Who Stays, What Grows: An Analysis of the Homeownership and Tree Survivorship in Worcester, MA, between 2010 and 2021

Aaron Richmond-Crosset

Spring 2025

An Honors Thesis

Submitted to the faculty of Clark University, Worcester, Massachusetts, in partial fulfillment of the requirements for the degree of Bachelor of Arts in the Department of Geography

And accepted on the recommendation of

John Rogan, Ph.D., Chief Instructor

Abstract

Who Stays, What Grows: An Analysis of the Homeownership and Tree Survivorship in Worcester, MA, between 2010 and 2021

Aaron Richmond-Crosset

Trees are crucial for residents, natural systems, and the surrounding community in urban environments due to their temperature control, energy saving, pollution mitigation, carbon sequestration, and increased property value. This study addresses how residential homeownership impacts tree survivorship and change in canopy cover in Worcester, Massachusetts, focusing on trees planted by the Massachusetts Department of Conservation and Recreation (DCR) between 2010 and 2021. By incorporating parcel-level home sales data, multi-year canopy cover, and individual DCR-planted tree data, this study assesses the relationship between homeownership and tree survivorship within neighborhoods impacted by the Longhorned Beetle (LB) outbreak and the tree planting that followed. Results show that tree survivorship was significantly higher on parcels without ownership changes (70.4%) compared to those that were sold (59.1%). Additionally, canopy cover losses were greater on sold parcels over the same period. While high-resolution remote sensing and maps created through the classification of digital aerial photography are valuable to assess canopy cover metrics, they lack the ability to create a holistic census of early-stage tree survivorship. It highlights the need to pair it with in situ data collection. Findings reinforce that urban tree-planting programs must go beyond tree counts and acknowledge that long-term maintenance, resident engagement, and the influence of homeownership shape the success of tree-planting programs.

Keywords: tree survivorship, homeownership, canopy cover, tree planting programs, remote sensing, Longhorn Beetle

John Rogan Ph.D.
Chief Instructor
Deborah Martin Ph.D.
Professor

Academic History

Name: Aaron Richmond-Crosset Date: Spring 2025

Baccalaureate Degree: Bachelor of Arts in Geography, expected graduation May 2025

Source: Undergraduate School of Geography, Clark University Date: Spring 2025

Acknowledgments

Thank you to the participating people and organizations for making this research possible. Thanks to the Clark University O'Connor Fund, Mat Cahill, and the DCR for their continued support of the HERO program. Personal thanks to John Rogan, Deborah Martin, Nicholas Geron, Adlai Nelson, Tanner Honnef and Adian Caron for their guidance throughout this research.

Contents

Introduction

Trees are critical in urban environments for the well-being of both the residents and natural systems (Meineke et al. 2016). The benefits range from aesthetic appeal with increased property values (McPherson et al. 2007), carbon sequestration, and pollution mitigation (U.S. Environmental Protection Agency, 2023) to energy savings through canopy shading and temperature control via evapotranspiration (Lee et al. 2018). Understanding how urban forests affect the community, particularly urban areas, and the natural environment confirms the value of urban trees and the organizations that plant and care for them (Breger et al. 2019, Nowak and Dwyer 2007).

Government and nonprofit organizations carry out tree planting programs to reduce disparities in urban tree canopy, meet targeted environmental objectives (such as planting a specified number of trees), or integrate into broader urban greening initiatives (Nguyen et al. 2017, Reidman et al. 2022, Sousa-Silva et al. 2023). Urban trees' ecological and public health advantages increase as the trees mature (Amer et al. 2023, Widney et al. 2016). Consequently, tree survivorship and tree health serve as critical indicators for assessing the success of planting programs, yet consistent tracking and documentation of these metrics remain lacking (Roman et al. 2016, Nguyen et al. 2017). Many tree planting programs lack resources for monitoring survivorship on private property and lack capacity for field work (Nguyen et al. 2017). Despite some urban forestry organizations in the US gathering tree mortality data (Roman et al 2013), such as Alliance for Community Trees (Turner and Mitchell, 2008), these studies rarely result in peer-reviewed literature (Roman et al. 2016), and there is little reliance on scholarly theory when it comes to understanding urban tree-planting programs (Nguyen et al. 2017). Unfortunately, existing data and said theories suggest challenges associated with depending on private individuals to support and sustain the public benefits associated with urban tree planting programs (Mincey et al., 2013). However, recent research has highlighted ways these challenges can be addressed. Decentralized environmental governance frameworks have shown that when residents are engaged as policy actors as opposed to passive recipients, tree planting programs can be more successful, even in dense urban neighborhoods (Geron, 2023). When incentives, choice, and opportunities exist to participate, programs foster stronger stewardship and strengthened community connections (Geron, 2023).

The initial 1-5 years after planting, referred to as the establishment phase, represents a period of heightened vulnerability for tree mortality because annual mortality tended to be higher during the first five years after planting (Hilbert et al., 2019, Nowak et al. 2004) Despite this, few studies have examined how survivorship factors differ between the establishment and post-establishment phases (Nowak et al. 2004, Roman et al. 2014, Nelson et al., 2024). Filling the gap in research will allow organizations to allocate resources to trees in the post-establishment phase. The selection of predictor variables in urban tree survivorship studies varies widely, frequently influenced by data accessibility and collection methods during planting documentation (Hilbert et al. 2019). For example, a tree respondent for TreeBaltamore, a tree planting program in Baltimore, stated they preferred to tie success with the number of people engaged rather than the tree survivorship. This was first due to the lack of resources and capacity to do fieldwork, but also because "the idea of trees [is put in their] mind" (Hilbert et al. 2019).

With a lack of resources and funding, using free or easily accessible data or imagery is likely to cause others to encounter 'noisy' issues. Even using high-resolution 1m LiDAR data can encounter similar barriers. Rosenblum (2015) found that only 26.5% of juvenile trees were detected using high-resolution 1m LiDAR data. All other trees were masked by larger tree canopies or by being in close proximity to other trees or human-made structures (Rosenblum, 2015).

Roman et al. (2014) looked at the socioeconomic, biophysical, and maintenance characteristics of a shade tree giveaway program in Sacramento, CA. They monitored a cohort of trees for five years on single-family residential properties. It was found that tree survivorship was higher in neighborhoods with higher educational attainment, tree species with lower water use demand, and owner-occupied properties with stable homeownership (Roman et al. 2014). Trees with "good" maintenance, or when there was evidence of irrigation, removed nursery stakes, present structural stakes, mulch, and there was no trunk wound, were significantly more likely to be found on properties with stable homeownership at a staggering 96% (Roman et al. 2014). Using conditional inference trees, a decision tree model often used to understand which variables are most important in predicting an outcome (Hothorn et al., 2006), found stable homeownership is the most important variable for urban tree survivorship during the establishment phase (Roman et al., 2014). Yet, there is still a gap in knowledge as to why that is.

Given the significance of urban tree survivorship in the context of homeownership, there is a clear need for further research on whether residential ownership patterns influence the success of private tree-planting programs in the post-establishment phase. Additionally, studies on urban trees between the establishment phase and full maturity, which is essential for understanding long-term tree survivorship, are lacking and limit our understanding of the relationship between homeownership stability and urban tree survivorship. This study addresses these concerns. The research questions are as follows:

1. Does the change in homeownership impact tree canopy in Worcester, MA, between 2010 and 2021?
2. Does the change in homeownership impact the Massachusetts Department of Conservation and Recreation (DCR) planted trees survivorship in Worcester, MA, between 2010 and 2021?

Study Area

The city of Worcester is located in central Massachusetts, west of Boston. Worcester experiences a moist mid-latitude climate, with 1,225 mm of annual precipitation and an average range of temperatures from 26.56°C in July to 0.17°C in January (US Climate Normals, 2024). Urban tree canopy cover in Worcester during 2015 was 34.9%, sustained by widespread woodlands such as the Broad Meadow Brook Wildlife Conservation Refuge and Green Hill Park (Elmes et al. 2017). As the second-largest city in New England, Worcester, with a population of 207,621, has 42% of its residents living in single-family homes, and 83.1% of the population has remained in the same residence for at least one year (U.S. Census Bureau, 2023). The research targets zip codes 01615, 01616, and 01619 in the city of Worcester (MA) (See Figure 1). This area includes the neighborhoods in the Northern portion of Worcester, including Brittan Square, Burncoat, Forest Grove, Greendale, Indian Hill, Indian Lake East, and North Lincoln Street.

The study area falls within a USDA-designated area established to quarantine the invasive Asian Longhorned Beetle (*Anoplophora glabripennis*), a wood-boring beetle that attacks maples, elms, and willows (Haack et al. 2010) (See Figure 1). This quarantine zone was implemented to prevent the beetle from spreading; it was prohibited by law to move or transport beetles, firewood, or lumber from the designated area to outside the zone (City of Worcester, n.d.). Since the detection of the beetle in Worcester in 2008, over 30,000 trees have been removed, 20,400 infested, and 10,250 high-risk trees were removed to stop the spread (Santos and Cole, 2012; Danko et al., 2016). Of those trees, 25,000 were located in the neighborhoods of Burncoat and Greendale (Palmer et al. 2014). By 2015, the tree canopy cover in the study area was 27.6% (Elmes et al. 2017). The Massachusetts Department of Conservation and Recreation (DCR) utilized funds received in 2009 through the American Recovery and Reinvestment Act to launch a tree planting program in the Longhorned Beetle Quarantine Zone (Danko et al. 2016). The tree planting program was intended to replace tree canopy cover, address public dissatisfaction regarding tree removals, and minimize ecological loss (Palmer et al. 2014). DCR crews and contractors planted trees on residential, commercial, and public land, with species determined by availability at local nurseries (Massachusetts DCR, pers. comm.).

Data and Methods

The DCR provided the data representing tree locations and species. Data indicating the properties sold between 2010 and 2023, their address, and the years they were sold were taken from Zillow (2024) (See Figure 2). These properties were geocoded and converted into a point file. Tree canopy cover for 2010 was provided by Hostetler (2013), for 2015 by Elmes et al. (2017), and for 2021 by Andrews (2023). A polygon layer was created for sold and unsold properties using the point data indicating sold properties. Overlaying Worcester tree canopy layers, new fields were created: percentage canopy 2010-2015, percentage canopy 2015-2021, and percentage canopy 2010-2021 for both sold and unsold properties. These were created by dividing the canopy area by the area of the parcel and multiplying that by 100. With that information, three new fields were created: percentage canopy change 2010-2015, percentage canopy change 2015-2021, and percentage canopy change 2010-2021. Change was depicted as an unclassed color gradient, with the darkest red indicating parcels with 50% greater canopy loss and the deepest blues indicating parcels with 50% greater canopy gain. These fields were created by comparing the differences between canopy layers per parcel. The average tree canopy was calculated for those periods with that information. Tree survivorship percentages were calculated using the DCR data collected by the survey team in 2023 and the previously sold and unsold layers. Data points were classified as being on either sold or unsold properties. From there, survivorship percentages were calculated for each homeownership status, and a chi-squared test of independence was conducted to examine the relationship between parcel sale status and tree survivorship.

Independent two-sample t-tests for 2010–2015, 2015–2021, and 2010–2021 were conducted to assess differences in canopy change between sold and unsold parcels. The tests compared the mean percent canopy change between the two groups. A significance threshold of $p < 0.05$ was used to determine statistical significance. Pearson correlation coefficients (r) were also calculated between canopy percentage in 2010 and canopy change over each period to examine the relationship between initial canopy cover and canopy change. The significance of the correlations was assessed using two-tailed p-values, and the exact significance thresholds were applied. All statistical analyses were performed using Python's scipy.stats package.

Results

Of the 2,309 DCR-planted trees recorded in the 2023 inventory, 1,531 (66.3%) were classified as alive, 725 (31.4%) as dead or removed, and 53 (2.3%) as unknown. Tree survivorship differed between sold and unsold parcels. Unsold parcels exhibited a higher survivorship rate, with 1,036 out of 1,472 trees (70.4%) alive (See Figure 3). In contrast, sold parcels had 495 of 837 trees (59.1%) alive (See Figure 3). The percentage of dead or removed trees was 27.6% on unsold parcels and 38.1% on sold parcels (See Figure 3). A chi-squared test of independence was conducted; the results revealed a significant association between the two variables, $\chi^2(1, N = 2{,}309) = [\chi^2$ value if needed], $p < 0.001$. In the zip code 01606, the area of Worcester, MA that was hit hardest by the LB tree cutting between 2008 and 2012, the highest amount of sold parcels were between 2010-2013 with 31% (550) of the sold parcels, and between 2014-2016 with 26% (470) of the 1750 parcels sold (See Figure 4).

Analysis of canopy cover change across parcel types revealed differences over three time intervals. Within the study area, there were 15,898 parcels. From 2010 to 2015, 9,530 parcels across the study area lost canopy, and the average canopy loss was -3.35% on unsold properties and -4.27% on sold properties, resulting in a net difference of -0.92% (See Table 1). This net difference was significant, with a p-value of 0.0014. Between 2010 and 2015, the correlation coefficient (r) was -0.49 *(p=<0.001)* (See Table 1), indicating that parcels with greater canopy cover in 2010 experienced more significant loss during this period (See Figure 5). Between 2015 and 2021, 6,244 parcels had canopy cover loss, but the average canopy change was minimal for both groups (-0.19% for unsold parcels and -0.18% for sold parcels), indicating a negligible difference of 0.01% (See Table 1). This failed to reject the null hypothesis. However, the correlation coefficient between 2015 and 2021 was -0.21 *(p=<0.001)* (See Table 1). Over the whole study period (2010–2021), a total of 8,679 parcels had canopy cover loss, with unsold parcels experiencing a total canopy loss of -3.55%, and sold parcels experiencing a total loss of -4.45%, a net difference of -0.90% with a p-value of 0.0051 (See Table 1). This period exhibited parcels with high initial canopy consistently lost the most over time, with a correlation coefficient of -0.61 *(p=<0.001)* (See Table 1). This time period experienced the greatest amount of canopy loss (See Figure 7). Between the periods of 2010-2015 and 2015-2021, there was more canopy loss between 2010-2015 (See Figure 6).

Discussion

This analysis reveals three key findings: it can not be assumed that planted trees survive to maturity, remotely sensed canopy data can mask critical subtleties, and residential homeownership patterns impact tree survivorship in the post-establishment phase.

First, the results dispelled the presumption that trees planted during urban tree planting programs will all survive. After about 12 years, 66.3% of the trees planted by DCR were still alive. This survival rate indicates high post-planting attrition, especially on parcels that were sold, where survival decreased to 59.1%. Trees are most vulnerable during the establishment phase (Hilbert, 2019), so improper management can greatly affect survivorship, especially if there is a change in homeownership (Roman et al., 2014). At times, homeowners don't think ahead when deciding when to plant their trees during these programs, resulting in the trees being replaced by a pool, shed, or deck a couple of years after planting them (HERO Survey, 2023). Homeowners with little knowledge of tree maintenance, such as a lack of watering, also contribute to the increased mortality of these trees during tree planting programs (Roman et al. 2014). Presumably, decreased survivorship on sold parcels is due to new homeowners receiving little to no communication on the tree planting program's importance and context. Similarly, they may also receive less information on the basics of taking care of a tree, such as watering, pruning, and mulching. The results underscore the significance of comprehensive long-term stewardship and maintenance in tree planning. Without long-term maintenance, tree mortality can greatly undermine the environmental and social benefits cities expect from their tree-planting investments (Widney et al., 2016).

Second, while remotely sensed canopy cover measurements are worthwhile, cost-effective, and easier to obtain, they cannot effectively reflect the overall tree planting program success. Throughout the study, overall canopy loss occurred on both sold and unsold parcels, but the amount of loss did not match the extent of loss found in the in situ tree survivorship data. For example, between 2015 and 2021, there was a lack of tree canopy loss. On the surface, this shows a story of little change in tree canopy cover, and therefore, this period had little to no difference between sold and unsold parcels in the context of the tree planting programs. However, these maps created through the classification of digital aerial photography fail to capture the whole picture. Saplings that have just been planted may be covered by a larger tree's overstory or masked by the shadow of a house. This flaw can be seen in the time period by its inability to reject the null hypothesis (<0.05). This could mean that the difference between the sold and unsold parcels is small. Still, in this case, the 2021 canopy data is of lower quality, and therefore, the inability to reject the null hypothesis introduces the idea that this data is noisy, meaning low-resolution imagery or data collection inconsistencies. With the lack of consistent tracking and documentation of trees post-planting (Roman et al. 2016), research like this is likely to lack resources and be underfunded. As noted in previous studies (e.g., Rosenblum 2015), even high-resolution technology often fails to detect juvenile or obscured trees. This limitation likely contributed to the inability to reject the null hypothesis in the 2021 canopy data, not because there was little difference between parcels, but because of the noisy or incomplete nature of the imagery. These limitations suggest that on-the-ground inventories complement remote sensing to accurately assess survivorship, particularly for newly planted or juvenile trees.

Third, homeownership significantly shapes tree survivorship. Properties not sold during the study had higher tree survivorship and lower canopy cover loss. These trends indicate that home ownership stability may be associated with improved tree care, maintenance, and protection. Between 2010 and 2015, tree mortality and canopy loss were higher. It is very likely that the removal of trees due to the longhorned beetle heavily impacted this change. The change in topography from the tree removals may have influenced some residents to consider relocating. However, given the limited data on property sales during this period, it's difficult to say for sure. Concerning DCR-planted trees, there was a significant difference between tree survivorship on sold parcels (59.1%) and unsold parcels (70.4%). A lower survivorship on sold properties is likely the result of new homeowners not being adequately informed about the significance and background of the tree planting initiative and the essentials of tree maintenance. For example, during replanting, the DCR recommended that homeowners use 15 gallons per week for tree care, with more detailed tree care information for homeowners more recently (Massachusetts DCR, per comm). Similarly, the higher significance levels *(p=<0.001)* suggest that property sales are associated with increased canopy loss or tree removal rates.

These results raise the importance of using methods to track urban tree planting programs that are sensitive to social dynamics, the long-term health of trees, and the potential of remote sensing technologies. Bridging these gaps will be critical in ensuring that tree planting programs achieve their desired environmental and social benefits in the future.

Conclusion

In this study, we analyzed the survival of trees planted by the Massachusetts Department of Conservation and Recreation's tree-planting program in Worcester, MA, between 2010 and 2021 in relation to homeownership change. Based on parcel-level sales data, tree inventory data, and remotely sensed canopy cover, it was found that residential ownership patterns affected trees' survivorship.

The results confirm that many trees did not reach maturity, emphasizing the importance of long-term care and maintenance programs. In addition, while canopy data through the classification of digital aerial photography provides important information, it cannot fully gauge the efficacy of tree planting programs, hiding finer-scale mortality and sub-canopy regeneration trends in individual trees. Finally, homeownership stability was linked to increased tree survival and decreased canopy loss, which implies that stable ownership stewardship accounts for some of the success of urban tree programs.

These outcomes underscore the importance of moving beyond planting quantities in urban greening programs to examine social and spatial dynamics that influence longer-term outcomes. Follow-up maintenance, homeowner participation, and holistic monitoring strategies will be critical to ensuring the ecological health and social benefits of future investments in urban trees.

References

Amer A, Franceschi E, Hjazin A, Shoqeir JH, Moser-Reischl A, Rahman MA, ... & Rötzer, T. (2023). *Structure and Ecosystem Services of Three Common Urban Tree Species in an Arid Climate City.* Forests, 14(4), 671. https://doi.org/10.3390/f14040671

City of Worcester. (n.d.). *Asian Longhorned Beetles*. [Accessed 2024, April 15] https://www.worcesterma.gov/parks/trees/asian-longhorned-beetles

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. https://doi.org/10.1016/j.ufug.2019.126382

Danko III JJ, Delauer V, Martin DG, & Rogan J. (2016). *Worcester, Massachusetts: A History of Urban Forestry Practices.* Northeastern Geographer, 8.

Elmes A, Rogan J, Williams C, Ratick S, Nowak D, & Martin D. (2017). *Effects of urban tree canopy loss on land surface temperature magnitude and timing.* ISPRS Journal of Photogrammetry and Remote Sensing, 128, 338-353. https://doi.org/10.1016/j.isprsjprs.2017.04.011

Geron, N., Martin, D., Rogan, J., & Healy, M. (2023). *Residents' roles as environmental policy actors using an urban governance framework: A case study of a tree planting program.* Cities, *135*, 104201. https://doi.org/10.1016/j.cities.2023.104201

Haack RA, Hérard F, Sun J, & Turgeon JJ. (2010). *Managing invasive populations of Asian* *longhorned beetle and citrus longhorned beetle: a worldwide perspective.* Annual Review of Entomology, 55, 521-546. https://doi.org/10.1146/annurev-ento-112408-085427

Hilbert DR, Roman, LA, Koeser AK, Vogt J, & van Doorn NS. (2019). *Urban tree mortality: A literature review.* Arboriculture & Urban Forestry (AUF), 45(5), 167-200. https://doi.org/10.48044/jauf.2019.015

Hostetler, A. E., Rogan, J., Martin, D., DeLauer, V., & O'Neil-Dunne, J. (2013). *Characterizing tree canopy loss using multi-source GIS data in Central Massachusetts, USA.* Remote Sensing Letters, 4(12), 1137–1146. https://doi.org/10.1080/2150704X.2013.852704

Hothorn, T., Hornik, K., & Zeileis, A. (2006). *Unbiased recursive partitioning: A conditional inference framework.* Journal of Computational and Graphical Statistics, 15(3), 651–674. https://doi.org/10.1198/106186006X133933

Lee, L. S., & Jim, C. (2018). Thermal-cooling performance of subtropical green roof with deep substrate and woodland vegetation. *Ecological Engineering*, *119*, 8-18. https://doi.org/10.1016/j.ecoleng.2018.05.014

McPherson, E. G. (2007). Benefit-based tree valuation. *Arboriculture & Urban Forestry*, *33*(1), 1–11. https://doi.org/10.48044/jauf.2007.001

Meineke, E., Youngsteadt, E., Dunn, R. R., & Frank, S. D. (2016). Urban warming reduces aboveground carbon storage. *Proceedings of the Royal Society B: Biological Sciences*, *283*(1840), 20161574. https://doi.org/10.1098/rspb.2016.1574

Mincey, S. K., Hutten, M., Fischer, B. C., Evans, T. P., Stewart, S. I., & Vogt, J. M. (2013). Structuring institutional analysis for urban ecosystems: A key to sustainable urban forest management. *Urban Ecosystems*, *16*, 553–571. https://doi.org/10.1007/s11252-013-0286-3

National Centers for Environmental Information. (2023). *U.S. climate normals*. National Oceanic and Atmospheric Administration. [Accessed 2024, April 9]. https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals

Nguyen VD, Roman LA, Locke DH, Mincey SK, Sanders JR, Smith Fichman E, Duran-Mitchell M, & Tobing SL. (2017). *Branching out to residential lands: Missions and strategies of five tree distribution programs in the U.S.* Urban Forestry & Urban Greening, 22, 24–35. https://doi.org/10.1016/j.ufug.2017.01.007

Nelson, A., Rogan, J., Geron, N., & Martin, D. G. (2024). *Factors influencing establishment and Post-establishment residential yard tree survivorship in Worcester, Massachusetts* [Unpublished manuscript]. Graduate School of Geography, Clark University

Nowak DJ, Kuroda M, & Crane DE. (2004). *Tree mortality rates and tree population projections in Baltimore, Maryland, USA.* Urban Forestry & Urban Greening, 2(3), 139-147. https://doi.org/10.1078/1618-8667-00030

Nowak, D. J., & Dwyer, J. F. (2007). Understanding the benefits and costs of urban forest ecosystems. In J. E. Kuser (Ed.), *Urban and community forestry in the Northeast* (pp. 25–46). Springer Netherlands. https://doi.org/10.1007/978-1-4020-4289-8_2

Palmer S, Martin D, DeLauer V, & Rogan J. (2014). *Vulnerability and Adaptive Capacity in Response to the Asian Longhorned Beetle Infestation in Worcester, Massachusetts.* Human Ecology, 42(6), 965–977. https://doi.org/10.1007/s10745-014-9695-z

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. https://doi.org/10.1016/j.ufug.2022.127597

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. https://doi.org/10.48044/jauf.2013.038

Roman LA, Battles JJ, & McBride JR.(2014). *Determinants of establishment survival for residential trees in Sacramento County, CA.* Landscape and Urban Planning, 129, 22–31. https://doi.org/10.1016/j.landurbplan.2014.05.004

Roman LA, Battles JJ, & McBride JR. (2016). *Urban tree mortality: A primer on demographic approaches.* GTR NRS-158. U.S. Department of Agriculture, Forest Service, Northern Research Station. 24 p. https://doi.org/10.2737/NRS-GTR-158

Rosenblum, H. S., Rogan, J., Elmes, A., & Martin, D. (2015). *Determining detectability of juvenile trees with airborne LiDAR*. [Unpublished manuscript]. Graduate School of Geography, Clark University.

Santos, R., & Cole, L. (2012). Massachusetts Asian Longhorned Beetle Cooperative Eradication

Program determines next steps for eradication efforts in Worcester County. *USDA-APHIS Newsroom*. https://www.aphis.usda.gov/newsroom/2012/04/alb_worcester.shtml

Scholz, T., Schmitt, T., & Weihermüller, L. (2022). *Phytodiversity and regulating ecosystem services of urban forests in the Ruhr Metropolitan Region (North Rhine–Westphalia, Germany)* (Doctoral dissertation). Ruhr University Bochum. https://doi.org/10.13154/294-9122

Sousa-Silva R, Duflos M, Ordóñez Barona C, & Paquette A. (2023). *Keys to better planning and integrating urban tree planting initiatives.* Landscape and Urban Planning, 231, 104649. https://doi.org/10.1016/j.landurbplan.2022.104649

Turner, C., & Mitchell, M. (2013). Planting the spaces in between: New York Restoration Project's tree giveaway program. *Cities and the Environment (CATE)*, *6*(1), Article 5. https://digitalcommons.lmu.edu/cate/vol6/iss1/5

Widney S, Fischer BC, & Vogt J. (2016). *Tree Mortality Undercuts Ability of Tree-Planting Programs to Provide Benefits: Results of a Three-City Study.* Forests, 7(3), Article 3. https://doi.org/10.3390/f7030065

U.S. Environmental Protection Agency. (2023). *Benefits of trees and vegetation*. https://www.epa.gov/heatislands/benefits-trees-and-vegetation

U.S. Census Bureau. (2023). *QuickFacts: Worcester city, Massachusetts*. U.S. Department of Commerce. [Accessed 2024, April 9]. https://www.census.gov/quickfacts/fact/table/worcestercitymassachusetts

Zillow. (2024). https://www.zillow.com

Figures

Table 1: Average percentage change in canopy cover over time for sold and unsold parcels, highlighting how residential turnover is associated with greater loss in canopy with the zip codes of 01605, 01506, and 01509. Significance: (*)p<0.05 (**) p<0.01(***)p<0.001

Year	Unsold Properties Average Canopy Change	Sold Properties Average Canopy Change	Differance (Sold-Unsold)	P-value	Correlation Coefficient	P-value
2010-2015	-3.35%	-4.27%	-0.92%	0.0014**	-0.49	<0.001***
2015-2021	-0.1%	-0.18%	0.01%	0.957	-0.21	<0.001***
2010-2021	-3.55%	-4.45%	-0.90%	0.0051**	-0.61	<0.001***

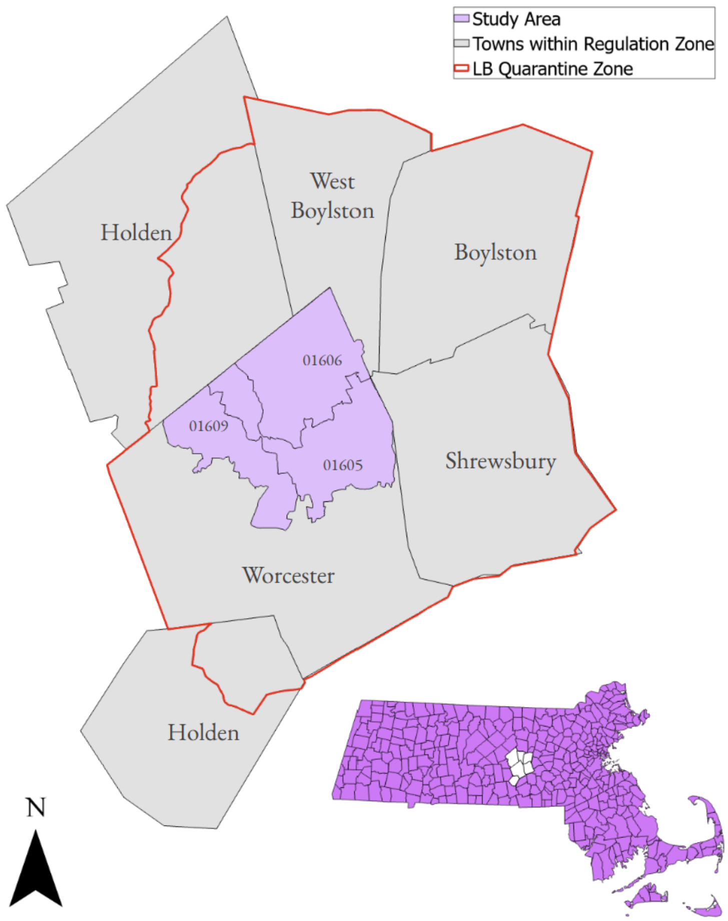

Figure 1: Study area map in the context of the Longhorned Beetle (LB) Regulation Zone and the state of Massachusetts, with a focus on the city of Worcester and the study of the zip codes 01605, 01605, and 01609

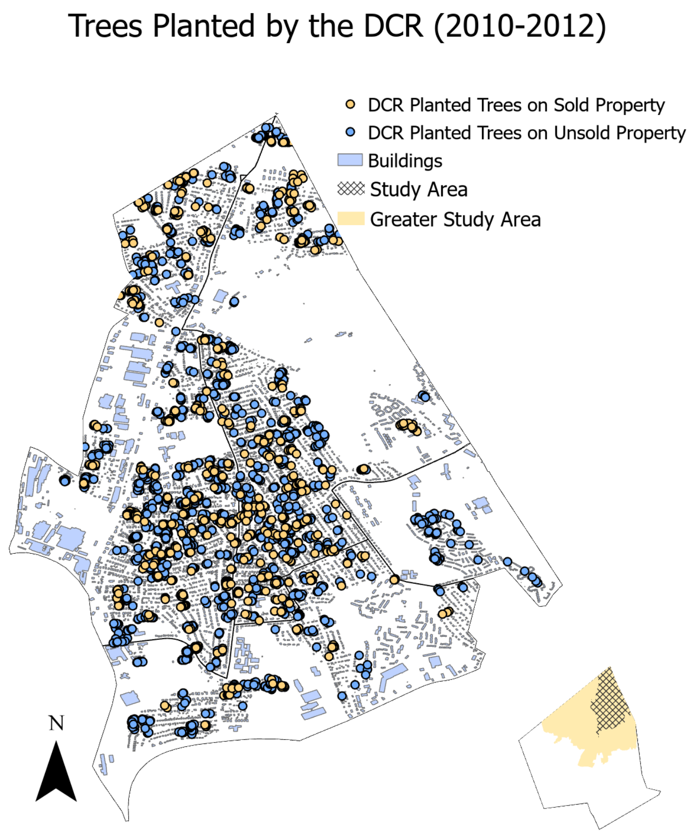

Figure 2: Study area map, showing points representing trees included in the analysis

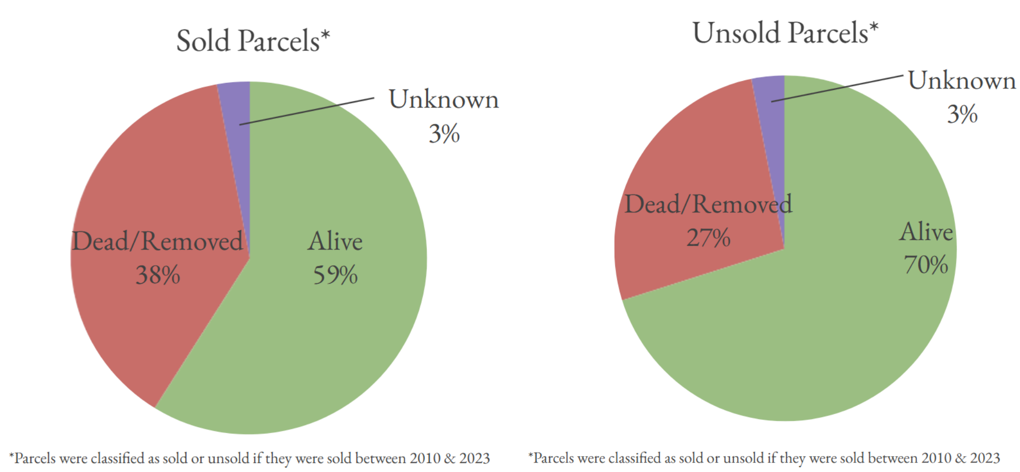

Figure 3: Pie chart showing the percentage of tree survivorship on sold and unsold parcels

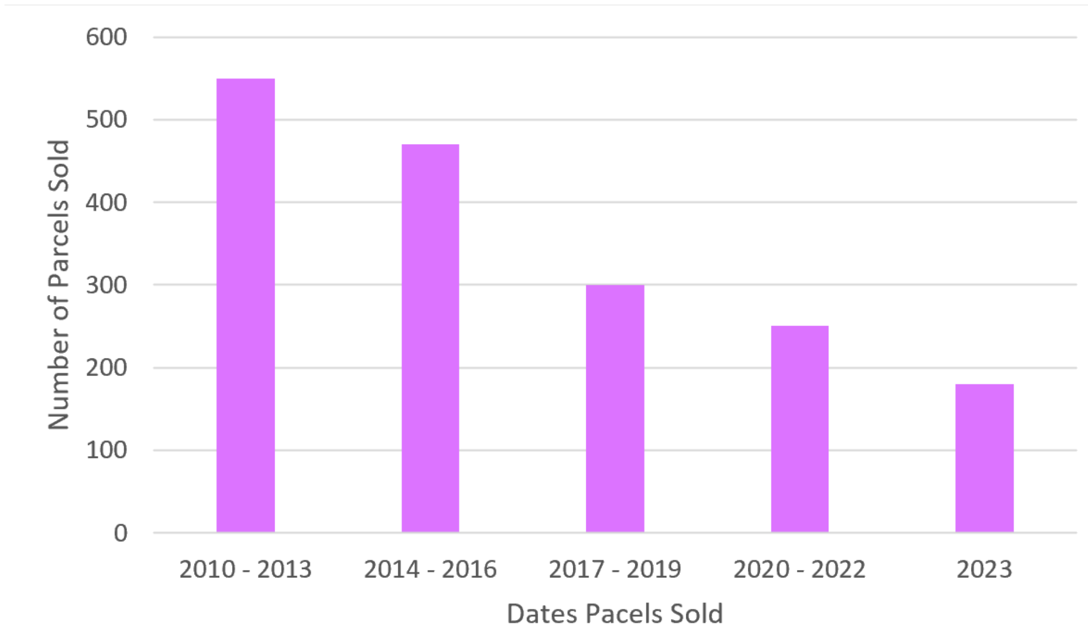

Figure 4: Bar chart depicting the number of parcel sales between 2010 and 2023 for the zip code 01606, the area of Worcester, MA that was hit hardest by the LB tree cutting between 2008 and 2012

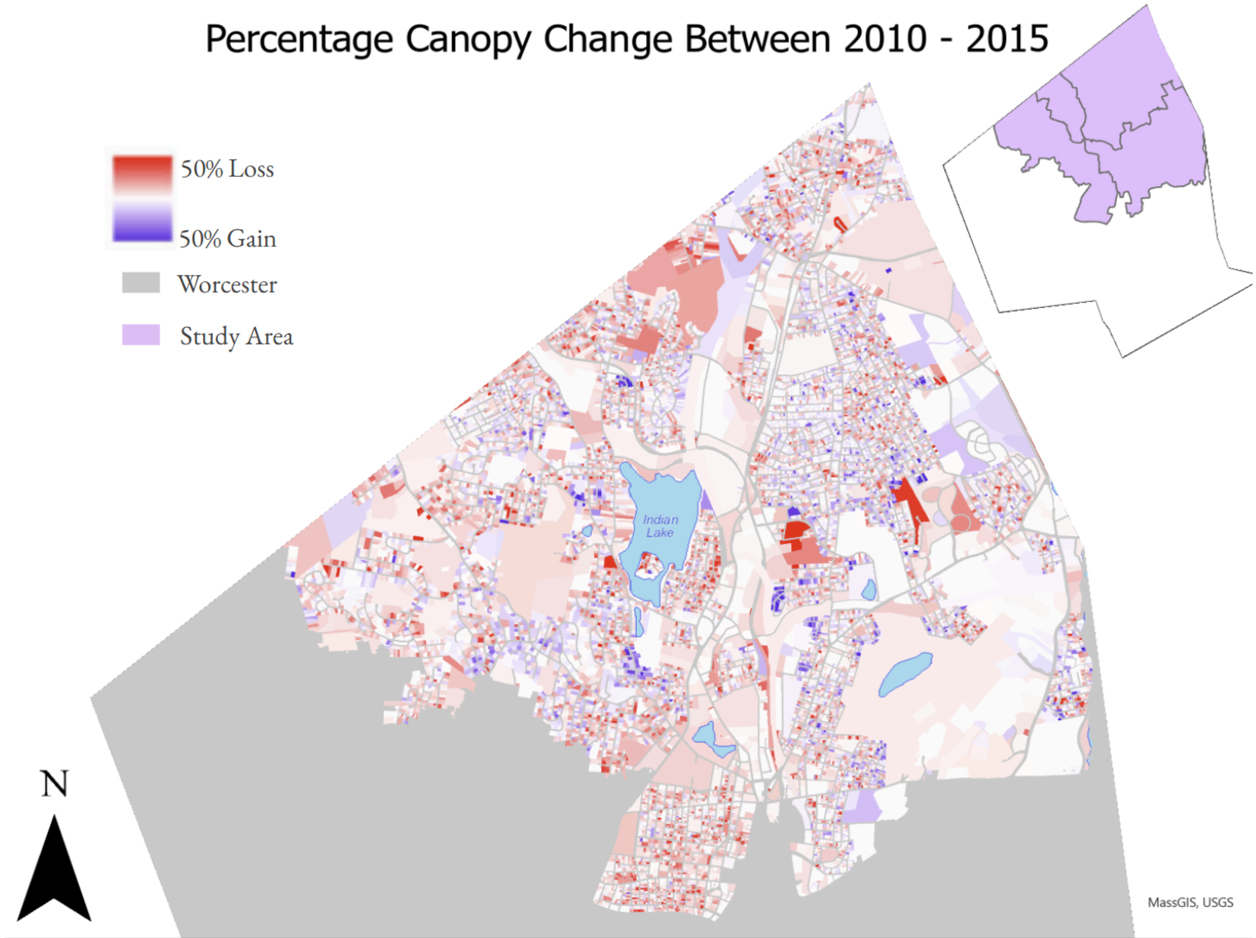

Figure 5: Average canopy change from 2010 to 2015

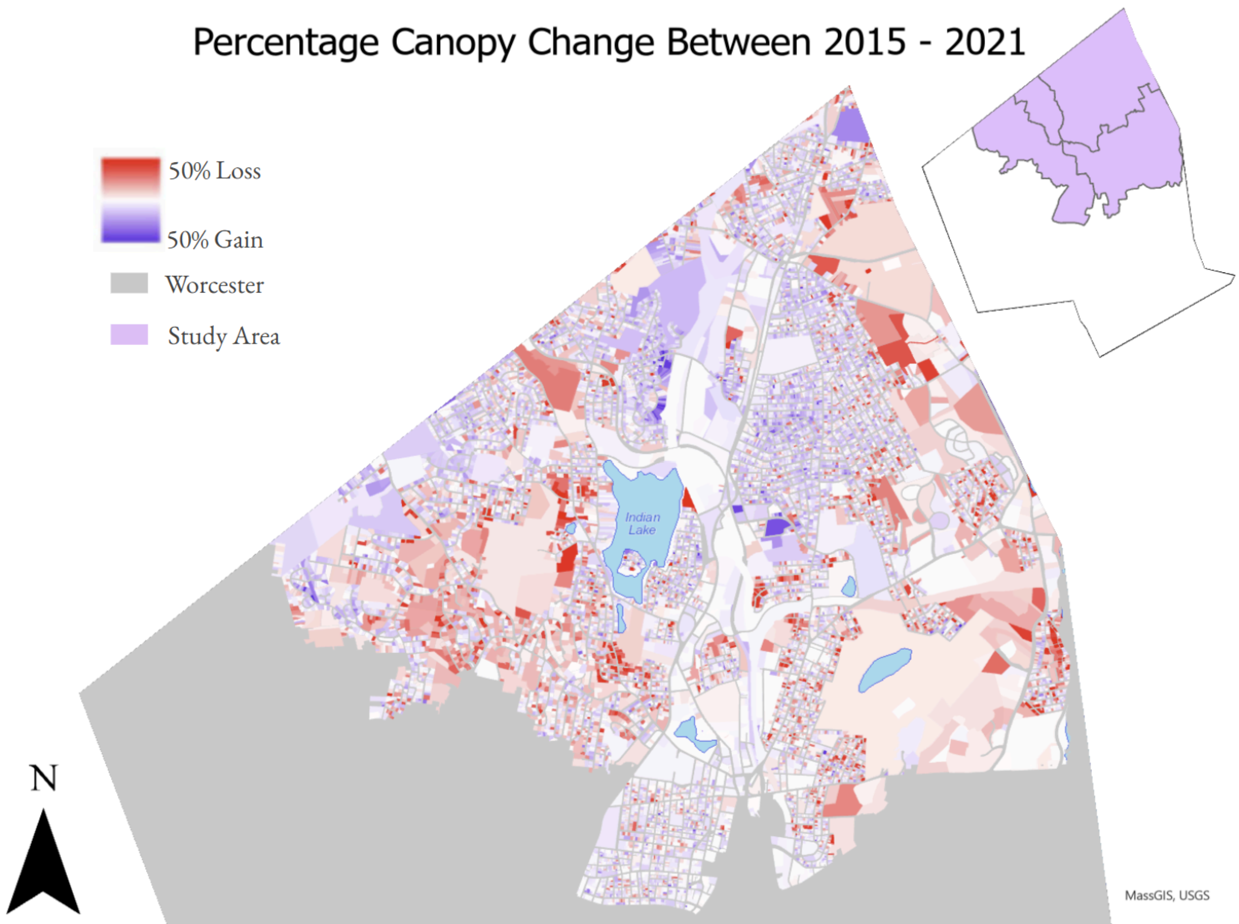

Figure 6: Average canopy change from 2015 to 2021

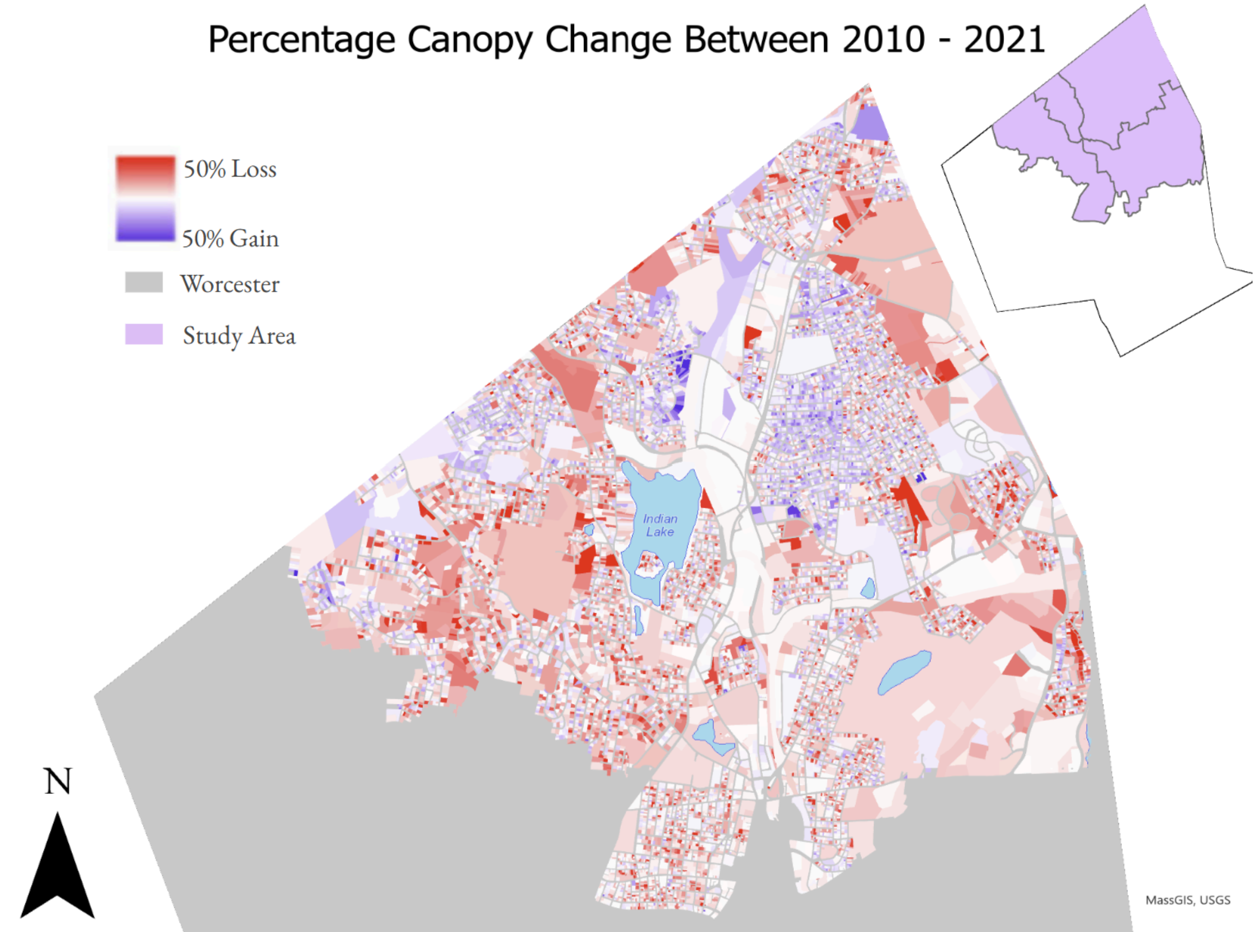

Figure 7: Average canopy change from 2010 to 2021