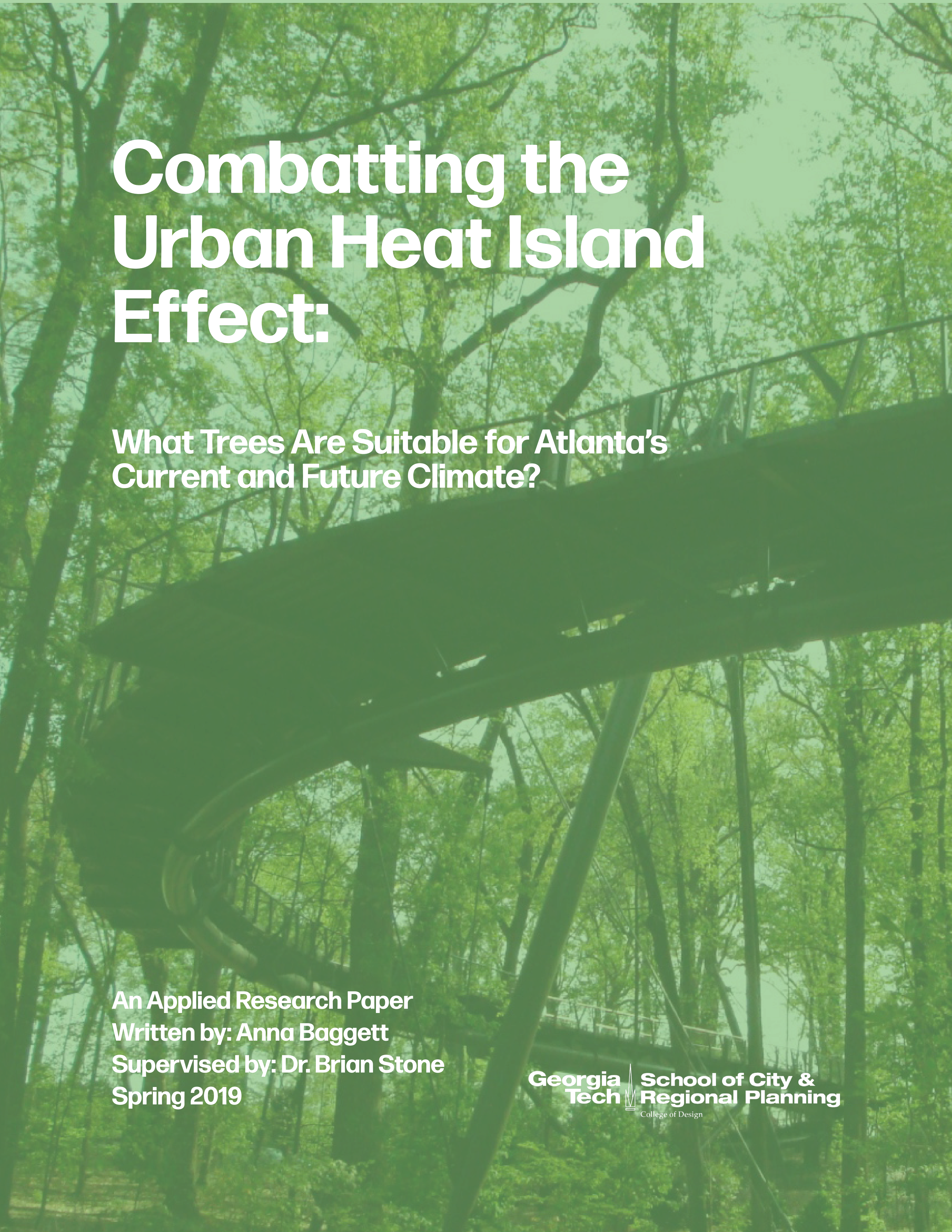

Combatting the Urban Heat Island Effect:

What Trees Are Suitable for Atlanta's Current and Future Climate?

An Applied Research Paper
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Introduction

Among many benefits, trees combat the urban heat island (UHI) effect in cities. As the climate changes and temperatures rise, some cities are looking to increase urban vegetation to minimize the effects of UHIs. Through evapotranspiration and shade benefits, urban trees are vital tools to making cities more resilient to extreme heat. Unfortunately, the very tools to combat this rising heat may also fall victim to it. As temperatures warm, certain tree species will not survive their future climates. While more city governments and tree-planting organizations realize the climate benefits of trees, it is also critical that they anticipate the changing adaptability of native tree species.

This paper focuses on Atlanta, a city with remarkable tree canopy. Specifically, the city of Atlanta has 47% tree canopy cover as of 2014 (Samuel 2018). In fact, the city has the highest percentage of urban tree canopy among major cities in the United States (Saporta 2017). Many of Atlanta's trees are on private land. As the city bounces back from the recession, tree advocates worry that increased development threatens the survival of the city's greatest natural resource. In response, the City of Atlanta announced in 2017 that it would revisit its tree protection ordinance as well as form a native tree replacement program. While development does indeed threaten Atlanta's tree canopy, this paper argues that the city, as well as other tree planting initiatives, should consider the changing climate when making its tree species recommendations as well.

Despite Atlanta's remarkable tree canopy, the metropolitan region suffers from an intense UHI effect. The UHI effect describes the increased temperatures in urban areas relative to the nearby countryside. In contrast to the vegetated surfaces of rural areas, the impervious surfaces characteristic of urban environments exhibit lower evaporation and higher heat absorption capacities. These surfaces reemit this heat as longwave radiation and thus, warm their nearby environments. The thermal properties of city surfaces and buildings coupled with anthropogenic sources of heat produce an overall warmer local climate (Lynn et al. 2009, 199). Specifically, the Atlanta metropolitan statistical area (MSA) has the 3rd worst UHI warming rate rank among major cities in the country (Stone and Lanza 2016, 76). Studies show that the Atlanta MSA's urban heat island ranges between 3-9 °F hotter than surrounding rural areas (Zhou and Shepherd 2010; Dixon and Mote 2003). It ranks this high because of its sprawling development pattern, as much of the region's land is urbanized at low densities.

Atlanta's tree canopy is a unique asset to combat its UHI effect. Unfortunately, climate change will only exacerbate its urban heat island. The city needs a resilient tree canopy to promote Atlanta's resilience to extreme heat. Therefore, the city's canopy must be composed of trees suited to the heat stresses of climate change. This predicament begs the following guiding question: What native and non-native tree species are most well-adapted to Atlanta's current and future climate?

Because of the changing climate, this study hypothesizes that many native tree species will no longer be suitable for Atlanta's predicted climate while other, non-native species will be better suited.

This paper first offers a review of current and relevant literature. Then, this paper discusses the approaches and methods used to conduct its study. The next section presents this study's findings. As a part of its recommendations, this paper offers a list of tree species well-adapted to Atlanta's current and future climate intended to inform policy recommendations for city's tree ordinance as well as guide local tree planting programs. Finally, this paper discusses the implications this study has for further research.

Literature Review

Before discussing what trees are suitable for Atlanta's climate, this paper must establish the current literature. The following section summarizes research and data related to the effectiveness of trees on reducing the UHI effect, shifting plant hardiness zones related to climate change, and finally, the significance of future climates on tree planting.

Trees and the UHI Effect

As mentioned, trees mitigate the UHI effect in two ways: shading and evapotranspiration. The Environmental Protection Agency summarized the existing research on the magnitude of these cooling effects. The EPA states that shaded materials range between 20–45°F cooler than the highest temperatures of their unshaded counterparts (EPA 2015). Furthermore, the EPA reports that vegetative evapotranspiration can cool high summer temperatures by upwards of 2–9°F (EPA 2015). Given that Atlanta's UHI can reach 9°F, vegetative evapotranspiration coupled with shading is relatively effective in combatting the UHI effect. In addition to the EPA report, several studies show the cooling effect of urban trees on the UHI effect in relation to other mitigation strategies.

Rosenzweig et al. measured the effectiveness of various UHI mitigation methods in New York City in 2006. Results showed that vegetation reduces surface temperatures more efficiently than mitigation strategies that increase albedo, or surface reflectivity. The study further claims that the "most effective mitigation strategy per unit area redeveloped is curbside planting" of vegetation (Rosenzweig et al. 2006, 3). Vegetation proved the most effective at reducing urban temperatures, and street trees proved most efficient of the vegetative methods with the highest cooling potential per unit area (Rosenzweig et al. 2006, 3). Specifically, results indicated that curbside tree plantings reduce near-surface air temperatures by an average of 0.6°F to 1.0°F throughout the day (Rosenzweig et al. 2006, 4). While this study presents a New York context, these temperature reductions are significant in comparison to Atlanta's 3-9°F UHI effect.

Lynn et al. applied a simulation approach to study UHI mitigation strategies in New York City using data from the summer of 2001. Contrary to Rosenzweig et al., Lynn et al. found that increasing the albedo of urban surfaces proved the most effective method at reducing surface and near-surface temperatures; however, this UHI mitigation strategy increased thermal stress of hypothetical, street-level individuals at the hottest time of the day because of reflected radiation. Lynn et al. found that street trees reduce "the urban heat island's impact on the city inhabitants during high noon… as well as elevated temperatures that would occur at the city surface after sundown" (Lynn et al. 2009, 212-213). The study concludes that "trees provided the best combination of reducing late afternoon/evening surface temperature and noontime radiation stress on a person at sidewalk level." Not only do urban trees combat the UHI effect, but they do so in a way that provides the most comfort to street-level pedestrians.

More recently, Loughner et al. examined the effects of tree canopy on the UHI effect in 2012. The study also employed a simulation, using the Weather Research and Forecasting model coupled with an urban canopy model to study the cooling effects of trees during a heat wave in Washington D.C. The study found that adding trees to their models resulted in reductions of peak daytime temperatures and minimum evening temperatures by 7.4 and 4.5 °F, respectively (Loughner et al. 2012, 1784). Again, these temperature reductions are found to be significant in comparison to Atlanta's 3-9°F UHI effect.

Kleerekoper et al. explores current urban design strategies that address heat stress associated with climate change and the UHI effect in the Netherlands. Much like the existing literature, Kleerekoper et al. recommends increasing the number of street trees throughout urban areas. The study explains that street trees at high quantities, even when dispersed, have significant cooling effects (Kleerekoper et al. 2012, 32). Specifically, Kleerekoper et al. reports that evapotranspiration alone on a hot, sunny day reduces temperatures equivalent to 20-30 kW of power, "comparable to that of more than 10 air-conditioning units" (Kleerekoper et al. 2012, 32).

Much of the current UHI mitigation literature focuses on the effectiveness of street trees. Kleerekoper et al. also assesses the cooling effects of urban forests. As expected, the study reports that urban forests have lower temperatures at air and surface levels. Urban forests produce a Park Cool Island effect, or PCI (Kleerekoper et al. 2012, 32). Specifically, it cites a study in Tel Aviv that measured the cooling effect of a park a little over a third of an acre in size. The park averaged a cooling effect of 2.7 °F and peaked at a 5.4 °F difference at noon (Kleerekoper et al. 2012, 32). Furthermore, Kleerekoper et al. referred to research in Göteborg that showed a 385-acre vegetated area produced a peak difference of 10.6°F (Kleerekoper et al. 2012, 32). Overall, planting street trees proves effective in mitigating the UHI effect, particularly near highly radiation-absorptive urban surfaces. Also, concentrated trees in urban forests and parks can form highly effective PCIs.

The existing research clearly indicates that trees and urban forests are incredibly effective tools in combatting the UHI effect, both planted near roadways as well as in concentrated urban forests.

Shifting Plant Hardiness Zones

Established by the USDA, plant hardiness zones inform planting decisions across the United States. Hardiness zones represent plant range limits with respect to their average extreme minimum temperature (Matthews et al. 2018, 11). The USDA assigns 13 zones that represent 10 °F intervals. For example, zone 1 represents an area that has an average annual extreme minimum temperature between -60 to -50 °F while zone 2 ranges between -50 to -40 °F. Every PHZ contains two sub-zones: 'a' and 'b,' representing 5 °F ranges (USDA 2012). Several studies recognize the direct effect of the average extreme minimum temperature on the distribution of tree species (Stone and Lanza 2016, 75). Therefore, plant hardiness zones are useful in predicting plant species suitability for different areas.

In response to temperature changes, the USDA has updated the plant hardiness zone maps accordingly (Matthews et al. 2018, 11). Specifically, hardiness zones have warmed by one half zone, or 5 °F, between 1990 and 2012 (Daly et al. 2012, 261). Recently, the USDA released hardiness zone projections based off recent climate prediction scenarios. Specifically, the USDA mapped potential shifts in hardiness zones based off the Representative Concentration Pathways (RCPs) from the IPCC 5th Climate Assessment (Matthews et al. 2018, 1). Originating from annual global carbon emissions, RCPs represent the projected global temperature change scenarios through the end of the 21st century. Each RCP varies depending on projected carbon emission mitigation or growth levels. For instance, RCP 4.5 projects a 1.1°C to 2.6°C global temperature increase given significant carbon mitigation. RCP 8.5 represents a 2.6°C to 4.8°C global temperature change given continued increasing carbon emissions (IPCC 2014, 10). The USDA modeled potential hardiness zone shifts based off RCPs 4.5 and 8.5 ((Matthews et al. 2018, 1). To support the creation of these maps, the USDA reasoned that the future zonal projections will prove useful to predict the future range potential of plant species (Matthews et al. 2018, 11).

Corresponding with these zonal changes, recent studies indicate that tree populations are migrating in response to changes in climate. Fei et al. studied the distributions of 86 tree species between the 1980's and 2010's. Of the studied species, 55% migrated their population centers significantly northward, and 65% migrated their population centers significantly westward (Fei et al. 2017, 2). While this study reflects the successional migration of naturally occurring forests rather than urban trees, this study provides evidence that tree populations are migrating in response to changing temperatures and precipitation levels associated with climate change.

The current literature establishes plant hardiness zones as a suitable temperature-specific measurement that predicts where tree and other plant species can survive. Furthermore, the current literature on the shifting of hardiness zones and natural tree migration suggests that many tree species may not be suitable in their current environments in the future, thus supporting the hypothesis of this study.

Future Climates and Tree Planting

Future climates are important to consider when planting because of the lifespans of trees. Urban trees typically live between 13 to 37 years (Mullaney et al. 2015, 161). While shorter than non-urban trees, these average lifespans will likely witness significant changes in climate in the coming years (Stone and Lanza 2016, 75).

Furthermore, older trees typically provide more shade and thus, more UHI mitigation benefits. Therefore, considering future climates when selecting a tree species has implications on the effectiveness of UHI mitigation. Planting trees appropriate for future climates will maximize UHI mitigation benefits as the tree matures and contributes to significant shade canopy. In addition to shade, selecting a tree species suitable for future climates will increase the chances of a longer lifespan and therefore, increase the time a tree can combat the UHI effect through both shade and evapotranspiration (Stone and Lanza 2016, 75).

Gaps in Current Literature

This paper builds off the current literature to examine tree species suitable for Atlanta's current and future climate. Primarily, this study builds off Stone and Lanza (2016) which researched tree suitability across 20 Metropolitan Statistical Areas. Like Stone and Lanza (2016), much of the existing literature on the suitability of tree species for future climates is limited to regional or cross-city contexts. This study aims address this gap in the literature by taking a more focused, localized approach at the city and metropolitan level. Because of this scale, the studied tree species is more extensive and specific to Atlanta.

Methods

This study conducts two tree species suitability analyses: 1) for the City of Atlanta and 2) for the Atlanta Metropolitan Statistical Area (MSA). Tree species constrained to hardiness zones predicted to predominantly shift out of metropolitan Atlanta are considered not suitable for the Atlanta MSA's climate. Similarly, species restricted to hardiness zones projected to predominantly move out of the Atlanta city limits are considered not adapted to the City of Atlanta's climate. For the purposes of this study, tree species restricted to hardiness zones that cover 15% or less of the geographic area are not considered adapted.

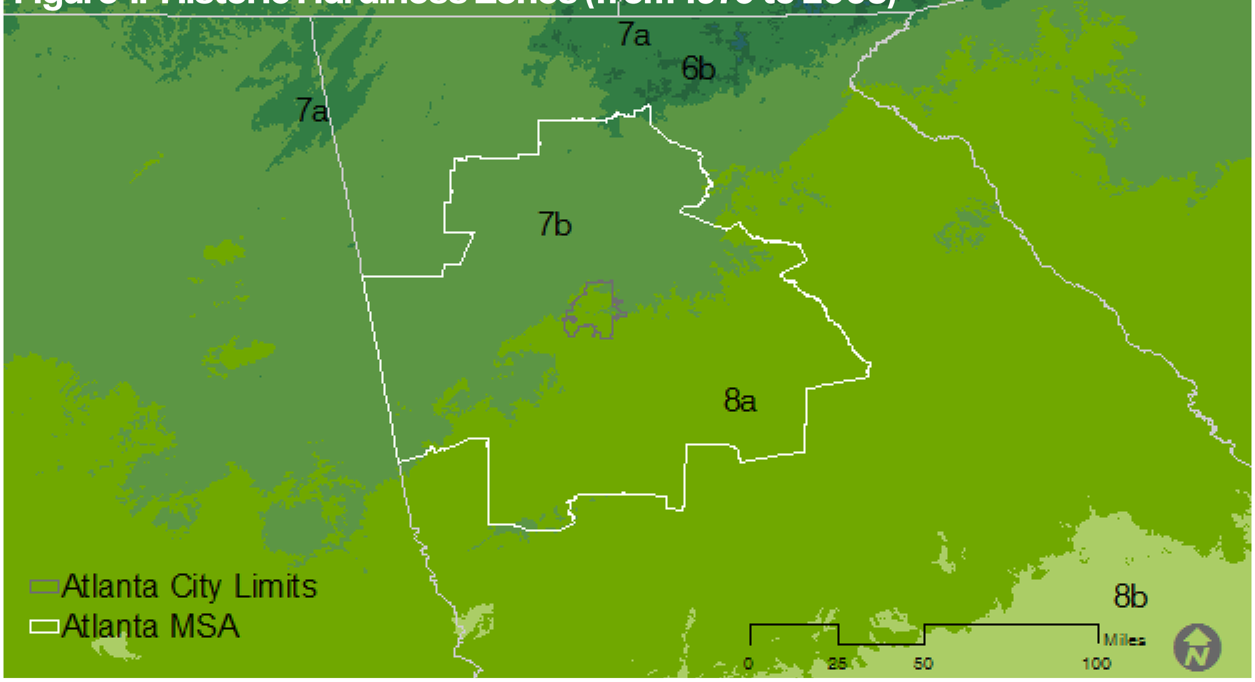
Hardiness Zones

To perform this analysis, hardiness zone geospatial data was used from two sources: Oregon State University (OSU) 1976-2005 hardiness zone maps and the United States Forest Service (USFS) projected hardiness zone maps through the end of the century. Published through the United States Department of Agriculture (USDA), the OSU maps inform planting decisions across the country. Planting guides often refer to this official hardiness zone map in their own recommendations. For instance, the UGA Extension's The Complete Guide to Native Plants for Georgia explicitly references hardiness zones in Georgia sourced from this map. Given the widespread use of this data, the OSU geospatial data serves as a baseline for the Atlanta area's historic climate and establishes the hardiness zones that currently inform planting decisions for the Atlanta area.

Shown in Figure 1, the OSU maps represent historic hardiness zones for the continental United States. The shapefile provided raster data converted to polygon format. Compared to the projected hardiness zone maps, the historic data provide much finer detail as the raster cell size appears much smaller. This difference has implications that are discussed later in this study.

Using ArcGIS, the historic hardiness zones were clipped to both the Atlanta MSA boundary and the City of Atlanta boundary, sourced from the US Census Bureau and the City of Atlanta Department of City Planning GIS portals, respectively. The 'calculate geometry tool' computed the areas of hardiness zones within these boundaries. These area calculations were analyzed in excel to produce percentages provided in Table 1.

Figure 1. Historic Hardiness Zones (from 1976 to 2005)



Shown in Figures 2, 3, and 4, the USFS maps represent current and future hardiness zones based off climate projection scenarios. The layer file contains maps using RCPs 4.5 and 8.5 projections. The USFS maps are the only reputable hardiness zone projection maps made publicly-available and thus, served as the main data source to inform this analysis. The 2018 Fourth National Climate Assessment indicates that global carbon emissions over the last two decades follow RCP 8.5 (USGCRP 2017, 31). Because of this recent report, this analysis uses the projected hardiness zones maps under the RCP 8.5 scenario rather than RCP 4.5.

The USFS maps projections extend throughout the 21st century and occur in three 29-year intervals: current hardiness zones representing 2010-2039, mid-century hardiness zones representing 2040-2069, and late-century hardiness zones 2070-2099. ArcGIS Online provided these maps in layer file format. The original layer file did not allow data manipulation and did not provide hardiness sub-zones. In order to perform the analysis using this data, polygons were drawn over this layer file to both delineate these "a" and "b" zones and calculate geographic area.

To construct sub-zones, ArcGIS's 'Identify' feature pinpointed the 'breakpoint' temperature along a latitude and longitude grid. For example, the threshold temperature between subzone 8a and 8b is – 9.4°C. The identify tool systematically traced the latitude and longitude grid to detect this breakpoint temperature within zone 8. Once found, a point manually marked the breakpoint temperature. These points connected formed the subzone boundary.

Like the historic hardiness zone data, the current and future hardiness zone polygons were clipped to both the Atlanta MSA boundary and the City of Atlanta boundary. The 'calculate geometry tool' calculated the areas of hardiness zones within these boundaries. These area calculations were recorded in excel and converted to percentages provided in Table 1.

Figure 2. Current Hardiness Zones (from 2010 to 2039)

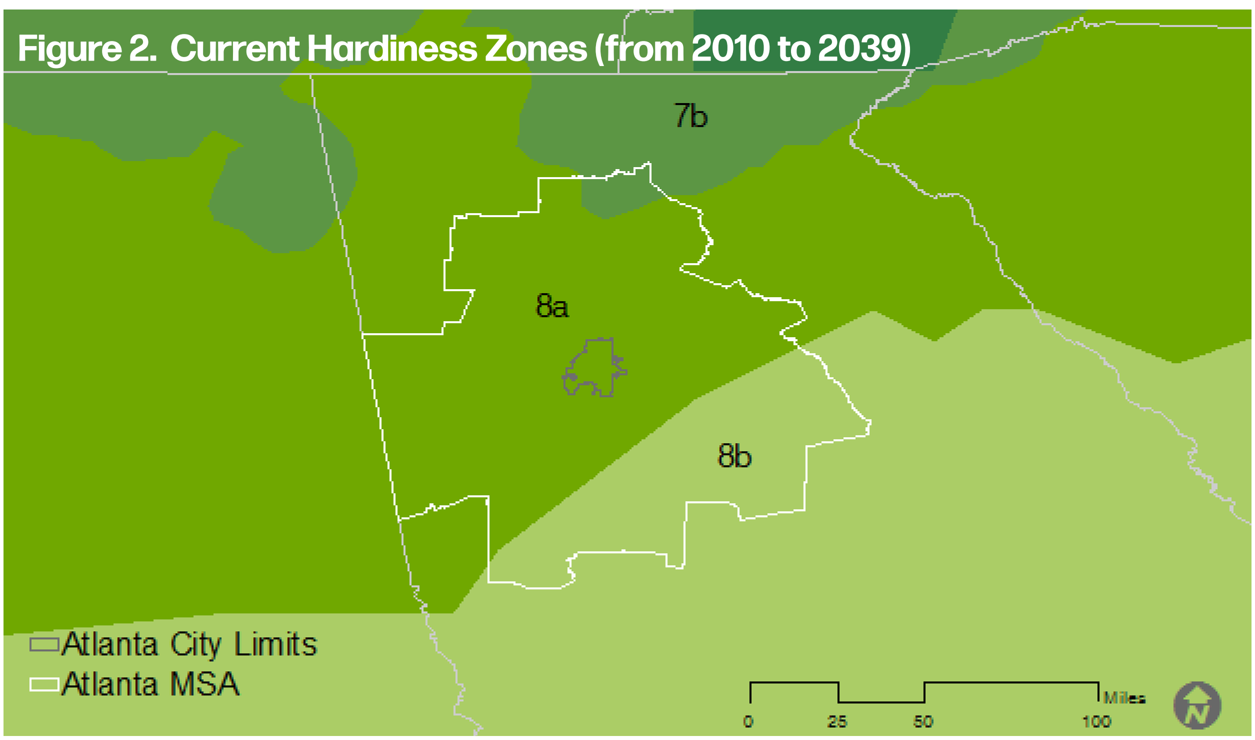


Figure 3. Mid-Century Hardiness Zones (from 2040 to 2069)

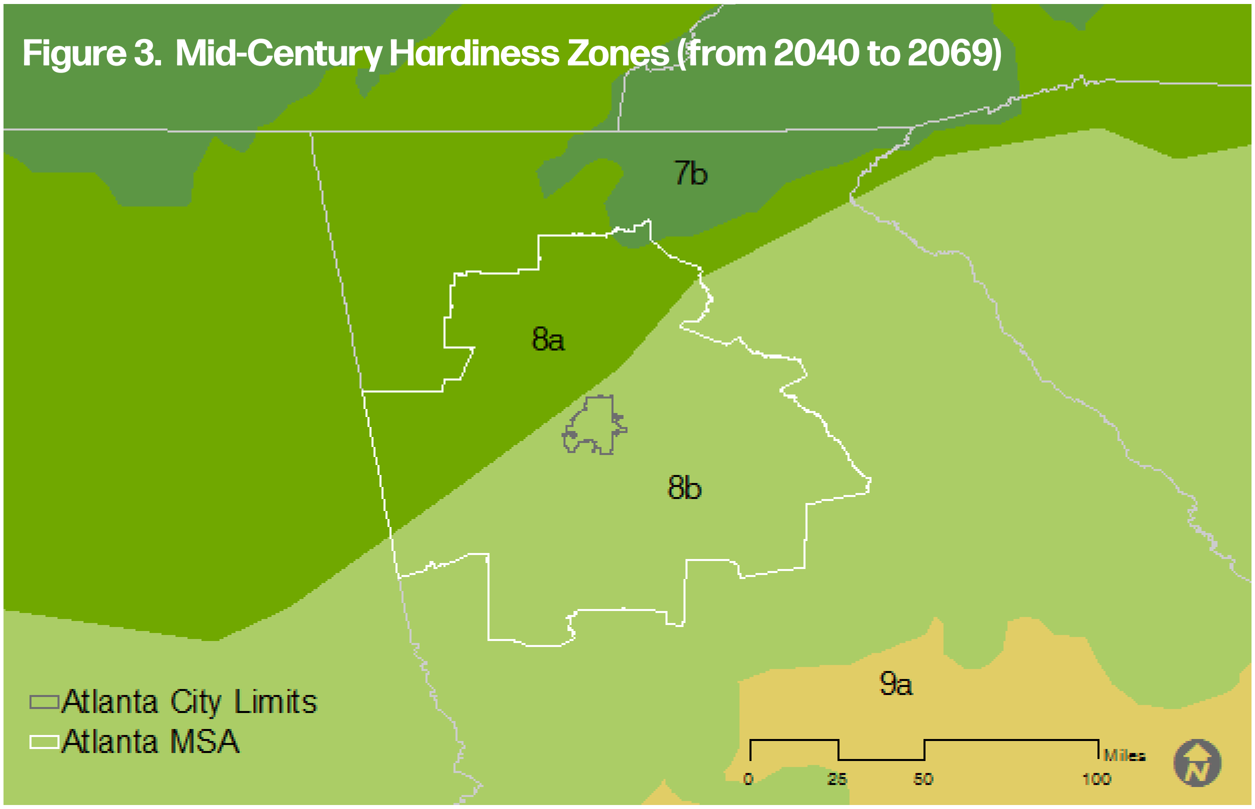


Figure 4. Late-Century Hardiness Zones (from 2070 to 2099)

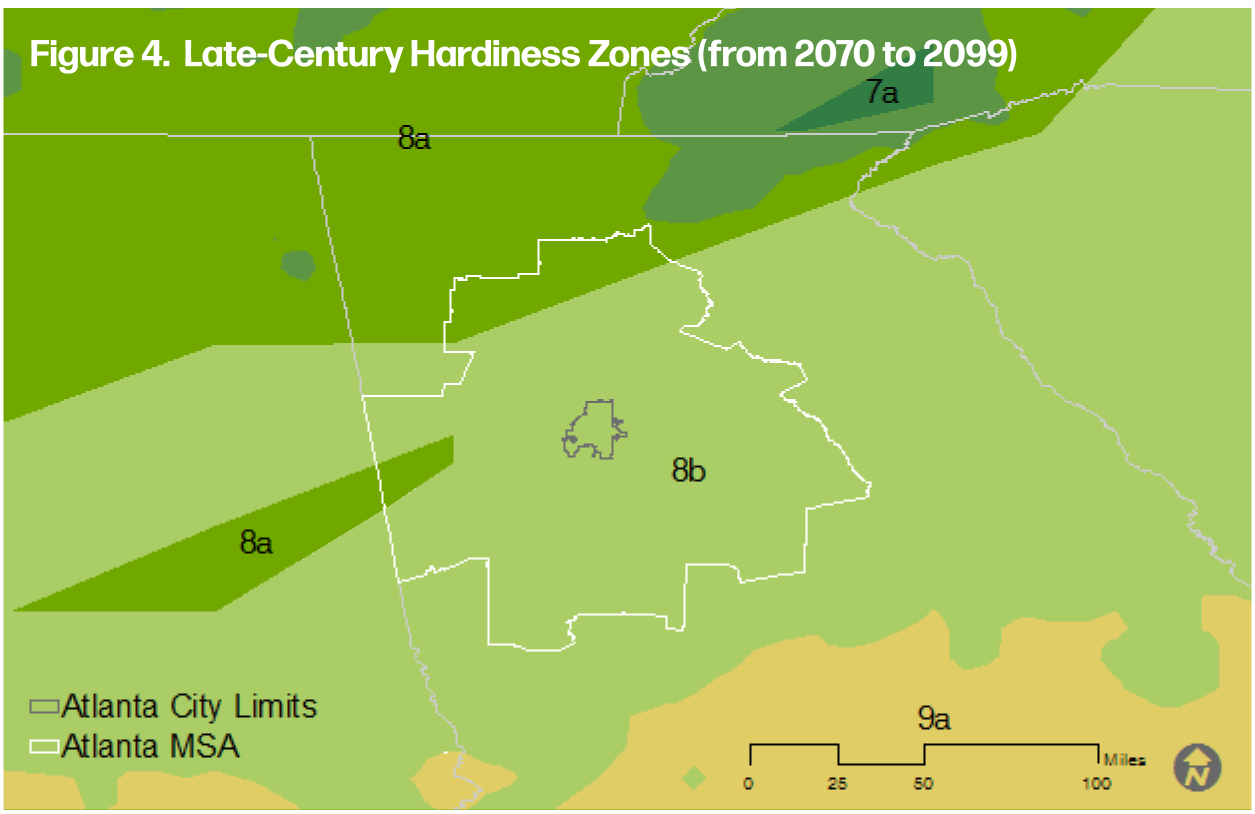


Table 1. Percent Area of Hardiness Subzone within Geographic Boundary								
	1976-2005		2010-2039		2040-2069		2070-2099	
Zone	City of Atlanta	Atlanta MSA	City of Atlanta	Atlanta MSA	City of Atlanta	Atlanta MSA	City of Atlanta	Atlanta MSA
7a	-	*0.4%*	-	-	-	-	-	-
7b	**19.4%**	**50.3%**	-	*2.2%*	-	*0.5%*	-	-
8a	**80.6%**	**49.3%**	**100%**	**69.3%**	-	**34.5%**	-	*10.6%*
8b	-	-	-	**28.5%**	**100%**	**65.0%**	**100%**	**89.4%**

Values over 15% were considered as hardiness zones representative of either the Atlanta MSA or the City of Atlanta. For example, in the late-century period, only hardiness zone 8b is representative of the Atlanta MSA per Table 1. While zone 8a is present within the metropolitan area, the percentage is below 15%. Therefore, tree species unable to survive in 8b are considered lost to the Atlanta MSA in its late 21st century climate.

The threshold needed to be large enough to eliminate hardiness zones that only covered minimal area of the study boundaries. These small zones cannot truly represent the entire Atlanta MSA. For example, zone 7a in the Atlanta MSA for the historic period is only 0.4% of its area. This value is too small to inform generalized policy recommendations. The threshold also needed to be small enough to capture significant values in a large metropolitan region. While 15% seems small, this metric speaks to a little over 1,325 square miles of Atlanta's MSA. The results for the City of Atlanta far exceeded the 15% threshold; therefore, this study kept the threshold consistent despite the differences in geographic area.

Tree Species

Four sources contributed to the tree species list for this analysis: UGA Extension's publication *The Complete Guide to Native Plants for Georgia: Trees, Shrubs, and Woody Vines*; the non-profit Trees Atlanta's plantings from the last 5 seasons (2012-2017), the official City of Atlanta Tree Planting List; and tree species planted at the Browns Mill Food Forest.

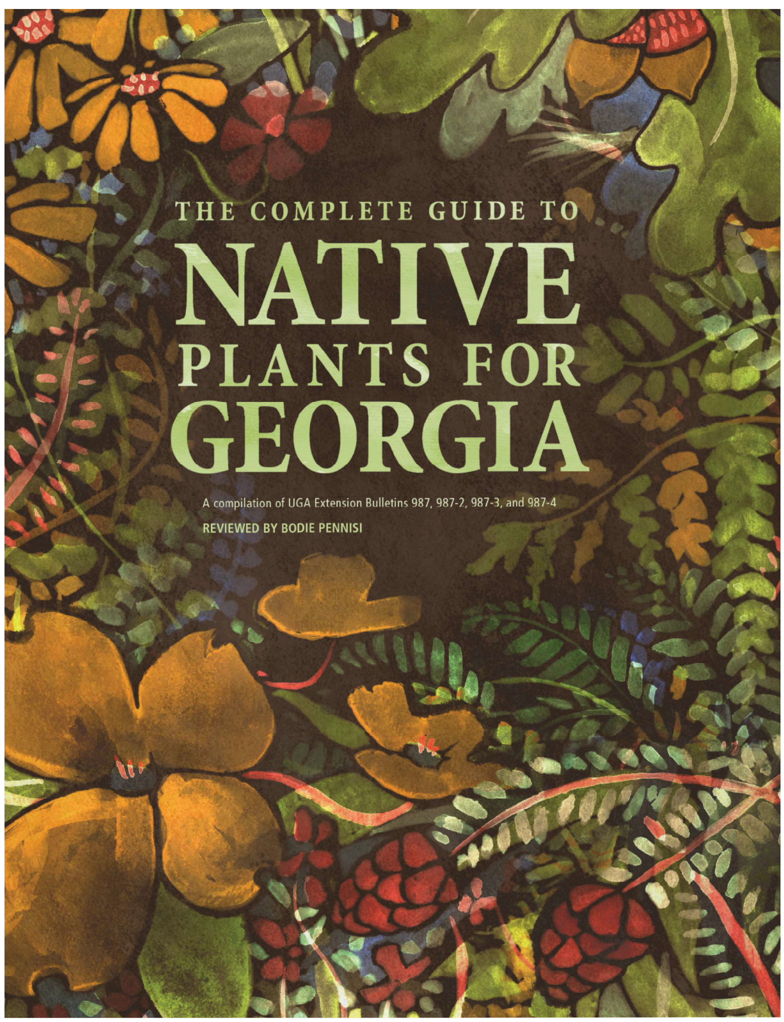
UGA Extension's publication provides a broad list of tree species native to Georgia. The state of Georgia has various climates throughout the state including coastal plains, mountains, and the piedmont. While Atlanta is situated in the Piedmont, all native trees from Georgia were incorporated into the list given that Atlanta's climate may be significantly warmer in the future. Trees accustomed to warmer climates in the southern part of Georgia may be more suited to Atlanta's climate in the future and therefore, were not excluded.

Trees Atlanta supplied their tree planting list from 2012-2017. Trees Atlanta is a non-profit committed to protecting and improving Atlanta's urban forest through tree planting, conservation advocacy, and education (Trees Atlanta 2019). When contacted, Trees Atlanta's 2018-2019 planting season had just commenced. Therefore, tree species unique to the most recent season were excluded. The non-profit chooses tree species based on current climate suitability, hardiness to urban environments, and nursery availability. While it strives to plant native species, Trees Atlanta does plant some non-native species. However, it never plants species considered invasive. For instance, the non-profit often plants cherry trees native to Japan. These trees do not occur naturally in Atlanta, but they also do not outcompete native tree species. Furthermore, Trees Atlanta plants trees within and around Atlanta. The non-profit plants trees throughout the metropolitan area such as Clarkston, Hapeville, and Sandy Springs. Overall, tree species sourced from Trees Atlanta represent common native and non-native species that are planted within and outside Atlanta city limits.

The City of Atlanta provides a tree planting list as a part of their tree protection ordinance. These species are city-approved species for tree replacement. The list indicates if the species is native to Georgia's piedmont but offers some non-native species as well. This tree planting list exemplifies common species planted within the city.

Finally, this analysis evaluates tree species planted in the Browns Mill Food Forest. Browns Mill is a 7-acre greenspace located in the southeastern neighborhood of Lakewood. It serves as the City of Atlanta's first official community urban food forest and as a pilot project for urban agriculture initiatives of the city's Office of Resilience (AgLanta 2019). The Office of Resilience plans to use Browns Mill as a model for other urban agriculture projects throughout Atlanta (Stokes 2017). Therefore, Browns Mill tree species are representative of species commonly planted in urban agricultural contexts now and in the future.

Tree species from these four sources were consolidated into an excel spreadsheet. This final list amounted to 192 unique tree species. This list represents current tree species commonly planted in the Atlanta metropolitan area and therefore, are suitable candidates for evaluation. In addition to the species name, the final list includes information on the species' common names, whether the species is native to Georgia, and the hardiness zones in which the trees can survive. The UGA Extension report, the Missouri Botanical Garden 'Plant Finder' website, and the Arbor Day Foundation website provided hardiness zone information.



Findings

As shown in Figures 2,3, and 4, hardiness zones in the Atlanta area shift from majority 8a to majority 8b by the end of the century. Based on these results, species considered 'adapted' must have a hardiness zonal range that includes both 8a and 8b at a minimum. However, this analysis extends this suitable range to 9a for its recommended species. The concluding section denoted 'Criteria' discusses the extended range.

For each time period, hardiness zones from Table 1 were cross-referenced in excel. Using the "highlight cell rules" feature, cells containing the representative hardiness zones were highlighted. For example, cells containing "8a" in the hardiness zones column were highlighted for the City of Atlanta during the mid-century (2040-2069) period because 8a is the only hardiness zone representative of the city's boundaries during that time period. Those not highlighted were recorded in excel as 'Species Lost' for each time period and geographic boundary.

For the historic period, only one species, the Fragrant Olive, is considered not adapted to either the City of Atlanta or the Atlanta MSA. This specific species thrives in warmer climates of the 9a hardiness zone and higher. Because the 9a hardiness zone does not enter either geographic boundary within the 21st century, this species is considered not adapted to either boundary during any time period. For the current time period (2010-2039), a total of 15 out of 192 species are lost between the City of Atlanta and the Atlanta MSA. For the mid-century period, the same 15 species are lost for the Atlanta MSA. The City of Atlanta loses a total of 22 species with 7 new species lost. For the late-century period, both the City of Atlanta and the Atlanta MSA lose a total of 22 species. Tables 2, 3, 4, and 5 summarize the species lost in each time period. For the purposes of this study, the 22 species lost by the end of the century do not appear on the recommended planting lists in the next section.

Table 2. Historic Period (1976-2005) Species Not Adapted

#	City of Atlanta (7b, 8a)	Atlanta MSA (7b, 8a)
1	Fragrant Olive (*Osmanthus fragrans*)	Fragrant Olive (*Osmanthus fragrans*)

Table 3. Current Period (2010-2039) Species Lost

#	City of Atlanta (8a)	Atlanta MSA (8a, 8b)
1	Sugar Maple (*Acer saccharum*)	Sugar Maple (*Acer saccharum*)
2	Three-Flowered Maple (*Acer triflorum*)	Three-Flowered Maple (*Acer triflorum*)
3	Yellow Buckeye (*Aesculus flava/Aesculus Octandra*)	Yellow Buckeye (*Aesculus flava/Aesculus Octandra*)
4	Ohio Buckeye (*Aesculus glabra*)	Ohio Buckeye (*Aesculus glabra*)
5	Green Hawthorn (*Crataegus viridis*)	Green Hawthorn (*Crataegus viridis*)
6	Common Beech (*Fagus sylvatica*)	Common Beech (*Fagus sylvatica*)
7	Butter nut (*Juglans cinerea*)	Butter nut (*Juglans cinerea*)
8	Sargent Crabapple (*Malus sargentii*)	Sargent Crabapple (*Malus sargentii*)
9	Fragrant Olive (*Osmanthus fragrans*)	Fragrant Olive (*Osmanthus fragrans*)
10	White Pine (*Pinus strobus*)	White Pine (*Pinus strobus*)
11	Chinkapin Oak (*Quercus muehlenbergii*)	Chinkapin Oak (*Quercus muehlenbergii*)
12	Oglethorpe Oak (*Quercus oglethorpensis*)	Oglethorpe Oak (*Quercus oglethorpensis*)
13	Japanese Arborvitae (*Thuja standishii*)	Japanese Arborvitae (*Thuja standishii*)
14	Littleleaf Linden (*Tilia cordata*)	Littleleaf Linden (*Tilia cordata*)
15	Eastern Hemlock (*Tsuga canadensis*)	Eastern Hemlock (*Tsuga canadensis*)

Table 4. Mid-Century (2040-2069) Species Lost		
#	City of Atlanta (8b)	Atlanta MSA (8a, 8b)
1	Sugar Maple (*Acer saccharum*)	Sugar Maple (*Acer saccharum*)
2	Three-Flowered Maple (*Acer triflorum*)	Three-Flowered Maple (*Acer triflorum*)
3	Yellow Buckeye (*Aesculus flava/Aesculus Octandra*)	Yellow Buckeye (*Aesculus flava/Aesculus Octandra*)
4	Ohio Buckeye (*Aesculus glabra*)	Ohio Buckeye (*Aesculus glabra*)
5	Green Hawthorn (*Crataegus viridis*)	Green Hawthorn (*Crataegus viridis*)
6	Common Beech (*Fagus sylvatica*)	Common Beech (*Fagus sylvatica*)
7	Butter nut (*Juglans cinerea*)	Butter nut (*Juglans cinerea*)
8	Sargent Crabapple (*Malus sargentii*)	Sargent Crabapple (*Malus sargentii*)
9	Fragrant Olive (*Osmanthus fragrans*)	Fragrant Olive (*Osmanthus fragrans*)
10	White Pine (*Pinus strobus*)	White Pine (*Pinus strobus*)
11	Chinkapin Oak (*Quercus muehlenbergii*)	Chinkapin Oak (*Quercus muehlenbergii*)
12	Oglethorpe Oak (*Quercus oglethorpensis*)	Oglethorpe Oak (*Quercus oglethorpensis*)
13	Japanese Arborvitae (*Thuja standishii*)	Japanese Arborvitae (*Thuja standishii*)
14	Littleleaf Linden (*Tilia cordata*)	Littleleaf Linden (*Tilia cordata*)
15	Eastern Hemlock (*Tsuga canadensis*)	Eastern Hemlock (*Tsuga canadensis*)
16	American Yellowwood (*Cladrastis kentukea*)	
17	Washington Hawthorn (*Crataegus phaenopyrum*)	
18	Carolina Silverbell (*Halesia tetraptera*)	
19	Big-Leaf Magnolia (*Magnolia macrophylla*)	
20	Virginia Pine (*Pinus virginiana*)	
21	Scarlet Oak (*Quercus coccinea*)	
22	Northern Red Oak (*Quercus rubra*)	

Table 5. Late-Century (2070-2099) Species Lost		
#	City of Atlanta (8b)	Atlanta MSA (8a, 8b)
1	Sugar Maple (*Acer saccharum*)	Sugar Maple (*Acer saccharum*)
2	Three-Flowered Maple (*Acer triflorum*)	Three-Flowered Maple (*Acer triflorum*)
3	Yellow Buckeye (*Aesculus flava/Aesculus Octandra*)	Yellow Buckeye (*Aesculus flava/Aesculus Octandra*)
4	Ohio Buckeye (*Aesculus glabra*)	Ohio Buckeye (*Aesculus glabra*)
5	Green Hawthorn (*Crataegus viridis*)	Green Hawthorn (*Crataegus viridis*)
6	Common Beech (*Fagus sylvatica*)	Common Beech (*Fagus sylvatica*)
7	Butter nut (*Juglans cinerea*)	Butter nut (*Juglans cinerea*)
8	Sargent Crabapple (*Malus sargentii*)	Sargent Crabapple (*Malus sargentii*)
9	Fragrant Olive (*Osmanthus fragrans*)	Fragrant Olive (*Osmanthus fragrans*)
10	White Pine (*Pinus strobus*)	White Pine (*Pinus strobus*)
11	Chinkapin Oak (*Quercus muehlenbergii*)	Chinkapin Oak (*Quercus muehlenbergii*)
12	Oglethorpe Oak (*Quercus oglethorpensis*)	Oglethorpe Oak (*Quercus oglethorpensis*)
13	Japanese Arborvitae (*Thuja standishii*)	Japanese Arborvitae (*Thuja standishii*)
14	Littleleaf Linden (*Tilia cordata*)	Littleleaf Linden (*Tilia cordata*)
15	Eastern Hemlock (*Tsuga canadensis*)	Eastern Hemlock (*Tsuga canadensis*)
16	American Yellowwood (*Cladrastis kentukea*)	American Yellowwood (*Cladrastis kentukea*)
17	Washington Hawthorn (*Crataegus phaenopyrum*)	Washington Hawthorn (*Crataegus phaenopyrum*)
18	Carolina Silverbell (*Halesia tetraptera*)	Carolina Silverbell (*Halesia tetraptera*)
19	Big-Leaf Magnolia (*Magnolia macrophylla*)	Big-Leaf Magnolia (*Magnolia macrophylla*)
20	Virginia Pine (*Pinus virginiana*)	Virginia Pine (*Pinus virginiana*)
21	Scarlet Oak (*Quercus coccinea*)	Scarlet Oak (*Quercus coccinea*)
22	Northern Red Oak (*Quercus rubra*)	Northern Red Oak (*Quercus rubra*)

Criteria

For the purpose of recommending resilient species, this study extends the suitable hardiness zonal range to 9a. The recommended species in the next section not only exclude Table 5's lost species but also exclude those that do not fit this extended hardiness zonal range criteria. Two reasons support this conclusion: the projected increase in number of extreme heat days and the limited ability for species to survive at the upper limits of their hardiness zonal ranges.

Atlanta's projected increase in heat waves call for more heat resilient tree species. Atlanta's UHI effect will exacerbate rising temperatures resulting from climate change, particularly with heat wave duration and frequency. (Constible 2017, 5). By the end of the century, the Atlanta region will suffer approximately 80 'dangerous heat days' each summer compared to its current 9 days (Constible 2017, 5). Adjusted to local climate conditions, dangerous heat days include define extreme heat that leads to major health problems and even death. This increase in dangerous heat days highlights the need for increased UHI mitigation as well as the need for species that can tolerate extreme heat. Hardiness zone maps use cold hardiness averages and therefore, do not account for future heat spikes and hotter urban microclimates. Including 9a in the suitable hardiness zonal range results in species that are acclimated to warmer climates and thus, more resilient to heat waves.

Furthermore, trees may not live as long or grow to maturity in the upper and lower extremes of their hardiness zonal ranges (Stone and Lanza 2016, 80). For example, the Eastern Redbud is shorter-lived in hardiness zones 8a and 8b (Wade et al. 2017, 25). If this analysis recommended a suitable range of just 8a and 8b, the Eastern Redbud would remain suitable for urban heat management in Atlanta. However, this species would be less capable than other species at mitigating the UHI effect in the future. Including 9a in the suitable hardiness zonal range provides an upper limit buffer and ensures recommended species will truly thrive in Atlanta's future climate.

Overall, the recommended species presented in the next section of this paper contain suitable hardiness zonal range of 8a, 8b, and 9a. Including hardiness zone 8a ensures that the species will thrive in Atlanta's current climate. Hardiness zone 8b ensure that the species will thrive in Atlanta's projected climate at the end of the century. Finally, hardiness zone 9a provides a buffer that accounts for extreme heat events and species' suitability at its hardiness zonal range limits. With these considerations, 110 out of 192 species fit this criteria. In other words, this analysis considers roughly 57% of the studied species to be well-adapted to Atlanta's current and future climate.

Recommendations

The following section discusses the key takeaways and recommendations from this study. First, this section establishes the intended audience for these results. Finally, this section offers recommendations on relevant policy as well as on tree species adapted to Atlanta's current and future climate.

Intended Audience

This study's tree species recommendations are intended for local government and relevant advocacy and non-profit organizations. This section identifies some specific government entities and non-profits that might find these recommendations useful; however, this list of potentially interested parties is not comprehensive. Specific local government entities include the City of Atlanta's Department of City Planning and City of Atlanta's Office of Resilience. Intended organizations include local non-profits like Trees Atlanta.

According to their website, the City of Atlanta Department of City Planning means to thoroughly evaluate its tree protection ordinance as a part of the Urban Ecology Framework between September 2018 and July 2019 (City of Atlanta 2019). Published schedules suggest that the ordinance rewrite begins in late April of 2019, a draft should be complete by late summer of 2019 (City of Atlanta 2019). Public meetings indicate that the ordinance might provide a native tree replacement program. Given this ongoing process, the recommendations of this paper may prove useful in developing a revised list of species and advocating for tree protections responsive to climate change effects.

In addition to the Department of City Planning, this analysis should be useful to Atlanta's Office of Resilience. The Office produced the *Resilient Atlanta* plan in 2017. This plan identified several goals and actions to make Atlanta more resilient to 21st century shocks and stresses including climate change. These recommendations did not specifically address rising heat or the UHI effect, so this paper minimally addresses this gap in Atlanta's resiliency planning literature.

Relevant goals in *Resilient Atlanta* include protecting and expanding Atlanta's urban forest and increasing access to fresh fruit and vegetables (Resilient Atlanta 2017, 86, 82-83). The Office of Resilience's Browns Mill Food Forest is exemplary of this commitment to both goals. Alongside its non-profit partners, the Office of Resilience plans to model future urban food forests after Browns Mill (AgLanta 2019). Because of these plans to replicate this model, evaluating the current tree species in Browns Mill may inform ongoing planting decisions in other urban agriculture spaces throughout Atlanta. Furthermore, urban forests, including those that produce food, are incredible assets for urban heat management. As mentioned in the literature review, urban forests produce cool spots that are highly effective at counteracting the UHI effect (Kleerekoper et al. 2012, 32). Although not a stated goal, these urban agriculture initiatives play their part in managing the UHI effect. If Atlanta hopes to grow a truly resilient system of urban food forests, it is important to choose fruit and nut tree species adapted to current and future climates.

Non-profit organizations may use the results of this study to inform their planting decisions and advocacy objectives. Each year, Trees Atlanta plants thousands of trees around Atlanta and its surrounding suburbs. Given their impact, the non-profit should consider planting tree species resilient to rising heat. As mentioned, Trees Atlanta not only plants trees throughout Atlanta, but it also advocates for conservation and tree protection. Recently, Trees Atlanta has advocated for a stricter tree protection ordinance for the City of Atlanta. In their effort to improve the ordinance, their call to action includes planting more native trees, buying more forested land, and saving existing canopy. Neither in its call to action or informational meeting did the organization address climate change's impact on Atlanta's canopy. Perhaps this study's recommendations will highlight the need to advocate for a tree ordinance that responds to rising heat as well as one that stresses trees' critical role in managing the UHI effect.

Recommendations

On a high level, this study recommends that any policy affecting Atlanta's urban forest should incorporate two themes: addressing climate change threats and reconsidering planting native-only species.

Local governments should consider climate change when crafting tree protection policies. Climate change is a real threat, and trees are scientifically proven to manage urban heat. Considering how climate change will impact this public asset is critical. The City of Atlanta invests a considerable amount of political and financial capital into protecting its urban forest. Through its current tree protection ordinance, the city collects fees from tree removal and uses the fund to finance tree planting contracts around the city. Considering this investment, incorporating climate change into the city's tree protection efforts is not only a decision that promotes resilience but also a wise financial decision. If Atlanta truly values its canopy, climate considerations must be made when crafting policies to protect and improve it.

Policymakers and tree advocates should also reconsider the native species imperative. Conversations over Atlanta's canopy often emphasize planting native species. This study suggests that policy makers and tree advocates relax this assumption and consider how a changing climate will affect what is native. According to this analysis, over 60% of the species lost by the end of the century are native to Atlanta. Furthermore, this study finds that over a quarter of the studied trees that fit the suitable hardiness zonal range criteria are non-native species. Rather than emphasizing native tree plantings, policies and advocacy groups should research and consider tree species resilient to hardiness zone shifts, some of which may be non-native, non-invasive species.

In addition to these overarching policy themes, this paper provides a comprehensive list of 110 tree species adapted to Atlanta's current and future climate in Appendix A. Appendix B highlights the 82 studied species that do not meet the suitable hardiness zonal range of 8a, 8b, and 9a. Both these tables provide the corresponding Latin names, native status, and data source. In the following section, the tree species lists present recommendations according to interest areas. The first list is a revised version of Atlanta's tree planting list under the current tree ordinance. Then, this section presents list of adapted tree species for the dual purposes of urban agriculture and heat management. Finally, this section highlights non-native species adapted to Atlanta's current and future climate. Regardless of interest area, all listed tree species in the following section mitigate the UHI effect.

Revised City of Atlanta Tree Planting List

The species featured in Table 6 on the facing page reflect trees currently on the City of Atlanta's recommended planting list that are adapted to Atlanta's current and future climate. As mentioned, hardiness zone 8a represents Atlanta's current climate while hardiness zones 8b and 9a represent its future climate. On page 17, Table 7 illustrates the species from the recommended planting list that do not meet this criteria, and therefore, the city should not recommend them.

Table 6. Fifty out of 80 species on the City of Atlanta Tree Planting List are well-adapted to Atlanta's current and future climate (zones 8a, 8b, and 9a)	
American Beech (*Fagus grandifolia*)	Pignut Hickory (*Carya glabra*)
American Elm/ Princeton Elm (*Ulmus americana Princeton*)	Pondcypress/Pond Cypress (*Taxodium ascendens*)
American Hornbeam/Ironwood/Musclewood (*Carpinus caroliniana*)	Post Oak (*Quercus stellata*)
Bald Cypress (*Taxodium distichum*)	Red Maple (*Acer rubrum*)
Bitternut Hickory (*Carya cordiformis*)	River Birch (*Betula nigra*)
Black Gum/ Tupelo (*Nyssa sylvatica*)	Sand Hickory (*Carya pallida*)
Black Oak (*Quercus velutina*)	Sassafras (*Sassafras albidum*)
Black Walnut (*Juglans nigra*)	Shumard Oak (*Quercus shumardii*)
Black Willow (*Salix Nigra*)	Slippery Elm (*Ulmus rubra*)
Chestnut Oak (*Quercus prinus*)	Sourwood (*Oxydendrum arboreum*)
Chinese fringe tree (*Chionanthus retusus*)	Southern Red Oak/Cherrybark (*Quercus falcata*)
Common Hackberry (*Celtis occidentalis*)	Sugarberry (*Celtis laevigata*)
Crapemyrtle (*Lagerstroemia fauriei*)	Swamp Chestnut Oak/Basket Oak (*Quercus michauxii*)
Eastern Hop Hornbeam/ American Hop Hornbeam (*Ostrya virginiana*)	Swamp/Stiff Dogwood (*Cornus foemina*)
Eastern Red Cedar (*Juniperus virginiana*)	Sweet Bay Magnolia (*Magnolia virginiana*)
Florida/Southern Sugar Maple (*Acer barbatum*)	Sweetgum (*Liquidambar styraciflua*)
Flowering Dogwood (*Cornus florida*)	Sycamore (*Platanus occidentalis*)
Foster Holly/Savannah Holly (*Ilex x attenuata*)	Trident Maple (*Acer buergeranum*)
Georgia Hackberry/Dwarf Hackberry (*Celtis tenuifolia*)	Tulip/Yellow Poplar (*Liriodendron tulipifera*)
Hardy Pecan (*Carya illinoinensis*)	Water Hickory (*Carya aquatica*)
Mockernut Hickory (*Carya tomentosa*)	Water Tupelo (*Nyssa aquatica*)
Osage Orange (*Maclura pomifera 'Whiteshield'*)	White Oak (*Quercus alba*)
Overcup Oak (*Quercus lyrata*)	Willow Oak (*Quercus phellos*)
Pawpaw (*Asimina triloba*)	Winged Elm (*Ulmus alata*)
Persimmon/American Persimmon (*Diospyros virginiana*)	Yaupon Holly (*Ilex vomitor*)

Table 7. Thirty out of 80 species on the City of Atlanta Tree Planting List are not adapted to Atlanta's current and future climate or do not have a hardiness zonal range that includes 8a, 8b, and 9a.	
American Linden/ Basswood (*Tilia americana*)	Maidenhair Tree (*Ginkgo biloba*)
American Yellowwood (*Cladrastis kentukea*)	Northern Red Oak (*Quercus rubra*)
Big-Leaf Magnolia (*Magnolia macrophylla*)	Nuttall Oak (*Quercus nuttallii*)
Carolina Silverbell (*Halesia tetraptera*)	Oglethorpe Oak (*Quercus oglethorpensis*)
Chalk Maple (*Acer leucoderme*)	Pagodatree (*Styphnolobium japonica*)
Chinkapin Oak (*Quercus muehlenbergii*)	Persian Ironwood (*Parrotia persica*)
Dawn Redwood (*Metasequoia glyptostroboides*)	Red Buckeye (*Aesculus pavia*)
Deodar Cedar (*Cedrus deodara*)	Red Mulberry (*Morus rubra*)
Downy Serviceberry (*Amelanchier arborea*)	Saucer Magnolia (*Magnolia x soulangiana*)
Eastern Redbud (*Cercis canadensis*)	Scarlet Oak (*Quercus coccinea*)
English Oak (*Quercus robur*)	Shagbark Hickory (*Carya ovata*)
European Hornbeam/ Common Hornbeam (*Carpinus betulus 'Fastigiata'*)	Southern Shagbark Hickory (*Carya ovata var. australis*)
Georgia Oak (*Quercus georgiana*)	Swamp White Oak (*Quercus bicolor*)
Japanese Maple (*Acer palmatum*)	Virginia Pine (*Pinus virginiana*)
Kousa Dogwood (*Cornus kousa*)	White Poplar (*Populus alba*)

Adapted Species for Urban Agriculture

Urban food forest models should incorporate well-adapted fruit and nut tree species. Urban food forests can serve dual purposes of urban agriculture and urban heat management. Table 8 presents 20 fruit and nut trees resilient to shifting hardiness zones.

Table 8. Twenty well-adapted tree species that serve dual purposes of urban agriculture and UHI mitigation.	
American Elderberry (*Sambucus canadensis*)	Loquat (*Eriobotrya japonica*)
American Hazelnut (*Corylus americana*)	Parsley Hawthorn (*Crataegus marshallii*)
Asian Pear (*Pyrus pyrifolia*)	Pawpaw (*Asimina triloba*)
Black Willow (*Salix Nigra*)	Persimmon/American Persimmon (*Diospyros virginiana*)
Chickasaw Plum (*Prunus angustifolia*)	Pineapple Guava/Feijoa (*Acca sellowiana*)
Common Fig (*Ficus carica*)	Pomegranate (*Punica granatum*)
Eastern Mayhaw (*Crataegus aestivalis*)	Sassafras (*Sassafras albidum*)
Eastern Sweetshrub/Carolina Allspice (*Calycanthus floridus*)	Spicebush (*Lindera benzoin*)
Flatwoods Plum (*Prunus umbellata*)	Sugarberry (*Celtis laevigata*)
Kaki/ Japanese Persimmon (*Diospyros kaki*)	Winged Sumac (*Rhus copallinum*)

Adapted Non-Native Species

Finally, Table 9 offers 30 non-native species for consideration. Many of these species are representative of common trees thriving in Atlanta already. While they are not native, they are still suitable for urban heat management now and in the future.

Table 9. Well-adapted tree species that are not native to the Atlanta piedmont.	
American Elm/Princeton Elm (*Ulmus americana Princeton*)	Hardy Pecan (*Carya illinoinensis*)
Apple Serviceberry (*Amelanchier grandiflora*)	Japanese Cedar (*Cryptomeria japonica*)
Arizona Cypress (*Cupressus arizonica/glabra*)	Japanese Flowering Cherry 'Kanzan' (*Prunus 'Kanzan'*)
Asian Pear (*Pyrus pyrifolia*)	Japanese Snowbell (*Styrax japonicus*)
Bamboo Leaf Oak (*Quercus myrsinifolia*)	Kaki/ Japanese Persimmon (*Diospyros kaki*)
Butterfly Magnolia (*Magnolia 'Butterflies'*)	Loquat (*Eriobotrya japonica*)
Chinese Elm (*Ulmus parvifolia*)	Magnolia 'Leonard Messel' (*Magnolia × loebneri 'Leonard Messel'*)
Chinese fringe tree (*Chionanthus retusus*)	Osage Orange (Maclura pomifera 'Whiteshield')
Chinese pistache (*Pistacia chinensis*)	Patriot Elm (*Ulmus 'Patriot'*)
Common Fig (*Ficus carica*)	Pineapple Guava/Feijoa (*Acca sellowiana*)
Crapemyrtle 'fauriei' (*Lagerstroemia fauriei*)	Pomegranate (*Punica granatum*)
Crapemyrtle 'indica' (*Lagerstroemia indica*)	Pondcypress/Pond Cypress (*Taxodium ascendens*)
Foster Holly/ Savannah Holly (*Ilex x attenuata*)	Stellar Pink Dogwood (*Cornus rutgan*)
Gala Apple Tree (*Malus domestica 'Gala'*)	Trident Maple (*Acer buergeranum*)
Golden Rain Tree (*Koelreuteria paniculata*)	Windmill Palm (*Trachycarpus fortunei*)

Conclusion

Users of the recommended planting lists should research additional species traits before choosing or recommending a tree on any of the lists provided. This study is limited in its scope of recommending tree species based on hardiness zones and for the purpose of heat management.

Considerations beyond the scope of this study should include other effects of climate change that may affect trees. These considerations include the changes in frequency, intensity, and duration of drought and extreme rain events. As the climate changes, unknown pests may pose threats to certain tree species as well.

In addition to these considerations, the data and methodology used in this study had its own limitations. The USFS hardiness zone projections used in this study follow RCP 8.5. While all current indicators point to this scenario, climate warming at RCP 8.5 is not a certain future. Future studies should explore other RCP scenarios. Furthermore, the USFS layer file did not include hardiness sub-zones. The methodology used to extrapolate these sub-zones may have missed small islands of sub-zones. Finally, the USFS layer file contains large, generalized raster cell sizes. The layer itself may overlook islands of hardiness zones that smaller cell sizes would catch. Overall, the GIS data and methodology limitations invite future research to build upon this study.

Hardiness zones as a proxy for species adaptability is also limiting. Hardiness zones do not predict a species' ability to resist heat stress. As the climate warms, trees will be subject to higher heat stress and heat waves particularly in urban environments. A metric that measures a tree's ability to survive this stress would be better suited for this study than a metric based off cold hardiness.

Overall, this study acts as a jumping off point for continued research and dialogue about the climate change effects on Atlanta's urban forest and its continued ability to manage heat. Policy-makers, particularly in long-term planning roles, need to have conversations with researchers about how to best protect Atlanta's most prominent natural resource in the future. Conversations about the conservation and improvement of urban tree canopy need to highlight its cooling benefits as well. Researchers should continue evaluating current and future hardiness zone shifts to update ongoing species recommendations.

Appendix A. Comprehensive list of 110 tree species well-adapted to Atlanta's current and future climate (8a, 8b, 9a).

#	Common Name	Latin Name	Native?	Source
1	American Beech	*Fagus grandifolia*	Yes	City of Atlanta; UGA Extension
2	American Elderberry	*Sambucus canadensis*	Yes	Browns Mill
3	American Elm/ Princeton Elm	*Ulmus americana Princeton*	No	City of Atlanta; Trees Atlanta
4	American Hazelnut	*Corylus americana*	Yes	Browns Mill
5	American Holly	*Ilex opaca*	Yes	UGA Extension
6	American Hornbeam/ Ironwood/ Musclewood	*Carpinus caroliniana*	Yes	City of Atlanta; UGA Extension
7	Apple Serviceberry	*Amelanchier grandiflora*	No	Trees Atlanta
8	Arizona Cypress	*Cupressus arizonica/glabra*	No	Trees Atlanta
9	Ashe magnolia	*Magnolia ashei*	Yes	Trees Atlanta
10	Asian Pear	*Pyrus pyrifolia*	No	Browns Mill
11	Bald Cypress	*Taxodium distichum*	Yes	City of Atlanta; UGA Extension
12	Bamboo Leaf Oak	*Quercus myrsinifolia*	No	Trees Atlanta
13	Bitternut Hickory	*Carya cordiformis*	Yes	City of Atlanta; Trees Atlanta
14	Black Cherry	*Prunus serotina*	Yes	Trees Atlanta
15	Black Gum/ Tupelo	*Nyssa sylvatica*	Yes	City of Atlanta; UGA Extension
16	Black Oak	*Quercus velutina*	Yes	City of Atlanta; Trees Atlanta
17	Black Walnut	*Juglans nigra*	Yes	City of Atlanta; UGA Extension

#	Common Name	Latin Name	Native?	Source
18	Black Willow	*Salix Nigra*	Yes	City of Atlanta; Browns Mill
19	Bluejack Oak	*Quercus incana*	Yes	Trees Atlanta
20	Butterfly Magnolia	*Magnolia 'Butterflies'*	No	Trees Atlanta
21	Carolina Buckthorn	*Frangula caroliniana*	Yes	UGA Extension
22	Catalpa	*Catalpa bignonioides*	Yes	Trees Atlanta
23	Chestnut Oak	*Quercus prinus (Leucobalanus)*	Yes	City of Atlanta; UGA Extension
24	Chickasaw Plum	*Prunus angustifolia*	Yes	Trees Atlanta; Browns Mill
25	Chinese Elm	*Ulmus parvifolia*	No	Trees Atlanta
26	Chinese fringe tree	*Chionanthus retusus*	No	City of Atlanta; Trees Atlanta
27	Chinese pistache	*Pistacia chinensis*	No	Trees Atlanta
28	Common Fig	*Ficus carica*	No	Browns Mill
29	Common Hackberry	*Celtis occidentalis*	Yes	City of Atlanta
30	Crapemyrtle ('fauriei')	*Lagerstroemia fauriei*	No	City of Atlanta; Trees Atlanta
31	Crapemyrtle ('indica')	*Lagerstroemia indica*	No	Trees Atlanta
32	Dahoon Holly	*Ilex cassine*	Yes	Trees Atlanta
33	Devilwood	*Osmanthus americanus*	Yes	Trees Atlanta
34	Durand Oak	*Quercus durandii*	Yes	Trees Atlanta
35	Dwarf Chestnut Oak	*Quercus prinoides*	Yes	Trees Atlanta
36	Eastern Hop Hornbeam/ American Hop Hornbeam	*Ostrya virginiana*	Yes	City of Atlanta; Trees Atlanta

#	Common Name	Latin Name	Native?	Source
37	Eastern Mayhaw	*Crataegus aestivalis*	Yes	UGA Extension; Browns Mill
38	Eastern Red Cedar	*Juniperus virginiana*	Yes	City of Atlanta; UGA Extension; Browns Mill
39	Eastern Sweetshrub (Carolina Allspice, Sweet Shrub)	*Calycanthus floridus*	Yes	Browns Mill
40	Flatwoods Plum	*Prunus umbellata*	Yes	Browns Mill
41	Florida/ Southern Sugar Maple	*Acer barbatum*	Yes	City of Atlanta; UGA Extension
42	Flowering Dogwood	*Cornus florida*	Yes	City of Atlanta; UGA Extension
43	Foster Holly (also Savannah Holly)	*Ilex x attenuata*	No	City of Atlanta; Trees Atlanta; Browns Mill
44	Fringetree/ Grancy-Greybeard	*Chionanthus virginicus*	Yes	UGA Extension
45	Gala Apple Tree	*Malus domestica 'Gala'*	No	Trees Atlanta
46	Georgia Hackberry/ Dwarf Hackberry	*Celtis tenuifolia*	Yes	City of Atlanta
47	Golden Rain Tree	*Koelreuteria paniculata*	No	Trees Atlanta
48	Green Ash	*Fraxinus pennsylvanica*	Yes	UGA Extension
49	Hardy Pecan	*Carya illinoinensis*	No	City of Atlanta; Trees Atlanta
50	Japanese Cedar	*Cryptomeria japonica*	No	Trees Atlanta
51	Japanese Flowering Cherry 'Kanzan'	*Prunus 'Kanzan'*	No	Trees Atlanta
52	Japanese Snowbell	*Styrax japonicus*	No	Trees Atlanta
53	Kaki/ Japanese Persimmon	*Diospyros kaki*	No	Trees Atlanta; Browns Mill
54	Laurel Oak	*Quercus hemisphaerica (Erythrobalanus)*	Yes	UGA Extension

#	Common Name	Latin Name	Native?	Source
55	Live Oak	*Quercus virginiana (Erythrobalanus)*	Yes	UGA Extension
56	Loblolly Bay	*Gordonia lasianthus*	Yes	UGA Extension
57	Loblolly Pine	*Pinus taeda*	Yes	UGA Extension
58	Longleaf Pine	*Pinus palustris*	Yes	UGA Extension
59	Loquat	*Eriobotrya japonica*	No	Browns Mill
60	Magnolia ('Leonard Messel')	*Magnolia × loebneri 'Leonard Messel'*	No	Trees Atlanta
61	Mockernut Hickory	*Carya tomentosa*	Yes	City of Atlanta; UGA Extension
62	Myrtle Oak	*Quercus myrtifolia*	Yes	Trees Atlanta
63	Ogeeche-lime/ Ogeeche Tupelo	*Nyssa Ogeche*	Yes	Trees Atlanta
64	Osage Orange	*Maclura pomifera 'Whiteshield'*	No	City of Atlanta
65	Overcup Oak	*Quercus lyrata*	Yes	City of Atlanta; Trees Atlanta
66	Palmetto Palm/ Cabbage Palm	*Sabal palmetto*	Yes	UGA Extension
67	Parsley Hawthorn	*Crataegus marshallii*	Yes	UGA Extension; Browns Mill
68	Patriot Elm	*Ulmus 'Patriot'*	No	Trees Atlanta
69	Pawpaw	*Asimina triloba*	Yes	City of Atlanta; Trees Atlanta; Browns Mill
70	Persimmon (American Persimmon)	*Diospyros virginiana*	Yes	City of Atlanta; Trees Atlanta; Browns Mill
71	Pignut Hickory	*Carya glabra*	Yes	City of Atlanta; UGA Extension
72	Pineapple Guava (also Feijoa)	*Acca sellowiana*	No	Browns Mill

#	Common Name	Latin Name	Native?	Source
73	Pomegranate	*Punica granatum*	No	Browns Mill
74	Pondcypress/Pond Cypress	*Taxodium ascendens*	No	City of Atlanta; Trees Atlanta
75	Possumhaw	*Ilex decidua*	Yes	UGA Extension
76	Post Oak	*Quercus stellata (Leucobalanus)*	Yes	City of Atlanta; UGA Extension
77	Red Maple	*Acer rubrum*	Yes	City of Atlanta; UGA Extension
78	River Birch	*Betula nigra*	Yes	City of Atlanta; UGA Extension
79	Sand Hickory	*Carya pallida*	Yes	City of Atlanta
80	Sassafras	*Sassafras albidum*	Yes	City of Atlanta; Trees Atlanta; Browns Mill
81	Shortleaf Pine	*Pinus echinata*	Yes	UGA Extension
82	Shumard Oak	*Quercus shumardii (Erythrobalanus)*	Yes	City of Atlanta; UGA Extension
83	Slash Pine	*Pinus elliottii*	Yes	UGA Extension
84	Slippery Elm	*Ulmus rubra*	Yes	City of Atlanta
85	Sourwood	*Oxydendrum arboreum*	Yes	City of Atlanta; Trees Atlanta
86	Southern Crabapple	*Malus angustifolia*	Yes	Trees Atlanta
87	Southern Magnolia	*Magnolia grandiflora*	Yes	UGA Extension
88	Southern Red Oak/ Cherrybark	*Quercus falcata (Erythrobalanus)*	Yes	City of Atlanta; UGA Extension
89	Spicebush	*Lindera benzoin*	Yes	Browns Mill
90	Spruce Pine	*Pinus glabra*	Yes	UGA Extension
91	Stellar Pink Dogwood	*Cornus rutgan*	No	Trees Atlanta

#	Common Name	Latin Name	Native?	Source
92	Sugarberry	*Celtis laevigata*	Yes	City of Atlanta; UGA Extension; Browns Mill
93	Swamp Chestnut Oak/Basket Oak	*Quercus michauxii (Leucobalanus)*	Yes	City of Atlanta; UGA Extension
94	Swamp/Stiff Dogwood	*Cornus foemina*	Yes	City of Atlanta
95	Sweet Bay Magnolia	*Magnolia virginiana*	Yes	City of Atlanta; Trees Atlanta
96	Sweetgum	*Liquidambar styraciflua*	Yes	City of Atlanta; UGA Extension
97	Sycamore	*Platanus occidentalis*	Yes	City of Atlanta; UGA Extension
98	Trident Maple	*Acer buergeranum*	No	City of Atlanta; Trees Atlanta
99	Tulip/Yellow Poplar	*Liriodendron tulipifera*	Yes	City of Atlanta; UGA Extension
100	Water Hickory	*Carya aquatica*	Yes	City of Atlanta; Trees Atlanta
101	Water Oak	*Quercus nigra (Erythrobalanus)*	Yes	UGA Extension
102	Water Tupelo	*Nyssa aquatica*	Yes	City of Atlanta
103	Western Soapberry	*Sapindus drummondii*	Yes	Trees Atlanta
104	White Ash	*Fraxinus americana*	Yes	UGA Extension
105	White Oak	*Quercus alba (Leucobalanus)*	Yes	City of Atlanta; UGA Extension
106	Willow Oak	*Quercus phellos (Erythrobalanus)*	Yes	City of Atlanta; UGA Extension
107	Windmill Palm	*Trachycarpus fortunei*	No	Trees Atlanta
108	Winged Elm	*Ulmus alata*	Yes	City of Atlanta; Trees Atlanta
109	Winged Sumac	*Rhus copallinum*	Yes	Browns Mill
110	Yaupon Holly	*Ilex vomitor*	Yes	City of Atlanta; UGA Extension

Appendix B. Studied tree species that do *not* fit the suitable hardiness zonal range criteria (8a, 8b, 9a)

#	Common Name	Latin Name	Native?	Source
1	Allegheny Serviceberry	*Amelanchier laevis*	Yes	Trees Atlanta
2	American Linden/ Basswood	*Tilia americana*	Yes	City of Atlanta, Trees Atlanta
3	American Smoke Tree	*Cotinus obovatus*	Yes	Trees Atlanta
4	American Yellowwood	*Cladrastis kentukea*	Yes	City of Atlanta, UGA Extension
5	Big-Leaf Magnolia	*Magnolia macrophylla*	Yes	City of Atlanta, UGA Extension
6	Bottlebrush Buckeye	*Aesculus parviflora*	Yes	Trees Atlanta
7	Bur Oak	*Quercus macrocarpa*	No	Trees Atlanta
8	Butter nut	*Juglans cinerea*	No	Trees Atlanta
9	Callaway Crabapple	*Malus 'Callaway'*	Yes	Trees Atlanta
10	Carolina Silverbell	*Halesia tetraptera*	Yes	City of Atlanta, UGA Extension
11	Chalk Maple	*Acer leucoderme*	Yes	City of Atlanta, Trees Atlanta
12	Chinese Chestnut	*Castanea mollissima*	No	Browns Mill
13	Chinkapin Oak	*Quercus muehlenbergii*	Yes	City of Atlanta, Trees Atlanta
14	Common Beech	*Fagus sylvatica*	No	Trees Atlanta
15	Common Pear (also Wild Pear, European Pear)	*Pyrus communis*	No	Trees Atlanta, Browns Mill
16	Cornelian Cherry Dogwood	*Cornus mas*	No	Trees Atlanta
17	Dawn Redwood	*Metasequoia glyptostroboides*	No	City of Atlanta, Trees Atlanta

#	Common Name	Latin Name	Native?	Source
18	Deodar Cedar	*Cedrus deodara*	No	City of Atlanta, Trees Atlanta
19	Downy Serviceberry	*Amelanchier arborea*	Yes	City of Atlanta, UGA Extension
20	Eastern Hemlock	*Tsuga canadensis*	Yes	UGA Extension
21	Eastern Redbud	*Cercis canadensis*	Yes	City of Atlanta, UGA Extension
22	English Oak	*Quercus robur*	No	City of Atlanta
23	European Hornbeam/ Common Hornbeam	*Carpinus betulus 'Fastigiata'*	No	City of Atlanta
24	Flowering Crabapple	*Malus 'Purple Prince'*	No	Trees Atlanta
25	Flowering Crabapple	*Malus 'Sutyzam'*	No	Trees Atlanta
26	Fragrant Olive	*Osmanthus fragrans*	No	Trees Atlanta
27	Fragrant Snowbell	*Styrax obassia*	No	Trees Atlanta
28	Franklin tree	*Franklinia alatamaha*	Yes	Trees Atlanta
29	Freeman's Maple	*Acer Freemanii (Autumn Blaze)*	No	Trees Atlanta
30	Fuji Apple Tree	*Malus Domestica 'Fuji'*	No	Trees Atlanta
31	Georgia Oak	*Quercus georgiana*	Yes	City of Atlanta, Trees Atlanta
32	Green Hawthorn	*Crataegus viridis*	Yes	Trees Atlanta
33	Higan Cherry	*Prunus subhirtella Autumnalis*	No	Trees Atlanta
34	Honey Locust	*Gleditsia triacanthos*	Yes	Trees Atlanta
35	Japanese Arborvitae	*Thuja standishii*	No	Trees Atlanta
36	Japanese Flowering Cherry	*Prunus serrulata*	No	Trees Atlanta

#	Common Name	Latin Name	Native?	Source
37	Japanese Maple	*Acer palmatum cvs*	No	City of Atlanta
38	Japanese Plum	*Prunus salicina*	No	Trees Atlanta
39	Japanese Zelkova	*Zelkova serrulata*	No	Trees Atlanta
40	Katsura Tree	*Cercidiphyllum japonicum*	No	Trees Atlanta
41	Kentucky coffee tree	*Gymnocladus dioica*	No	Trees Atlanta
42	Kousa Dogwood	*Cornus kousa*	No	City of Atlanta, Trees Atlanta
43	Littleleaf Linden	*Tilia cordata*	No	Trees Atlanta
44	Lois Magnolia	*Magnolia 'Lois'*	No	Trees Atlanta
45	Maidenhair Tree	*Ginkgo biloba*	No	City of Atlanta, Trees Atlanta
46	Mexican Plum	*Prunus mexicana*	No	Browns Mill
47	Nectarine	*Prunus persica*	No	Browns Mill
48	Northern Red Oak	*Quercus rubra (Erythrobalanus)*	Yes	City of Atlanta, UGA Extension
49	Nuttall Oak	*Quercus nuttallii*	Yes	City of Atlanta, Trees Atlanta
50	Oglethorpe Oak	*Quercus oglethorpensis*	Yes	City of Atlanta, Trees Atlanta
51	Ohio Buckeye	*Aesculus glabra*	No	Trees Atlanta
52	Pagodatree	*Styphnolobium japonica*	No	City of Atlanta
53	Paperbark Maple	*Acer griseum*	No	Trees Atlanta
54	Persian Ironwood	*Parrotia persica*	No	City of Atlanta, Trees Atlanta
55	Red Buckeye	*Aesculus pavia*	Yes	City of Atlanta, Trees Atlanta

#	Common Name	Latin Name	Native?	Source
56	Red Mulberry	*Morus rubra*	Yes	City of Atlanta
57	Sargent Crabapple	*Malus sargentii*	No	Trees Atlanta
58	Saucer Magnolia	*Magnolia x soulangiana*	No	City of Atlanta, Trees Atlanta
59	Scarlet Oak	*Quercus coccinea (Erythrobalanus)*	Yes	City of Atlanta, UGA Extension
60	Serviceberry	*Amelanchier canadensis*	Yes	Trees Atlanta, Browns Mill
61	Shagbark Hickory	*Carya ovata*	Yes	City of Atlanta, UGA Extension
62	Shantung Maple	*Acer truncatum*	No	Trees Atlanta
63	Shingle Oak	*Quercus imbricaria*	No	Trees Atlanta
64	Silky Dogwood	*Cornus amomum*	Yes	Browns Mill
65	Southern Shagbark Hickory	*Carya ovata var.australis*	Yes	City of Atlanta
66	Star Magnolia	*Magnolia stellata*	No	Trees Atlanta
67	Sugar Maple	*Acer saccharum*	Yes	UGA Extension
68	Swamp White Oak	*Quercus bicolor*	No	City of Atlanta, Trees Atlanta
69	Sweet Cherry	*Prunus avium*	No	Browns Mill
70	Three-Flowered Maple	*Acer triflorum*	No	Trees Atlanta
71	Two-Winged Silverbell	*Halesia diptera*	Yes	UGA Extension
72	Virginia Pine	*Pinus virginiana*	Yes	City of Atlanta, UGA Extension
73	Washington Hawthorn	*Crataegus phaenopyrum*	Yes	UGA Extension
74	Weeping Willow	*Salix babylonica*	No	Trees Atlanta

#	Common Name	Latin Name	Native?	Source
75	Western Mayhaw	*Crataegus opaca*	No	Browns Mill
76	White Pine	*Pinus strobus*	Yes	UGA Extension
77	White Poplar	*Populus alba*	No	City of Atlanta
78	Wild Plum (American Plum)	*Prunus americana*	Yes	Trees Atlanta
79	Yellow Bird Magnolia	*Magnolia × brooklynensis 'Yellow Bird'*	No	Trees Atlanta
80	Yellow Buckeye	*Aesculus flava/Aesculus Octandra*	Yes	UGA Extension
81	Yellow Lantern Magnolia	*Magnolia Yellow Lantern*	No	Trees Atlanta
82	Yoshino Cherry	*Prunus x yedoensis*	No	Trees Atlanta

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