Lexington Street Tree Analysis

A pilot study conducted by the UK Urban Forest Initiative Core Team

2018-2021

Claire Hilbrecht, Mary Arthur, Ph.D, Nic Williamson, M.S.,

Lynne Rieske-Kinney, Ph.D, and Chris Sass, Ph.D

Table of Contents

Lexington Street Tree Analysis Executive Summary

A pilot study conducted by the UK Urban Forest Initiative Core Team, 2018 - 2021

Introduction

Street trees, defined as those trees that are growing in the easements between sidewalk and street, and in medians, are an important component of the urban tree canopy in any city. In Lexington, these trees are the fiscal responsibility of homeowners but are also under the purview of city government regulations. As such, they represent a subset of the trees in Lexington, with tree species, condition, size, and other attributes a reflection of past land use and developer decisions, homeowner choices, city regulations, and neighborhood age and socio-economic status. The University of Kentucky Urban Forest Initiative (UFI) core team sought to learn more about the species composition, health, condition, and size distribution of these important trees by sampling and mapping a subset of street trees in Lexington neighborhoods. Between April 2018 and July 2021 we mapped and measured 5,565 trees in 35 neighborhoods selected to represent a range of neighborhood age and socio-economic status (SES) using random sampling of streets within selected neighborhoods. Neighborhoods ranged in estimated age from 120 years old to neighborhoods built within the last decade. Sampling of street trees captured more neighborhoods estimated to be middle income SES, but also included those in low, low middle, upper middle and upper SES neighborhoods. It is worth noting that neighborhoods with no street trees were excluded from this study, and that more low SES neighborhoods fell into this category.

With this executive summary, which is a synthesis of key findings from the UFI street tree pilot study, we aim to impart notable findings based on the information we collected about each street tree (species, diameter, health condition, location, climate vulnerability rating) within our sample. The purpose of this study is to highlight the species diversity and health condition of these trees and consider the future trajectory of the street tree canopy, based on our subsampling, in the context of those attributes. Our aim is to provide the Lexington-Fayette Urban County Government (LFUCG) Urban Forestry group, LFUCG councilmembers, the Lexington Tree Board, and local residents with a tool for guiding future planting decisions and ongoing management of street trees, particularly in the face of a changing climate and other threats to Lexington's tree canopy. This summary highlights a few key findings; a much more detailed report follows and has been shared with Heather Wilson, the Urban Forestry Program Manager Sr. We will also share our data with the LFUCG Urban Forestry group, as it will enable them to use geo-located data to explore specific neighborhoods and streets to more specifically query key street tree attributes and deficits.

Key Attributes of Lexington's Street Trees

Tree Species

Lexington's street trees were grossly over-represented by red maple (*Acer rubrum*) and Callery pear (*Pyrus calleryana*). Using the 30-20-10 guideline for assessing a biodiverse tree canopy, there should be no more than 30% of trees of any one plant family, no more than 20% of any plant genus, and no more than 10% of any species. Using this guideline, both red maple and Callery pear were overrepresented, as were maples as a genus and the family to which maple belongs (Figure 1).

As expected, ash trees of all species had low representation in Lexington's tree canopy, with losses due to the emerald ash borer.

Ten percent of street tree locations inventoried were empty tree wells.

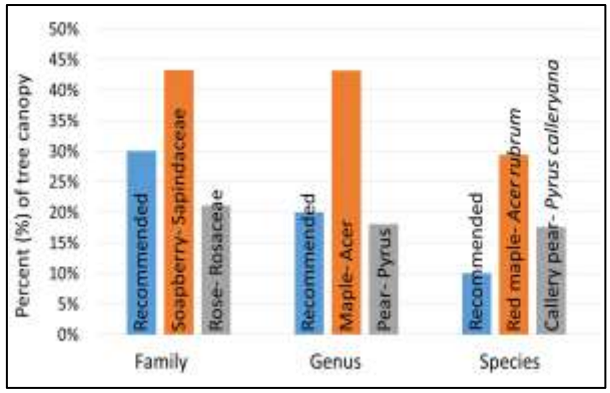


Figure 1. Comparison of Santamour's (1990) 30-20-10 rule and Lexington's street tree canopy based on a random sample of Lexington street trees inventoried from 2018-2021 and applied to maple and pear, two species that are overrepresented.

There were 123 individual species sampled; however, 111 of those species each occupied <1% of the street trees measured, with a few species dominating the street tree canopy.

Recommendations:

1. Plant alternative species to red maple, and to maples in general (the proportion of street trees that were in the maple (*Acer*) genus is 43%), to reduce the relative proportion of maples. Not only are maples susceptible to the Asian longhorn beetle, a potential future threat, their dominance reduces the biodiversity of the street tree canopy, making the canopy as a whole more susceptible to future threats.
2. Increase the relative proportion of species suitable to the soils and climate (including future projected climate) in Lexington generally, and in planting spots specifically ("right tree, right place"), to improve the sustainability of the street tree canopy. Tree species should be selected from the LFUCG approved list (https://www.lexingtonky.gov/planting-manual), keeping in mind that red maple is on the list, yet planting of it should be greatly reduced (despite the ease of acquiring it).
3. The loss of ash and the presence of empty tree wells offer an opportunity to diversify the canopy. With 10% of tree wells lacking a tree, working to ensure that trees are planted into these locations is essential for building a robust tree canopy.
4. Callery pear, a known invasive tree species with weak wood, cannot be planted as a Lexington street tree, as codified in the LFUCG Planting Manual. Because of the problems this species presents to the health of our tree canopy, strategies for removal of current pear trees should be developed, with plans to replace those trees with approved species.

Tree Size and Health Condition

Lexington's street trees were reasonably well distributed across size classes, but with an overabundance of trees in the 8-16" size class (Figure 2). Generally, pin oaks were the largest street trees in Lexington, and made up 25% of trees greater than or equal to 24". Red maple trees made up 41% of small trees, (those less than 8" in diameter), which means that the disproportionate number of red maples in our street tree canopy is "baked in" for the foreseeable future.

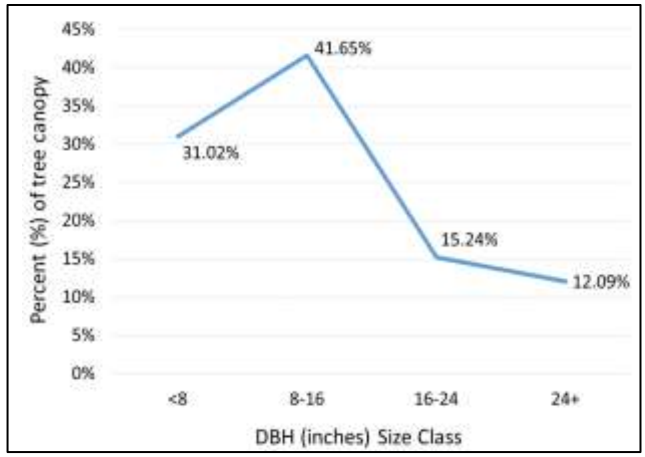


Figure 2. Size class distribution for Lexington street tree canopy based on a random sample of Lexington street trees inventoried from 2018-2021.

Sixty-nine percent of street trees were in good condition, whereas 6% were in "poor" or "dead/dying" condition. Interestingly, health condition was not evenly distributed across size classes. Although a higher proportion of trees in large size classes were poor or dead/dying (11%), because there were so many trees in the 8-16" size class, a much larger percentage of poor or dead/dying trees were in this size class (34%; Table 1). Trees in these condition classes were also not evenly distributed across species. Within the greater than or equal to 24" size class, 25% of trees were pin oaks, of which 7% were in poor or dead/dying condition, 18% were Callery pear with 13% in poor and dead/dying condition, 14% were sugar maple (17% poor and dead/dying), and 10% were silver maple (16% poor and dead/dying).

Table 1: Percent of trees in poor or dead/dying condition by size class. Within size class, larger trees had higher percent poor or dead/dying (A). However, of all the poor or dead/dying trees, more were found among trees 8-16" diameter (B).

Size class	A: % poor or dead/dying within size class	B: % of total poor or dead/dying in this size class
<8 in	4.5	23
8-16 in	4.8	33.6
16-24 in	8.8	22
≥24 in	10.8	20.8

A higher percentage of poor or dead/dying street trees resided in younger neighborhoods (1990-2010). However, ~5% of street trees in both older (1900-1950) and younger neighborhoods were poor or dead/dying (Table 2).

Table 2: Percent of trees in poor or dead/dying condition by neighborhood age. Within neighborhood age, street trees had a fairly equal percent poor or dead/dying (A). However, of all the poor or dead/dying trees, more were found in neighborhoods built between 1990 and 2010 (B).

Decade Developed	A: % poor or dead/dying within these neighborhoods	B: % of total poor or dead/dying in these neighborhoods
1900-1950	5.3%	34.2%
1990-2010	5.5%	45.8%

Recommendations:

1. Protect the 89% of street trees in the greater than or equal to 24" size class that are healthy; these trees are providing the most significant services to Lexington residents.
2. Plant trees, and specific species, in sites that can sustain them to promote the development of a tree canopy that can support young trees into maturity.

Climate Adaptation

Climate adaptation is the ability of our urban forests to respond to climate change to avoid future canopy losses and promote a healthy tree canopy. Some elements of a climate adapted tree canopy are high biodiversity, a wide size class distribution, and high adaptability to various environmental pressures and disturbances. Importantly, urban forests are situated in a social and political environment and require policies and management that are focused on supporting and maintaining a resilient canopy across all neighborhoods regardless of socio-economic status while simultaneously helping to mitigate the worst impacts of climate change. **Intentional and thoughtful planning within the context of climate change can help promote a tree canopy that is well adapted to future ecological and climatic changes**.

Climate vulnerability ratings are a measure of how vulnerable a species is to climate change based on climate change projections and individual tree species' adaptive capacity to respond to various environmental factors. Climate vulnerability ratings can be useful for guiding climate-forward thinking, and should be applied in a manner that supports the steps that urban forest managers are already using to promote a healthy and robust tree canopy for our city (i.e. "right tree, right place" and other site-specific considerations such as soil suitability). Climate vulnerability ratings of tree species provide an additional framework through which we can view the resilience of the urban forest to future changes and prepare the canopy for climate change (Figure 3).

52% of Lexington's street tree canopy had a low to low-moderate climate vulnerability rating. However, 42% of street trees had a moderate to high vulnerability rating. (Note that 5% of street trees were species that do not have vulnerability ratings). Climate vulnerability ratings provide a lens through which to evaluate the potential for a species to perform well as climate changes, *but must be combined with an understanding of the tree species that are best adapted to the soils of the Inner Bluegrass region, or that are impacted by development.*

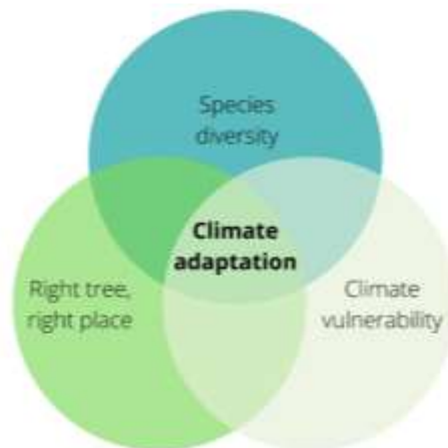


Figure 3. A framework for preparing our tree canopy for climate change.

Recommendations:

1. Choose a diversity of tree species that are well suited to Lexington's current environment and are expected to perform well in a changing climate, while attending to specific site limitations and requirements.
2. Engage and support residents in caring for their street trees, especially in low SES neighborhoods. Neighborhoods with poor tree canopies will require greater focus on tree healthcare from the city.

References:

Brandt, L., Lewis, A. D., Fahey, R., Scott, L., Darling, L., & Swanston, C. (2016). A framework for adapting urban forests to climate change. *Environmental Science & Policy*, *66*, 393-402.

Ordóñez, C., & Duinker, P. N. (2014). Assessing the vulnerability of urban forests to climate change. *Environmental Reviews*, *22*(3), 311-321.

Santamour, F. "Trees for urban planting: diversity, uniformity, and common sense in 7th Conference of the Metropolitan Tree Improvement Alliance." The Morton Arboretum, Lisle (1990).

Introduction

Street trees, defined as those trees that are growing in the easements between sidewalk and street, and in medians, are an important component of the urban tree canopy in any city. In Lexington, these trees are the fiscal responsibility of homeowners but are also under the purview of city government regulations. As such, they represent a subset of the trees in Lexington, with tree species, condition, size, and other attributes reflecting past land use and developer decisions, homeowner choices, city regulations, and neighborhood age and socioeconomic status. To prepare our urban forest for our changing climate, the University of Kentucky Urban Forest Initiative (UFI) core team sought to learn more about the species composition, health, condition, and size distribution of these important trees by sampling and mapping a subset of street trees in Lexington neighborhoods. Our aim is to provide the Lexington-Fayette Urban County Government (LFUCG) Urban Forestry group, LFUCG councilmembers, the Lexington Tree Board, and local residents with a tool for guiding future planting decisions and ongoing management of street trees, particularly in the face of a changing climate and other threats to Lexington's tree canopy.

Between April 2018 and July 2021 we mapped and measured 5,565 trees in 35 neighborhoods selected to represent a range of neighborhood age and socio-economic status (SES) using random sampling of streets within selected neighborhoods. Neighborhoods ranged in estimated age from 120 years old to those built within the last decade. Our sample captured more neighborhoods estimated to be middle income SES, but also included those in low, low middle, upper middle and upper SES neighborhoods. Neighborhood SES was determined by a combination of median household income and property value. Neighborhoods with no street trees were excluded from this study, and more low SES neighborhoods fell into this category.

With this report, which is a synthesis of the UFI street tree pilot study, we aimed to impart notable findings based on the information we collected about each street tree (species, diameter, health condition, location, climate vulnerability rating) within our sample. The purpose of this study is to highlight the species diversity and health condition of these trees and consider the future trajectory of the street tree canopy, based on our subsampling, in the context of those attributes. *We assumed that our subsample was a reasonable representation of the Lexington street tree canopy and refer to it as such.* This report will be shared with Heather Wilson, the Urban Forestry Program Manager Sr., to help inform future management decisions in the face of a changing climate. Additionally, this report will enable the LFUCG Urban Forestry group to use geo-located data to explore specific neighborhoods and streets to more specifically query key street tree attributes and deficits for use in management.

Key Attributes of Lexington's Street Trees

The street tree canopy attributes revealed in this study can help urban forest managers anticipate potential problems with our street tree canopy and develop solutions with the goal of enhancing the canopy's resilience to climate change. This report begins with an analysis of tree species composition and a comparison of Lexington's street tree canopy using Santamour's (1990) 30-20-10 rule for assessing biodiversity. Then, we discuss tree size and health together to reveal relationships between size class and heath condition. The climate adaptation section highlights the climate vulnerability of Lexington's street tree canopy by species, and addresses possible opportunities for climate resilience in Lexington. Finally, the report ends with an analysis of the relationships between Lexington street tree composition and the age and socioeconomic status of the corresponding neighborhoods that were inventoried in this study.

Tree Species Diversity

Lexington's street trees, innocuously, were grossly over-represented by red maple (*Acer rubrum)* and Callery pear (*Pyrus calleryana).* Using Santamour's (1990) 30-20-10 guideline for assessing a biodiverse tree canopy, there should be no more than 30% of trees of any one plant family, no more than 20% of any plant genus, and no more than 10% of any species. Using this guideline, both red maple and Callery pear were overrepresented, as were maples as a genus and the family to which maple belongs (Figure 1). Red maple and Callery pear made up 29% and 18% of the trees sampled, respectively. Maples as a genus (*Acer*) represented 43% of the tree canopy. Finally, 43% of trees were in the soapberry family (which includes maples).

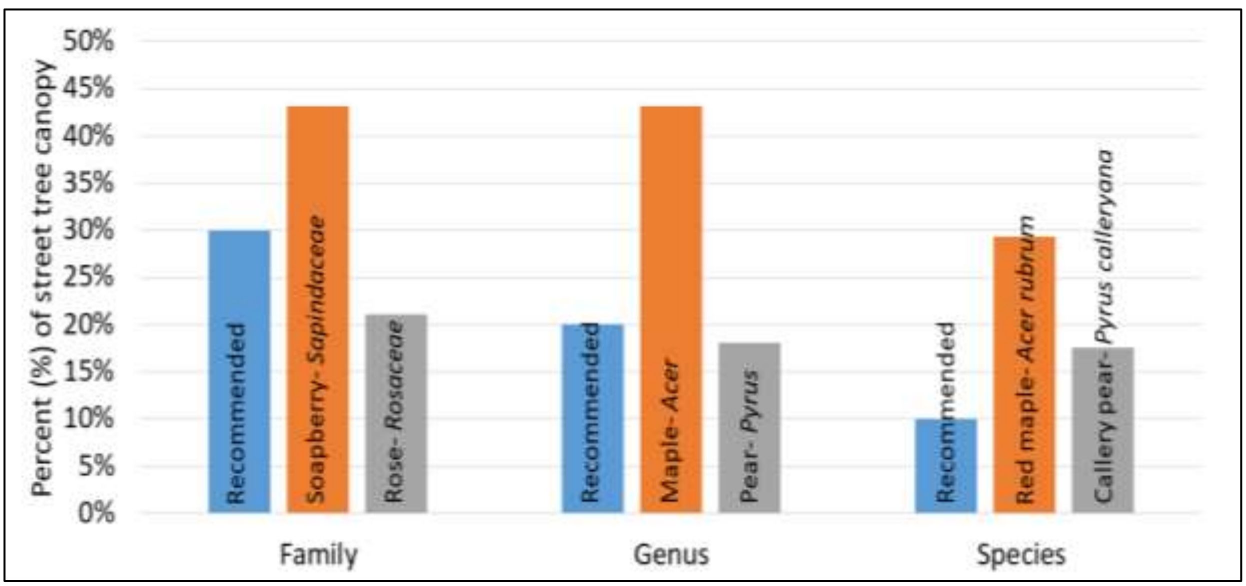


Figure 1. Comparison of Santamour's (1990) 30-20-10 rule and Lexington's street tree canopy based on a sub-sample of Lexington street trees inventoried from 2018-2021, applied to red maple and Callery pear, two species that were overrepresented.

Street trees in our study were lacking diversity across the board, with only a few species, genera, and families representing the vast majority of street trees. This is cause for concern, as low diversity may pose risks to the tree canopy, especially in the face of a changing climate when pests, pathogens, and other environmental pressures are becoming more frequent. Increasing biodiversity and thereby decreasing the relative abundance of any one species, genus, or family can promote resilience in our tree canopy by reducing the likelihood that large swaths of our canopy are wiped out by encroaching threats to a specific type of tree.

There were 123 individual tree species sampled in our study; however, a few species dominated the street tree canopy, with only 12 species accounting for 78% of the street trees measured (Figure 2). The other 111 species made up a combined 22% of the tree canopy.

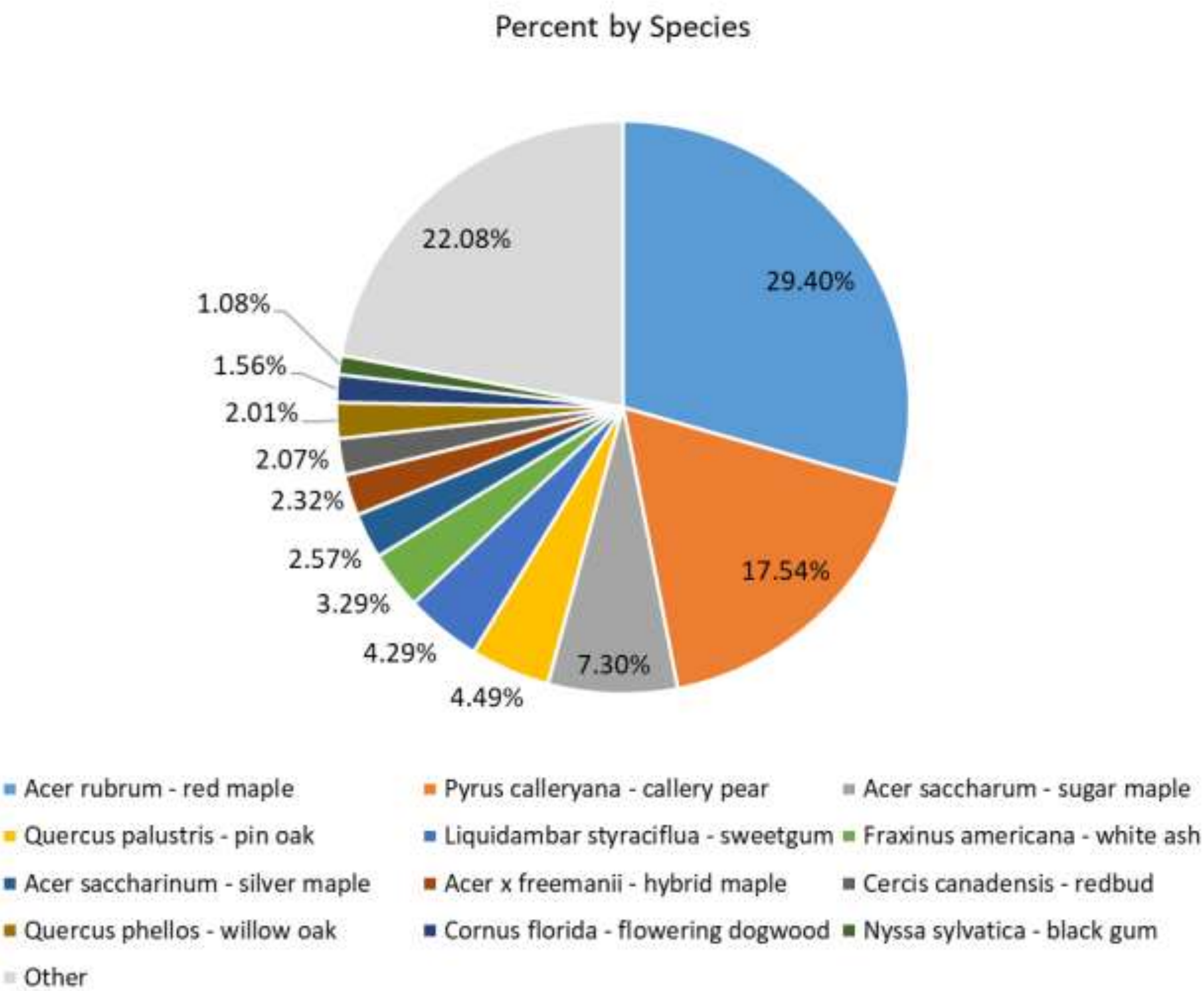


Figure 2. Percent of each tree species in Lexington based on a sub-sample of Lexington street trees inventoried from 2018-2021. Species shown each made up at least 1% of the canopy. A full list of tree species and their relative abundance can be found in Appendix C.

There were 52 genera recorded, with only 10 genera representing 88% of the street trees in our sample (Figure 3). The other 42 genera made up a combined 12% of the tree canopy. As expected, ash (*Fraxinus*) trees of all species had low representation in Lexington's tree canopy, making up only 4% of the tree canopy, with losses due to the emerald ash borer. This is a significant decline in ash trees; in 2006, 11% of Lexington's street trees were ash (Lexington Street Tree Windshield Survey, 2006).

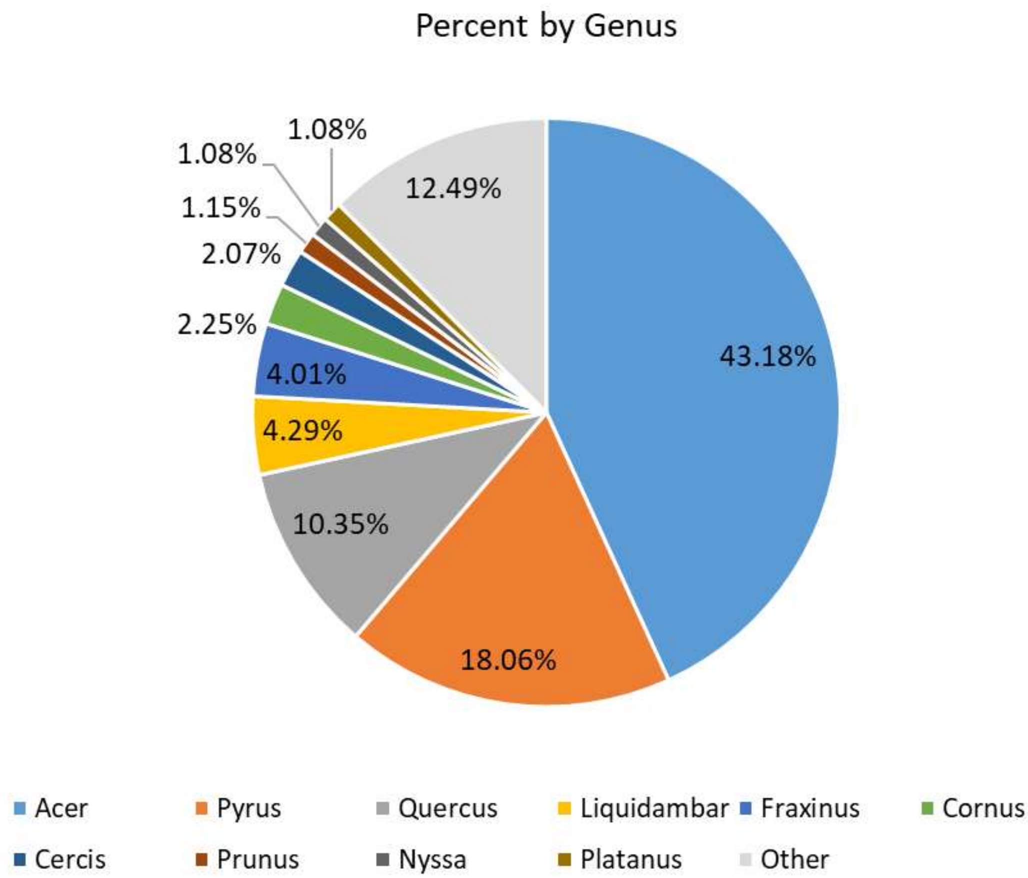


Figure 3. Percent of tree species, shown by genera, in Lexington based on a sub-sample of Lexington street trees inventoried from 2018-2021. Genera shown each made up at least 1% of the canopy.

There were 29 different families represented in our sample, with only 12 families representing 96% of the street trees in our sample (Figure 4). The other 17 families made up a combined 4% of the tree canopy.

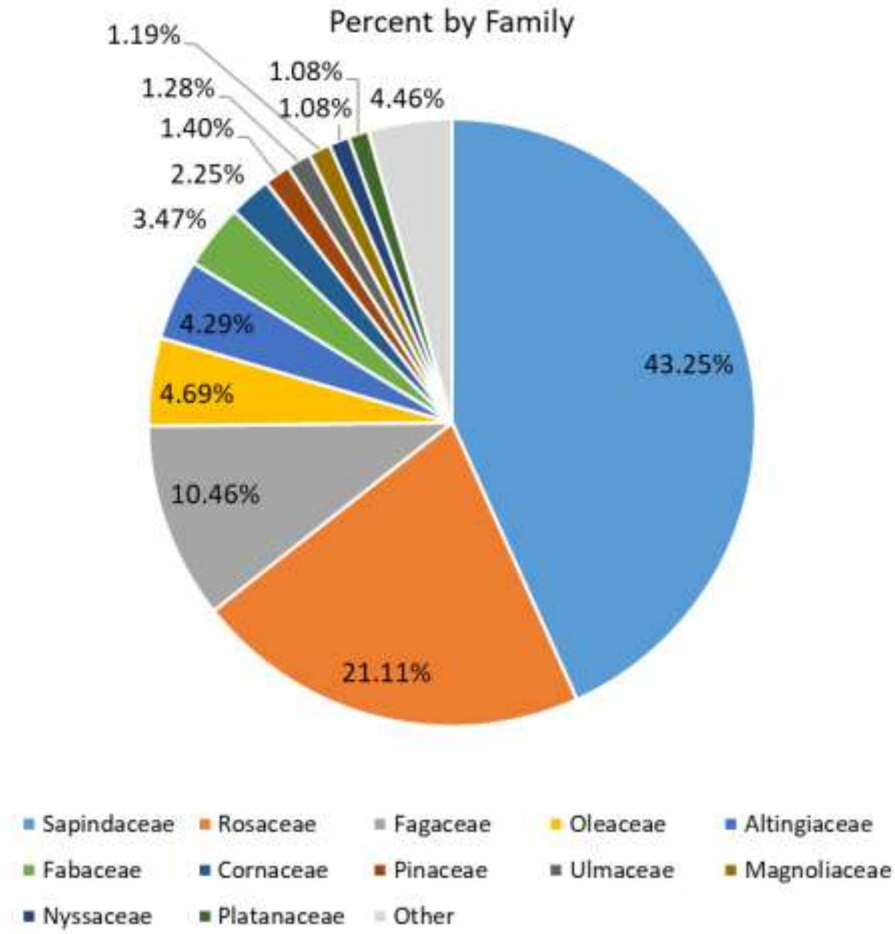


Figure 4. Percent of tree species, shown by family, in Lexington based on a sub-sample of Lexington street trees inventoried from 2018-2021. Families shown each made up at least 1% of the canopy.

Recommendations:

1. **Increase tree species diversity.** Plant alternatives to red maple, and to maples in general (the proportion of street trees that were in the maple (*Acer*) genus was 43%), to reduce the relative proportion of maples. Not only are maples susceptible to the Asian longhorn beetle, a potential future threat, their dominance reduces the biodiversity of the street tree canopy, making the canopy as a whole more susceptible to other future threats.
2. **Improve resilience through "right tree, right place".** Increase the relative proportion of species suitable to the soils and climate (including future projected climate) in Lexington generally, and in planting spots specifically, to improve the sustainability of the street tree

canopy. Tree species should be selected from the LFUCG approved list (https://www.lexingtonky.gov/planting-manual), keeping in mind that red maple is on the list, yet planting of it should be greatly reduced (despite the ease of acquiring it).

3. **Transition away from undesired species.** Callery pear, a known invasive tree species with poor branch structure subject to wind and ice damage, cannot be planted as a Lexington street tree, as codified in the LFUCG Planting Manual. This species is problematic to our municipal and regional tree canopy. Strategies for removal of current pear trees should be developed, with plans to replace removed trees with approved species.
4. **Replant in ash tree removal sites.** The loss of ash trees, and the presence of empty tree wells in general, offer an opportunity to diversify the canopy.

Tree Size, Health, & Condition

When analyzed together, tree size, health, and condition reveal important information about our street tree canopy, such as how health and condition are distributed across size classes. These relationships are particularly important as we plan for our future tree canopy, as we can focus our efforts improving the health of particular subsections of our tree street tree canopy.

Lexington's street trees were reasonably well distributed across size classes, but with an overabundance of trees in the 8-16" diameter-at-breast height (DBH) size class compared to the recommended distribution (Richards, 1983; Figure 5).

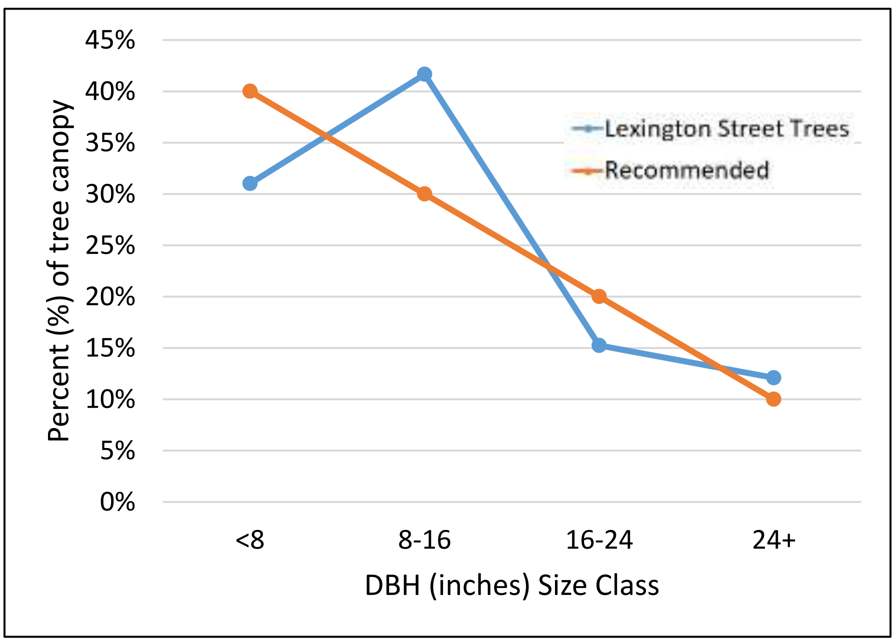


Figure 5. Size class distribution for Lexington street trees based on a sub-sample of Lexington street trees inventoried from 2018-2021.

Generally, pin oaks were the largest street trees in Lexington, and made up 25% of trees greater than or equal to 24" in diameter. Red maple trees made up 41% of small trees, (those less than 8" in diameter), which means that the disproportionate number of red maples in our street tree canopy is "baked in" for the foreseeable future.

We assessed the condition of each tree using four classifications: good, fair, poor, and dead/dying. Table 1 shows how we determined the condition of each tree.

Table 1: Determinants of tree condition. The term "leaf discoloration" here refers to mottled or spotted leaves, indicative of fungus or frost damage.

Condition	Wood	Percent Deadwood	Leaves
Good	No outstanding issues	<10%	No outstanding issues
Fair	Some deadwood	10-25%	Some discoloration
Poor	Significant deadwood	25-75%	Wilted, severely discolored
Dead/Dying	Mostly or all deadwood	>75%	Little to no leaves

Sixty-nine percent of street trees were in good condition, 25% were in fair condition, and 6% were in poor or dead/dying condition (Figure 6).

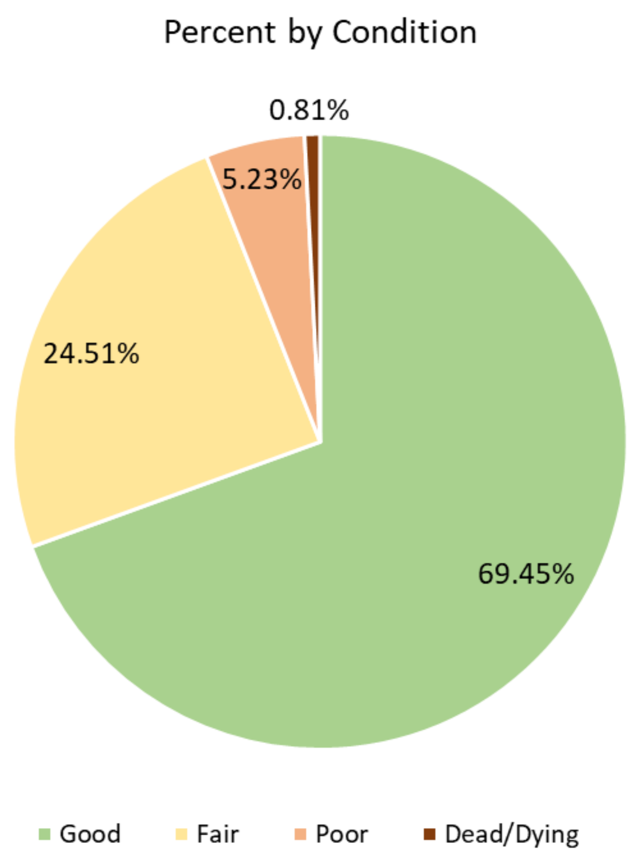


Figure 6. Percent of trees by condition for Lexington neighborhoods based on a sub-sample of Lexington street trees inventoried from 2018-2021.

Interestingly, health condition was not evenly distributed across size classes (Table 2). Although a higher proportion of trees greater than or equal to 24 inches were poor or dead/dying compared to other size classes, the greatest percentage of all poor or dead/dying trees were in the 8-16” size class. In other words, poor or dead/dying trees were concentrated in the 8-16” size class, rather than in the greater than or equal to 24” size class, even though 11% of greater than or equal to 24” trees were poor or dead/dying compared to 5% of 8-16” trees. This is because there were so many trees in the 8-16” size class.

Additionally, as shown in Table 2, a higher proportion of trees within larger size classes were poor or dead/dying compared to smaller size classes. However, the majority of poor or dead/dying trees were in smaller size classes, as small trees made up the majority of our street tree canopy. This poses a problem because 57% of the poor or dead/dying trees in our canopy were found in small size classes and are not likely to survive to adulthood.

Table 2: Percent relative abundance of trees in each size class and percent of trees in poor or dead/dying condition by size. Smaller trees had a greater relative abundance than larger trees (A). Within each size class, larger trees had higher percent poor or dead/dying (B). However, of all the poor or dead/dying trees, more were found among trees 8-16” diameter (C).

Size Class	A: % relative abundance of trees in each size class	B: % poor or dead/dying trees within each size class	C: % of total poor or dead/dying trees by size class
<8 in	31	4.5	23
8-16 in	41.7	4.8	33.6
16-24 in	15.2	8.8	22
$\geq$24 in	12.1	10.8	20.8

Trees in the combined condition classes of poor and dead/dying trees were also not evenly distributed across species (Table 3). Importantly, pin oaks made up ¼ of the trees greater than or equal to 24 inches in our sample, but only 7% of these trees were poor or dead/dying, despite the narrative that all large pin oaks are dying. Rather, the majority of large trees that were poor or dead/dying were Callery pear, sugar maple, and silver maple.

Table 3: Percent relative abundance and percent poor or dead/dying of the four most abundant large tree species in our sample.

Species	A: % relative abundance of trees $\geq$ 24 in within this species	B: % poor or dead/dying for this species
Pin oak - *Quercus palustris*	24.6	7.3
Callery pear - *Pyrus calleryana*	17.6	12.7
Sugar maple- *Acer saccharum*	14	17
Silver maple- *Acer saccharinum*	10	16.4

Recommendations:

1. **Protect the large, healthy trees in our street tree canopy.** Eighty-nine percent of trees greater than or equal to 24 inches in diameter were healthy. These trees should be protected, as they provide the most significant services to Lexington residents.
2. **Begin shifting toward a more diverse street tree canopy.** Consider ways to remove Callery pear trees that are already in poor and dead/dying condition to speed the process of shifting the street tree canopy away from Callery pear. This same approach could be applied to the maples that are in poor and dead/dying condition.
3. **Plant trees in sites that can support them.** Plant specific tree species in appropriate sites that can promote full development of tree canopy and tree maturity.

Climate Adaptation

Climate adaptation is the ability of our urban forests to respond to changing climate, avoid future canopy losses, and support a healthy tree canopy (Ordóñez & Duinker, 2014). Some elements of a climate resilient tree canopy are high biodiversity, a wide size class distribution, and high adaptability to various environmental pressures and disturbances (Ordóñez & Duinker, 2014). Importantly, urban forests are impacted by social and political factors. Therefore, they require policies and management to support and maintain a resilient canopy across all neighborhoods regardless of socio-economic status while working to mitigate the worst impacts of climate change. **Intentional and thoughtful planning with climate resilience in mind can help promote a tree canopy that is well adapted to future ecological and climatic changes and provide a more livable urban environment for people in the face of climate change** (Ordóñez & Duinker, 2014).

Climate vulnerability ratings can help us plan for climate resilience. These ratings are a measure of how vulnerable a species is to climate change based on climate change projections and the species' capacity to adapt to various environmental factors (Brandt, et al., 2016). Climate vulnerability ratings account for species hardiness, resistance to pests and diseases, tolerance to urban conditions, and other relevant species characteristics. Appendix D provides an in-depth description of the climate vulnerability rating process.

Climate vulnerability ratings can help Lexington's urban forest managers evaluate the resilience of our tree canopy to climate change, but *must be combined* with an understanding of the tree species that are best adapted to the soils of the Inner Bluegrass region and areas highly impacted by development. Climate vulnerability ratings should be used to help guide species selection toward climate resilient tree species or call attention to at-risk species in our canopy that may need more care in the

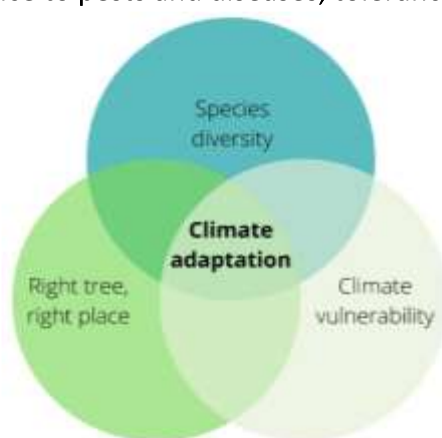


Figure 7. A framework for preparing our tree canopy for climate change.

future. Additionally, climate vulnerability ratings should help support the steps that Lexington's urban forest managers are already using to promote a healthy and robust tree canopy for our city, such as "right tree, right place" and increasing species diversity. Together, these management tools provide a framework through which we can view the resilience of the urban forest to future changes and prepare the canopy for our changing climate (Figure 7).

Fifty-two percent of street trees sampled in this study had a low to low-moderate climate vulnerability rating, meaning that they should fare well in a changing climate (all other things being equal). However, 42% of street trees had a moderate to high vulnerability rating (Figure 8; note that 5% of street trees were species that do not have vulnerability ratings). Thus, just over half of the sampled trees are projected to withstand future changes, while the remaining 42% are vulnerable to these changes based off species-level adaptation factors.

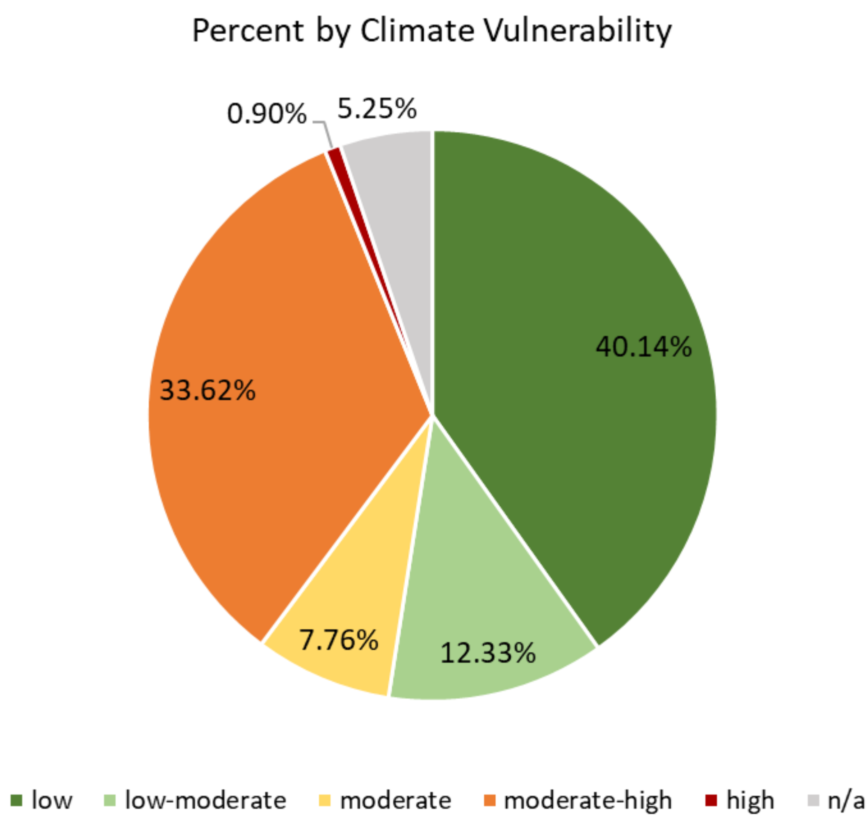


Figure 8. Percent of trees by climate vulnerability for Lexington neighborhoods based on a sub-sample of Lexington street trees inventoried from 2018-2021. "N/A" represents species for which we did not yet have vulnerability ratings.

Thirty-four percent of species had a 'moderate-high' vulnerability rating. This was primarily due to the large amount of Callery pear on the landscape, which has this rating. Of the trees with this climate vulnerability rating, Callery pear made up 52% of trees in our study (Figure 9). *Again, this does not mean that we should not plant the trees with a moderate-high vulnerability rating, unless the planting of a certain species is restricted for another reason.* However, urban forest managers should pay special attention to species that are projected to be moderately to highly vulnerable to climate change, as these trees may be at risk as climate change continues to unfold.

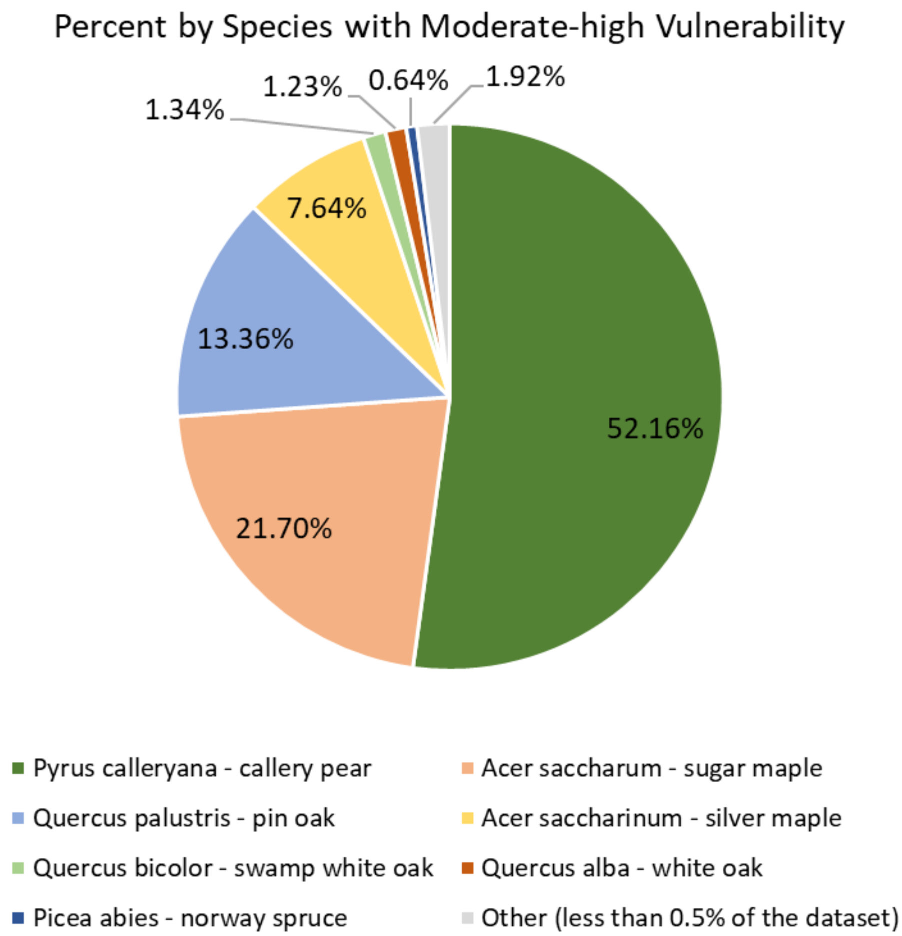


Figure 9. Percent of tree species with moderate-high vulnerability ratings for Lexington neighborhoods based on a sub-sample of Lexington street trees inventoried from 2018-2021. "Other" species made up a combined 2% of the dataset, with 15 other species represented.

To enhance climate resilience in our street tree canopy, seven species in particular should be not be planted as street trees (Figure 10). These species were chosen based on their high relative abundance currently in the Lexington street tree canopy and/or their high vulnerability to climate change (Appendix E). For example, red maple, though it had a low climate vulnerability rating, should not be planted due to its very high relative abundance (almost 30% of street trees in our study were red maple). Species in the top right corner of the graph had a relative abundance greater than the recommended 10% and a "moderate" to "moderate-high" vulnerability rating, so should be avoided for further planting. Species in the bottom right corner of the graph were "highly vulnerable" to climate change, and should not be planted for that reason.

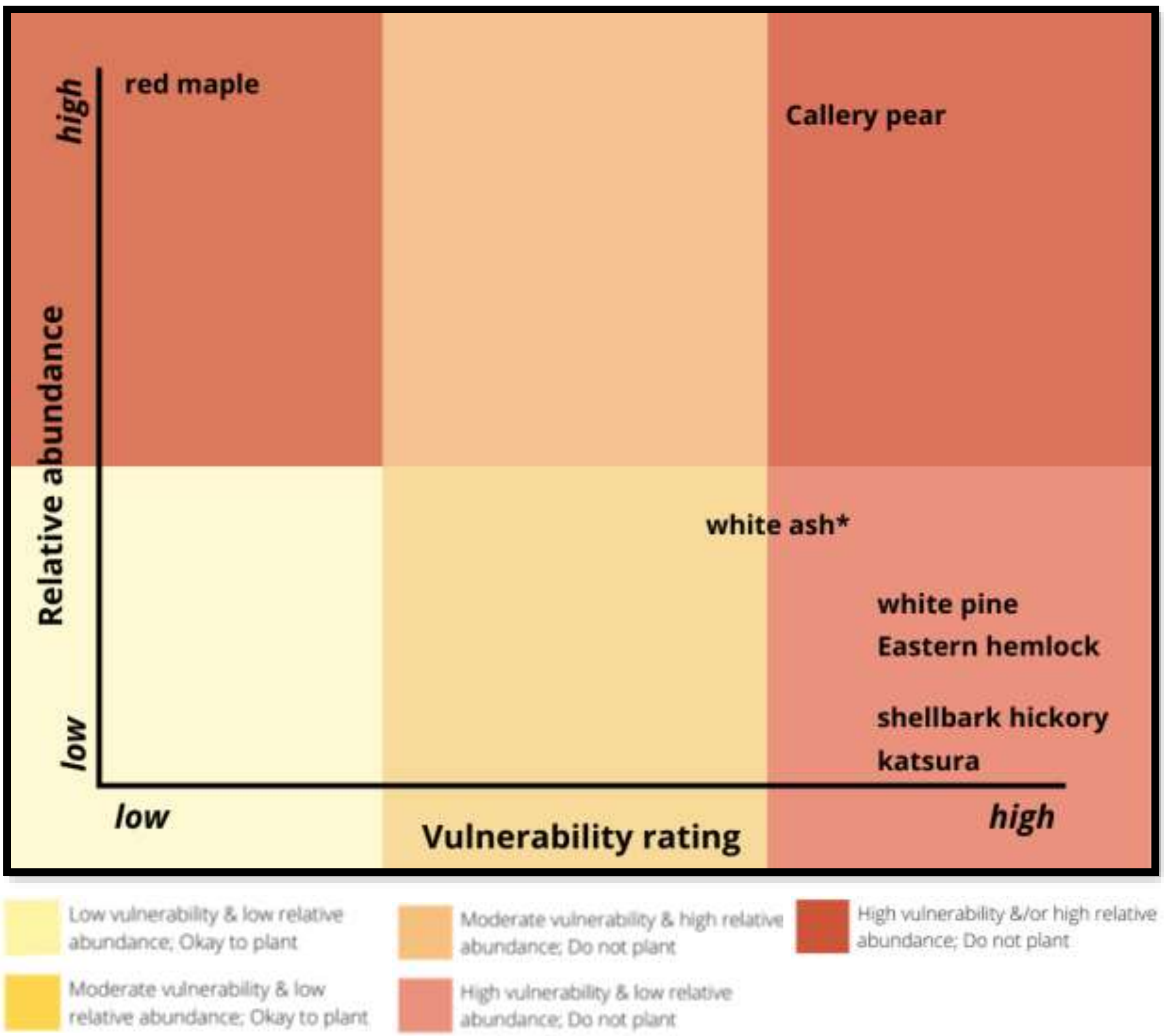


Figure 10. Seven tree species that should not be planted for the foreseeable future as street trees in Lexington. These species should be avoided due to their high relative abundance in Lexington's current street tree canopy and/or their high vulnerability to climate change. *White ash should be avoided as a street tree due to the Emerald Ash Borer.

Recommendations:

1. **Plant resilient tree species that are adapted to Lexington's urban environment.** For all future tree plantings, choose from among a diversity of tree species that are well suited to Lexington's current environment and are expected to perform well in a changing climate, while attending to specific site limitations and requirements.
2. **Increase access to diverse and resilient tree species.** Support residents in purchasing a diversity of resilient tree species.
3. **Support neighborhoods with poorly developed street tree canopies.** Engage and support residents in caring for their street trees, especially in low SES neighborhoods. Neighborhoods in low SES neighborhoods will require greater focus on tree healthcare from the city.

Neighborhood Age & Socioeconomic Status

For this study, street trees were sampled in a manner that allowed us to evaluate the relationships between the street tree canopy and the age and socioeconomic status (SES) of neighborhoods. To do this, we used the stem density of street trees, as well as a metric that serves as a surrogate for the size of the tree canopies (basal area) to examine the quality and quantity of the street trees in relationship to neighborhood and SES. We also assessed species diversity and tree health and condition by neighborhood age. For those assessments, we classified neighborhoods built between 1900 and 1950 as "old" and those built between 1990 and 2010 as "young." We omitted neighborhoods built between 1960 and 1980 from those assessments due to tree ordinances during that time which greatly impacted street tree plantings.

Stem Density

Stem density, defined as the number of trees within a specific area, or in this case, the length of sampled road, allows us to examine how fully treed a street is. For this study, we estimated stem density as the number of stems per 100 feet sampled along a road, and assessed the relationships between stem density and age and SES of the neighborhoods in our sample.

According to this study, younger neighborhoods had a higher stem density than older neighborhoods (Figure 11). The high stem density in younger neighborhoods may be attributed to the street tree ordinance adopted by City Council in 1978, requiring street trees in all new residential developments (T. Queary, LFUCG Urban Forester, personal communication, January 25, 2022). Stem density was low in neighborhoods built between 1960 and 1980, which is most likely because street trees in Lexington were banned between 1958-1978 due to a major ice storm circa 1958 (Ibid).

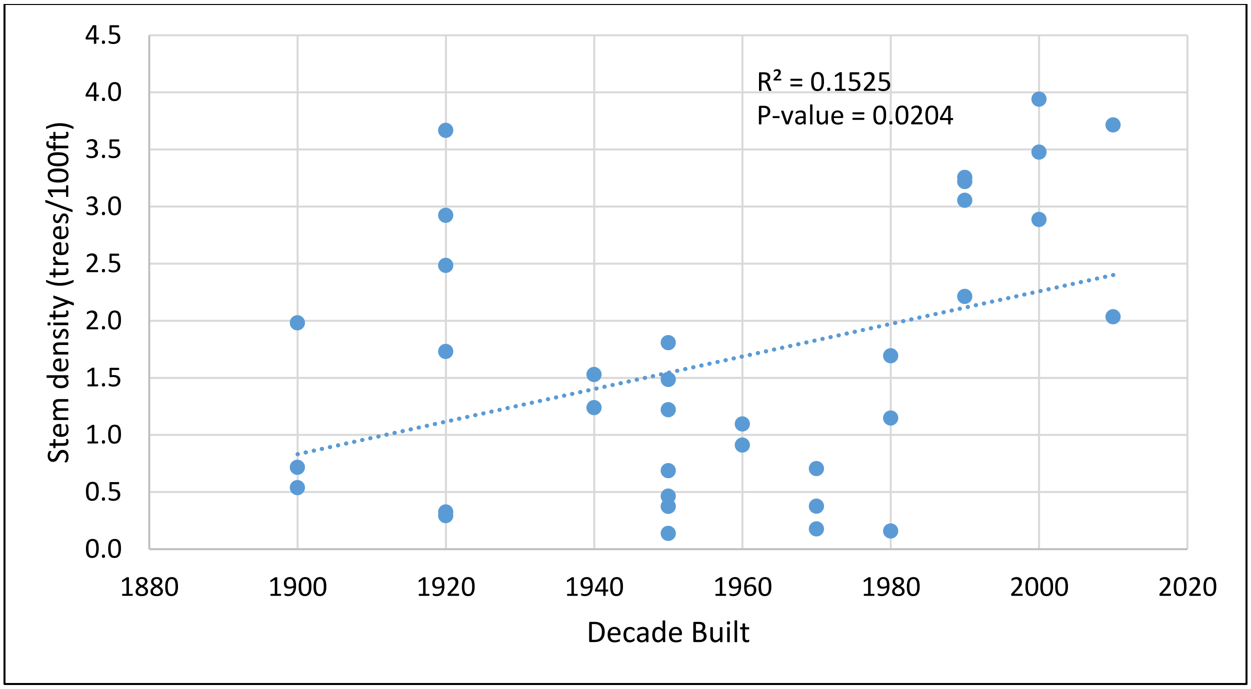


Figure 11. Stem density by the decade Lexington neighborhoods were built based on a sub-sample of Lexington street trees inventoried from 2018-2021.

Additionally, stem density increased with socioeconomic status (Figure 12). This suggests that neighborhoods with higher socioeconomic status had more street trees compared to neighborhoods with lower socioeconomic status.

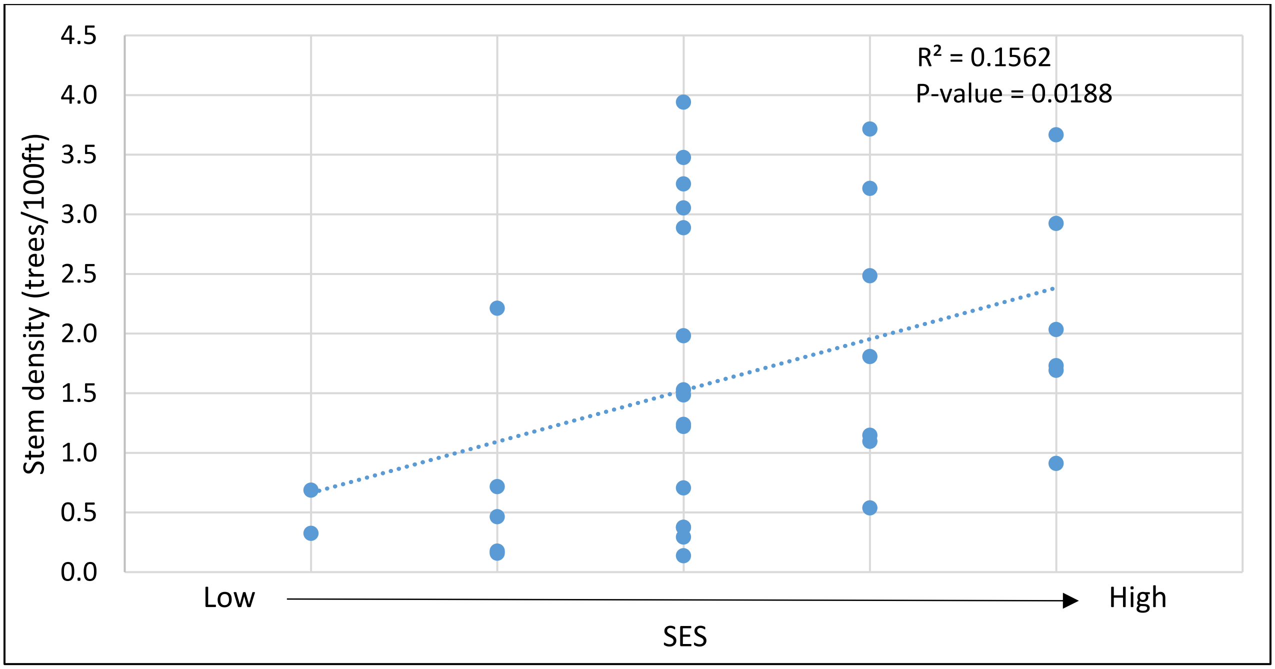


Figure 12. Stem density by the socioeconomic status of Lexington neighborhoods based on a sub-sample of Lexington street trees inventoried from 2018-2021.

Basal Area

Basal area, defined in this study as the total area occupied by all the tree trunks within a given space, was calculated as the total area (in inches squared) occupied by trees per 100 feet along a road. While this is an unconventional way to report basal area, it provided an estimate of how much space was occupied by street trees within a given neighborhood and allowed us to compare among ages and SES of neighborhoods.

In general, younger neighborhoods tended to have a lower basal area compared to older neighborhoods (Figure 13). This finding makes sense: despite that younger neighborhoods tended to have more trees, the trees themselves were smaller. Generally speaking, older trees are larger trees, so neighborhoods that have had trees for longer, and the same trees, should tend towards higher tree basal area.

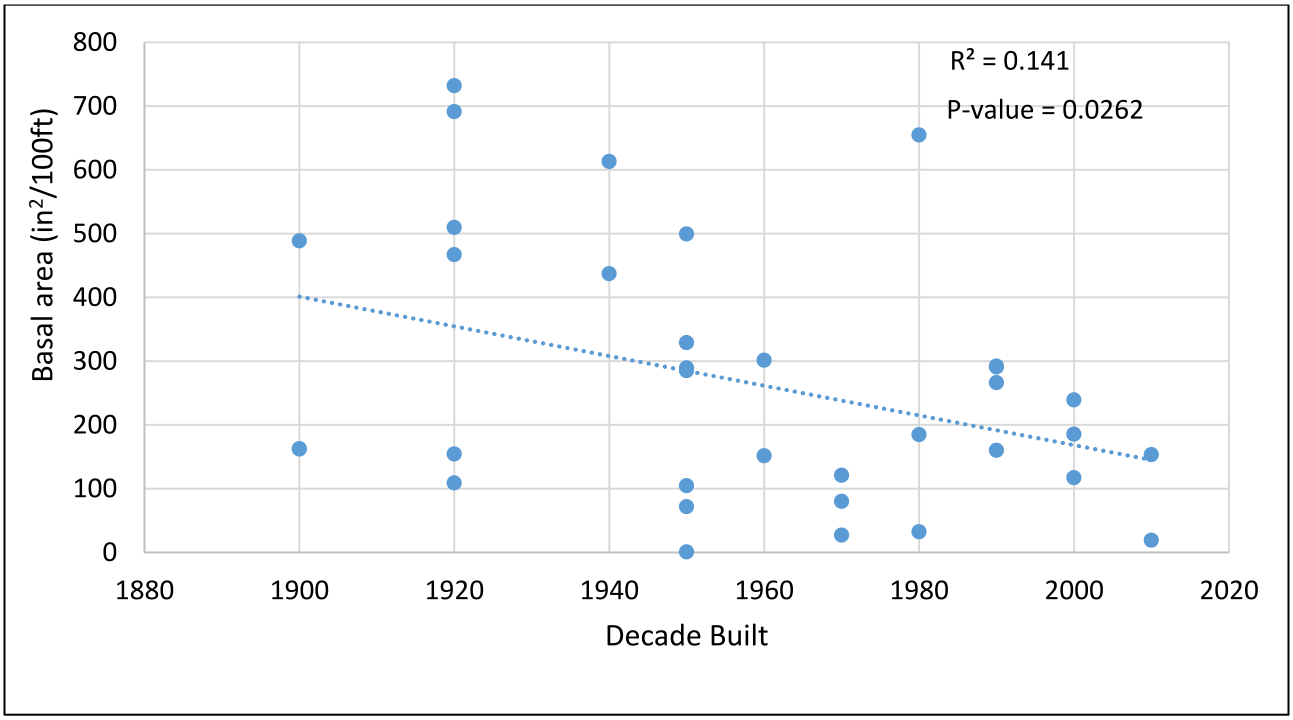


Figure 13. Street tree basal area by the decade Lexington neighborhoods were built based on a sub-sample of Lexington street trees inventoried from 2018-2021.

Additionally, high SES neighborhoods had a higher street tree basal area than low SES neighborhoods (Figure 14). This means that high SES neighborhoods were able to benefit more directly from the ecosystem services provided by trees, as they had larger trees capable of reaching their full ecosystem service potential, such as providing shade and cooling, intercepting stormwater runoff, and sequestering carbon dioxide. This relationship reveals two things about street tree basal area and SES: 1) high SES neighborhoods tended to have larger trees and 2) street tree canopies were smaller in low SES neighborhoods.

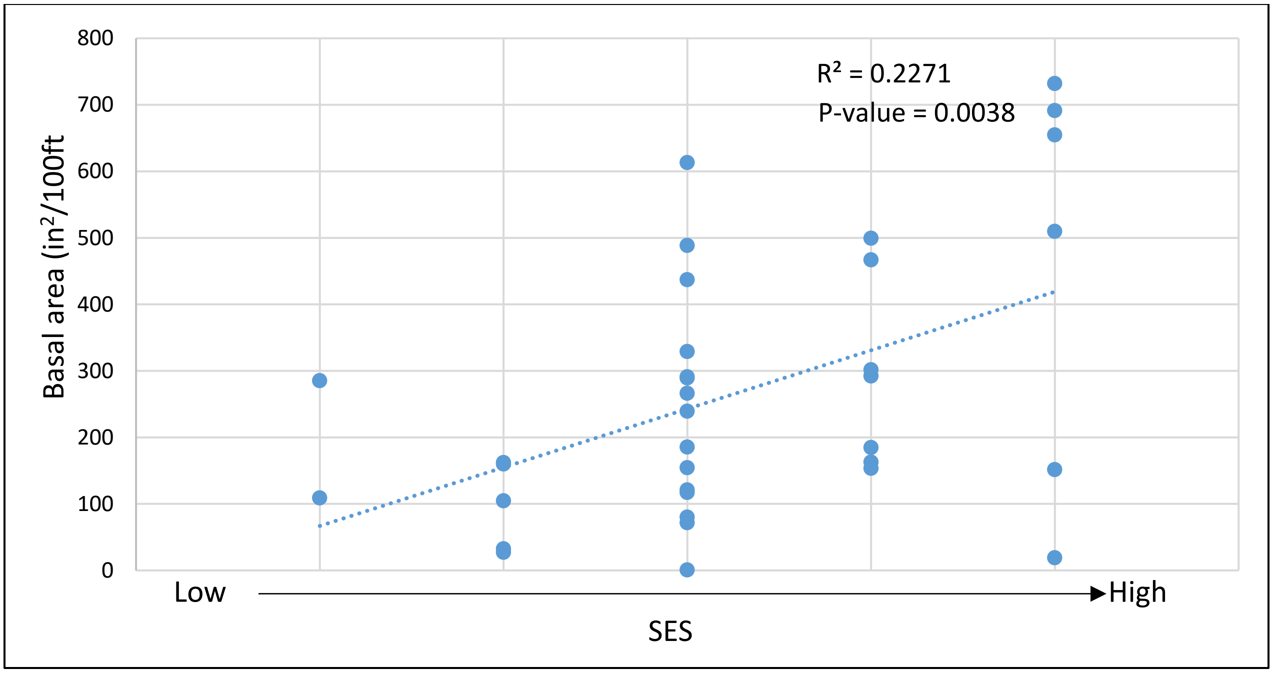


Figure 14. Street tree basal area by the socioeconomic status of Lexington neighborhoods based on a sub-sample of Lexington street trees inventoried from 2018-2021.

Importantly, this study revealed that low SES neighborhoods had street tree canopies that were both low in number of street trees and in the size of their tree canopies, indicating severe deficits in the street tree canopies of low SES neighborhoods. These street tree deficits are an environmental justice issue caused by a long history of institutional racism in Lexington, such as redlining and gentrification. Attempts to address these inequities will require intentional and thoughtful planning by the city in collaboration with local residents.

Tree Species

According to the 30-20-10 rule, red maple and Callery pear were highly overrepresented in younger neighborhoods, but not in older neighborhoods (1990-2010; Figure 15). As seen in the graph, red maple and Callery pear represented a higher percentage of trees in younger neighborhoods compared to older neighborhoods (1900-1950). Additionally, maples and the family to which maples belong were grossly overrepresented in younger neighborhoods compared to the recommended values (maples as a genus and the soapberry family each represented 61% of trees in younger neighborhoods). In contrast, street tree composition in older neighborhoods was relatively well distributed; maples as a genus were the only group that were overrepresented in older neighborhoods (representing 27% of street trees in older neighborhoods).

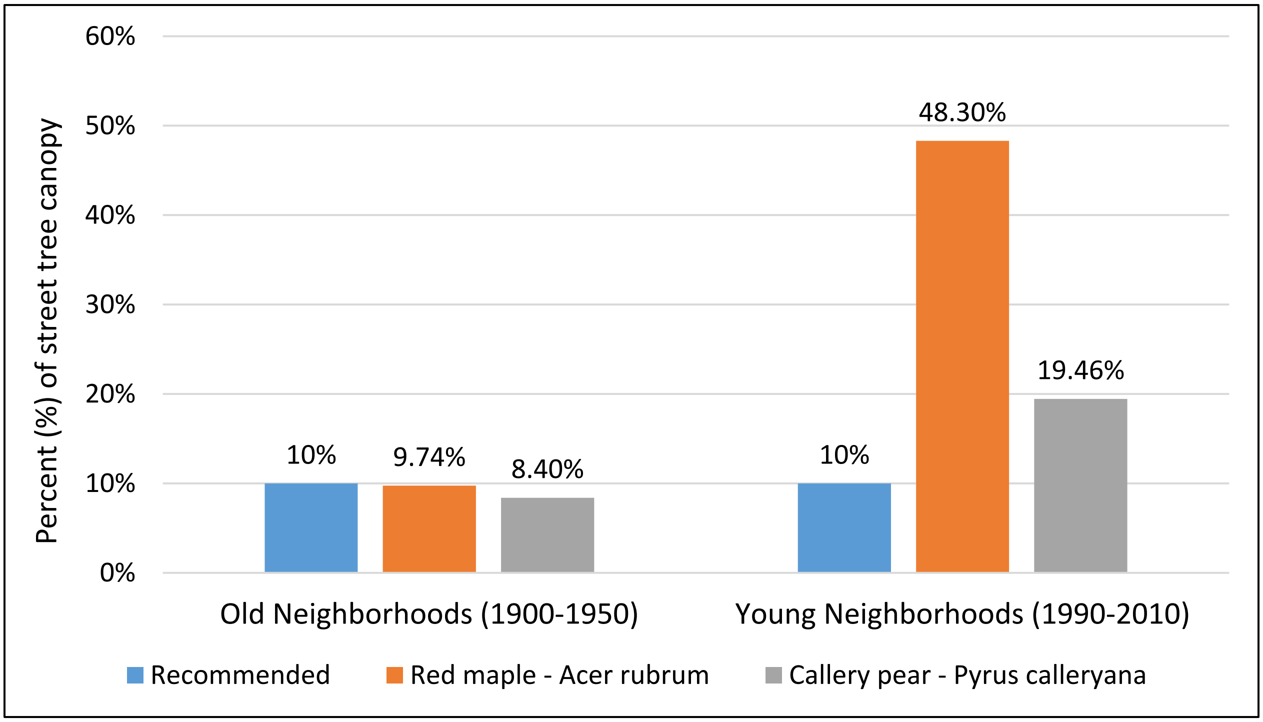


Figure 15. Comparison of Santamour's (1990) 30-20-10 rule and Lexington's street tree canopy in young and old neighborhoods by species based on a sub-sample of Lexington street trees inventoried from 2018-2021, applied to red maple and Callery pear, two species that were overrepresented in young neighborhoods.

In general, the tree canopy in younger neighborhoods was less diverse than in older neighborhoods, with 45 species represented in younger neighborhoods compared to 116 species in older neighborhoods (Figure 16; Figure 17). Additionally, tree species were more widely distributed across older neighborhoods, with no one species dominating the street tree canopy, compared to young neighborhoods, where red maple and Callery pear together made up 68% of street trees. It is worth noting that Figures 15-17 show the relative abundance of tree species across all young and old neighborhoods, respectively, and as such, do not represent average species composition for young and old neighborhoods. Nonetheless, these findings are important indicators of a lack of biodiversity in young neighborhoods tied to an overabundance of red maple and Callery pear.

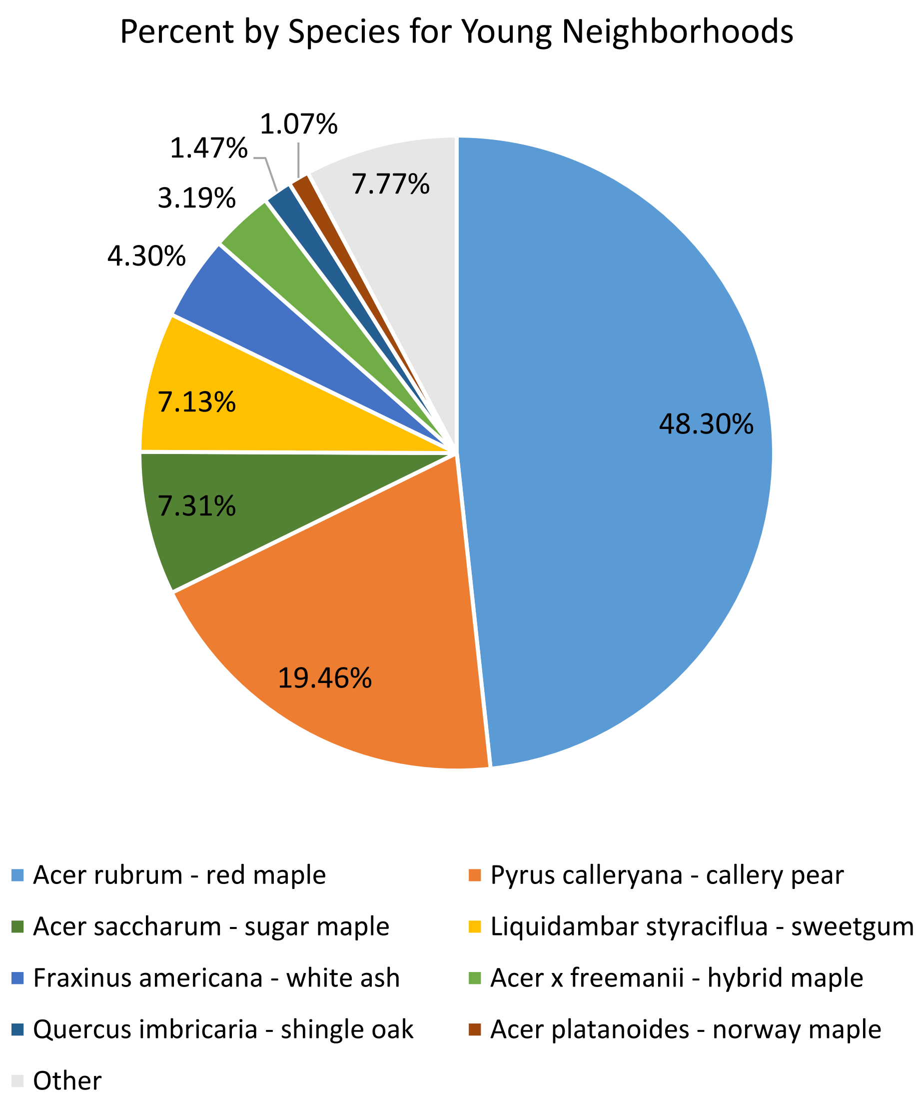


Figure 16. Percent of each tree species for Lexington neighborhoods built between 1990 and 2010 based on a sub-sample of Lexington street trees inventoried from 2018-2021. Species shown each made up at least 1% of the canopy. Other species made up a combined 8% of the tree canopy, with at least 37 other species represented.

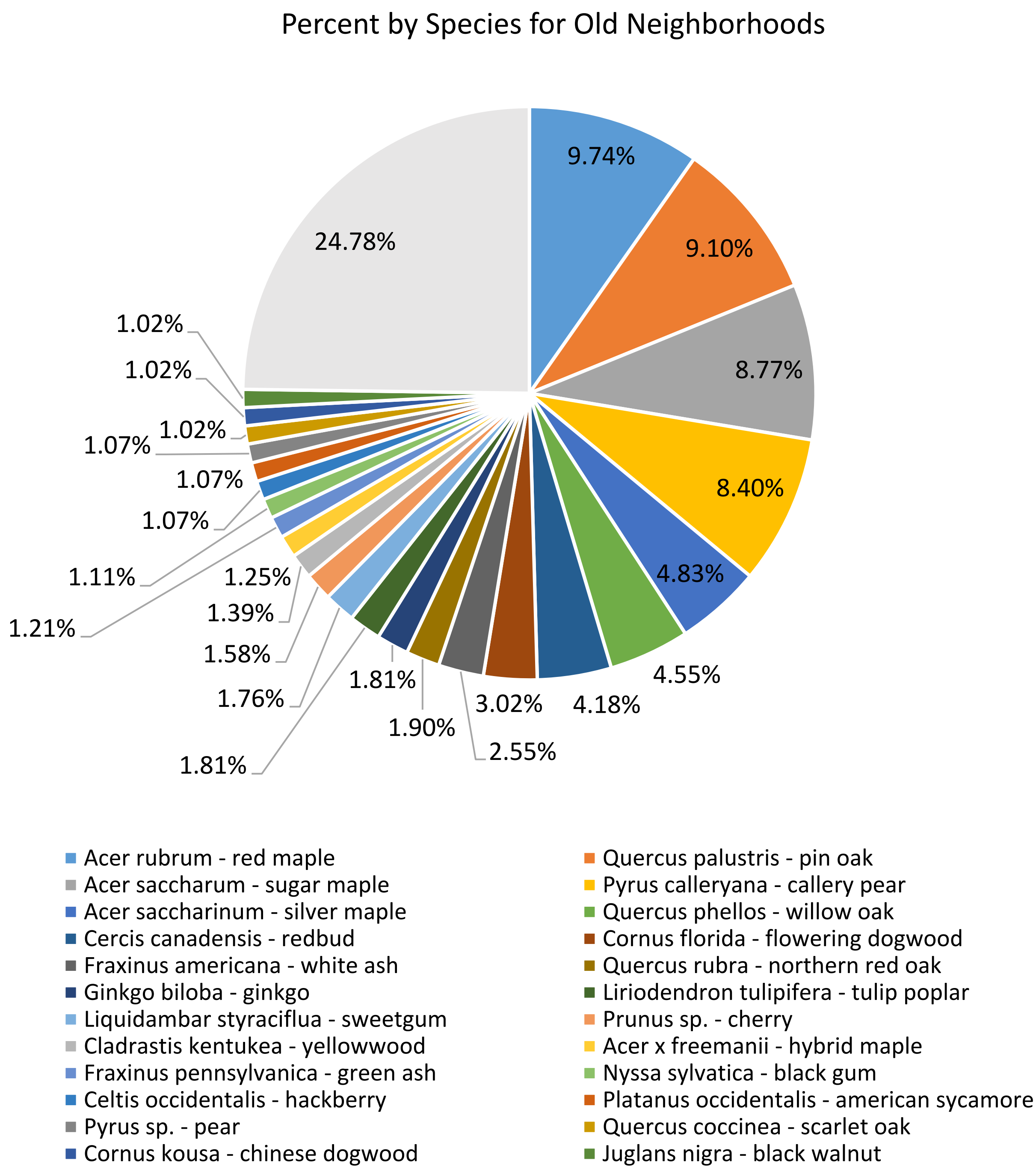


Figure 17. Percent of each tree species for Lexington neighborhoods built between 1900 and 1950 based on a sub-sample of Lexington street trees inventoried from 2018-2021. Species shown each made up at least 1% of the canopy. Other species made up a combined 25% of the tree canopy, with at least 92 other species represented.

Tree Health & Condition

When examining tree health and condition across neighborhood age, we found that a higher percentage of poor or dead/dying street trees resided in younger neighborhoods (45%; Table 4). This is most likely due to the high stem density in younger neighborhoods, and does not indicate a causal relationship between neighborhood age and tree health. Indeed, approximately 5% of street trees in both older and younger neighborhoods were poor or dead/dying, suggesting that tree health is not greatly impacted by neighborhood age.

Table 4: Percent of trees in poor or dead/dying condition by neighborhood age. Within neighborhood age, street trees had similar percentages of poor or dead/dying trees (A). However, of all the poor or dead/dying trees, more were found in neighborhoods built between 1990 and 2010 (B).

Decade Built	A: % poor or dead/dying within these neighborhoods	B: % of total poor or dead/dying in these neighborhoods
1900-1950	5.3	34.2
1990-2010	5.5	45.8

Empty Tree Wells

Ten percent of street tree locations inventoried were empty tree wells. Empty tree wells are defined in this study as spaces where there were clearly trees in the past, but where those trees were removed and not replaced. We used the presence of sidewalk bump outs, divots in the lawn, piles of woodchips, or remaining stumps to locate empty tree wells. We analyzed the relationship between the percent of tree locations inventoried that were empty tree wells and neighborhood age and socioeconomic status. Empty tree wells were only recorded for neighborhoods inventoried between 2020-2021. See Appendices F and G for Maps 2 and 3, which depict empty tree wells by socioeconomic status and age of LFUCG neighborhoods.

This study found that more empty tree wells were found in older neighborhoods compared to younger neighborhoods (Figure 18). Since street trees in younger neighborhoods were younger, having been planted within the last thirty years, it makes sense that there were not very many empty tree wells in younger neighborhoods. However, this trend also indicates that in older neighborhoods, street trees are not being replaced after they have been removed.

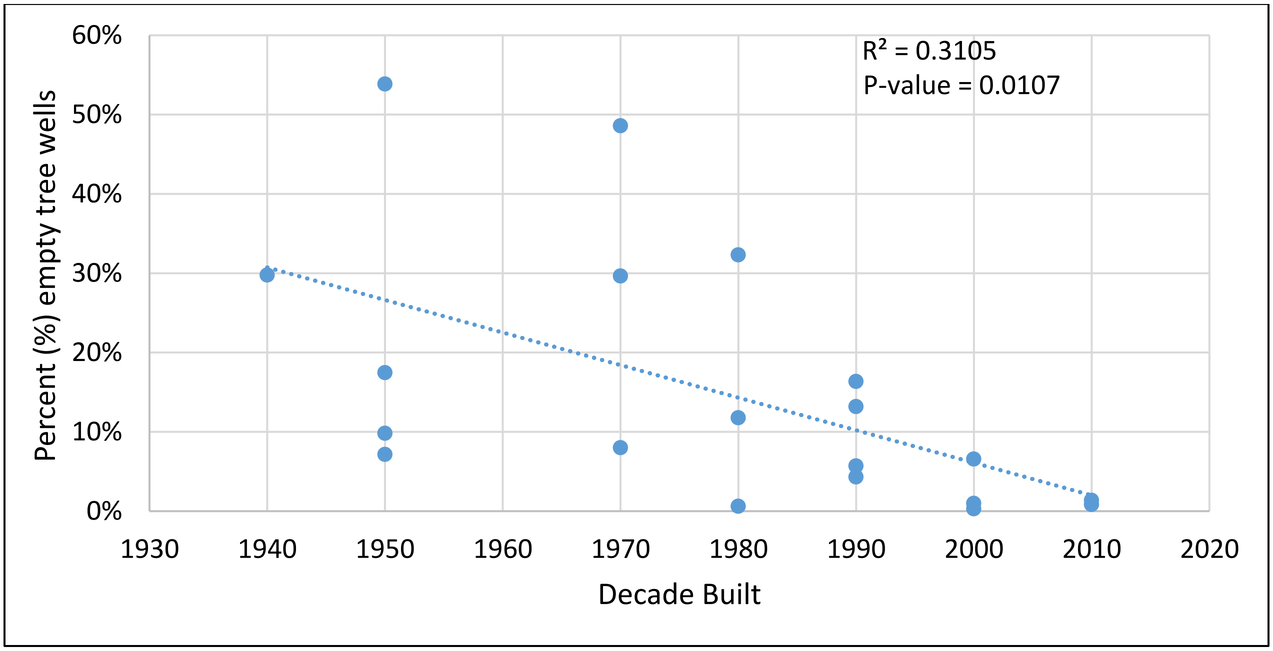


Figure 18. Percent empty tree wells by the decade Lexington neighborhoods were built based on a sub-sample of Lexington street trees inventoried from 2020-2021.

Additionally, empty tree wells tended to increase as socioeconomic status decreased (Figure 19). This indicates that street trees are not being replaced in low SES neighborhoods. This lack of street tree replacement in low SES neighborhoods may indicate accessibility gaps pertaining to street tree maintenance and planting due to cost or tree ownership (in the case of renters).

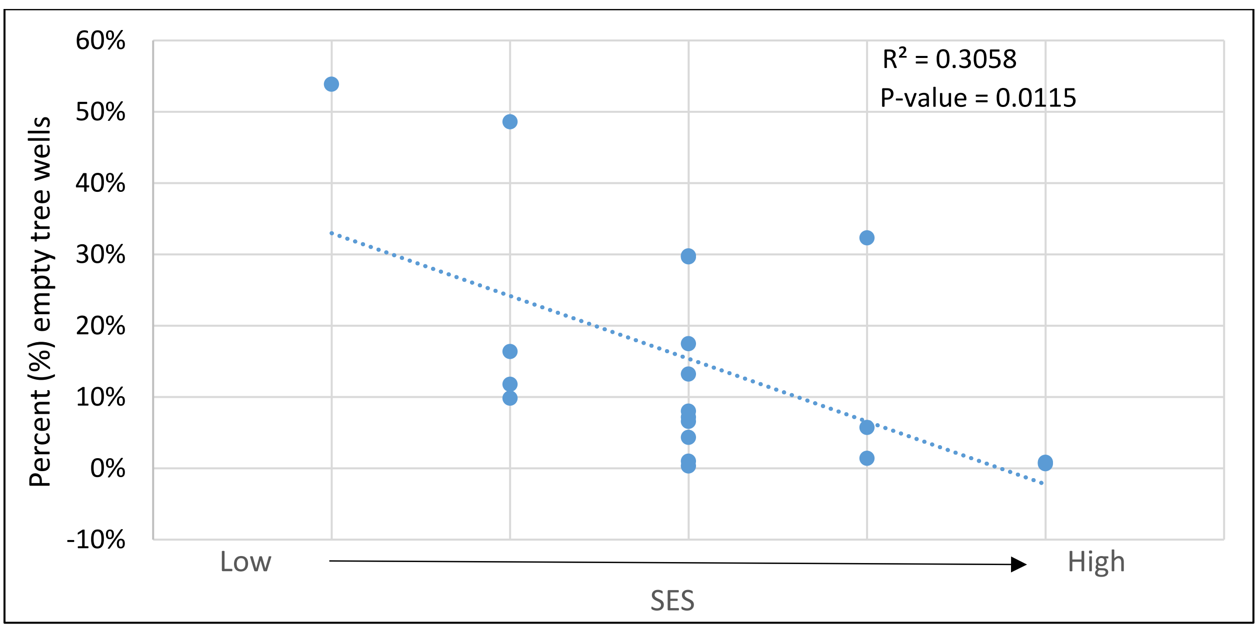


Figure 19. Percent empty tree wells by the socioeconomic status of Lexington neighborhoods based on a sub-sample of Lexington street trees inventoried from 2020-2021.

Recommendations:

1. **Work with owner occupied residents and landlords in low SES areas to find ways to facilitate street tree plantings.** Special attention should be given to the 54% of tree wells that were empty in low SES neighborhoods. Use Lexington's Street Tree Cost Share program to help low income property owners overcome financial barriers to planting or maintaining street trees, or develop other tree planting and maintenance programs with community members. However, this recommendation does not address the issue of property rights, which may be a barrier for renters to have agency over their street trees.
2. **Engage and support residents in younger neighborhoods in caring for their street trees**. Younger neighborhoods tended to have high stem density, low street tree basal area, and high percentage of trees in poor to dead/dying condition, and therefore require attention to ensure that the street tree canopy can grow to its fullest and healthiest potential.
3. **Expand approved street tree lists in neighborhood and homeowners associations to promote species diversity.** Work with neighborhood and homeowners associations to update approved street tree species lists to increase species diversity in neighborhoods, with special attention to younger neighborhoods.
4. **Replace trees in empty tree wells, especially in older and low SES neighborhoods.** With 10% of tree wells inventoried lacking a tree, working to ensure that trees are planted into these locations is essential for building a robust tree canopy.

References

Brandt, L., Lewis, A. D., Fahey, R., Scott, L., Darling, L., & Swanston, C. (2016). A framework for adapting urban forests to climate change. *Environmental Science & Policy*, *66*, 393-402.

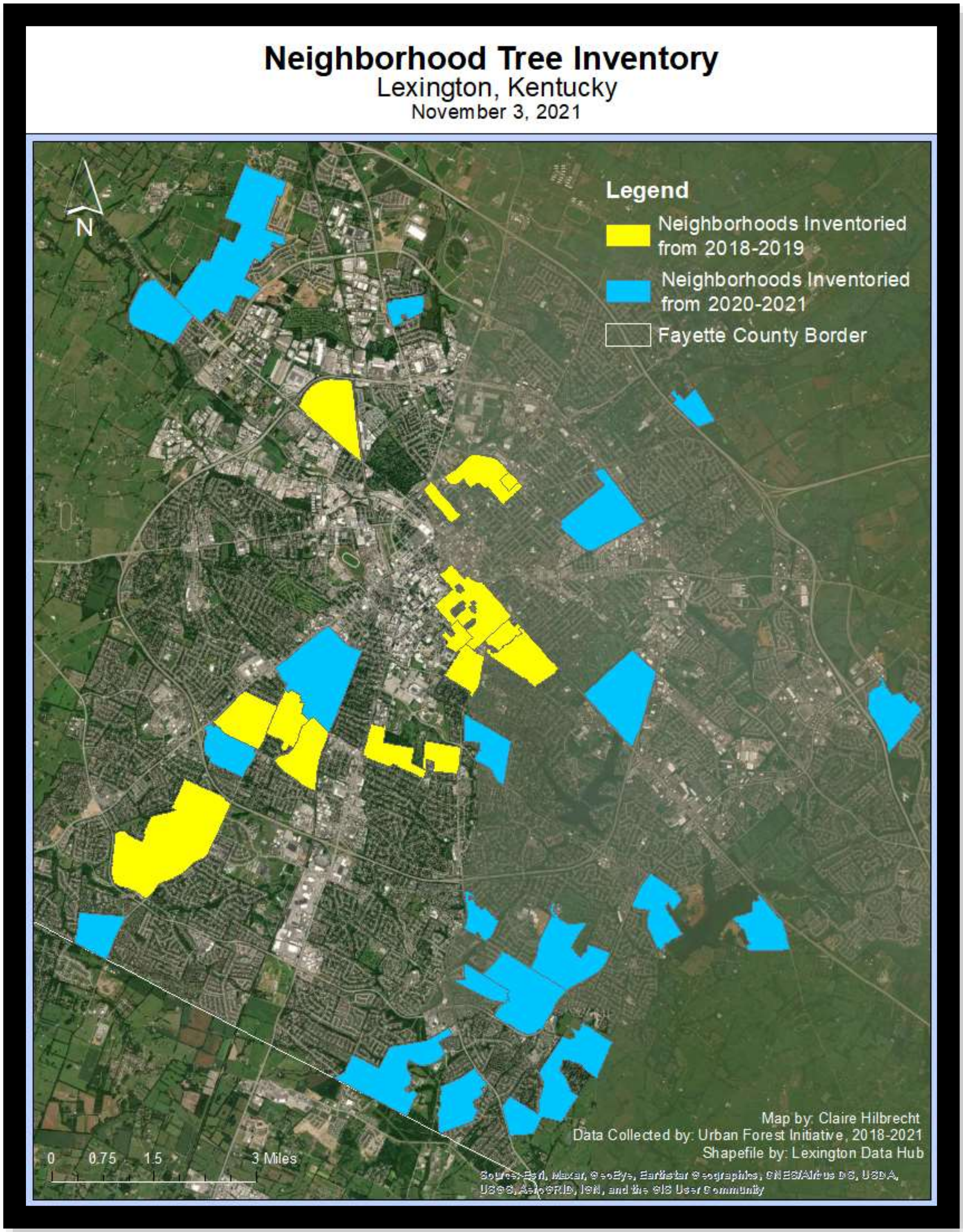
Ordóñez, C., & Duinker, P. N. (2014). Assessing the vulnerability of urban forests to climate change. *Environmental Reviews*, *22*(3), 311-321.

Richards, N.A. (1983). Diversity and stability in a street tree population. *Urban Ecology*, 7(2), 159-171.

Santamour, F. (1990). "Trees for urban planting: diversity, uniformity, and common sense in 7th Conference of the Metropolitan Tree Improvement Alliance." The Morton Arboretum, Lisle.

Appendix

Appendix A. Map 1: Lexington Street Tree Inventory from 2018-2021.



Appendix B. Methodology

The socioeconomic status of a neighborhood was determined by a combination of median household income and property value. Median household income was taken from the 2019 Census Block Group Data. If neighborhood boundaries spanned more than one census block group, then the median household income range among block groups was obtained. However, since household income is not always a good indicator of socioeconomic status due to factors like retirement, this metric was primarily used as a comparison against property value to ensure that the assessment of socioeconomic status was relatively consistent across multiple points of reference. Property value was determined using the Lexington PVA website. Five to ten homes within a neighborhood were selected at random and the range among property values was obtained. These two metrics were used to determine socioeconomic status, which was defined by 5 categories: low, low-middle, middle, upper-middle, and upper. Neighborhoods were placed in these categories based on a 2020 income study by the Pew Research Center. Property value was weighted heavier than median household income for the reasons listed above.

Neighborhood age was determined using the Lexington PVA website. The same 5-10 randomly selected homes used to determine property value were used to determine the approximate decade in which the neighborhood was developed. The property reports of each of these homes were reviewed to determine when each home was built. The neighborhood was then placed into categories representing the appropriate decade based on the information obtained from these reports.

Neighborhoods were selected based on size to facilitate a random selection of street trees along a similar total street length. Neighborhood size was determined by total street length within the neighborhood boundary, excluding major non-residential streets, such as New Circle Road. If the total street length within a neighborhood was at least 9,700 feet, then it was considered for further review. Streets within a neighborhood boundary were then assigned numbers and selected at random using a random number generator. Each street selected was assessed using aerial footage to ensure that it was a residential street and that it contained street trees. If the street contained neither residential homes nor trees, it was tossed out of the selection. Streets were selected until the total street length reached between 9,700 ± 300ft, depending on the sample. Street trees along each street in the sample were inventoried to obtain a random sample of street trees in each neighborhood. In some cases, the total street length in each sample was below or above the ideal range. This was due to variations in the length of streets that were randomly selected within a neighborhood (for example, one street could be 80ft while another could be 4,000ft), as well as street tree disparities among neighborhoods (for example, some neighborhoods contained less than 20 street trees within the whole neighborhood, which may have accounted for a smaller selection of streets in that neighborhood). Additionally, it is important to note that street tree inventories were conducted across entire neighborhoods in 2018 and 2019 by the Urban Forest Initiative for alternative projects, rather than through a random sample selection method. Therefore, the street trees in neighborhoods inventoried prior to 2020 were retroactively sampled at random using the same process described above, but those neighborhoods did not necessarily meet the street length criteria due to their small size and small street tree canopy. For example, Brucetown neighborhood, inventoried in 2019, only contained 6,787 feet of streets with street trees. However, this neighborhood was still included in the project to enhance our sample size and distribution.

Figure 20 shows neighborhood distribution across SES, and Figure 21 shows neighborhood distribution across neighborhood age for the neighborhoods inventoried in this study.

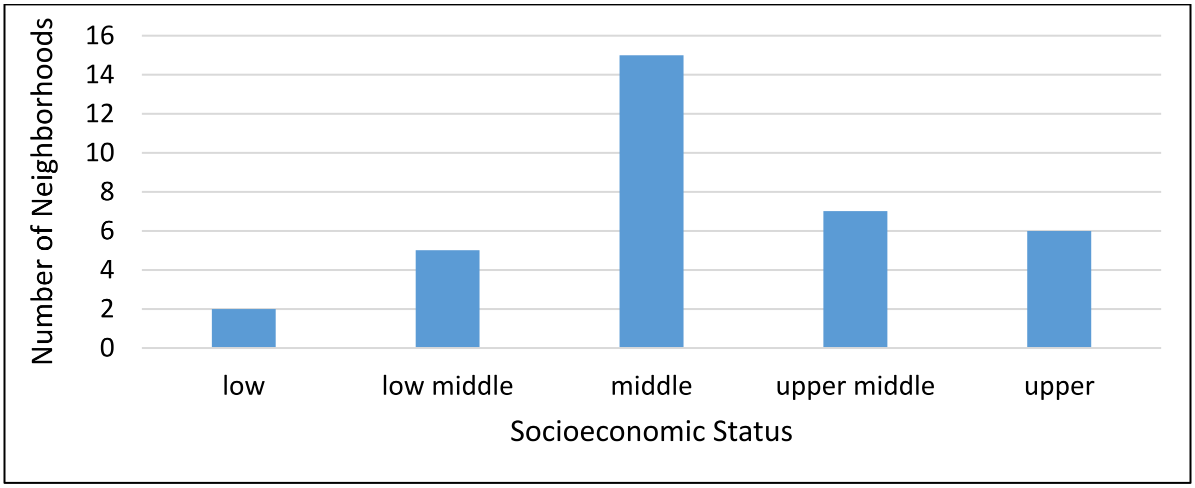


Figure 20. Neighborhood distribution across SES for the neighborhoods used in this study.

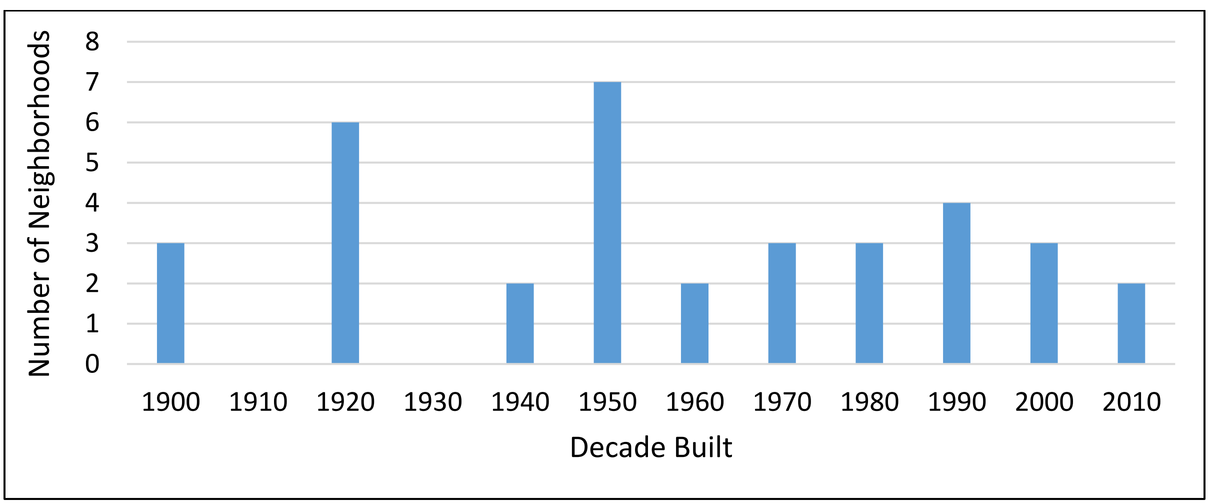


Figure 21. Neighborhood distribution across neighborhood age for the neighborhoods used in this study.

Appendix C. Tree species sampled and their relative abundance for LFUCG neighborhoods based on a sub-sample of LFUCG street trees inventoried from 2018-2021.

Species	Relative Abundance
Acer rubrum - red maple	29.40%
Pyrus calleryana - callery pear	17.54%
Acer saccharum - sugar maple	7.30%
Quercus palustris - pin oak	4.49%
Liquidambar styraciflua - sweetgum	4.29%
Fraxinus americana - white ash	3.29%
Acer saccharinum - silver maple	2.57%
Acer x freemanii - hybrid maple	2.32%
Cercis canadensis - redbud	2.07%
Quercus phellos - willow oak	2.01%
Cornus florida - flowering dogwood	1.56%
Nyssa sylvatica - black gum	1.08%
Quercus rubra - northern red oak	0.90%
Liriodendron tulipifera - tulip poplar	0.88%
Ginkgo biloba - ginkgo	0.86%
Acer platanoides - norway maple	0.77%
Prunus sp.	0.74%
Quercus imbricaria - shingle oak	0.74%
Platanus occidentalis - american sycamore	0.72%
Syringa reticulata - japanese tree lilac	0.68%
Pinus strobus - white pine	0.66%
Cladrastis kentukea - yellowwood	0.59%
Fraxinus pennsylvanica - green ash	0.56%
Celtis occidentalis - hackberry	0.49%
Cornus kousa - chinese dogwood	0.47%
Quercus bicolor - swamp white oak	0.45%
Ulmus americana - american elm	0.43%
Pyrus sp.	0.41%
Quercus alba - white oak	0.41%
Gleditsia triacanthos - honey locust	0.40%
Juglans nigra - black walnut	0.40%
Quercus coccinea - scarlet oak	0.40%
Platanus x acerifolia - london plane tree	0.36%
Zelkova serrata - japanese zelkova	0.36%
Acer palmatum - japanese maple	0.32%
Crataegus sp.	0.31%
Malus angustifolia - southern crabapple	0.31%
Quercus macrocarpa - bur oak	0.31%

Acer campestre - hedge maple	0.27%
Crataegus phaenopyrum - washington's hawthorn	0.27%
Amelanchier arborea - downy serviceberry	0.25%
Malus sp.	0.22%
Picea abies - norway spruce	0.22%
Prunus serotina - black cherry	0.22%
Malus coronaria - american crabapple	0.20%
Juniperus virginiana - eastern red cedar	0.18%
Tsuga canadensis - eastern hemlock	0.18%
Betula nigra - river birch	0.16%
Fraxinus sp.	0.16%
Magnolia virginiana - sweetbay magnolia	0.16%
Quercus shumardii - shumard oak	0.16%
Thuja plicata - giant arborvitae	0.16%
Gymnocladus dioicus - kentucky coffee tree	0.14%
Ilex opaca - american holly	0.14%
Robinia pseudoacacia - black locust	0.14%
Taxodium distichum - bald cypress	0.14%
Ulmus rubra - red elm, slippery elm	0.14%
Acer sp.	0.13%
Amelanchier sp.	0.13%
Cornus sp.	0.13%
Gleditsia triacanthos var. inermis - thornless honey locust	0.13%
Quercus sp.	0.13%
Ulmus sp.	0.13%
Amelanchier laevis - allegheny serviceberry	0.11%
Magnolia grandiflora - southern magnolia	0.11%
Picea pungens	0.11%
Pyrus communis - common pear	0.11%
Ulmus parvifolia - chinese elm	0.11%
Ulmus pumila - siberian elm	0.11%
Diospyros virginiana - persimmon	0.09%
Juniperus communis - common juniper	0.09%
Picea glauca - white spruce	0.09%
Prunus pensylvanica - pin cherry	0.09%
Prunus serrulata - japanese cherry	0.09%
Picea sp.	0.07%
Quercus x - hybrid oak	0.07%
Tilia cordata - little-leaf linden	0.07%
Aesculus glabra - ohio buckeye	0.05%
Ailanthus altissima - tree of heaven	0.05%

Amelanchier x grandiflora - apple serviceberry	0.05%
Carya sp.	0.05%
Fagus grandifolia - american beech	0.05%
Quercus acutissima - sawtooth oak	0.05%
Quercus muehlenbergii - chinkapin oak	0.05%
Quercus stellata - post oak	0.05%
Quercus velutina - black oak	0.05%
Rhododendron sp. - azalea	0.05%
Thuja occidentalis - white cedar	0.05%
Acer ginnala - amur maple	0.04%
Acer negundo - boxelder	0.04%
Acer nigrum - black maple	0.04%
Carpinus caroliniana - musclewood	0.04%
Carya illinoinensis - pecan	0.04%
Carya laciniosa - shellbark hickory	0.04%
Castanea x - hybrid chestnut	0.04%
Cornus drummondii - rough-leaf dogwood	0.04%
Cornus racemosa - gray dogwood	0.04%
Crataegus crus-galli - cockspur hawthorne	0.04%
Hamamelis virginiana - witchhazel	0.04%
Hibiscus sp.	0.04%
Morus rubra - red mulberry	0.04%
Pinus sp.	0.04%
Quercus falcata - southern red oak	0.04%
Quercus montana - chesnut oak	0.04%
Abies concolor - white fir	0.02%
Abies sp.	0.02%
Aesculus flava - yellow buckeye	0.02%
Amelanchier sanguinea - roundleaf serviceberry	0.02%
Asimina triloba - pawpaw	0.02%
Carya glabra - pignut hickory	0.02%
Catalpa speciosa - catalpa	0.02%
Cercidiphyllum japonicum - katsura	0.02%
Cornus amomum - silky dogwood	0.02%
Crataegus mollis - downy hawthorn	0.02%
Fagus sylvatica - european beech	0.02%
Lonicera maackii, L. fragrantissima, L. standishii - bush honeysuckles	0.02%
Magnolia macrophylla - bigleaf magnolia	0.02%
Magnolia sp.	0.02%
Populus deltoides - eastern cottonwood	0.02%
Prunus virginiana - chokecherry	0.02%

Salix babylonica - weeping willow	0.02%
Tilia americana - basswood	0.02%
Tilia sp.	0.02%
Unknown	1.08%

Appendix D. Climate Vulnerability Ratings

In the spring of 2020, the Urban Forest Initiative (UFI) participated in a climate adaptation workshop developed by the Northern Institute of Applied Climate Science (NIACS). This workshop walked participants through the climate adaptation planning and management process, including the use of climate vulnerability ratings.

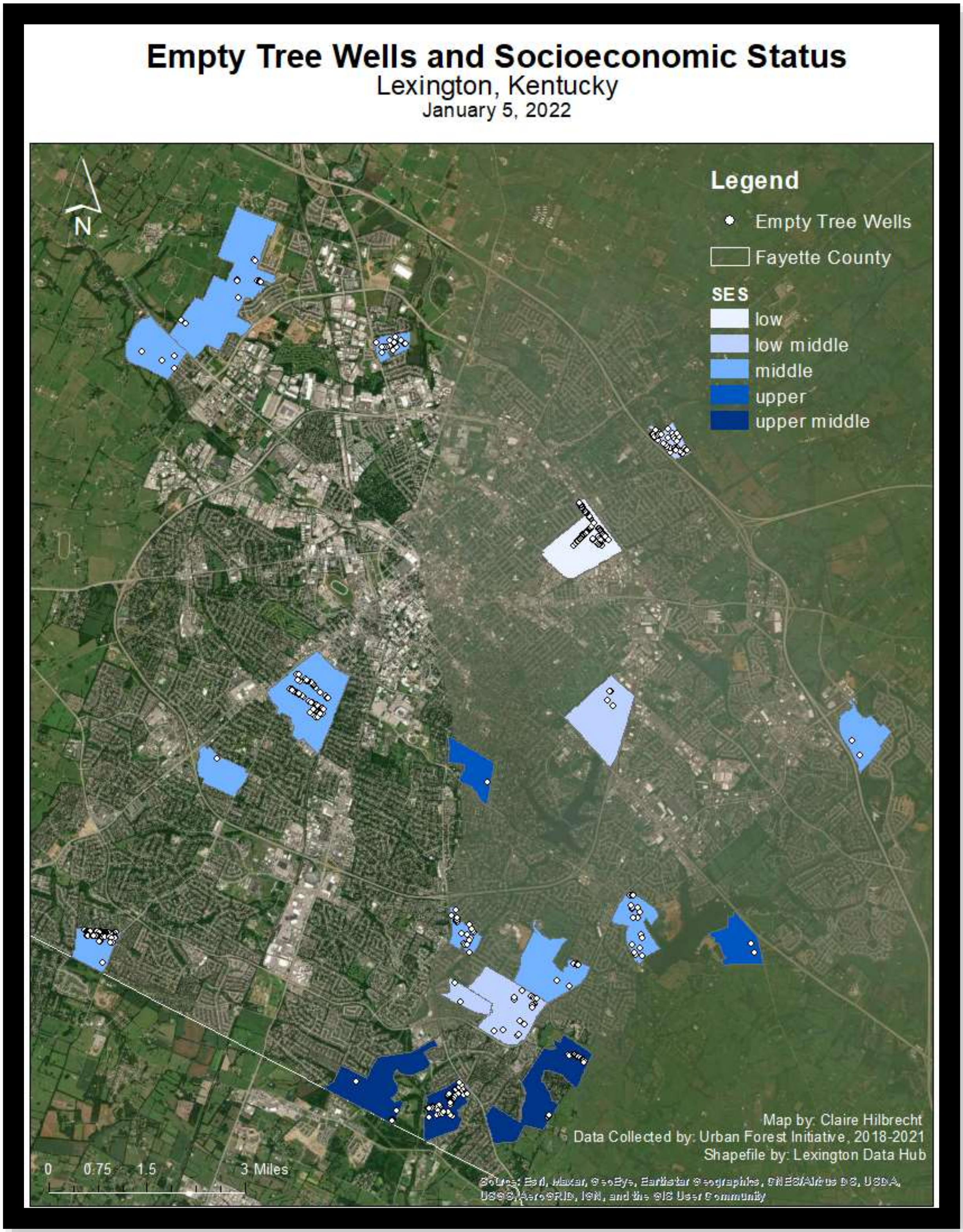
The process for developing vulnerability ratings includes extensive research about the tree species, including information about drought tolerance, heat and hardiness zones, wind and ice tolerance, growth habit, etc. Thirty-five species characteristics were assessed in the research process. These characteristics were then scored based on their relevance to the species' adaptive capacity within the context of future climate projections. A score of -3 would suggest that the character would negatively affect the species' ability to reproduce, grow, or survive, while a score of +3 would have a positive effect on the species. Next, these scores were weighted and converted into an overall vulnerability score for the tree species. The scoring of each species was then verified by an expert on the NIACS team.

It is worth noting that these ratings are a coarse assessment of climate adaptation across a landscape, because they are developed through species-level considerations and do not account for individual environmental conditions or genetic diversity within a species. However, they are still useful to predict how an urban tree canopy may respond to climate change by classifying species as having a low, low-moderate, moderate, moderate-high, or high vulnerability to climate change. NIACS developed a list of 144 vulnerability ratings for common Lexington street trees, allowing us predict the climate vulnerability for 95% of our street tree canopy. However, vulnerability ratings were not developed for 5% of the trees in our sample, resulting in a vulnerability rating of n/a for those species.

Appendix E. We identified seven tree species that should not be planted as street trees in Lexington based on their high relative abundance in Lexington's street tree canopy, and/or their high climate vulnerability rating (for explanation of climate vulnerability ratings, see Appendix D). *White ash should not be planted due to the Emerald Ash Borer.

Species	Species Relative Abundance	Vulnerability Rating
Acer rubrum - red maple	29.40%	low
Pyrus calleryana - Callery pear	17.54%	moderate-high
Fraxinus americana - white ash*	3.29%	moderate-high
Carya laciniosa - shellbark hickory	0.04%	high
Cercidiphyllum japonicum - katsura	0.02%	high
Pinus strobus - white pine	0.66%	high
Tsuga canadensis - Eastern hemlock	0.18%	high

Appendix F. Map 2: Empty Tree Wells and Socioeconomic Status of Lexington Neighborhoods. Neighborhoods shown are neighborhoods inventoried between 2020-2021.



Appendix G. Map 3: Empty Tree Wells and Neighborhood Age of Lexington Neighborhoods. Neighborhoods shown are neighborhoods inventoried between 2020-2021.