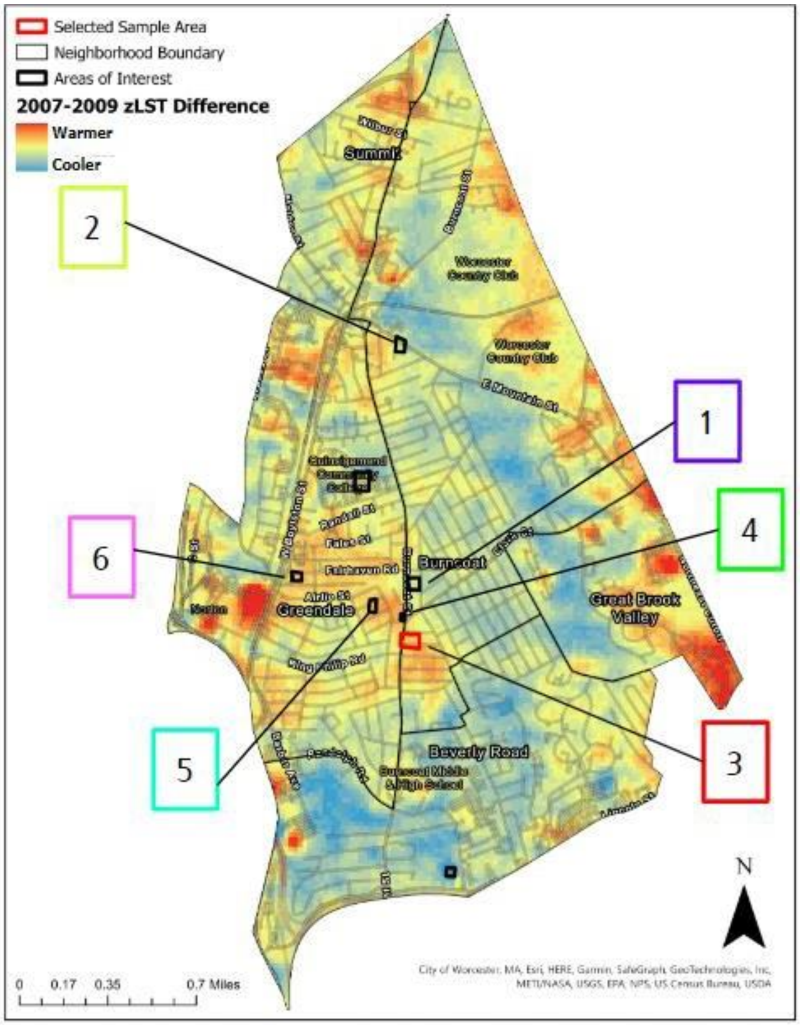

Figure 64. This figure shows zScore difference in temperature between 2007 and 2009 as well as areas of interest used for further analysis. Many of the red areas in the map represent new, darker, roofs as well as new housing developments while many of the blue spots represent lighter colored roofs on structures. The maximum change in zScore was found to be 1.69 while the minimum change was found to be -1.22.

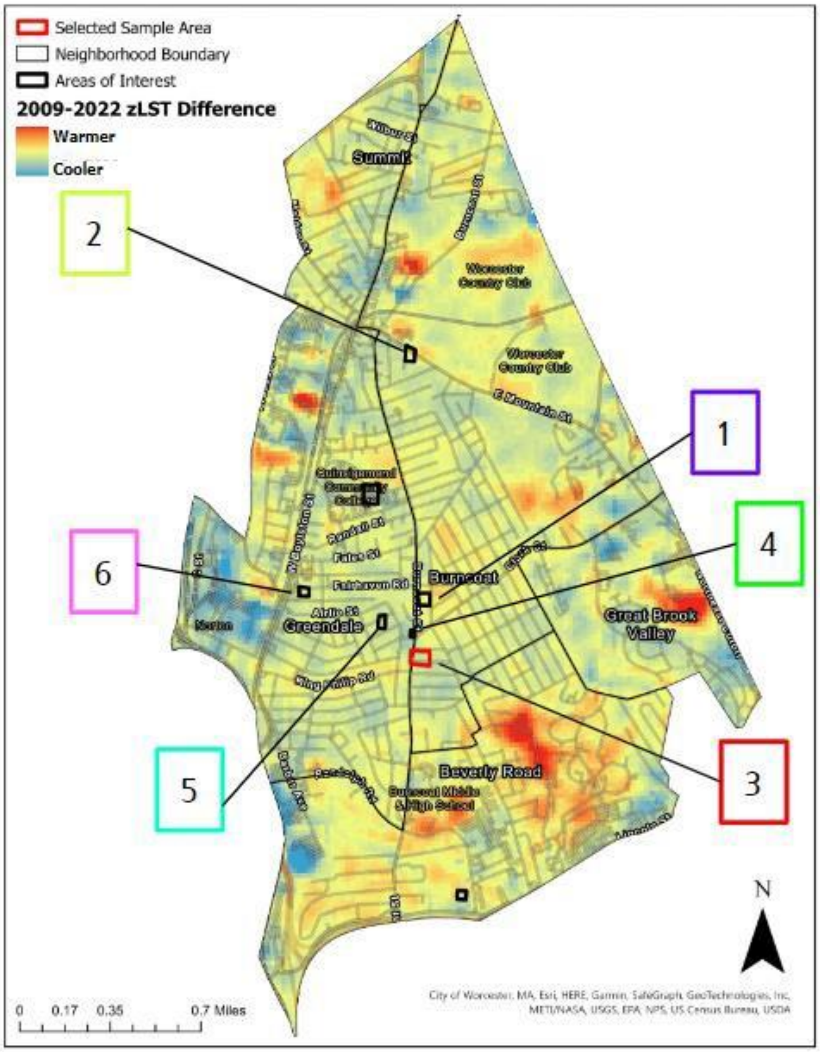

Figure 65. This figure shows zScore difference in temperature between 2009 and 2022 as well as areas of interest used for further analysis. Many of the red areas in the map represent new, darker, roofs as well as new housing developments while many of the blue spots represent lighter colored roofs on structures. The maximum change in zScore was found to be 1.93 while the minimum change was found to be -2.15.

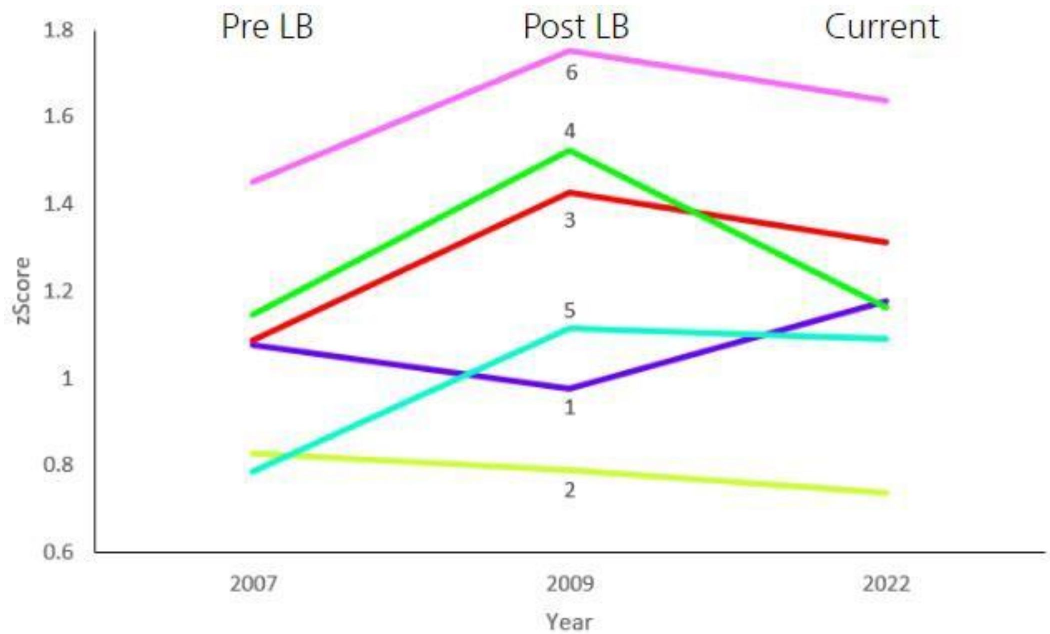

Figure 66. zScore of areas of interest in figure 65 before the Longhorned Beetle infestation, after the Longhorned Beetle infestation, and in 2022

Figure 67. Satellite images collected before the Longhorned Beetle infestation, after the Longhorned Beetle infestation, and in 2022 of the selected sample area and the points showing the areas where DCR planted private trees and WTI planted street trees were planted

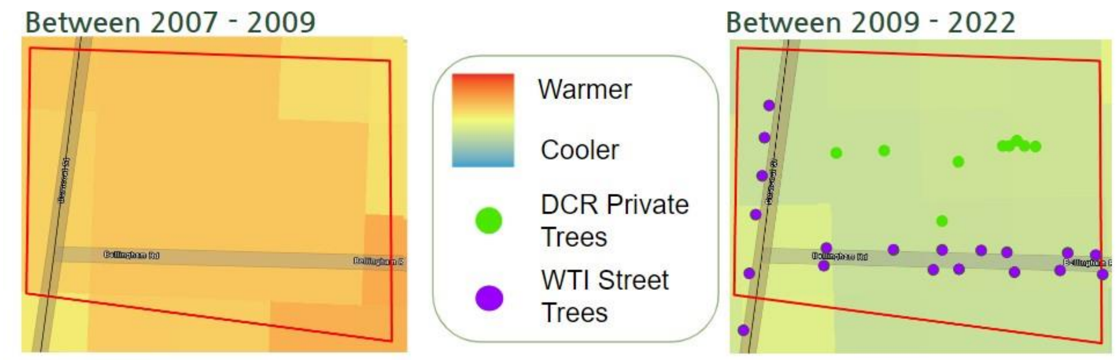

Figure 68. zScore difference of the selected sample area between 2007 and 2009 as well as between 2009 and 2022 as well as the planting locations of the DCR private trees and the WTI street trees

8. Discussion/Conclusion

8.1 Lessons learned from this study

Overall, the street trees and the private trees appear to be doing well. We infer, based on field observations and informal conversations, that residents remove trees for yard developments, such as decks, pools, or sheds. Additionally, shade trees may have been removed when residents felt that they were growing too close to structures on their properties. Within the neighborhoods, the canopy recovery was varied; some streets would have more canopy recovery than others.

From this study, we found *Tilia* (linden), *Tilia cordata* (littleleaf linden), and *Gleditsia Triacanthos* (honeylocust) to have the highest survivorships of the shade trees planted by the DCR on private properties. In addition, we found *Syringa reticulata* (Japanese tree lilacs) and *Prunus serrulata* (snow goose cherry) to have the highest survivorships of ornamental trees. Troubling results were found with the *Ginkgo Biloba* (ginkgo)'s survivorship which was just over 44%. We expected a much higher survivorship from the *Ginkgo Biloba* (ginkgo). We also found that street trees have a higher survivorship than private trees. Private trees were found to have a survivorship of 66.9% in 2023 which was 10.2% lower than that found in the baseline survey. A similar trend was found with the street trees which were found to have an 88.6% survivorship which was 9.9% less than that found in the baseline survey. We suspect the difference in initial survivorship was due to may be a result of the regular watering program that was put in place by the WTI for the first two years after the street trees were planted. Residents were encouraged to water their trees regularly, but this was not enforced. From this, along with the higher tree survivorships associated with regular initial watering on private properties, we can conclude that watering is crucial to the survivorship of the trees. If there had been a regular watering program for the private trees, the survivorship may have been much higher. Residents reported that the largest benefit of trees was the shade they provide, but shade trees were found to have a lower survivorship than the ornamental and evergreen trees. As a result, we can infer that residents want shade trees, but the challenges posed by shade trees to maintaining their properties sometimes outweigh the benefits.

8.2 Recommendations for Tree Planting

We suggest that residents plant *Tilia cordata* (littleleaf linden), *Liriodendron tulipifera* (tulip), *Quercus palustris* (pin oak), and *Gleditsia Triacanthos* (honeylocust), when they desire a shade tree. When residents desire an ornamental tree, they should plant *Prunus serrulata* (snow goose cherry), *Syringa reticulata* (Japanese tree lilacs), *Cornus kousa* (kousa dogwood), or *Metasequoia Glyptostroboides* (dawn redwood). In these selections we considered factors such as survivorship, height, width, DBH, vigor, and condition of the species planted by the DCR. We suggest that future trees are planted in front yards of single family residential homes because those have the highest survivorships and vigor. In addition, extra coordination and stewardship programs for multi-family residences such as triple-deckers and apartment complexes would help bolster survivorship in this land use category. We suggest enhanced communication with residents to ensure high rates of survivorship as well as a retention contract when planting private trees to prevent residents or landlords from removing them when changing landscaping. Ongoing health assessments, conducted by professionals, would also be useful in informing residents of their tree's condition and ways to implement tree care. A coordinated watering program during the first few years after tree planting would be beneficial for the survivorship of private trees and street trees.

8.3 Future Research

We are interested in conducting future research on the full Longhorned Beetle regulation zone. Other possibilities for future research include investigating ways to reduce the removal of mature, healthy trees, how survivorship factors vary in short and medium terms, planting and stewardship practices to maximize ecosystem services and residential satisfactions, and how shifts in home ownership impact tree survival rates and overall health.

August 2023-December 2023

August-December 2023: Tree survey within the Longhorned Beetle Regulation Zone

1.0 Introduction

Following on the work conducted between June and July 2023, we conducted a similar survey of the trees planted within the Longhorned Beetle Regulation Zone using the same protocols presented previously. The map below (Figure 1) shows the known distribution of trees planted by the DCR following the Longhorned Beetle outbreak.

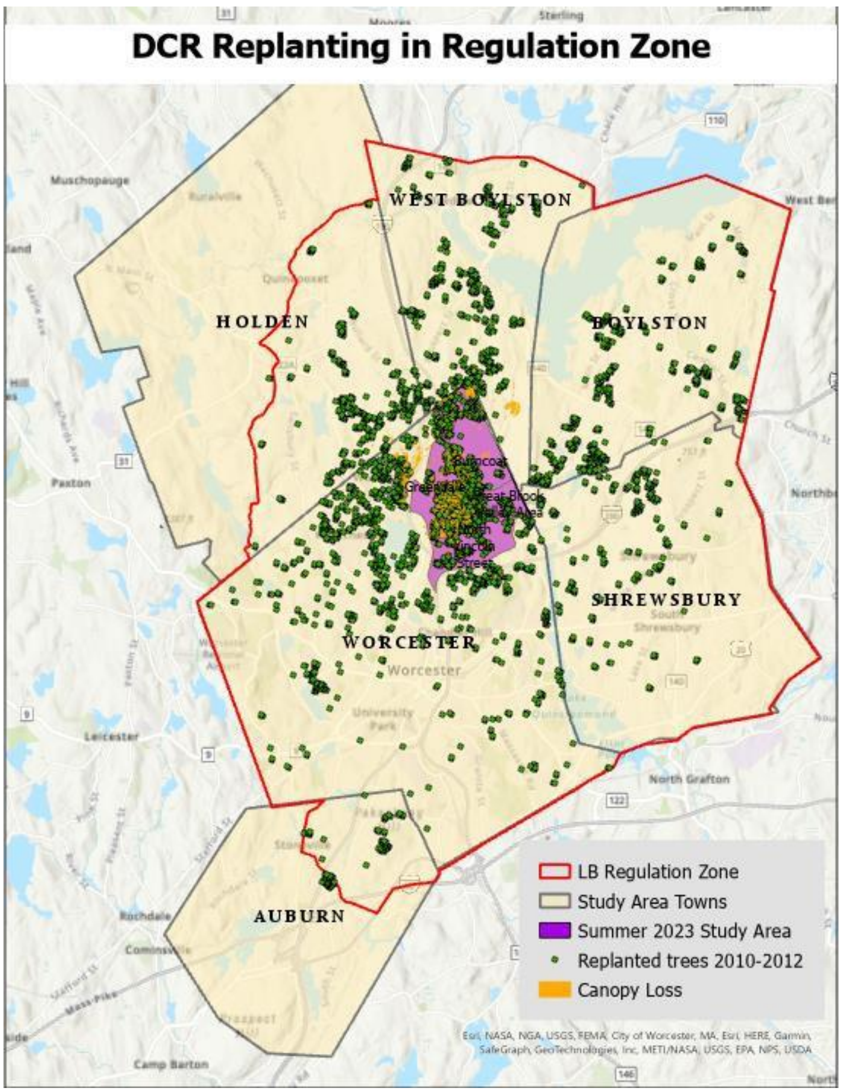

Figure 1. Map of trees planted by DCR in the Asian Longhorned Beetle Regulation Zone in MA

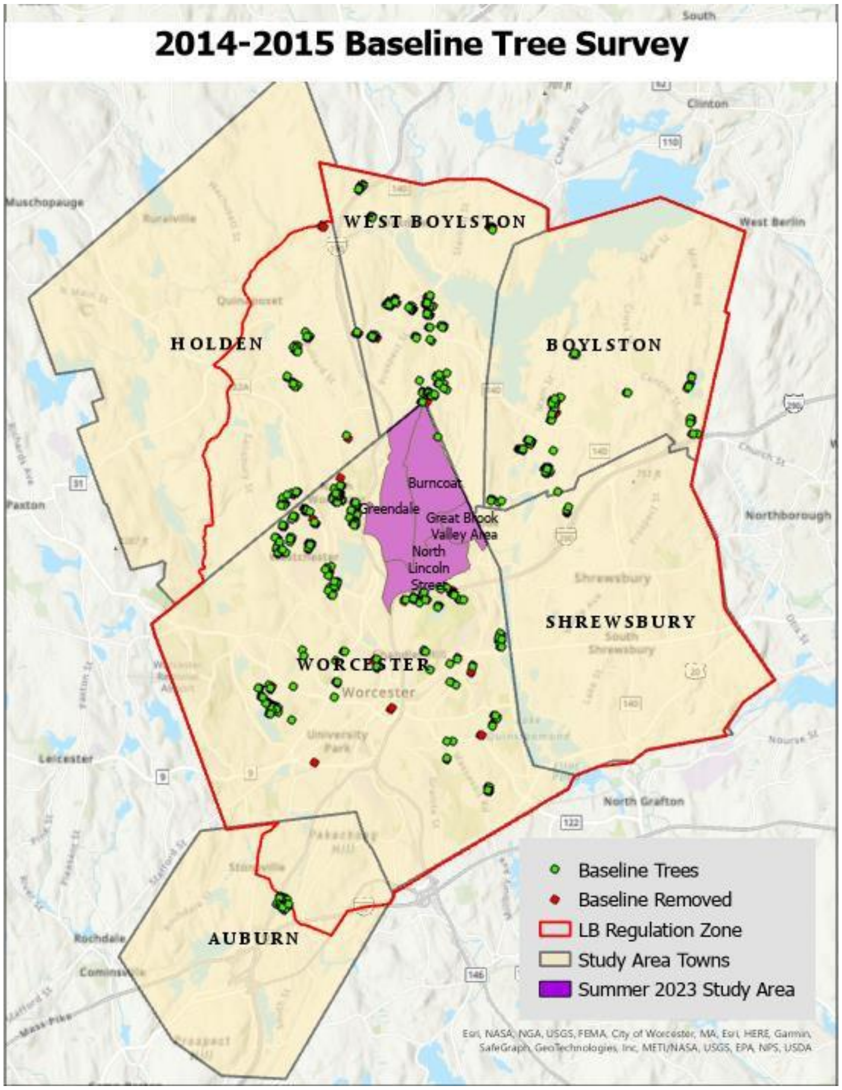

Figure 2. Map of the 2014-2015 baseline tree survey which was replicated in the 2023 survey (HERO 2014-2015 (baseline) surveyed 1452 trees. Of these, 274 are either Arborvitae, Juniper, or White fir, which we omitted, leaving 1178 trees. Of these, 326 were recorded as dead at baseline, leaving 852 living trees to be surveyed in our fall 2023 sample

2.0 Results

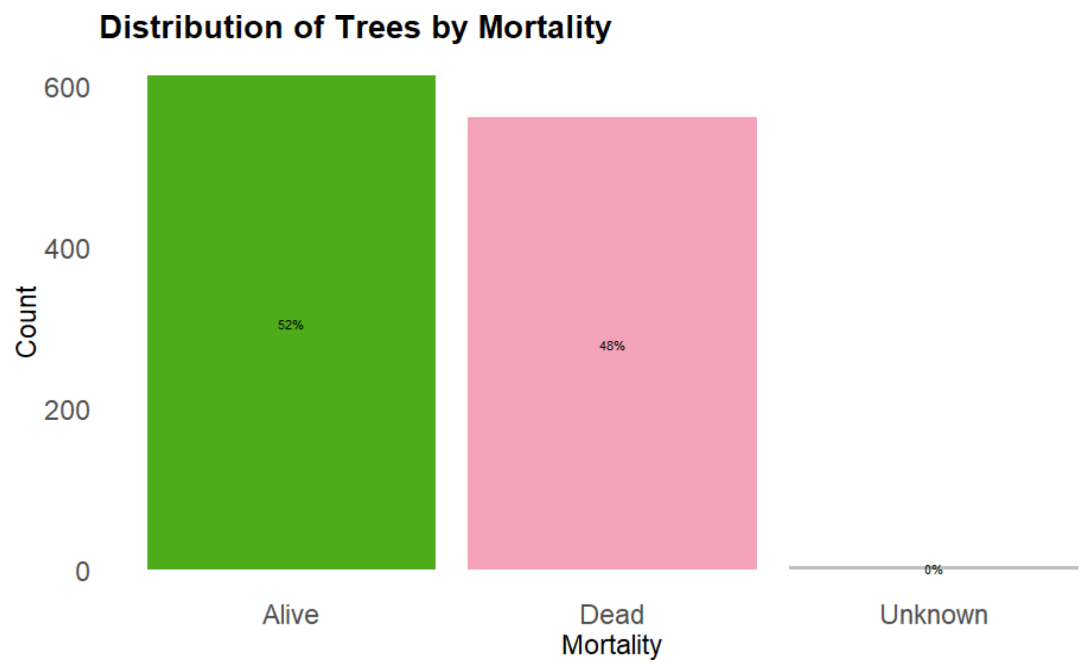

Figure 3. Distribution of trees re-measured in Fall 2023 in terms of survival and mortality

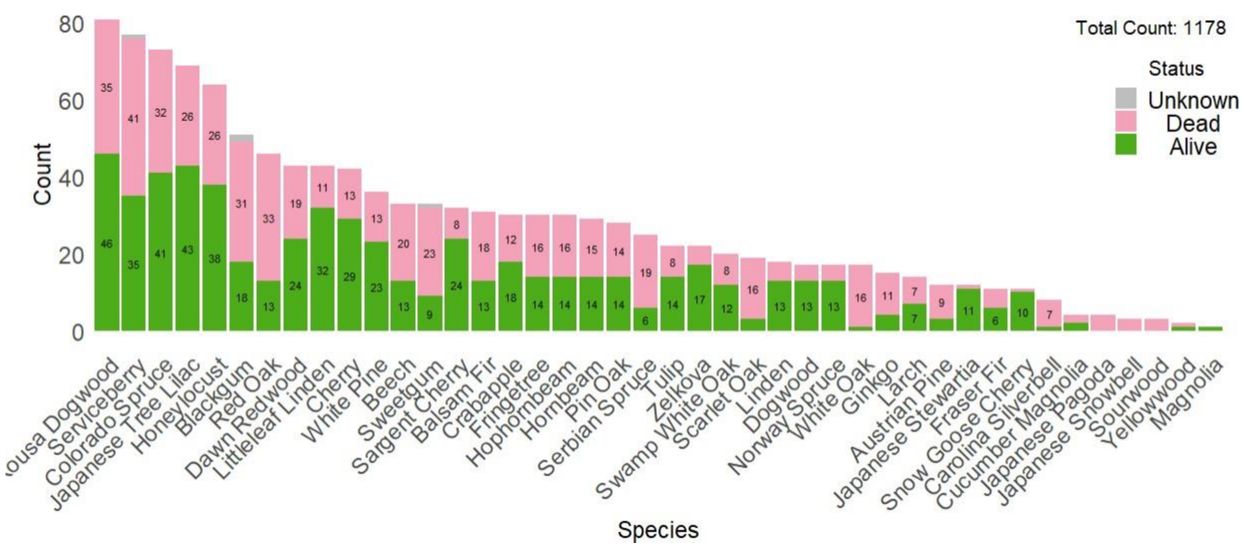

Figure 4. Distribution of tree re-measured in Fall 2023 by species count, and survivorship

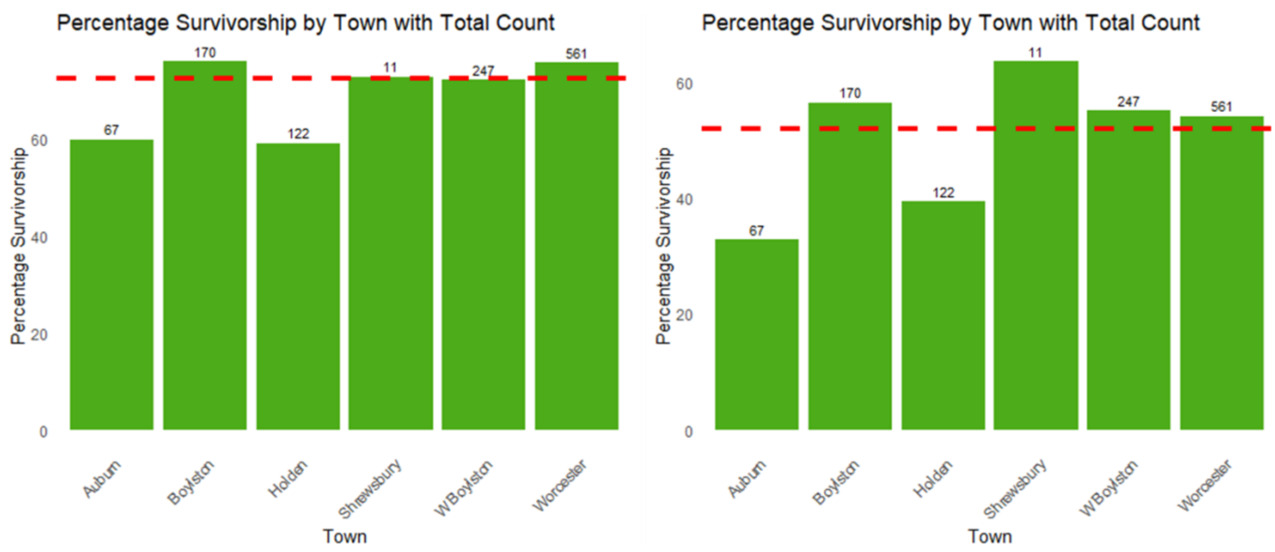

Figure 5. Tree survivorship by town within the Asian Longhorned Beetle Regulation Zone (Baseline left, and fall 2023 survey, right)

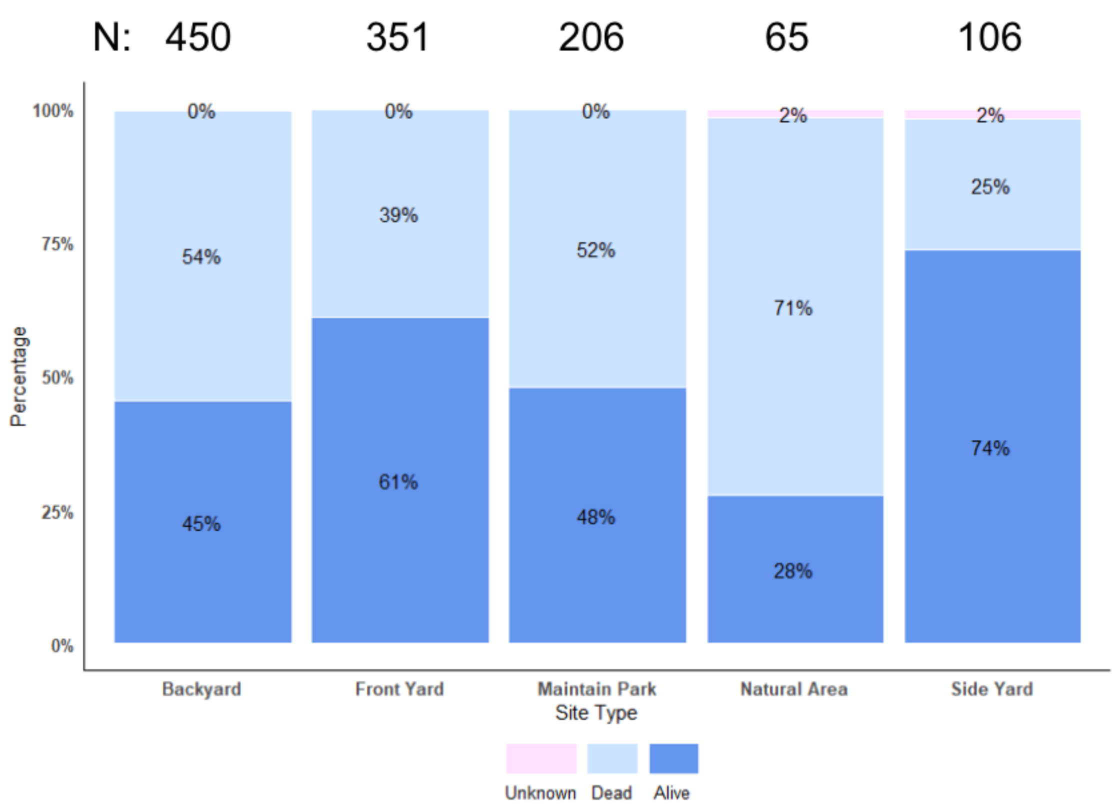

Figure 6. Tree survivorship according to site type in the fall 2023 survey

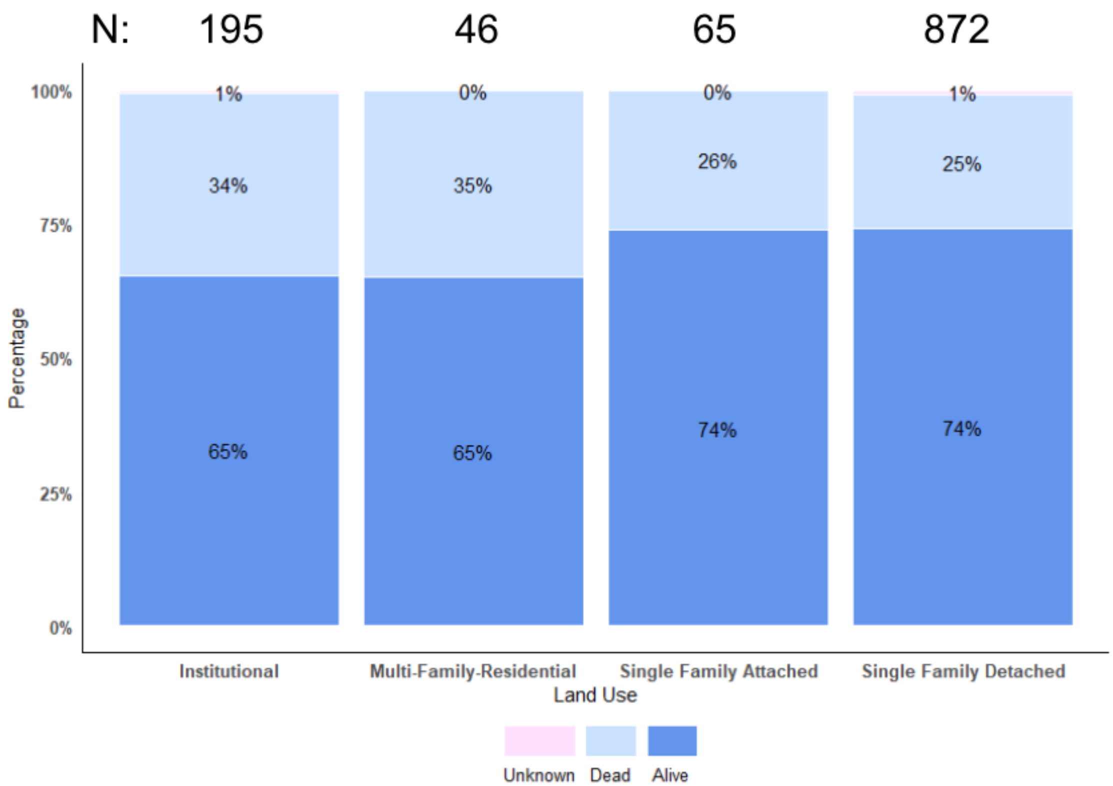

Figure 7. Tree survivorship according to land use in the Fall 2023 survey

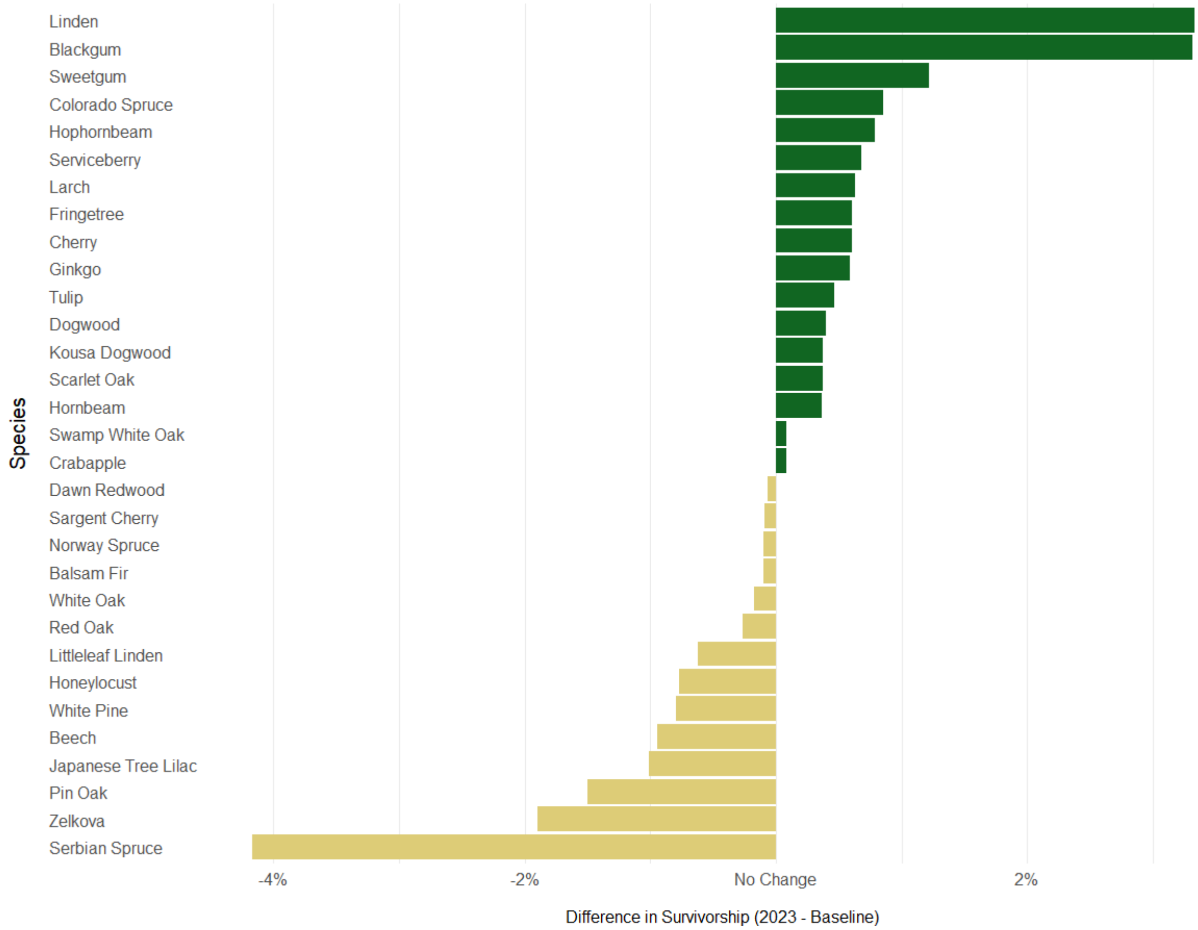

Figure 8. Change in annual survivorship by species between the 2014/2015 baseline and Fall 2023 Green bars indicate improved survivorship whereas yellow bars indicate declining survivorship by tree species groups

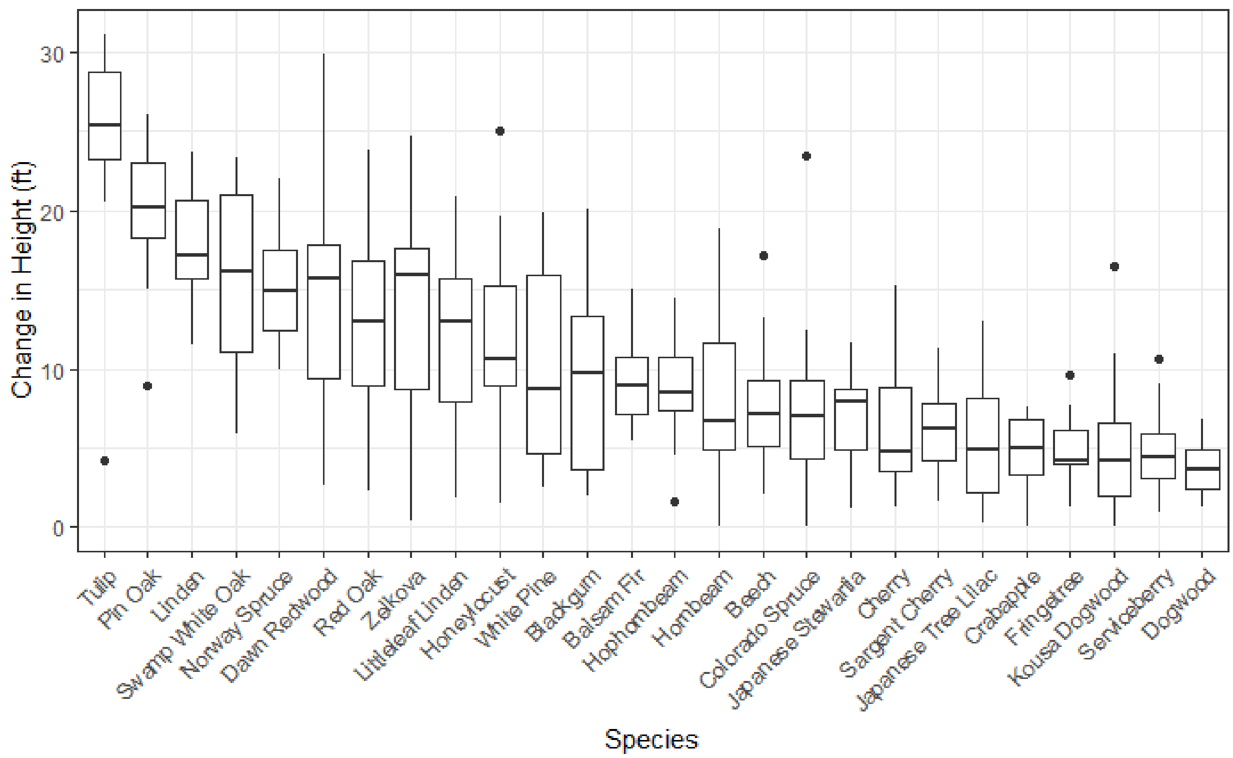

Figure 9. Change in tree height by species between 2014/2015 and fall 2023

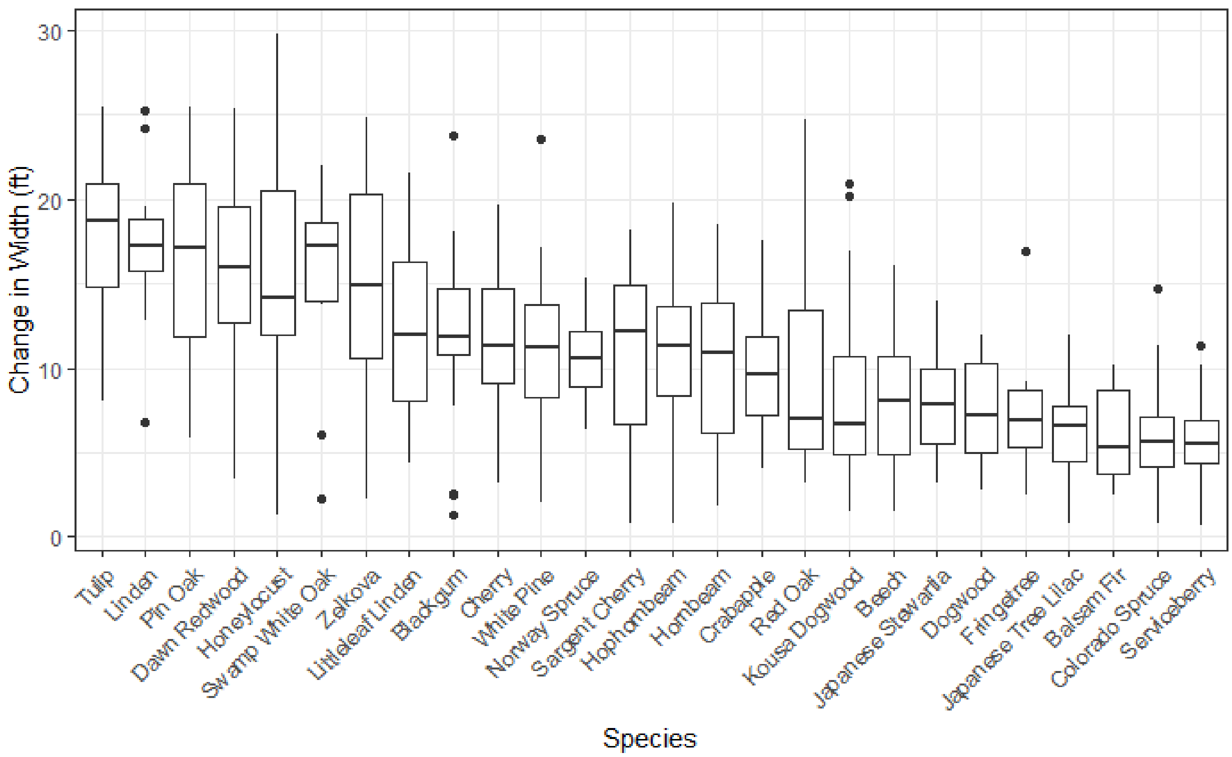

Figure 10. Change in tree crown width by species between 2014/2015 and fall 2023

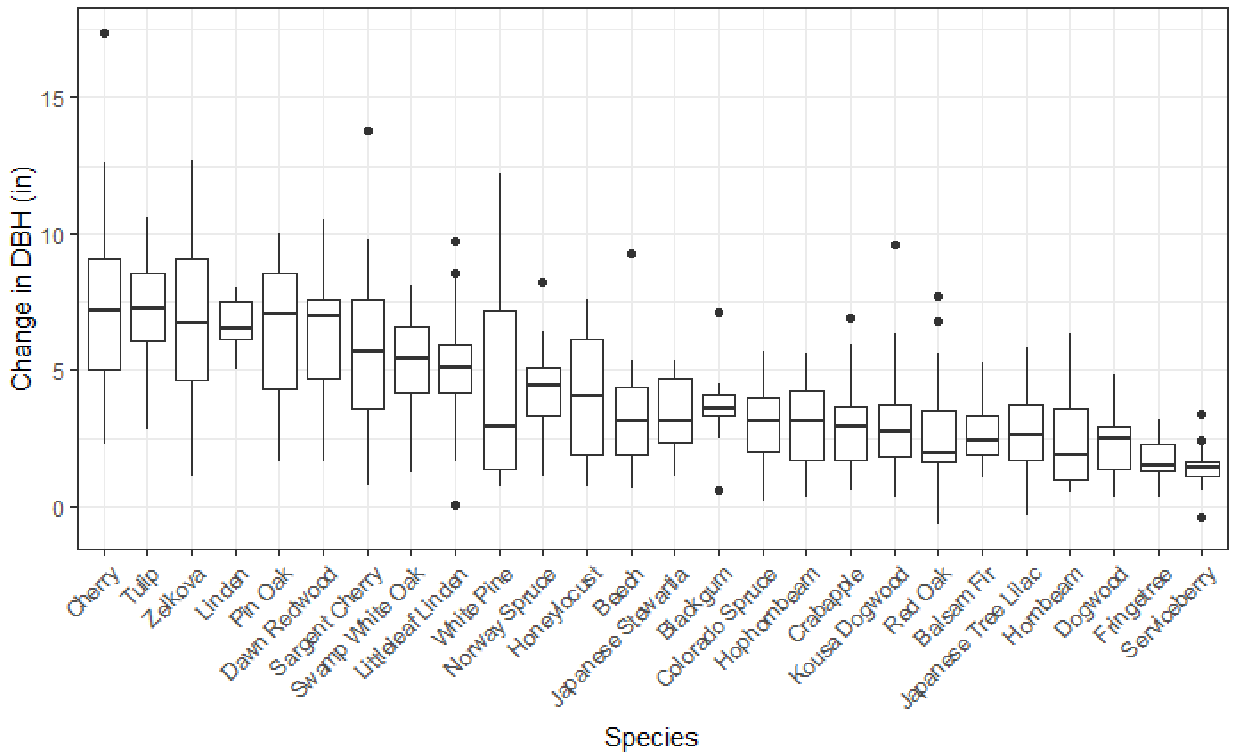

Figure 11. Change in tree DBH by species between 2014/2015 and Fall 2023

3.0 Summary

Standout Species:

- **Zelkova, Dogwood,** and **Norway Spruce** had the highest survivorship rates
- **Tulip tree** had biggest increase in **height** and **crown width**
- **Cherry** had largest increase in **DBH** (**Tulip** second)

Poor Performance: **Oaks** did not do well

- **White Oak** – 5.8%
- **Scarlet Oak** - 15.8 %
- **Red Oak** - 28.25%
- **Pin Oak** - 50%
- S**wamp White Oak** - 60%

Other low percentage survivorship:

- **Serbian Spruce** - 24%
- **Sweetgum** - 27.3%

Analysis Based on Factors:

- **Front and side yard trees** have the **highest survivorship** for site type
- **Single-family residences** have the **highest survivorship** of any land use type

Trees planted in **natural area** had lowest survivorship of any site type

January-June 2024: Tree canopy mapping in the City of Worcester, MA

1.0 Introduction

During this phase of the project, LIDAR and high spatial resolution digital aerial photographs were used to create a new tree canopy layer for the City of Worcester. The map produced is 1-meter spatial resolution.

2.0 Results

Figure 1. Example of LIDAR imagery used to create the tree canopy layer for 2021

Figure 2. Example map of new tree data layer for the City of Worcester (Burncoat Neighborhood). New tree canopy (planted by DCR), or intact canopy since 2010 can be seen in yellow. Canopy from 2010 can be seen in purple.

3.0 Summary

The 2012 tree canopy gap shows substantial gains in tree canopy compared to 2010 (immediate post-host tree removal). Considering the Burncoat and Greendale neighborhoods, tree canopy has increased by 15% since 2010. The increase is canopy is associated with the planting performed by the DCR and the Worcester Tree Initiative.

The 2021 tree canopy map is provided in this online webmap **https://www.arcgis.com/home/item.html?id=1a8c8f59d93e4c8a9d83e155b4bcb6b6**

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Appendix A

Interview Guide

Background: Personal History & Experience with DCR

1. Were you living in this neighborhood during the Longhorned Beetle infestation? **(Y/N)**

If yes	If no
Are you living on the same property now? Did you have any trees removed on your property due to the Longhorned Beetle infestation? a. Were any trees removed nearby? Looking back, what do you think about the tree removal policy? Could you tell us about your experience with DCR and the re-planting process? a. How many trees were planted on your property? Are all your trees planted by DCR still alive? a. **If yes**, move to the next question. b. **If not**, when & how did they die? 1. Did you have a chance to care for it at all before it died?	When did you move here? Do you know about the Longhorned Beetle Infestation?

2. Would you plant a new tree on your property?
    1. If you would, what would you do differently than last time?

Tree Stewardship (If some trees are alive)

3. How are your trees doing healthwise?
4. Who maintains the trees on your property, if anyone?
    1. *Prompts: Landscapers, yard mowers, neighbors, family members, yourself*
    2. If "yourself": Where did you learn how to care for your tree?
        1. *Prompts: Personal knowledge, DCR, Internet, Friends*
5. What are the ways that your trees are taken care of (**watering, pruning, mulching**)?
6. How often do these trees receive care or maintenance?

5	4	3	2	1
Very often (daily/weekly)	Often (monthly)	Occasionally (every few months)	Rarely (1-2 times per year)	Never

7. How has the maintenance of your tree changed over the last 10 years?
    1. *Prompt: Now that it is older, do you water it as much?*
8. What difficulties have you encountered caring for your tree?
    1. *Prompts: time, money, knowledge/expertise, interest, safety, capacity*
9. Do you care for other trees in the neighborhood?

Perception of Trees

10. What are the benefits and challenges of having trees on your property? *Table 1.*
    1. What are your motivations for having trees on your property?
11. Why did you choose between a shade, ornamental, fruit evergreen tree?
    1. *Prompts: Appearance, location, value*
    2. Do you wish you had planted a different tree type?
    3. Would you plant that species now?
    4. How do you feel about planting (non-invasive) non-native species?
12. Have you noticed any economic impacts of having trees present?

Perception of Neighborhood

13. How would you describe your neighborhood to someone who doesn't know it?
    1. Especially its appearance/aesthetics?
    2. *Prompts: Trees and greenspace, cleanliness, safety, community, noise*
14. What do you think about how your neighbors take care of their yards?
15. How & where do you spend your time outside?
    1. *Where prompts: Backyard, front yard, neighborhood*
    2. *How prompts: Socializing, recreation, appreciating nature, watching wildlife*
    3. **If Yes to Question 1**: How has your time spent outside changed since the Longhorned Beetle?
16. Are trees an important part of a neighborhood for you?
    1. **If Yes to Question 1**: Does the neighborhood feel similar to before the Longhorned Beetle outbreak?
    2. **If No to Question 1**: Did the presence of trees in the neighborhood factor when moving to this neighborhood?
17. Do you think your neighborhood should have more trees, less trees, or the same?

Environmental Concerns

18. Do you have any concerns about the environment in the next 10 years?
    1. *Weather events prompts: Flooding, snow, droughts, trees, heat waves, and climate change etc…*
    2. *Environmental quality prompts: temperature, air, water, soil, wind, smell, noise, wildlife*
19. What do you think about the quality of parks or other similar public spaces in Worcester?
    1. *Prompt: places where you can be in nature/natural environments*
    2. Do you wish there were more of those spaces in this neighborhood?

Demographics

Please answer the following questions by circling or filling in responses as indicated [hand over demographics sheet]. Responses are not mandatory. You may choose to answer as many or as few questions as you are comfortable with. These responses will not be used in any way to identify you, all responses will remain anonymous, but any information you choose to provide will greatly help our research.

Age:

☐ 18 to 24 years

☐ 25 to 34 years

☐ 35 to 44 years

☐ 45 to 54 years

☐ 55 to 64 years

☐ Age 65 or older

What is the highest level of education you have completed:

☐ Less than high school

☐ High school/GED

☐ Some college

☐ Trade/technical/vocational training

☐ Associate's degree

☐ Bachelor's degree

☐ Master’s degree

☐ Doctoral degree (Ph.D., M.D, J.D., etc)

Race/Ethnicity (check all that apply):

☐ Black or African American

☐ Asian

☐ South Asian

☐ Pacific Islander/Native Hawaiian

☐ Hispanic, Latino or Spanish Origin

☐ White

☐ Middle Eastern-North African

☐ American Indian or Alaska Native
Other_____________

Language(s) Spoken at Home: _____________________

Gender:

☐ Female

☐ Male

☐ Non-binary

☐ Other

Household Income:

☐ Less than $25,000

☐ $25,000 to $34,999

☐ $35,000 to $49,999

☐ $50,000 to $74,999

☐ $75,000 to $99,999

☐ $100,000 to $149,999

☐ $150,000 or more

Which statement best describes your current living arrangement?

☐ I pay rent for my housing

☐ I own my home

☐ I live in housing where I do not pay rent

How many people, including yourself, live in your household? ____
How long have you been living in your house? (months/years) _____

Thank you for taking the time to participate in this survey!