Boston Region: Tree Species Vulnerability Assessment

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Abstract

As the climate changes over the 21st century, the urban forest in the Boston region will be impacted by changing temperatures and precipitation regimes. This shift in climate will impact tree species differently, and has the potential to compromise the ecosystem services provided by the urban forest. This report summarizes mid- and end-of-century climate change projections for the Boston region and provides an assessment of tree species vulnerability in the region, as well as human health considerations related to the urban forest.

We used projected shifts in plant hardiness and heat zones to understand how species of interest are projected to tolerate future conditions. We also assessed the adaptability of existing trees to stressors such as drought, flooding, wind damage, and air pollution, as well as environmental conditions such as shade, soils, and restricted rooting. The region has been warming at a rate of about 0.70 °F per decade since 1960. The average annual temperature is projected to increase by 5.3 °F to 9.3 °F by the end of the century compared to the 1971-2000 historical average.

Precipitation in the region has been increasing by 0.74 inches per decade since 1960. Average annual precipitation is projected to increase by 3.9 to 5.4 inches by the end of the century compared to the 1971-2000 historical average. Depending on the Representative Concentration Pathway (RCP) trajectory (which corresponds with global greenhouse gas emission concentrations), the Boston region is projected to shift from hardiness zone 7 to zones 8 (RCP4.5) or 9 (RCP8.5), and from heat zone 4 to heat zones 6 (RCP4.5) or 8 (RCP8.5) by the end of the century

Of the evaluated tree species in the Boston region, 32% received a high adaptability score, 51% received a medium adaptability score, and 17% received a low adaptability score. Considering both heat and hardiness zones, under a low climate change scenario, the majority of tree species assessed fall into the low-moderate vulnerability category (47.5%), followed by low vulnerability (31.5%), moderate (13.6%), moderate-high (3%), and high (3%). Under a high climate change scenario, the majority of trees species assessed fall into the moderate-high (27.8%) and moderate (27.8%) vulnerability categories, followed by low-moderate (22.8%), low (12.4%), and high (8%). The vulnerability ratings are different between low and high climate change scenarios because the projected heat and hardiness zones are different under both scenarios through the end of the century.

Human health considerations, including an overview of extreme heat and air quality, and species-specific scores for carbon benefits, and human health benefits and disservices, are also included. Management considerations and related resources are provided in the final section. These projected changes in climate and their associated impacts and vulnerabilities will have important implications for urban forest management, including the planting and maintenance of street and park trees, equity and environmental justice efforts, and long-term planning from partnerships to green infrastructure.

Preface

Context, Scope, and Goals

This assessment is a fundamental component of the Urban Forestry Climate Change Response Framework project (www.forestadaptation.org/urban). This project incorporates lessons learned from the Climate Change Response Framework: a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management. The Boston Tree Species Vulnerability Assessment serves as a simplified version of previous urban climate vulnerability assessments (Brandt et al. 2017 and Brandt et al. 2020). It uses methods developed in the Chicago Wilderness region pilot (Brandt et al. 2017) and Vulnerability Assessment of Austin's Urban Forest and Natural Areas (Brandt et al. 2020), and includes three main three components: climate observations and projections, tree species climate vulnerability and adaptability, and human health considerations related to the urban forest of the Boston region. For the purposes of this assessment, we define the Boston Region as the urban and peri-urban areas including and surrounding the City of Boston, extending approximately 25 miles in a radial fashion from the center of the downtown area. We define the urban forest as all publicly and privately-owned trees within an urban area—including individual trees along streets and in backyards, as well as forested parks and natural areas. The 161 assessed species include those that are most abundant and/or commonly planted in Boston, as well as a variety of species that are recommended for urban environments in Massachusetts

We designed the assessment to be a synthesis of the best available scientific information on tree species in the region or under consideration for planting. The primary goal of this report is to inform those that work, study, recreate, and care about the urban forests and natural areas in the Boston region to ensure that urban forests will continue to provide benefits to the people who live in urban communities as the climate changes, especially frontline communities who are disproportionately burdened by rising temperatures and reduced air quality. As new scientific information arises, we expect that efforts will need to be undertaken to reflect that acquired knowledge and understanding. Most importantly, this assessment does not make recommendations about how this information should be used.

Author Contributions and Acknowledgements

Climate Adaptation Specialists with the Northern Institute of Applied Climate Science led the project. Madeline Baroli developed the tree species list and conducted the assessment, and wrote the final report, with substantial assistance from Annamarie Rutledge. The assessment builds on Leslie Brandt's previous work. Brandt provided professional guidance and developed the assessment methodology, including the tree species vulnerability report structure.

We wish to thank the individuals from Boston private, nonprofit, academic, and governmental organizations who attended our presentation and provided feedback on the tree species vulnerability section of this report. We also wish to thank Jack Schleifer of The Emerald Necklace Conservancy and Patricia Leopold of the USDA Forest Service, State, Private, and Tribal Forestry organization for serving as technical reviewers. The Tree Species Vulnerability assessment was developed with support from the Fidelity Foundation in collaboration with American Forests and is part of a suite of tools and activities that will help advance and celebrate Tree Equity in the Boston region.

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Executive Summary

This assessment evaluates the vulnerability of urban trees and forests in the Boston region to a range of future climate scenarios. It is part of the Urban Forestry Climate Change Response Framework project, a collaborative approach among researchers, managers, and landowners to incorporate climate change considerations into urban forest management.

The assessment identifies past and projected trends in climate and provides an analysis of the climate vulnerability and adaptability of tree species identified as present in or relevant to the Boston region. It also includes an overview of human health considerations related to the urban forest, and an analysis of carbon benefits, health services and disservices for each tree species. This information, along with local knowledge and expertise, can be used to better understand urban forest vulnerability and inform adaptation actions for the Boston region.

CHAPTER 1: Climate Trends and Projections

Summary

This chapter includes past observations and projected future changes in climate in the Boston region. It examines how climate may change over the next century using two models representing a range of possible futures that are downscaled in order to be relevant to local decision making.

Key Points

- Annual mean temperature is projected to increase by 5.3 °F by the end of the century under a *low* climate change scenario, and by as much as 9.3 °F by the end of the century under a *high* climate change scenario.

- Days with a heat index equal to or greater than 90 degrees are projected to increase from the historical value of about 14 days a year, to 42 days a year under a *low* climate change scenario, and up to 70 days a year under a *high* climate change scenario.

- Rises in temperature may lead to a shift of one to two hardiness zones and two to five heat zones.

- While annual precipitation is projected to increase under both low and high climate change scenarios, precipitation is likely to decrease in the summer through the end of the century, and increase in the fall, winter and spring seasons.

- Accelerating sea level rise along the Northeast Atlantic coast is projected to rise between 2 feet and 4.5 feet (0.6 m and 1.4 m) on average in the region by 2100. This will result in inundation in some areas and make coastal flooding more frequent and severe.

CHAPTER 2: Tree Species Vulnerability & Adaptability

Summary

This chapter synthesizes the potential impacts of climate change on urban forests in the Boston region, with an emphasis on changes in habitat suitability and the adaptive capacity of different species.

Key Points

- The adaptive capacity of 161 species was evaluated using a scoring system for planted environments, with the majority of assessed species (82 species, 51%) found to have moderate adaptability, followed by 52 species (32%) found to have high adaptability, and 27 species (17%) found to have low adaptability.

- An analysis of vulnerability that combines model projections, shifts in hardiness and heat zones, and adaptive capacity showed that only 10 tree species are moderately-high to highly vulnerable under a low climate change scenario. 58 tree species are moderately-high to highly vulnerable under a high climate change scenario.

CHAPTER 3: Human Health & Management Considerations

Summary

This chapter provides a brief overview of the intersection between urban forests and human health. It examines the relationship between tree canopy, extreme heat, and air quality in Boston, with an emphasis on environmental justice. An analysis of carbon benefits, health benefits and disservices, is included, as well as further information and resources for management.

Key Points

- There are substantial disparities between Boston neighborhoods in terms of tree cover and overall Urban Heat Island Index (UHII) values, and high risk of heat-related illness in dense and developed areas with little to no canopy.

- Urban greening can be used as both a heat and pollution-mitigation approach, in addition to supporting mental health and social well-being.

- Trees improve air quality by reducing the amount of respiratory irritants in the air, but planting decisions should consider that some species can also exacerbate respiratory issues based on their production of pollen and volatile organic compounds.

- Leaf area index and allergenicity ratings, as well as overall ratings for carbon benefits, health benefits, and health disservices are provided for the 161 assessed tree species.

- This assessment is not intended to serve as a recommended planting guide and does not provide management recommendations. Rather, it emphasizes that urban forest management in a changing climate should account for both the vulnerability and adaptive capacity of tree species, and encompass ecological, organizational, economic, and social considerations.

Climate Observations & Projections

Climate, the average weather over a long-term period for a particular location, can change substantially on the scale of thousands of years. Precipitation and temperature are changing at a global scale and the rate is projected to increase in the coming decades. However, these changes will impact different areas in different ways and these changes are best summarized at a local level for informed decision-making. To assist in evaluating these local changes, this section summarizes past and projected changes in precipitation and temperature in the Boston region.

Observed Climate Trends

Historical climate trends were retrieved from the National Oceanic and Atmospheric Administration's (NOAA) Climate at a Glance tool (NOAA, 2022). Climate at a Glance was developed to facilitate near real-time analysis of monthly temperature and precipitation data across the contiguous U.S. and intended for the study of climate variability and change.

Observed Precipitation Trends

Annual precipitation in Boston has increased by 0.74 inches per decade since 1960 (Figure 1; NOAA, 2022). This trend varies by season. Precipitation has increased the greatest in March-May (+0.12 inches/decade) followed by June-August (+0.9inches/decade). Precipitation has increased by +0.05 inches per decade from September to November, and +0.04 inches per decade from December to February.

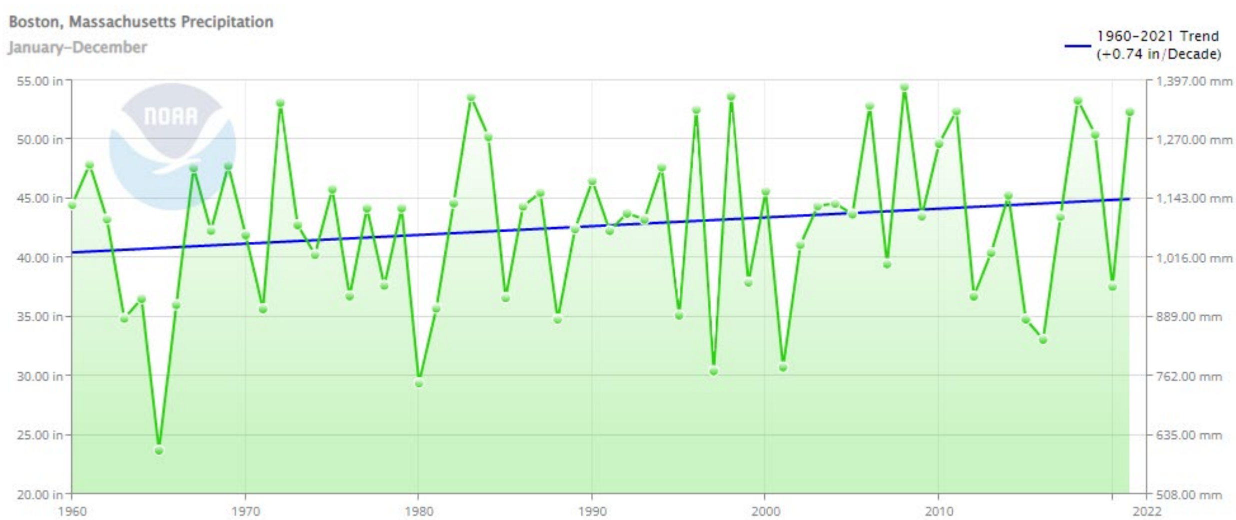
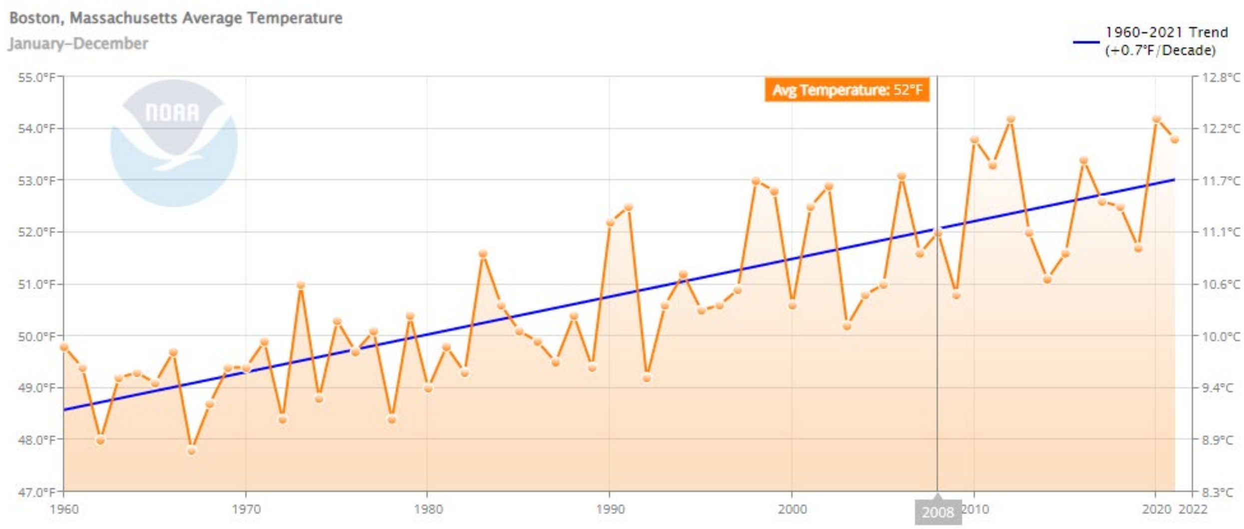
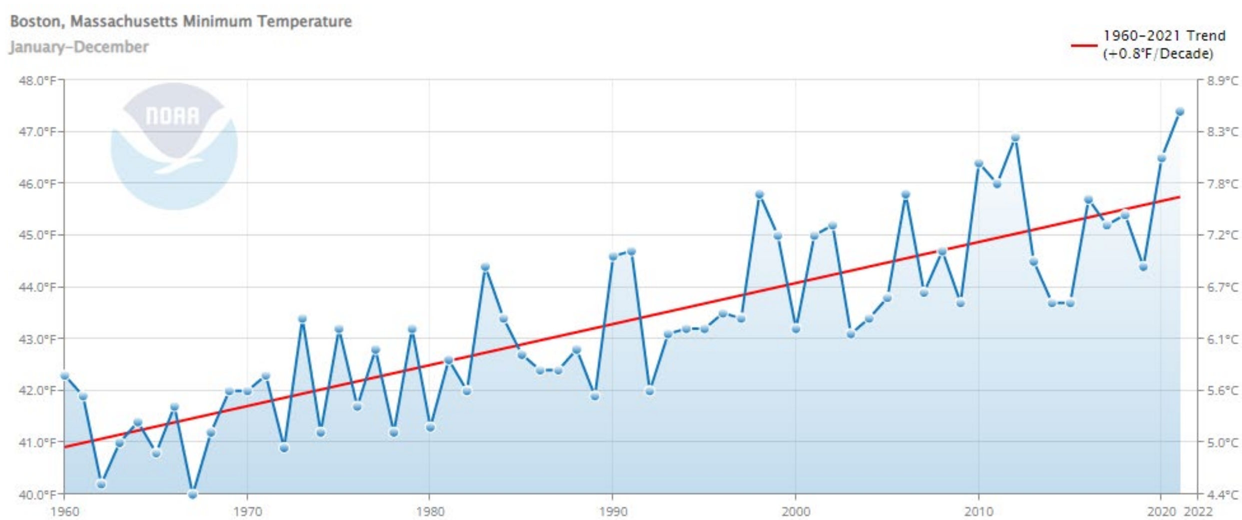


Figure 1.—Changes in annual precipitation over the observational record from 1960 to 2021 for Boston, Massachusetts including average, minimum, and maximum temperatures January - December. The gray line indicates the 1960-1990 average and the blue line shows the trend over the observational record (NOAA, 2022).

Observed Temperature Trends

The average annual temperature in Boston has increased by 0.7 °F per decade since 1960. The average annual minimum (+0.8 °F/decade) and maximum (+0.7 °F) temperatures follow a similar trend (Figure 2; NOAA, 2022). The trend varies by season, increasing the most in December-January (+0.58 °F/decade), followed by March-May (+0.40 °F/decade). Temperature has increased by 0.37 °F per decade from June to August, and 0.34 °F per decade from September-November.





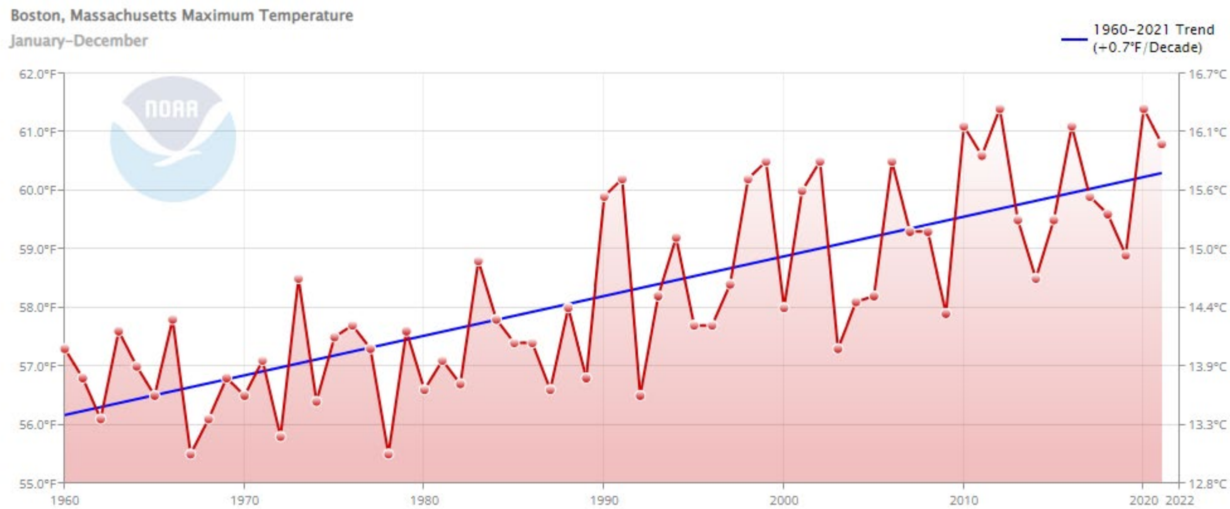


Figure 2.—Changes in annual temperature over the observational record from 1960 to 2021 for Boston, Massachusetts, including average, minimum, and maximum temperatures from January - December. The grey line indicates the 1960-1990 average and the blue line shows the trend over the observational record (NOAA, 2022).

Observed Sea-Level Rise Trends

The sea level along the coastline of Boston has risen by about 10 inches of over the last 92 years of records, with about 8 of those inches of rise occurring since 1950. The rate of rise has been accelerating over the last ten years, and is now rising by about 1 inch every 8 years (Surging Seas, Climate Central 2022). Changes in ocean circulation and ice melt, which has been increasing significantly since 1992, are the main drivers of the rising sea levels along Massachusetts' coast.

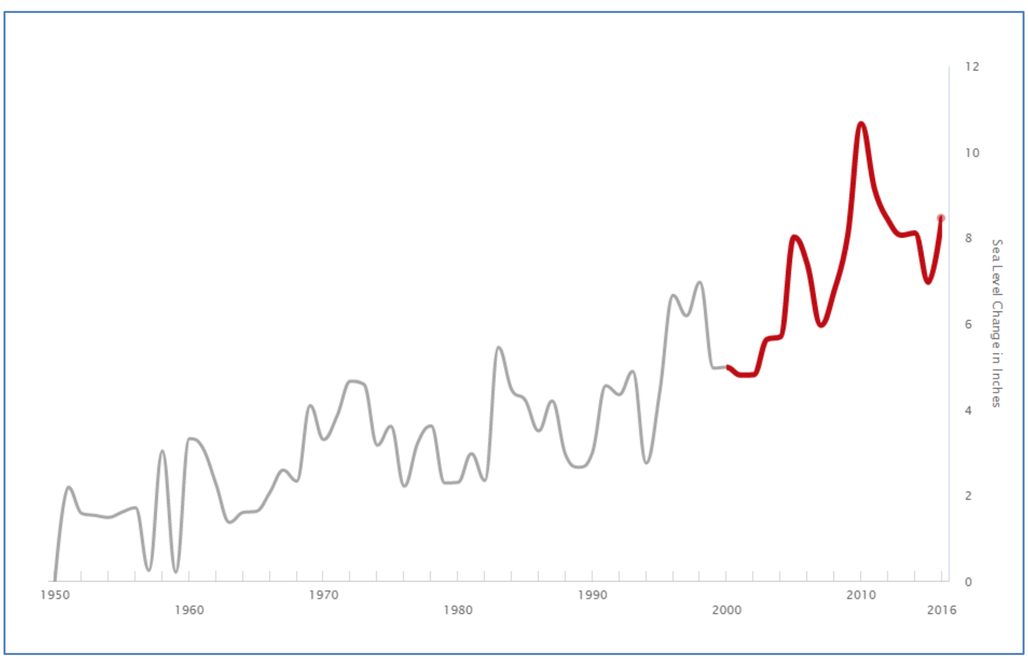
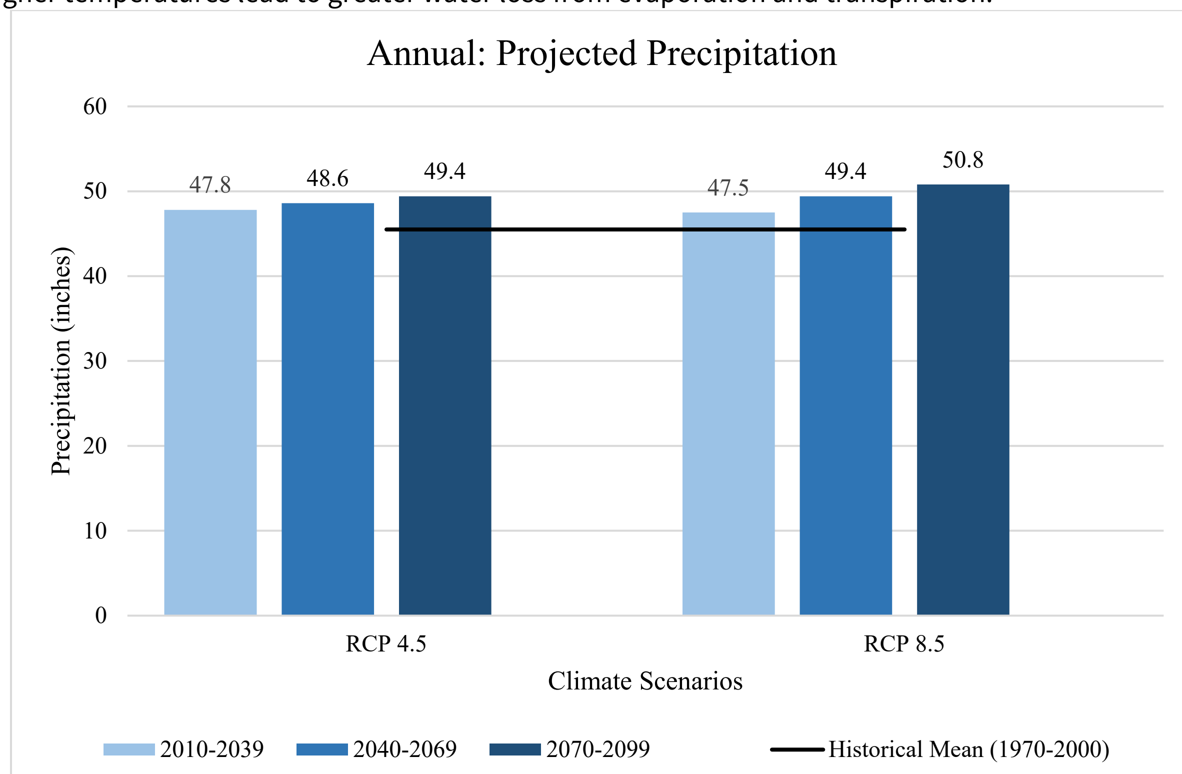


Figure 3.—Sea level measurement from the Boston Area Tide Gauge since 1950 (NOAA Tide Predictions and Data, 2022). The red section of the line highlights the acceleration in sea level rise since the year 2000.

Precipitation Projections

Precipitation is projected to increase under both the low Representative Concentration Pathway (RCP 4.5) and high Representative Concentration Pathway (RCP 8.5) climate change scenarios through the end of the century in all seasons (Figure 3). Annual precipitation is projected to increase by 3.9 inches by the end of the century under a *low* climate change scenario, and by as much as 5.4 inches by the end of the century under a *high* climate change scenario.

The greatest precipitation increases are expected to occur during the winter, when warmer temperatures will result in more winter precipitation falling as rain instead of snow. There is greater uncertainty whether precipitation may increase or decrease during the growing season. Even with moderate precipitation increases, there may be greater moisture-stress in summer or fall because higher temperatures lead to greater water loss from evaporation and transpiration.



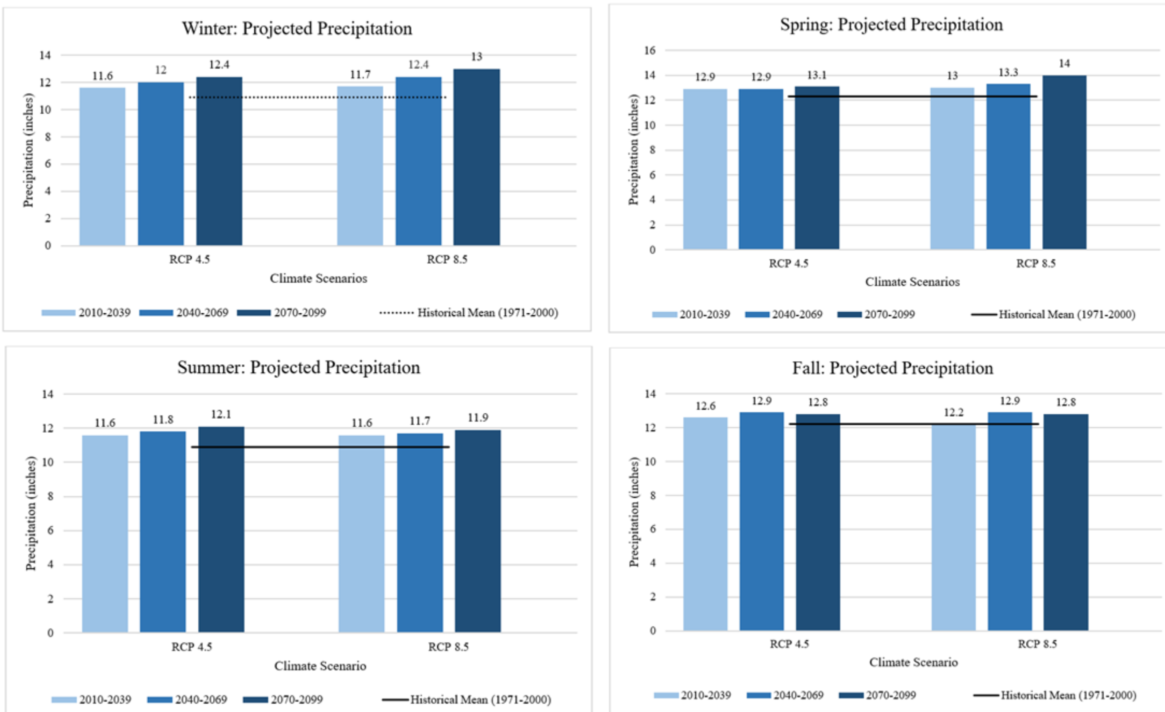


Figure 4. —Projected precipitation in the Boston region under RCP 4.5 and RCP 8.5 climate change scenarios.

Temperature Projections

Mean, minimum, and maximum temperature is projected to increase under both low (RCP 4.5) and high (RCP 8.5) climate change scenarios in every season through the end of the century (Table 1). Annual mean temperature is projected to increase by 5.3 °F by the end of the century under a *low* climate change scenario, and by as much as 9.3 °F by the end of the century under a *high* climate change scenario. Days with a Heat Index ≥90 °F are expected to increase to a total of approximately 42 days per year by the end of the century under a *low* climate change scenario, and up to 70 days per year under a *high* climate change scenario. The Heat Index, also known as the apparent temperature, refers to what the temperature feels like to the human body when relative humidity is combined with the air temperature

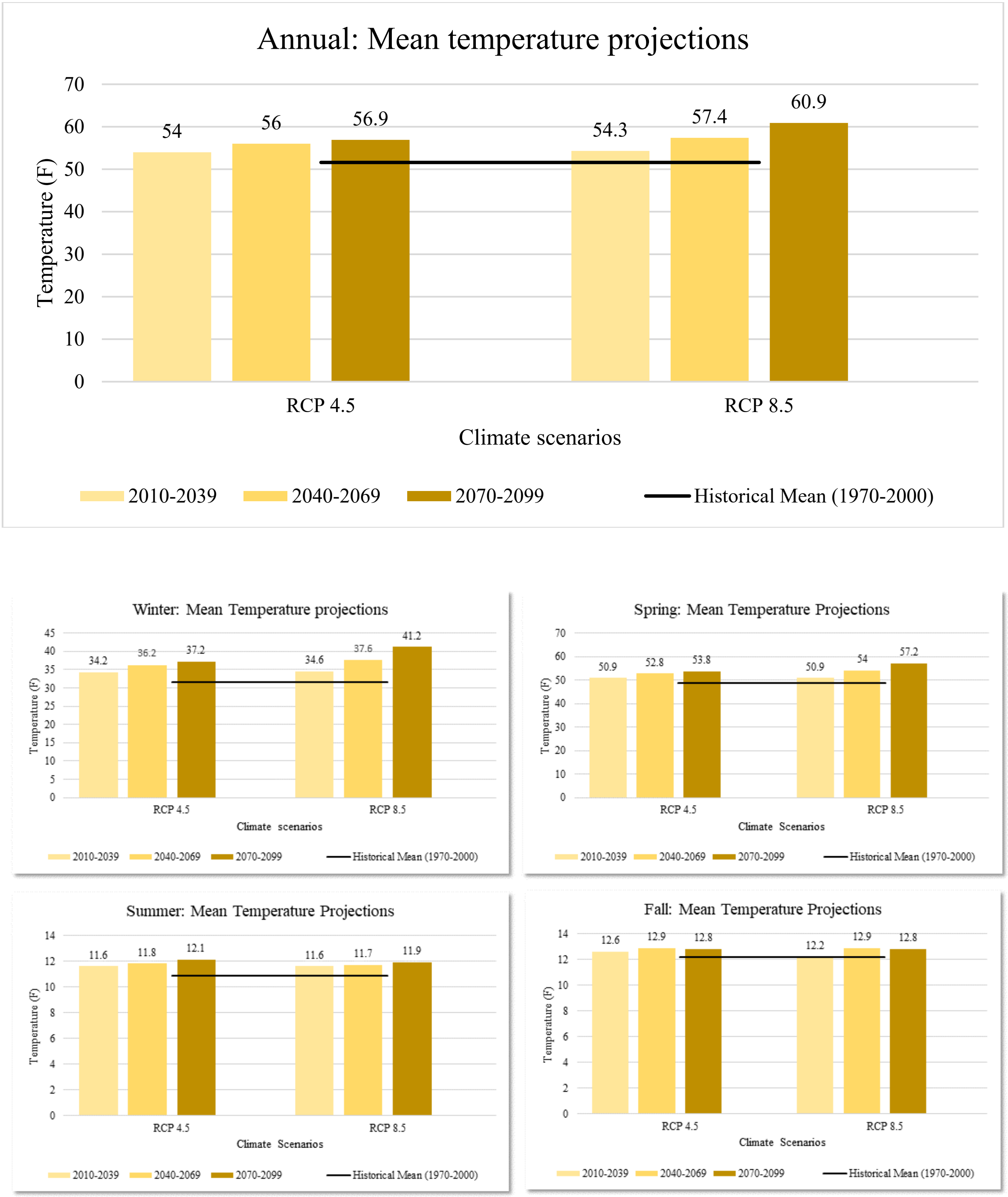
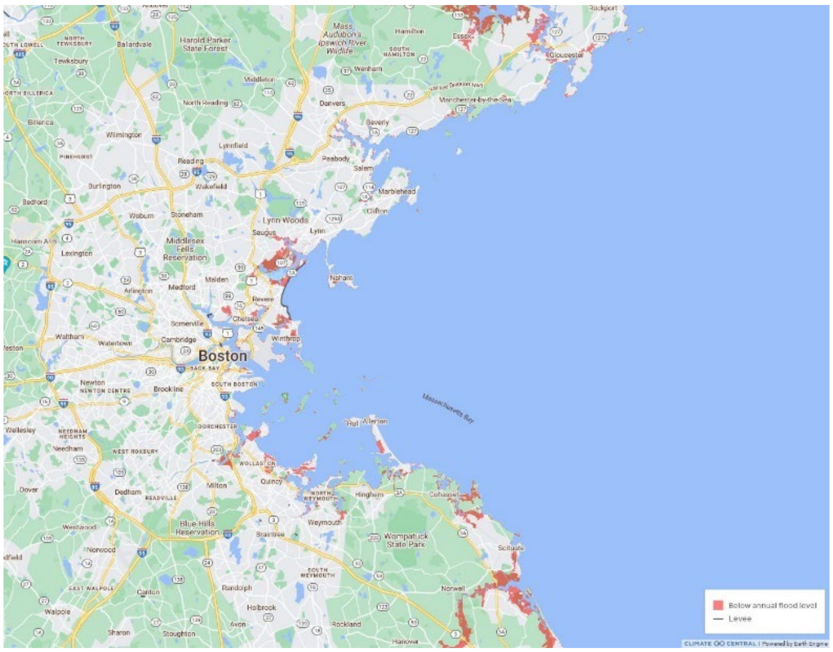


Figure 6. —Projected temperature in the Boston Region under RCP 4.5 and RCP 8.5 climate change scenarios.

Sea-Level Rise Projections

All global climate models agree that sea level will continue to rise over the next century. Under the most probable scenarios, sea levels along the Northeast Atlantic coast are projected to rise between 2 feet and 4.5 feet (0.6 m and 1.4 m) on average in the region by 2100 (Dupigny-Giroux 2018). This will make coastal floods more frequent and severe by raising the starting point for storm surges and high tides. Shorter-term fluctuations in the variability of ocean dynamics, atmospheric shifts, and ice mass loss from Greenland and Antarctica have been connected to recent accelerations in the sea level rise rate in this region. Worst-case and lowest-probability scenarios project that sea levels in the region could rise upwards of 11 feet (3 m) on average by the end of the century.

Sea level rise may have varying impacts on different locations along the coast; rocky, heavily developed areas and low-elevation areas will become gradually inundated, whereas more dynamic environments, such as mainland and barrier beaches, bluffs, and coastal wetlands, are likely to migrate landward, narrow, or erode.



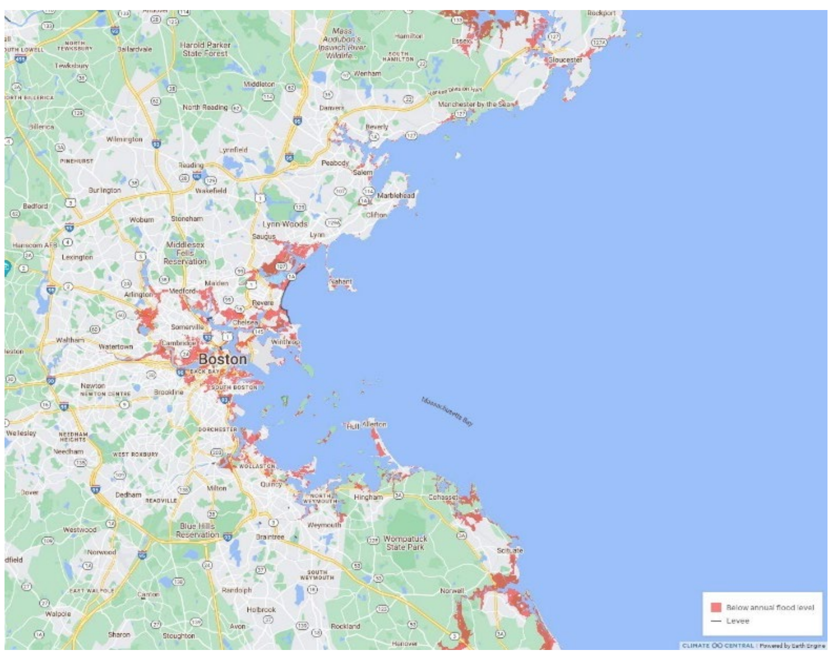


Figure 5.—Land projected to be below annual flood level in 2050 (left) and 2090 (right) based on NOAA's "Intermediate" sea level rise scenario, in which the global average sea level rises 3.3 feet (1 meter) by 2100. This sea level increase best corresponds with 5 °C of global warming by 2100, consistent with the very high emissions scenario designated as SSP5-8.5 by the IPCC, in which global net carbon emissions rise continually through 2080 before leveling off. Both maps exclude all potentially protected areas, which are areas that are projected below water level, but would potentially be protected by levees, natural ridges, or other features.

Table 1. —Precipitation and temperature projections for the Boston Region under RCP 4.5 and RCP 8.5 climate change scenarios. Values indicate the multi-model mean derived from 20 downscaled CMIP5 models. Data retrieved from https://climatetoolbox.org/tool/climate-mapper

Precipitation (inches)							
	2010-2039		**2040-2069**		**2070-2099**		**Historical Average**
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**1971-2000**
Annual	48.7 (+2.3)	48.5 (+2.1)	49.5 (+3.1)	50.4 (+4)	50.3 (+3.9)	51.8 (+5.4)	46.4
Winter (Dec - Feb)	11.6 (+0.7)	11.7 (+0.8)	12 (+1.1)	12.4 (+1.5)	12.4 (+1.5)	13 (+2.1)	10.9
Spring (Mar-May)	12.9 (+0.6)	13 (+0.7)	12.9 (+0.6)	13.3 (+1.0)	13.1 (+0.8)	14 (+1.7)	12.3
Summer (June - Aug)	11.6 (+0.7)	11.6 (+0.7)	11.8 (+0.9)	11.7 (+0.8)	12.1 (+1.2)	11.9 (+1)	10.9
Fall (Sept - Nov)	12.6 (+0.4)	12.2 (+-0)	12.9 (+0.7)	12.9 (+0.7)	12.8 (+0.6)	12.8 (+0.6)	12.2

Mean Temperature (°F)							
	2010-2039		**2040-2069**		**2070-2099**		**Historical Average**
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**1971-2000**
Annual	54 (+2.4)	54.3 (+2.7)	56 (+4.4)	57.4 (+5.8)	56.9 (+5.3)	60.9 (+9.3)	51.6
Winter (Dec - Feb)	34.2 (+2.6)	34.6 (+3)	36.2 (+4.6)	37.6 (+6)	37.2 (+5.6)	41.2 (+9.6)	31.6
Spring (Mar-May)	50.9 (+2.2)	50.9 (+2.2)	52.8 (+4.1)	54 (+5.3)	53.8 (+5.1)	57.2 (+8.5)	48.7
Summer (June - Aug)	73.5 (+2.3)	73.8 (+2.6)	75.4 (+4.2)	77.1 (+5.9)	76.3 (+5.1)	80.6 (+9.4)	71.2

Fall (Sept - Nov)	56.5 (+1.5)	56.7 (+1.7)	58.3 (+4.3)	59.7 (+5.7)	59.3 (+5.3)	63.4 (+9.4)	54

Minimum Temperature (°F)							
	2010-2039		**2040-2069**		**2070-2099**		**Historical Average**
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**1971-2000**
Annual	45.7 (+2.4)	46 (+2.7)	47.7 (+3.4)	49.1 (+5.8)	48.7 (+5.4)	52.7 (+9.4)	43.3
Winter (Dec - Feb)	26.9 (+2.8)	27.4 (+3.3)	29.2 (+5.1)	30.7 (+6.6)	30.2 (+6.1)	34.5 (+10.4)	24.1
Spring (Mar-May)	42.7 (+2.3)	42.7 (+2.3)	44.5 (+4.1)	45.7 (+5.3)	45.5 (+5.1)	49 (+8.6)	40.4
Summer (June - Aug)	64.9 (+2.3)	65.2 (+2.6)	66.8 (+4.2)	68.4 (+5.8)	67.7 (+5.1)	71.9 (+9.3)	62.6
Fall (Sept - Nov)	48.5 (+2.5)	48.7 (+2.7)	50.3 (+4.3)	51.7 (+5.7)	51.2 (+5.2)	55.5 (+9.5)	46

Maximum Temperature (°F)							
	2010-2039		**2040-2069**		**2070-2099**		**Historical Average**
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**1971-2000**
Annual	61.8 (+2.4)	62 (+2.6)	63.7 (+4.3)	65.1 (+5.7)	64.6 (+5.2)	68.5 (+9.1)	59.4
Winter (Dec - Feb)	41.1 (+2.1)	41.8 (+2.8)	43.3 (+4.3)	44.6 (+5.6)	44.1 (+5.1)	47.8 (+8.8)	39
Spring (Mar-May)	59.1 (+2.2)	59.1 (+2.2)	61 (+4.1)	62.3 (+5.4)	62.1 (+5.2)	65.4 (+8.5)	56.9
Summer (June - Aug)	82.1 (+2.4)	82.3 (+2.6)	84.1 (+4.4)	85.8 (+6.1)	85 (+5.3)	89.3 (+9.6)	79.7
Fall (Sept - Nov)	64.6 (+2.6)	64.8 (+2.2)	66.3 (+4.3)	67.8 (+5.8)	67.3 (+5.3)	71.4 (+9.4)	62

Days with Heat Index ≥ 90 °F							
	2010-2039		2040-2069		2070-2099		Historical Average
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	1971-2000
Annual	24.8 (+11.1)	26.6 (+12.9)	35.8 (+22.1)	46.5 (+32.8)	42.4 (+28.7)	70.4 (+56.7)	13.7

Tree Species Vulnerability & Adaptability

Changes in climate have the potential to profoundly affect trees in the Boston region. Some tree species that are currently present may experience declines in habitat suitability under warmer temperatures and altered precipitation patterns. Other tree species may be less vulnerable to these conditions. Some species not currently present could potentially be planted in the area as hardiness zones shift with milder winters. Climate change can also have indirect effects on the urban forests in the region by changing insect pests, pathogens, and nonnative invasive species, as well as the probability, severity, and extent of severe storms. Tree species in the area will differ in their capacity to adapt to such stressors. This section summarizes expected changes in habitat suitability and the adaptive capacity of different species in the region's developed areas.

Please note that this analysis is intended to help determine the overall vulnerability and adaptability of tree species in the urban forest to climate change; while it can be used to inform planting and management decisions, it is not a recommended planting guide. This is a qualitative assessment that provides an estimate of potential changes in habitat suitability based on temperature extremes and specific disturbance and biological factors. It does not directly consider additional factors such as changes in precipitation and habitat requirements. This analysis should be combined with knowledge in the region, as well as additional factors of consideration such as allergenicity, wildlife and cultural values, and local planting lists. While this guide was reviewed by experts in the region and feedback was incorporated to adjust the adaptability scores as necessary, it is important to take on-the-ground observations into account as decisions are made.

Shifts in Heat and Hardiness Zones

Heat and hardiness zones are geographic areas that define which species or cultivars are considered suitable for planting and survival. These zones are critical for understanding tree species selection under a changing climate. Defined by the U.S. Department of Agriculture, climate hardiness zones help arborists, gardeners, farmers, and others interested in tree and plant growth compare their local climate to that where a specific tree or plant is known to grow well. Each hardiness zone is 10°F warmer (or colder) than the adjacent zone to its north (or south). It is significant, therefore, that hardiness zones have migrated north by one-half, to one full level since 1990 (USDA Forest Service, 2022).

The Boston Region is historically (1980-2009) in hardiness zones 6 and 7. Future hardiness and heat zones were obtained from Matthews et al. (2018). Under the *low* climate change scenario, RCP 4.5, which assumes a reduction in global emissions of greenhouse gases, the hardiness zone is projected to stay in Zone 7 in the Boston region through the end of the century. Under the high climate change scenario, RCP 8.5, the hardiness zone is projected to shift to zone 8 between 2040-2069 and zone 8-9 by the end of the century.

The American Horticultural Society has established heat zones for determining the upper temperature limits trees are able to tolerate. The average number of days greater than 86°F (30 °C) determines heat zones. The Boston Region is historically (1980-2009) in heat zone 4 (15 to 30 days greater than or equal to 30 °C). Under RCP 4.5, the heat zone is projected to shift to heat zone 5 (>30 to 45 days greater than or equal to 30 °C) by 2039, zone 6 (>45 to 60 days greater than or equal to 30 °C) between 2040-2069, and zone 6 to zone 7 (>60-90 days greater than or equal to 30 °C) between 2070-2099. Under RCP 8.5, the heat zone is projected to shift to zone 6 by 2039, zone 7 to 8 (>90 to 120 days greater than or equal to 30 °C) between 2040-2069, and zone 8 to 9 (>120 to 150 days greater than or equal to 30 °C) between 2070-2099.

Table 2.—Hardiness and heat zone shifts by climate scenario (RCP4.5 and RCP8.5) and time period (2010-2039, 2040-2069, and 2070-2099) compared to the 1980-2009 range in Boston, Massachusetts.

Time Period	**Hardiness Zone Range**		**Heat Zone Range**	
1980-2009	Zone 6-7		Zone 4	
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
2010-2039	Zone 6-7	Zone 7	Zone 5	Zone 6
2040-2069	Zone 7	Zone 8	Zone 6	Zone 7-8
2070-2099	Zone 7	Zone 8-9	Zone 6-7	Zone 8-9

As the climate warms, the composition of forests changes. Many tree species are moving northward; following this trend, certain tree species are expected to lose their advantage and may be replaced within the next century by more southerly varieties (Groffman et al., 2014). When significantly warmer temperatures occur over a period of time long enough to cause a change in hardiness zone classification, trees' vulnerability to mortality from insect infestations, temperature, soil moisture levels, and disease will increase. How climate change impacts the future diversity and vitality of trees in the Boston region still depends, in part, on land-use and tree planting decisions residents, businesses, and city governments make today.

Projected Suitability from Heat Zones

Model information is not available for all species and cultivars that are found in the Boston region or for some of the species being considered for future planting. These species are usually either too rare in the region to be modeled reliably, have a range that extends outside of the U.S., are not native to North America, or are cultivars. To understand how climate change may affect these species, one approach is to examine heat zone ranges of the species to see how they compare to projected future zones in the region. Note that using heat zones to estimate which species will benefit or fare worse in a changing climate does not take into account changes in precipitation, seasonal climate changes, and other habitat requirements such as soil texture. This analysis is only meant to provide a coarse estimate of potential changes in habitat suitability based on temperature extremes. While the defined heat and hardiness zones for each species are used in this analysis, it is possible that species are able to survive in zones above the defined maximum.

A species' hardiness and heat zone ranges are the areas in which the species is considered suitable for planting. For this particular assessment, we include heat and hardiness zone suitability. Suitability was determined by the current and projected heat zones for the Boston region through the end of the century. For some species, only the hardiness zone ranges were available, and heat zone suitability was not determined (marked N/A).

For heat zone suitability, a tree species was considered to be 'suitable' under the *low* climate change scenario if its maximum heat zone was greater than or equal to heat zone 6. Under a high climate change scenario, a tree species was considered to be 'suitable' if its maximum heat zone was greater than or equal to zone 8. For hardiness zone suitability, the species was considered to be suitable under both low and high climate change scenarios if its minimum hardiness zone was less than or equal to hardiness zone 7.

Table 3. —Heat zone suitability and heat and hardiness zone suitability under low (RCP 4.5) and high (RCP 8.5) climate change scenarios for species that are currently found in the Boston region or are being considered for planting in the area. N/A= not available.

Scientific Name	Common Name	Hardiness Zone	Max. Heat Zone	Heat and Hardiness Zone Suitability – Low (RCP 4.5)	Heat and Hardiness Zone Suitability – High (RCP 8.5)
Abies balsamea	Balsam fir	3 to 6	6	Not suitable	Not suitable
Abies concolor	White fir	3 to 7	7	Suitable	Not suitable
Acer buergerianum	Trident Maple	5 to 9	9	Suitable	Suitable
Acer campestre	Hedge Maple	5 to 8	8	Suitable	Not suitable
Acer ginnala	Amur Maple	3 to 8	7	Suitable	Not suitable

Acer griseum	Paperbark Maple	5 to 8	8	Suitable	Not suitable
Acer miyabei	Miyabei Maple	4 to 8	8	Suitable	Not suitable
Acer pensylvanicum	Striped maple	3 to 7	Not defined	Suitable	Not suitable
Acer platanoides	Norway Maple	4 to 7	7	Suitable	Not suitable
Acer platanoides 'Crimson King'	Crimson King maple	3 to 7	7	Suitable	Not suitable
Acer rubrum	Red Maple	3 to 9	9	Suitable	Suitable
Acer saccharinum	Silver Maple	3 to 9	8	Suitable	Suitable
Acer saccharum	Sugar Maple	3 to 8	8	Suitable	Not suitable
Acer truncatum	Shantung maple, Purpleblow maple	4 to 8	8	Suitable	Not suitable
Acer x freemanii	Freeman maple	4 to 7	8	Suitable	Not suitable
Aesculus hippocastanum	European Horsechesnut	3 to 8	8	Suitable	Not suitable
Aesculus x carnea	Red horsechestnut	5 to 9	8	Suitable	Suitable
Amelanchier arborea	Downy serviceberry	4 to 9	9	Suitable	Suitable
Amelanchier laevis	Allegheny serviceberry	3 to 9	9	Suitable	Suitable
Amelanchier x grandiflora	Apple serviceberry	3 to 7	7	Suitable	Not suitable

Asimina triloba	Pawpaw	6 to 9	8	Suitable	Suitable
Betula alleghaniensis	Yellow birch	3 to 7	7	Suitable	Not suitable
Betula lenta	Sweet birch	3 to 7	7	Suitable	Not suitable
Betula nigra	River Birch	4 to 9	9	Suitable	Suitable
Betula papyrifera	Paper birch	2 to 6	7	Not suitable	Not suitable
Betula populifolia	Gray Birch	3 to 6	6	Not suitable	Not suitable
Carpinus betulus	Common hornbeam, European hornbeam	4 to 7	8	Suitable	Not suitable
Carpinus caroliniana	American Hornbeam	3 to 9	9	Suitable	Suitable
Carya alba	Mockernut hickory	4 to 9	9	Suitable	Suitable
Carya cordiformis	Bitternut hickory	4 to 9	9	Suitable	Suitable
Carya glabra	Pignut hickory	4 to 9	8	Suitable	Suitable
Carya illinoinensis	Pecan	5 to 9	9	Suitable	Suitable
Carya laciniosa	Shellbark hickory	4 to 9	8	Suitable	Suitable
Carya ovata	Shagbark hickory	4 to 8	8	Suitable	Not suitable
Carya texana	Black hickory	5 to 9	Not defined	Suitable	Suitable
Castanea dentata	American chestnut	5 to 8	8	Suitable	Not suitable

Catalpa speciosa	Northern catalpa	4 to 8	8	Suitable	Not suitable
Celtis laevigata	Sugarberry	5 to 9	Not defined	Suitable	Suitable
Celtis occidentalis	Common hackberry	2 to 9	9	Suitable	Suitable
Cercidiphyllum japonicum	Katsura tree	4 to 8	8	Suitable	Not suitable
Cercis canadensis	Eastern redbud	4 to 8	9	Suitable	Not suitable
Chamaecyparis thyoides	Atlantic white cedar	3 to 8	8	Suitable	Not suitable
Chionanthus virginicus	White fringetree	4 to 9	9	Suitable	Suitable
Cladrastis kentukea	Yellowwood	4 to 8	9	Suitable	Not suitable
Cornus Florida	Flowering Dogwood	5 to 9	9	Suitable	Suitable
Cornus kousa	Kousa Dogwood	5 to 8	8	Suitable	Not suitable
Cornus mas	Cornelian cherry dogwood	4 to 8	8	Suitable	Not suitable
Corylus colurna	Turkish filbert	4 to 7	7	Suitable	Not suitable
Cotinus obovatus	American smoketree	4 to 8	Not defined	Suitable	Not suitable
Crataegus × mordenensis	Morden hawthorn	4 to 7	Not defined	Suitable	Not suitable
Crataegus crus-galli 'Inermis'	Thornless cockspur hawthorn	3 to 7	7	Suitable	Not suitable
Crataegus crusgalli	Cockspur thorn	3 to 7	7	Suitable	Not suitable

Crataegus laevigata	Midland Hawthorn / English Hawthorn	4 to 8	8	Suitable	Not suitable
Crataegus monogyna	Common Hawthorn	5 to 7	7	Suitable	Not suitable
Crataegus phaenopyrum	Washington hawthorn	4 to 8	8	Suitable	Not suitable
Crataegus viridis 'Winter King'	Green hawthorn 'Winter King'	4 to 8	7	Suitable	Not suitable
Diospyros virginiana	Common persimmon	4 to 9	9	Suitable	Suitable
Eucommia ulmoides	Hardy Rubber Tree	4 to 7	7	Suitable	Not suitable
Fagus grandifolia	American beech	4 to 9	9	Suitable	Suitable
Fraxinus americana	White Ash	4 to 9	10	Suitable	Suitable
Fraxinus pennsylvanica	Green Ash	3 to 9	9	Suitable	Suitable
Ginkgo biloba	Ginkgo	4 to 9	9	Suitable	Suitable
Gleditsia triacanthos	Honeylocust	4 to 8	9	Suitable	Not suitable
Gymnocladus dioicus	Kentucky Coffeetree	4 to 8	9	Suitable	Not suitable
Halesia tetraptera, Halesia carolina	Carolina silverbell	4 to 8	8	Suitable	Not suitable
Hamamelis virginiana	American witchhazel	4 to 8	8	Suitable	Not suitable

Ilex opaca	American holly	5 to 10	9	Suitable	Suitable
Juglans cinerea	Butternut	3 to 7	7	Suitable	Not suitable
Juglans nigra	Eastern black walnut	4 to 9	9	Suitable	Suitable
Juniperus virginiana	Eastern redcedar	3 to 9	9	Suitable	Suitable
Koelreuteria paniculata	Golden Raintree	5 to 9	9	Suitable	Suitable
Liquidambar styraciflua	American Sweetgum	5 to 9	10	Suitable	Suitable
Liriodendro n	Tulip tree	5 to 7	9	Suitable	Suitable
Maackia amurensis	Amur maackia	3 to 7	7	Suitable	Not suitable
Maclura pomifera	Osage-orange	4 to 9	10	Suitable	Suitable
Magnolia acuminata	Cucumbertree	4 to 8	7	Suitable	Not suitable
Magnolia virginiana	Sweet bay magnolia	4 to 8	9	Suitable	Not suitable
Malus spp.	Crabapple	4 to 8	9	Suitable	Not suitable
Metasequoia	Dawn Redwood	5 to 9	10	Suitable	Suitable
Morus rubra	Red mulberry	4 to 9	9	Suitable	Suitable
Nyssa biflora	Swamp tupelo	6 to 9	11	Suitable	Suitable
Nyssa sylvatica	Blackgum, Black tupelo	6 to 9	9	Suitable	Suitable

Ostrya virginiana	Eastern hophornbeam, Ironwood	3 to 9	9	Suitable	Suitable
Oxydendrum arboreum	Sourwood	5 to 9	9	Suitable	Suitable
Parrotia persica	Persian Ironwood	5 to 8	8	Suitable	Not suitable
Picea abies	Norway Spruce	3 to 8	8	Suitable	Not suitable
Picea glauca	White spruce	2 to 6	7	Not suitable	Not suitable
Picea omorika	Serbian spruce	4 to 7	8	Suitable	Not suitable
Picea rubens	Red spruce	2 to 5	Not defined	Not suitable	Not suitable
Pinus cembra	Swiss stone pine	3 to 9	7	Suitable	Not suitable
Pinus clausa	Sand pine	7 to 10	Not defined	Suitable	Suitable
Pinus echinata	Shortleaf pine	6 to 9	Not defined	Suitable	Suitable
Pinus palustris	Longleaf pine	7 to 10	11	Suitable	Suitable
Pinus resinosa	Red pine	2 to 5	7	Not suitable	Not suitable
Pinus rigida	Pitch pine	4 to 7	7	Suitable	Not suitable
Pinus serotina	Pond pine	7 to 9	10	Suitable	Suitable
Pinus strobus	Eastern white pine	3 to 8	7	Suitable	Not suitable
Pinus taeda	Loblolly pine	6 to 9	Not defined	Suitable	Suitable

Pinus virginiana	Virginia pine	5 to 8	8	Suitable	Not suitable
Plantanus x acerifolia	London planetree	4 to 8	8	Suitable	Not suitable
Platanus occidentalis	American sycamore	4 to 9	9	Suitable	Suitable
Populus deltoides	Eastern cottonwood	3 to 9	9	Suitable	Suitable
Populus grandidenta ta	Bigtooth aspen	2 to 5	Not defined	Not suitable	Not suitable
Populus tremuloides	Quaking aspen	2 to 6	8	Not suitable	Not suitable
Prunus 'Accolade'	'Accolade' flowering cherry	5 to 8	8	Suitable	Not suitable
Prunus 'Snowgoose'	Snowgoose Cherry	5 to 8	8	Suitable	Not suitable
Prunus × yedoensis	Yoshino Cherry	5 to 6	8	Not suitable	Not suitable
Prunus pensylvanic a	Pin cherry	2 to 8	Not defined	Suitable	Not suitable
Prunus persica	Peach	5 to 9	9	Suitable	Suitable
Prunus sargentii	Sargent Cherry	5 to 8	9	Suitable	Not suitable
Prunus serotina	Black cherry	3 to 9	9	Suitable	Suitable
Prunus serrulata	Japanese cherry	5 to 6	9	Not suitable	Not suitable
Prunus subhirtella	Higan cherry	5 to 8	8	Suitable	Not suitable
Prunus virginiana	Chokecherry	2 to 7	Not defined	Suitable	Not suitable

Prunus x incam 'Okame'	Okame Cherry, Taiwan Cherry	5 to 8	8	Suitable	Not suitable
Ptelea trifoliata	Common hoptree (wafer ash)	4 to 9	Not defined	Suitable	Suitable
Pyrus calleryana	Callery Pear	5 to 9	8	Suitable	Suitable
Quercus alba	White oak	3 to 9	8	Suitable	Suitable
Quercus bicolor	Swamp White Oak	4 to 8	8	Suitable	Not suitable
Quercus coccinea	Scarlet oak	4 to 9	9	Suitable	Suitable
Quercus falcata	Southern red oak	6 to 9	Not defined	Suitable	Suitable
Quercus ilicifolia	Scrub oak	6 to 7	7	Suitable	Not suitable
Quercus imbricaria	Shingle oak	4 to 8	8	Suitable	Not suitable
Quercus laevis	Turkey oak	7 to 9	8	Suitable	Suitable
Quercus macrocarpa	Bur oak	3 to 8	9	Suitable	Not suitable
Quercus macrocarpa x robur	Heritage Oak	4 to 7	Not defined	Suitable	Not suitable
Quercus marilandica	Blackjack oak	6 to 9	Not defined	Suitable	Suitable
Quercus michauxii	Swamp chestnut oak	5 to 9	8	Suitable	Suitable
Quercus muehlenbergii	Chinkapin oak	4 to 7	8	Suitable	Not suitable

Quercus nigra	Water oak	6 to 9	9	Suitable	Suitable
Quercus pagoda	Cherrybark oak	5 to 9	Not defined	Suitable	Suitable
Quercus palustris	Pin Oak	4 to 8	7	Suitable	Not suitable
Quercus phellos	Willow oak	6 to 9	9	Suitable	Suitable
Quercus prinus	Chestnut oak	4 to 8	8	Suitable	Not suitable
Quercus robur	English Oak, Common oak	3 to 8	8	Suitable	Not suitable
Quercus rubra	Northern red Oak	4 to 8	9	Suitable	Not suitable
Quercus shumardii	Shumard oak	5 to 10	9	Suitable	Suitable
Quercus stellata	Post oak	5 to 9	9	Suitable	Suitable
Quercus velutina	Black oak	3 to 9	8	Suitable	Suitable
Robinia pseudoacacia	Black locust	4 to 8	9	Suitable	Not suitable
Salix babylonica	Weeping willow	4 to 9	9	Suitable	Suitable
Salix nigra	Black willow	4 to 9	Not defined	Suitable	Suitable
Sassafras albidum	Sassafras	3 to 9	10	Suitable	Suitable
Sciadopitys verticillata	Japanese umbrella pine	5 to 9	9	Suitable	Suitable
Styphnolobium japonicum	Japanese Pagoda Tree	5 to 8	9	Suitable	Not suitable

Syringa reticulata	Japanese Tree Lilac	3 to 7	7	Suitable	Not suitable
Taxodium distichum	Baldcypress	5 to 11	12	Suitable	Suitable
Thuja occidentalis	Northern white-cedar	3 to 7	7	Suitable	Not suitable
Tilia americana	American basswood/linde n	3 to 8	8	Suitable	Not suitable
Tilia cordata	Littleleaf linden	3 to 7	8	Suitable	Not suitable
Tilia tomentosa	Silver linden	6 to 9	Not defined	Suitable	Suitable
Tsuga canadensis	Canadian hemlock, Eastern hemlock	4 to 8	8	Suitable	Not suitable
Ulmus Accolade	Accolade elm	5 to 8	8	Suitable	Not suitable
Ulmus alata	Winged elm	6 to 9	Not defined	Suitable	Suitable
Ulmus americana	American elm	3 to 9	9	Suitable	Suitable
Ulmus crassifolia	Cedar elm	7 to 9	9	Suitable	Suitable
Ulmus parvifolia	Chinese elm	5 to 9	9	Suitable	Suitable
Ulmus rubra	Slippery elm	3 to 9	10	Suitable	Suitable
Viburnum sieboldii	Siebold viburnum	5 to 8	8	Suitable	Not suitable
Zelkova serrata	Japanese zelkova	5 to 8	9	Suitable	Not suitable

Adaptability Scores: Planted Environments

The results presented above provide information on potential changes in tree species habitat suitability across a range of projected extreme high and low temperatures (in the case of hardiness and heat zones), but do not account for factors such as changes in flood regime, extreme weather events such as high winds, insects and disease, and nonnative invasive species. To understand the capacity of tree species and cultivars in the area to adapt to these other effects of climate change, we relied on a scoring system developed by Matthews et al. (2011) called "modification factors." Other scoring systems have been developed (Roloff et al., 2009), but we found the system developed by Matthews et al. to be the most comprehensive for all potential climate change–related stressors.

Modification factors can include life history traits or environmental factors that make a species more or less likely to persist on the landscape (Matthews et al., 2011). Examples of modification factors include fire or drought tolerance, dispersal ability, shade tolerance, site specificity, and susceptibility to insect pests and diseases (Table 4). These factors can then be weighted by their intensity, the level of uncertainty about their impacts, and relative importance of future changes to tree mortality and survival to arrive at a numerical score (see Appendix 1). Modification factors are highly related to the adaptive capacity of a species: the ability to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2014). A species with a large number of positive modification factors would have a high adaptive capacity, and a species with a large number of negative modification factors would have a low adaptive capacity.

We used the modification factors developed for the Chicago Wilderness vulnerability assessment to better capture the unique environment of urban areas (Brandt et al., 2017). **Modification factor scores were developed for 161 species and varieties that are either present or potentially relevant for the Boston region. These scores were developed specifically considering these species in a planted or developed environment (street trees, yards, parks, etc.) and not natural areas. This selection of tree species does not represent the entire urban forest for the Boston region, but includes species that are most abundant and/or commonly planted in Boston, as well as a variety of species that are recommended for urban environments in Massachusetts by the Massachusetts Department of Conservation and Recreation (Massachusetts DCR) and University of Massachusetts – Amherst (University of Massachusetts, 2019).** Scores were then converted to categories of high (>4.5), medium (3.5 to 4.5), and low (<3.5) adaptive capacity. It is important to note that modification factors are meant to be used as a general summary of a species' adaptive capacity across its entire range, and not meant to capture site-specific factors that may enhance or reduce a species ability to withstand stressors.

In planted and developed conditions, **161 species were scored for adaptability. Fifty-two species (32%) were found to have high adaptability, while the majority were found to have (82 species, 51%) were found to have moderate adaptability, and 27 species (17%) were found to have low adaptability.**

Table 4.—Trait codes for adaptability tables. Traits are listed if they were among the main contributors to the overall adaptability score. N=applies to naturally occurring trees; P=applies to planted trees. See Appendix A for more information. NA= Not available.

Factor	Code	Type	Description (if positive)	Description (if negative)
Air pollution	AIP	N, P	Tolerant of air pollution	Intolerant of air pollution
Browse	BRO	N, P	Resistant to browsing	Susceptible to browsing
Competition-light	COL	N, P	Tolerant of shade or limited light conditions	Intolerant of shade or limited light conditions
Disease	DISE	N, P	Disease-resistant	Has a high number and/or severity of known pathogens that attack the species
Drought	DRO	N, P	Drought-tolerant	Susceptible to drought
Edaphic specificity	ESP	N, P	Wide range of soil tolerance	Narrow range of soil requirements
Environmental habitat specificity	EHS	N	Wide range of slopes/aspects/topographic positions	Small range of slopes/aspects/topographic positions
Flood	FLO	N, P	Flood-tolerant	Flood-intolerant
Ice	ICE	N, P	N/A	Susceptible to breakage from ice storms
Insect pests	INS	N, P	Pest-resistant	Has a high number and/or severity of insects that may attack the species
Invasive plants	INPL	N, P	N/A	Strong negative effects of invasive plants on the species, either through competition for nutrients or as a pathogen
Invasive potential	INPO	P	N/A	Species has the potential to become invasive and thus disfavored for planting
Land-use and planting site specificity	LPS	P	Can be planted on a wide variety of sites	Can only be planted in a narrow range of sites or as a specimen
Maintenance required	MAR	P	Little pruning, watering, or cleanup required	Requires considerable pruning, watering, or cleanup of debris

Nursery propagation	NUP	P	Easily propagated in nursery and widely available	Not easily propagated/not usually available
Planting establishment	PLE	P	Easily transplanted and requires little care to establish	Difficult to transplant or requires considerable care to establish
Restricted rooting conditions	RRC	P	Can tolerate restricted rooting conditions	Intolerant of restricted rooting conditions
Soil and water pollution	SWP	N, P	Tolerant of soil and/or water pollution	Intolerant of soil and/or water pollution
Temperature gradients	TEM	N, P	Wide range of temperature tolerances	Narrow range of temperature requirements
Wind	WIN	N, P	N/A	Susceptible to breakage from wind storms

Table 5.—Adaptability scores for trees in planted areas. Native trees are considered those native to North America. See Table 4 for Trait Codes.

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Abies balsamea	Balsam fir	Yes	4.22	Medium	NUP	DRO TEM AIP
Abies concolor	White fir	Yes	3.87	Medium	-	DRO AIP
Acer buergerianum	Trident Maple	No	4.2	Medium	RRC	FLO LPS
Acer campestre	Hedge Maple	No	4.5	Medium	NUP	INS LPS
Acer ginnala	Amur Maple	No	4.5	Medium	TEM LPS DRO	INPO

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Acer griseum	Paperbark Maple	No	3.3	Low	-	DRO TEM AIP NUP
Acer miyabei	Miyabei Maple	No	5.1	High	SAL	AIP
Acer pensylvanicum	Striped maple	Yes	3.8	Medium	-	DRO AIP
Acer platanoides	Norway Maple	No	5.21	High	DRO FLO ESP RRC NUP	INS INPO
Acer platanoides 'Crimson King'	Crimson King maple	No	4.85	High	INS TEM AIP NUP	RRC INPO
Acer rubrum	Red Maple	Yes	4.25	Medium	FLO TEM ESP LPS NUP	INS DRO AIP
Acer saccharinum	Silver Maple	Yes	4.05	Medium	FLO TEM NUP	RRC
Acer saccharum	Sugar Maple	Yes	4.17	Medium	NUP	INS FLO AIP

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Acer truncatum	Shantung maple, Purpleblow maple	No	5.41	High	DRO TEM LPS RRC NUP	INS
Acer x freemanii	Freeman maple	-	4.91	High	TEM ESP LPS NUP	-
Aesculus hippocastanum	European Horsechesnut	No	4.1	Medium	TEM	AIP
Aesculus x carnea	Red horsechestnut	No	3.9	Medium	-	-
Amelanchier arborea	Downy serviceberry	Yes	4.97	Low	TEM NUP	AIP
Amelanchier laevis	Allegheny serviceberry	Yes	4.66	High	LPS	DRO AIP
Amelanchier x grandiflora	Apple serviceberry	No	5.06	High	LPS RRC NUP	DRO FLO AIP
Asimina triloba	Pawpaw	Yes	4.3	Medium	-	NUP
Betula alleghaniensis	Yellow birch	Yes	4.6	High	NUP	TEM DRO BRO INS

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Betula lenta	Sweet birch	Yes	4.05	Medium	-	DRO
Betula nigra	River Birch	Yes	3.85	Medium	TEM LPS NUP	DISE DRO PLE
Betula papyrifera	Paper birch	Yes	3.65	Medium	NUP	DRO TEM AIP
Betula populifolia	Gray Birch	Yes	3.22	Low	-	DISE INS AIP LPS
Carpinus betulus	Common hornbeam, European hornbeam	No	4.6	High	TEM	-
Carpinus caroliniana	American Hornbeam	Yes	4.75	High	FLO TEM NUP	DRO AIP
Carya alba	Mockernut hickory	Yes	4.8	High	TEM	AIP
Carya cordiformis	Bitternut hickory	Yes	3.83	Medium	DRO	AIP
Carya glabra	Pignut hickory	Yes	4.1	Medium	TEM	-

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Carya illinoinensis	Pecan	Yes	3.15	Low	NUP	AIP LPS RRC
Carya laciniosa	Shellbark hickory	Yes	3.26	Low	-	-
Carya ovata	Shagbark hickory	Yes	3.51	Medium	TEM	AIP
Carya texana	Black hickory	Yes	2.92	Low	-	FLO AIP NUP
Castanea dentata	American chestnut	Yes	3.1	Low	-	RRC NUP
Catalpa speciosa	Northern catalpa	Yes	3.45	Low	-	AIP
Celtis laevigata	Sugarberry	Yes	3.81	Medium	DRO FLO TEM	WIN AIP NUP
Celtis occidentalis	Common hackberry	Yes	4.6	High	DRO TEM LPS NUP ESP	MAR WIN
Cercidiphyllum japonicum	Katsura tree	No	3.3	Low	DISE NUP	DRO WIN AIP RRC

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Cercis canadensis	Eastern redbud	Yes	3.9	Medium	FLO TEM NUP	AIP LPS
Chamaecyparis thyoides	Atlantic white cedar	Yes	4.74	High	FLO TEM NUP	AIP
Chionanthus virginicus	White fringetree	Yes	4.9	High	DRO TEM LPS RRC NUP	-
Cladrastis kentukea	Yellowwood	Yes	4.3	Medium	TEM RRC	AIP DRO
Cornus Florida	Flowering Dogwood	Yes	3.8	Medium	TEM NUP	DRO FLO AIP RRC LPS
Cornus kousa	Kousa Dogwood	No	4.6	High	NUP	DRO AIP
Cornus mas	Cornelian cherry dogwood	No	4.1	Medium	TEM	AIP
Corylus colurna	Turkish filbert	No	4.3	Medium	DRO TEM LPS RRC	SAL NUP

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Cotinus obovatus	American smoketree	Yes	3.86	Medium	DRO LPS RRC	AIP
Crataegus × mordenensis	Morden hawthorn	-	4.29	Medium	NUP	AIP
Crataegus crus-galli 'Inermis'	Thornless cockspur hawthorn	Yes	5.64	High	DRO FLO TEM AIP ESP RRC NUP	-
Crataegus crusgalli	Cockspur thorn	Yes	4.5	Medium	DRO TEM LPS RRC NUP	INS AIP DISE FLO
Crataegus laevigata	Midland Hawthorn / English Hawthorn	No	3.81	Moderate	DRO NUP	INS FLO INPO
Crataegus monogyna	Common Hawthorn	No	4.41	Moderate	TEM	INPO
Crataegus phaenopyrum	Washington hawthorn	Yes	4.32	Medium	DRO TEM RRC NUP	DISE INS
Crataegus viridis 'Winter King'	Green hawthorn 'Winter King'	-	4.2	Medium	LPS RRC	FLO

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Diospyros virginiana	Common persimmon	Yes	4.76	High	DRO FLO TEM ESP RRC NUP	-
Eucommia ulmoides	Hardy Rubber Tree	No	4.7	High	DRO	FLO
Fagus grandifolia	American beech	Yes	3.55	Medium	-	FLO AIP LPS RRC
Fraxinus americana	White Ash	Yes	3.22	Low	TEM NUP	INS AIP RRC
Fraxinus pennsylvanica	Green Ash	Yes	3.9	Medium	FLO NUP	INS MAR
Ginkgo biloba	Ginkgo	No	5.97	High	DRO TEM LPS RRC NUP	FLO
Gleditsia triacanthos	Honeylocust	Yes	4.26	Medium	DRO TEM RRC NUP	-
Gymnocladus dioicus	Kentucky Coffeetree	Yes	4.6	High	DRO LPS NUP	AIP

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Halesia tetraptera, Halesia carolina	Carolina silverbell	Yes	3.77	Medium	DRO TEM	AIP NUP
Hamamelis virginiana	American witchhazel	Yes	4.06	Medium	TEM	INS AIP
Ilex opaca	American holly	Yes	5.07	High	TEM RRC NUP PLE	FLO AIP
Juglans cinerea	Butternut	Yes	3.02	Low	FLO	ESP LPS PLE
Juglans nigra	Eastern black walnut	Yes	3.97	Medium	-	DRO AIP LPS RRC
Juniperus virginiana	Eastern redcedar	Yes	4.71	Medium	DRO TEM LPS RRC	AIP
Koelreuteria paniculata	Golden Raintree	No	4.55	High	DRO TEM LPS RRC NUP	INPO
Liquidambar styraciflua	American Sweetgum	Yes	3.74	Medium	-	INS DRO RRC
Liriodendron	Tulip tree	Yes	3.47	Low	NUP	DRO AIP RRC

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Maackia amurensis	Amur maackia	No	4.85	High	DRO TEM LPS RRC NUP	FLO
Maclura pomifera	Osage-orange	Yes	5.15	High	DRO TEM ESP RRC NUP	AIP
Magnolia acuminata	Cucumbertree	Yes	3.8	High	NUP	DRO AIP
Magnolia virginiana	Sweet bay magnolia	Yes	4.25	Medium	-	FLO
Malus spp.	Crabapple	Yes (not all spp.)	4.01	Medium	TEM LPS RRC NUP	DISE INS AIP
Metasequoia	Dawn Redwood	No	4.35	Medium	TEM	AIP
Morus rubra	Red mulberry	Yes	3.97	Medium	TEM NUP	AIP
Nyssa biflora	Swamp tupelo	Yes	2.26	Low	FLO	DRO ESP LSP RRC NUP PLE
Nyssa sylvatica	Blackgum, Black tupelo	Yes	4.72	High	RRC	AIP

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Ostrya virginiana	Eastern hophornbeam , Ironwood	Yes	5.41	High	DRO TEM LPS RRC NUP	FLO AIP
Oxydendrum arboreum	Sourwood	Yes	4.6	High	TEM	AIP RRC
Parrotia persica	Persian Ironwood	No	5.60	High	DRO TEM LPS RRC NUP	SAL
Picea abies	Norway Spruce	No	3.61	Medium	NUP	INS FLO AIP
Picea glauca	White spruce	Yes	4.15	Medium	-	INS
Picea omorika	Serbian spruce	No	4.06	Medium	NUP	INS
Picea rubens	Red spruce	Yes	3.61	Medium	NUP	DRO AIP LPS RRC
Pinus cembra	Swiss stone pine	No	4.52	High	DRO	FLO
Pinus clausa	Sand pine	Yes	3.24	Low	DRO	AIP LPS RRC

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Pinus echinata	Shortleaf pine	Yes	3.2	Low	-	DRO AIP RRC
Pinus palustris	Longleaf pine	Yes	4.24	Medium	INS DRO	FLO RRC
Pinus resinosa	Red pine	Yes	2.7	Low	-	INS DRO AIP RRC
Pinus rigida	Pitch pine	Yes	3.2	Low	TEM	FLO RRC
Pinus serotina	Pond pine	Yes	3.25	Low	FLO TEM	DRO
Pinus strobus	Eastern white pine	Yes	2.9	Medium	NUP	DISE INS DRO TEM AIP LPS RRC
Pinus taeda	Loblolly pine	Yes	4.46	Medium	DRO NUP	-
Pinus virginiana	Virginia pine	Yes	3.4	Low	NUP	AIP
Plantanus x acerifolia	London planetree	No	4.42	Medium	DRO FLO TEM NUP	DISE AIP
Platanus occidentalis	American sycamore	Yes	3.95	Medium	TEM NUP	-

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Populus deltoides	Eastern cottonwood	Yes	3.1	High	TEM NUP	DISE INS AIP LPS RRC
Populus grandidentata	Bigtooth aspen	Yes	3.45	Low	-	-
Populus tremuloides	Quaking aspen	Yes	3.37	Low	TEM NUP	INS DRO AIP RRC INPO
Prunus 'Accolade'	‘Accolade’ flowering cherry	-	4.21	Medium	TEM NUP	FLO
Prunus 'Snowgoose'	Snowgoose Cherry	-	4.85	High	NUP	-
Prunus × yedoensis	Yoshino Cherry	No	3.2	Low	-	AIP LPS
Prunus pensylvanica	Pin cherry	Yes	3.1	Medium	-	DRO AIP LPS
Prunus persica	Peach	No	3.61	Medium	NUP	DRO FLO
Prunus sargentii	Sargent Cherry	No	3.82	Medium	TEM LPS RRC	WIN AIP

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Prunus serotina	Black cherry	Yes	2.39	Low	DRO TEM	AIP LPS RRC
Prunus serrulata	Japanese cherry	No	4.3	Medium	TEM LPS NUP	-
Prunus subhirtella	Higan cherry	No	3.58	Medium	-	FLO AIP RRC
Prunus virginiana	Chokecherry	Yes	3.56	Medium	NUP	DISE FLO AIP
Prunus x incam 'Okame'	Okame Cherry, Taiwan Cherry	-	4.81	High	NUP	AIP
Ptelea trifoliata	Common hoptree (wafer ash)	Yes	4.48	Medium	TEM RRC NUP	AIP
*Pyrus calleryana**	Callery Pear*	No	4	Medium	DRO TEM RRC NUP	INS INPO
Quercus alba	White oak	Yes	4.25	Medium	TEM ESP LPS	FLO AIP
Quercus bicolor	Swamp White Oak	Yes	4.57	High	TEM RRC NUP	AIP

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Quercus coccinea	Scarlet oak	Yes	4.59	High	ESP LPS	AIP
Quercus falcata	Southern red oak	Yes	4.45	Medium	DRO LPS	-
Quercus ilicifolia	Scrub oak	Yes	3.66	Medium	DRO	AIP NUP
Quercus imbricaria	Shingle oak	Yes	4.8	High	DRO NUP	DISE INS AIP
Quercus laevis	Turkey oak	No	3.9	Medium	DRO TEM	-
Quercus macrocarpa	Bur oak	Yes	4.54	High	DRO TEM AIP LPS NUP	DISE INSE FLO
Quercus macrocarpa x robur	Heritage Oak	-	5.19	High	DRO TEM LPS NUP	DISE INS
Quercus marilandica	Blackjack oak	Yes	2.87	Low	DRO TEM	DISE FLO AIP LPS RRC NUP
Quercus michauxii	Swamp chestnut oak	Yes	3.86	Medium	FLO	NUP

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Quercus muehlenbergii	Chinkapin oak	Yes	4.4	Medium	DRO TEM LPS	DISE INS AIP
Quercus nigra	Water oak	Yes	3.55	Medium	FLO TEM NUP	DISE AIP
Quercus pagoda	Cherrybark oak	Yes	3.8	Medium	-	INS
Quercus palustris	Pin Oak	Yes	3.91	Medium	FLO TEM RRC NUP	DISE INS AIP
Quercus phellos	Willow oak	Yes	4.8	High	FLO LPS RRC NUP	-
Quercus prinus	Chestnut oak	Yes	4.7	High	LPS	INS AIP
Quercus robur	English Oak, Common oak	No	4.2	Medium	DRO TEM	-
Quercus rubra	Northern red Oak	Yes	5.02	High	TEM LPS NUP	DISE INS INPL
Quercus shumardii	Shumard oak	Yes	4.57	High	DRO FLO TEM LPS RRC NUP	-

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Quercus stellata	Post oak	Yes	2.92	Low	TEM	DISE FLO AIP LPS NUP
Quercus velutina	Black oak	Yes	4	Medium	DRO TEM	DISE INS
Robinia pseudoacacia	Black locust	Yes	3.55	Medium	DRO TEM	FLO AIP LPS RRC INPO
Salix babylonica	Weeping willow	No	3.57	Medium	FLO TEM NUP	INS AIP LPS RRC
Salix nigra	Black willow	Yes	3.25	Low	FLO	INS DRO AIP RRC
Sassafras albidum	Sassafras	Yes	4.12	Medium	DRO NUP	-
Sciadopitys verticillata	Japanese umbrella pine	No	3.98	Medium	-	AIP
Styphnolobium japonicum	Japanese Pagoda Tree	No	5.3	High	DRO TEM LPS RRC NUP SAL ESP AIP	FLO

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Syringa reticulata	Japanese Tree Lilac	No	4.6	High	LPS RRC NUP ESP PLE	AIP FLO INPO DISE
Taxodium distichum	Baldcypress	Yes	4.9	High	FLO RRC NUP	AIP
Thuja occidentalis	Northern white-cedar	Yes	4.44	Medium	NUP	DRO AIP
Tilia americana	American basswood/linden	Yes	4.01	Medium	FLO TEM NUP	AIP RRC
Tilia cordata	Littleleaf linden	No	4.59	High	LPS NUP	INS SAL
Tilia tomentosa	Silver linden	No	4.01	Medium	TEM NUP	INS AIP
Tsuga canadensis	Canadian hemlock, Eastern hemlock	Yes	3.21	Low	NUP	DRO AIP LPS
Ulmus Accolade	Accolade elm	-	4.76	High	TEM LPS NUP	-

Scientific Name	Common Name	Native to North America?	Planted Adapt Score	Planted Adapt Class	Planted Positive Factors	Planted Negative Factors
Ulmus alata	Winged elm	No	4.17	Medium	FLO LPS RRC	DISE AIP INPO
Ulmus americana	American elm	Yes	3.92	Medium	NUP	DISE DRO
Ulmus crassifolia	Cedar elm	Yes	5.82	High	FLO AIP EPS LPS RRC NUP DRO	-
Ulmus parvifolia	Chinese elm	No	5.5	High	DRO TEM EDS LPS RRC NUP	INPO
Ulmus rubra	Slippery elm	Yes	3.99	Medium	TEM LPS	DISE
Viburnum sieboldii	Siebold viburnum	No	5.12	High	INS ESP PLE	INPO
Zelkova serrata	Japanese zelkova	No	4.6	High	TEM LPS RRC NUP	-

Overall Vulnerability of Tree Species in the Boston Region

Vulnerability is the susceptibility of a system to the adverse effects of climate change (IPCC, 2007). It is a function of potential climate change impacts and the adaptive capacity of the system. The overall vulnerability of assessed tree species in the Boston region (Table 7) was estimated by considering the impacts on individual tree species using the zone suitability and the adaptive capacity of tree species as described in the previous section (adapt class in Table 5) together in a matrix (Table 6). As an example, the vulnerability ratings for the top twenty-one most prevalent *urban street tree* species in the City of Boston (City of Boston Parks & Recreation 2021) are provided (Table 8).

Table 6.—Vulnerability scoring matrix based on Brandt et al. (2017).

Habitat or Zone Suitability-end of century	**Adapt Class**		
	Low	**Medium**	**High**
Not suitable	High Vulnerability	Moderate-high Vulnerability	Moderate Vulnerability
Suitable	Moderate Vulnerability	Low-moderate Vulnerability	Low Vulnerability

Table 7.—Vulnerability ratings for trees in the Boston region based on heat and hardiness zones under low and high climate change scenarios.

Scientific Name	**Common Name**	**Vulnerability Under Low Climate Change Scenario**	**Vulnerability Under High Climate Change Scenario**
Abies balsamea	Balsam fir	Moderate-high vulnerability	Moderate-high vulnerability
Abies concolor	White fir	Low-moderate vulnerability	Moderate-high vulnerability
Acer buergerianum	Trident maple	Low-moderate vulnerability	Low-moderate vulnerability
Acer campestre	Hedge maple	Low-moderate vulnerability	Moderate-high vulnerability
Acer ginnala	Amur maple	Low-moderate vulnerability	Moderate-high vulnerability
Acer griseum	Paperbark maple	Moderate vulnerability	High vulnerability
Acer miyabei	Miyabei maple	Low vulnerability	Moderate vulnerability
Acer pensylvanicum	Striped maple	Low-moderate vulnerability	Moderate-high vulnerability
Acer platanoides	Norway maple	Low vulnerability	Moderate vulnerability
Acer platanoides 'Crimson King'	Crimson King maple	Low vulnerability	Moderate vulnerability
Acer rubrum	Red maple	Low-moderate vulnerability	Low-moderate vulnerability
Acer saccharinum	Silver maple	Low-moderate vulnerability	Low-moderate vulnerability
Acer saccharum	Sugar maple	Low-moderate vulnerability	Moderate-high vulnerability
Acer truncatum	Shantung maple, Purpleblow maple	Low vulnerability	Moderate vulnerability
Acer x freemanii	Freeman maple	Low vulnerability	Moderate vulnerability

Scientific Name	Common Name	Vulnerability Under Low Climate Change Scenario	Vulnerability Under High Climate Change Scenario
Aesculus hippocastanum	European horsechesnut	Low-moderate vulnerability	Moderate-high vulnerability
Aesculus x carnea	Red horsechestnut	Low-moderate vulnerability	Low-moderate vulnerability
Amelanchier arborea	Downy serviceberry	Moderate vulnerability	Moderate vulnerability
Amelanchier laevis	Allegheny serviceberry	Low vulnerability	Low vulnerability
Amelanchier x grandiflora	Apple serviceberry	Low vulnerability	Moderate vulnerability
Asimina triloba	Pawpaw	Low-moderate vulnerability	Low-moderate vulnerability
Betula alleghaniensis	Yellow birch	Low vulnerability	Moderate vulnerability
Betula lenta	Sweet birch	Low-moderate vulnerability	Moderate-high vulnerability
Betula nigra	River Birch	Low-moderate vulnerability	Low-moderate vulnerability
Betula papyrifera	Paper birch	Moderate-high vulnerability	Moderate-high vulnerability
Betula populifolia	Gray birch	High vulnerability	High vulnerability
Carpinus betulus	Common hornbeam, European hornbeam	Low vulnerability	Moderate vulnerability
Carpinus caroliniana	American hornbeam	Low vulnerability	Low vulnerability
Carya alba	Mockernut hickory	Low vulnerability	Low vulnerability
Carya cordiformis	Bitternut hickory	Low-moderate vulnerability	Low-moderate vulnerability
Carya glabra	Pignut hickory	Low-moderate vulnerability	Low-moderate vulnerability
Carya illinoinensis	Pecan	Moderate vulnerability	Moderate vulnerability
Carya laciniosa	Shellbark hickory	Moderate vulnerability	Moderate vulnerability
Carya ovata	Shagbark hickory	Low-moderate vulnerability	Moderate-high vulnerability
Carya texana	Black hickory	Moderate vulnerability	Moderate vulnerability
Castanea dentata	American chestnut	Moderate vulnerability	High vulnerability
Catalpa speciosa	Northern catalpa	Moderate vulnerability	High vulnerability
Celtis laevigata	Sugarberry	Low-moderate vulnerability	Low-moderate vulnerability
Celtis occidentalis	Common hackberry	Low vulnerability	Low vulnerability
Cercidiphyllum japonicum	Katsura tree	Moderate vulnerability	High vulnerability
Cercis canadensis	Eastern redbud	Low-moderate vulnerability	Moderate-high vulnerability
Chamaecyparis thyoides	Atlantic white cedar	Low vulnerability	Moderate vulnerability
Chionanthus virginicus	White fringetree	Low vulnerability	Low vulnerability
Cladrastis kentukea	Yellowwood	Low-moderate vulnerability	Moderate-high vulnerability
Cornus Florida	Flowering dogwood	Low-moderate vulnerability	Low-moderate vulnerability

Scientific Name	Common Name	Vulnerability Under Low Climate Change Scenario	Vulnerability Under High Climate Change Scenario
Cornus kousa	Kousa dogwood	Low vulnerability	Moderate vulnerability
Cornus mas	Cornelian cherry dogwood	Low-moderate vulnerability	Moderate-high vulnerability
Corylus colurna	Turkish filbert	Low-moderate vulnerability	Moderate-high vulnerability
Cotinus obovatus	American smoketree	Low-moderate vulnerability	Moderate-high vulnerability
Crataegus × mordenensis	Morden hawthorn	Low-moderate vulnerability	Moderate-high vulnerability
Crataegus crus-galli 'Inermis'	Thornless cockspur hawthorn	Low vulnerability	Moderate vulnerability
Crataegus crusgalli	Cockspur thorn	Low-moderate vulnerability	Moderate-high vulnerability
Crataegus laevigata	Midland hawthorn / English hawthorn	Low-moderate vulnerability	Moderate-high vulnerability
Crataegus monogyna	Common hawthorn	Low-moderate vulnerability	Moderate-high vulnerability
Crataegus phaenopyrum	Washington hawthorn	Low-moderate vulnerability	Moderate-high vulnerability
Crataegus viridis 'Winter King'	Green hawthorn 'Winter King'	Low-moderate vulnerability	Moderate-high vulnerability
Diospyros virginiana	Common persimmon	Low vulnerability	Low vulnerability
Eucommia ulmoides	Hardy rubber tree	Low vulnerability	Moderate vulnerability
Fagus grandifolia	American beech	Low-moderate vulnerability	Low-moderate vulnerability
Fraxinus americana	White ash	Moderate vulnerability	Moderate vulnerability
Fraxinus pennsylvanica	Green ash	Low-moderate vulnerability	Low-moderate vulnerability
Ginkgo biloba	Ginkgo	Low vulnerability	Low vulnerability
Gleditsia triacanthos	Honeylocust	Low-moderate vulnerability	Moderate-high vulnerability
Gymnocladus dioicus	Kentucky coffeetree	Low vulnerability	Moderate vulnerability
Halesia tetraptera, Halesia carolina	Carolina silverbell	Low-moderate vulnerability	Moderate-high vulnerability
Hamamelis virginiana	American witchhazel	Low-moderate vulnerability	Moderate-high vulnerability
Ilex opaca	American holly	Low vulnerability	Low vulnerability
Juglans cinerea	Butternut	Moderate vulnerability	High vulnerability
Juglans nigra	Eastern black walnut	Low-moderate vulnerability	Low-moderate vulnerability
Juniperus virginiana	Eastern redcedar	Low-moderate vulnerability	Low-moderate vulnerability
Koelreuteria paniculata	Golden Raintree	Low vulnerability	Low vulnerability
Liquidambar styraciflua	American Sweetgum	Low-moderate vulnerability	Low-moderate vulnerability
Liriodendron	Tulip tree	Moderate vulnerability	Moderate vulnerability
Maackia amurensis	Amur maackia	Low vulnerability	Moderate vulnerability

Scientific Name	**Common Name**	**Vulnerability Under Low Climate Change Scenario**	**Vulnerability Under High Climate Change Scenario**
Maclura pomifera	Osage-orange	Low vulnerability	Low vulnerability
Magnolia acuminata	Cucumbertree	Low vulnerability	Moderate vulnerability
Magnolia virginiana	Sweet bay magnolia	Low-moderate vulnerability	Moderate-high vulnerability
Malus spp.	Crabapple	Low-moderate vulnerability	Moderate-high vulnerability
Metasequoia	Dawn Redwood	Low-moderate vulnerability	Low-moderate vulnerability
Morus rubra	Red mulberry	Low-moderate vulnerability	Low-moderate vulnerability
Nyssa biflora	Swamp tupelo	Moderate vulnerability	Moderate vulnerability
Nyssa sylvatica	Blackgum, Black tupelo	Low vulnerability	Low vulnerability
Ostrya virginiana	Eastern hophornbeam, Ironwood	Low vulnerability	Low vulnerability
Oxydendrum arboreum	Sourwood	Low vulnerability	Low vulnerability
Parrotia persica	Persian Ironwood	Low vulnerability	Moderate vulnerability
Picea abies	Norway Spruce	Low-moderate vulnerability	Moderate-high vulnerability
Picea glauca	White spruce	Moderate-high vulnerability	Moderate-high vulnerability
Picea omorika	Serbian spruce	Low-moderate vulnerability	Moderate-high vulnerability
Picea rubens	Red spruce	Moderate-high vulnerability	Moderate-high vulnerability
Pinus cembra	Swiss stone pine	Low vulnerability	Moderate vulnerability
Pinus clausa	Sand pine	Moderate vulnerability	Moderate vulnerability
Pinus echinata	Shortleaf pine	Moderate vulnerability	Moderate vulnerability
Pinus palustris	Longleaf pine	Low-moderate vulnerability	Low-moderate vulnerability
Pinus resinosa	Red pine	High vulnerability	High vulnerability
Pinus rigida	Pitch pine	Moderate vulnerability	High vulnerability
Pinus serotina	Pond pine	Moderate vulnerability	Moderate vulnerability
Pinus strobus	Eastern white pine	Low-moderate vulnerability	Moderate-high vulnerability
Pinus taeda	Loblolly pine	Low-moderate vulnerability	Low-moderate vulnerability
Pinus virginiana	Virginia pine	Moderate vulnerability	High vulnerability
Plantanus x acerifolia	London planetree	Low-moderate vulnerability	Moderate-high vulnerability
Platanus occidentalis	American sycamore	Low-moderate vulnerability	Low-moderate vulnerability
Populus deltoides	Eastern cottonwood	Low vulnerability	Low vulnerability
Populus grandidentata	Bigtooth aspen	High vulnerability	High vulnerability
Populus tremuloides	Quaking aspen	High vulnerability	High vulnerability
Prunus 'Accolade'	‘Accolade’ flowering cherry	Low-moderate vulnerability	Moderate-high vulnerability

Scientific Name	Common Name	Vulnerability Under Low Climate Change Scenario	Vulnerability Under High Climate Change Scenario
Prunus 'Snowgoose'	Snowgoose Cherry	Low vulnerability	Moderate vulnerability
Prunus × yedoensis	Yoshino Cherry	High vulnerability	High vulnerability
Prunus pensylvanica	Pin cherry	Low-moderate vulnerability	Moderate-high vulnerability
Prunus persica	Peach	Low-moderate vulnerability	Low-moderate vulnerability
Prunus sargentii	Sargent Cherry	Low-moderate vulnerability	Moderate-high vulnerability
Prunus serotina	Black cherry	Moderate vulnerability	Moderate vulnerability
Prunus serrulata	Japanese cherry	Moderate-high vulnerability	Moderate-high vulnerability
Prunus subhirtella	Higan cherry	Low-moderate vulnerability	Moderate-high vulnerability
Prunus virginiana	Chokecherry	Low-moderate vulnerability	Moderate-high vulnerability
Prunus x incam 'Okame'	Okame Cherry, Taiwan Cherry	Low vulnerability	Moderate vulnerability
Ptelea trifoliata	Common hoptree (wafer ash)	Low-moderate vulnerability	Low-moderate vulnerability
Pyrus calleryana	Callery Pear	Low-moderate vulnerability	Low-moderate vulnerability
Quercus alba	White oak	Low-moderate vulnerability	Low-moderate vulnerability
Quercus bicolor	Swamp White Oak	Low vulnerability	Moderate vulnerability
Quercus coccinea	Scarlet oak	Low vulnerability	Low vulnerability
Quercus falcata	Southern red oak	Low-moderate vulnerability	Low-moderate vulnerability
Quercus ilicifolia	Scrub oak	Low-moderate vulnerability	Moderate-high vulnerability
Quercus imbricaria	Shingle oak	Low vulnerability	Moderate vulnerability
Quercus laevis	Turkey oak	Low-moderate vulnerability	Low-moderate vulnerability
Quercus macrocarpa	Bur oak	Low vulnerability	Moderate vulnerability
Quercus macrocarpa x robur	Heritage Oak	Low vulnerability	Moderate vulnerability
Quercus marilandica	Blackjack oak	Moderate vulnerability	Moderate vulnerability
Quercus michauxii	Swamp chestnut oak	Low-moderate vulnerability	Low-moderate vulnerability
Quercus muehlenbergii	Chinkapin oak	Low-moderate vulnerability	Moderate-high vulnerability
Quercus nigra	Water oak	Low-moderate vulnerability	Low-moderate vulnerability
Quercus pagoda	Cherrybark oak	Low-moderate vulnerability	Low-moderate vulnerability
Quercus palustris	Pin Oak	Low-moderate vulnerability	Moderate-high vulnerability
Quercus phellos	Willow oak	Low vulnerability	Low vulnerability

Scientific Name	Common Name	Vulnerability Under Low Climate Change Scenario	Vulnerability Under High Climate Change Scenario
Quercus prinus	Chestnut oak	Low vulnerability	Moderate vulnerability
Quercus robur	English Oak, Common oak	Low-moderate vulnerability	Moderate-high vulnerability
Quercus rubra	Northern red Oak	Low vulnerability	Moderate vulnerability
Quercus shumardii	Shumard oak	Low vulnerability	Low vulnerability
Quercus stellata	Post oak	Moderate vulnerability	Moderate vulnerability
Quercus velutina	Black oak	Low-moderate vulnerability	Low-moderate vulnerability
Robinia pseudoacacia	Black locust	Low-moderate vulnerability	Moderate-high vulnerability
Salix babylonica	Weeping willow	Low-moderate vulnerability	Low-moderate vulnerability
Salix nigra	Black willow	Moderate vulnerability	Moderate vulnerability
Sassafras albidum	Sassafras	Low-moderate vulnerability	Low-moderate vulnerability
Sciadopitys verticillata	Japanese umbrella pine	Low-moderate vulnerability	Low-moderate vulnerability
Styphnolobium japonicum	Japanese Pagoda Tree	Low vulnerability	Moderate vulnerability
Syringa reticulata	Japanese Tree Lilac	Low vulnerability	Moderate vulnerability
Taxodium distichum	Baldcypress	Low vulnerability	Low vulnerability
Thuja occidentalis	Northern white-cedar	Low-moderate vulnerability	Moderate-high vulnerability
Tilia americana	American basswood/linden	Low-moderate vulnerability	Moderate-high vulnerability
Tilia cordata	Littleleaf linden	Low vulnerability	Moderate vulnerability
Tilia tomentosa	Silver linden	Low-moderate vulnerability	Low-moderate vulnerability
Tsuga canadensis	Canadian hemlock, Eastern hemlock	Moderate vulnerability	High vulnerability
Ulmus Accolade	Accolade elm	Low vulnerability	Moderate vulnerability
Ulmus alata	Winged elm	Low-moderate vulnerability	Low-moderate vulnerability
Ulmus americana	American elm	Low-moderate vulnerability	Low-moderate vulnerability
Ulmus crassifolia	Cedar elm	Low vulnerability	Low vulnerability
Ulmus parvifolia	Chinese elm	Low vulnerability	Low vulnerability
Ulmus rubra	Slippery elm	Low-moderate vulnerability	Low-moderate vulnerability
Viburnum sieboldii	Siebold viburnum	Low vulnerability	Moderate vulnerability
Zelkova serrata	Japanese zelkova	Low vulnerability	Moderate vulnerability

Table 8. Vulnerability ratings for the top twenty-one most prevalent street tree species in the City of Boston under low and high climate change scenarios.

Common Name	Vulnerability – Low Climate Change Scenario	Vulnerability – High Climate Change Scenario	Common Name	Vulnerability – Low Climate Change Scenario	Vulnerability – High Climate Change Scenario
Honeylocust	Low-moderate	Moderate-high	Red Maple	Low-moderate	Low-moderate
Littleleaf Linden	Low	Moderate	Hedge Maple	Low-moderate	Moderate-high
Basswood Linden	Low-moderate	Moderate-high	Freeman Maple	Low	Moderate
Pin Oak	Low-moderate	Moderate-high	Crimson King Maple	Low	Moderate
Northern Red Oak	Low	Moderate	Accolade Elm	Low	Moderate
Green Ash	Low-moderate	Low-moderate	American Elm	Low-moderate	Low-moderate
Japanese Zelkova	Low	Moderate	Callery Pear	Low-moderate	Low-moderate
Japanese Pagoda	Low	Moderate	Ginkgo	Low	Low
Japanese Tree Lilac	Low	Moderate	Crabapple spp.	Low-moderate	Moderate-high
London Planetree	Low-moderate	Moderate-high	Sweetgum	Low-moderate	Low-moderate
Norway Maple	Low	Moderate			

Human Health Considerations

Populations residing in urban areas can be particularly vulnerable to climate change due to extensive impervious cover, increased pollution, greater population densities, and a concentration of built structures that intensify impacts from urban heat, drought, and extreme weather. Urban communities are at risk from a variety of climate stressors, which can contribute to both physical and mental harm.

Urban forests and tree cover play a critical role both in helping cities address climate change and enhancing human health by reducing the impacts of extreme heat, air pollution and an altered climate, and supporting mental health and social wellbeing. Trees and landscapes, if properly located and maintained, can improve human health and quality of life in many ways.

Low-income communities and communities of color are experiencing disproportionately negative climate and health impacts due to a legacy of structural and institutional racist practices such as redlining. There are opportunities to address issues of environmental justice; empowering communities to enhance their surrounding urban forest through forestry programs and activities can help address health disparities across underserved populations, as well as inequities in distribution of trees and green spaces across communities. Community engagement that respects local and indigenous knowledge while incorporating community needs and traditions can support urban forestry projects that promote tree and human health.

The content within this section is meant to provide a brief overview of human health factors as they relate to the population and urban forest of the Boston region. For more comprehensive information on the social and human health dimensions of climate change in the City of Boston, the following sources are recommended:

- Climate Ready Boston Executive Summary (2016): In addition to climate projections, this resource provides a comprehensive evaluation of risks associated with three major climate hazards (extreme heat, stormwater flooding, and coastal and riverine flooding) for the people, buildings, infrastructure, and economy of Boston. It also provides an analysis of impacts for eight specific areas within Boston.

- Heat Resilience Solutions for Boston (2022): This comprehensive report provides an overview of heat trends and projections, a citywide heat analysis, information on five focus neighborhoods, and citywide heat resilience strategies that center environmental justice and equity.

- Exploring Tree Equity in Boston (2021): This interactive map series developed by Speak for the Trees – Boston is designed to help residents, organizations, and municipal officials explore the distribution of canopy across Boston and the relationship between trees, demographics, and environmental justice.

- EPA's Environmental Justice Screening and Mapping Tool (2022): This tool uses nationally consistent data and an approach that combines environmental and demographic indicators in maps and reports. It includes 12 environmental indicators, 7 demographic indicators, and 12 environmental justice indices.

Extreme Heat

One of the primary public health concerns regarding climate change is the increased intensity and frequency of heat waves. Extreme heat events cause more deaths in the United States annually than all other weather-related causes combined (including hurricanes, lightning, tornadoes, and floods). The effects of these events are most pronounced in urban areas due to the urban heat island effect, which is the result of extensive dark, paved, and impervious surfaces (such as roads, black roofs, asphalt, etc.) absorbing more heat than vegetated or light colored surfaces and radiating the heat back into the surrounding environment.

For Boston, the number of days over 80 °F, currently about 62 per year, will most likely increase from 73 to 91 days in the 2030s to 84 to 107 days by the 2070s (Boston Heat Resilience Plan, 2022). Under an extreme scenario, the number of very hot days (over 90 °F) could reach up to 87 days by the 2080s. In addition to extreme daytime temperatures, the number of warmer nights has also increased over the last decade and is expected to continue increasing; this extends the need for heat relief into the night, and can contribute to increased health risks and higher energy costs at home.

Dense and developed areas that have high amounts of impervious cover and less tree canopy cover stay hotter for longer during periods of extreme heat. There are substantial disparities between Boston neighborhoods in terms of tree cover and overall Urban Heat Island Index (UHII) values; areas that were 'redlined' in the 1930s (a federal racial segregation tactic that effectively prohibited Black and immigrant populations from accessing mortgage financing and resulted in decades of underinvestment in these communities) are 7.5 °F hotter in the day, 3.6 °F hotter at night, and have 20% less parkland and 40% less tree canopy than areas which were rated highly by mortgage lenders at the time ([Boston Heat Resilience Plan, 2022]) (Figure 7).

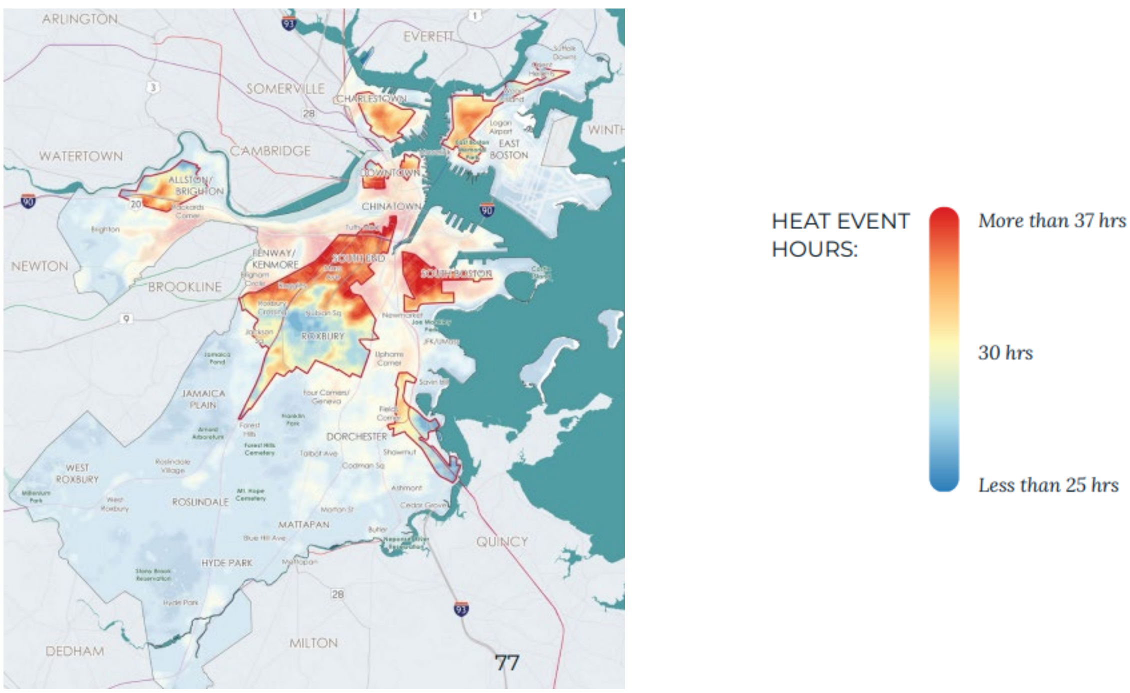


Figure 7. Redlining boundaries are overlaid on a heat event hours dataset to visually explore how heat intensity and length during a heat wave affects redlined neighborhoods. Data Source: City of Boston and Robert K. Nelson, LaDale Winling, Richard Marciano, Nathan Connolly, et al., "Mapping Inequality," American Panorama, ed. Robert K. Nelson and Edward L. Ayers

Increased heat is associated with higher rates of both heat stroke and hyperthermia; mortality rates may be even greater than reported because heat events trigger serious complications from pre-existing health conditions (Bowler et. al, 2010). Certain populations are at higher risk of heat-related illness, including those who are elderly, very young, disabled, poor, or live alone; those with existing cardiovascular medical conditions; and those living in areas with high air pollution or in buildings without air conditioning.

Urban greening, and increasing tree cover in particular, is a heat-mitigation approach. Groups of trees cool the immediate, and sometimes extended adjacent, area by way of evapotranspiration and shading, and also by affecting air movements and heat exchange. In warmer climates, shaded surfaces can range from 25 °F to 35 °F cooler than the peak temperatures of exposed surfaces. Large trees with a high amount of leaf surface area, as well as clusters of trees and understory vegetation, can generally reduce extreme heat within an area and also create distinct ‘thermal refuges’ in public spaces. Thermal comfort is improved when people spend time in tree-covered spaces, and trees have been found to reduce the risk for heatstroke and heat-related ambulance calls during extreme heat events (Kilbourne et al. 1982).

Table 9.—Tree species in the Boston region with moderate to high leaf area ratings based on i-Tree data. Data uses maximum leaf area reached over the species’ lifespan. Leaf area is defined simply as the amount of surface area (one-sided) of leaves on a tree.

Scientific Name	Common Name	Leaf Area Rating
Acer rubrum	Red maple	Moderate
Acer saccharinum	Silver maple	Moderate
Carya ovata	Shagbark hickory	Moderate
Castanea dentata	American chestnut	Moderate
Celtis occidentalis	Common hackberry	Moderate
Corylus colurna	Turkish filbert	Moderate
Eucommia ulmoides	Hardy Rubber Tree	Moderate
Ilex opaca	American holly	Moderate
Juglans cinerea	Butternut	Moderate
Juniperus virginiana	Eastern redcedar	Moderate
Metasequoia glyptostroboides	Dawn redwood	Moderate
Morus rubra	Red mulberry	Moderate
Picea glauca	White spruce	Moderate
Picea rubens	Red spruce	Moderate
Quercus bicolor	Swamp white oak	Moderate
Quercus imbricaria	Shingle oak	Moderate
Quercus michauxii	Swamp chestnut oak	Moderate
Quercus muehlenbergii	Chinkapin oak	Moderate
Quercus robur	English oak	Moderate
Quercus shumardii	Shumard oak	Moderate
Thuja occidentalis	Northern white cedar, Arborvitae	Moderate
Tilia americana	American linden, Basswood	Moderate
Tsuga canadensis	Eastern hemlock	Moderate
Ulmus alata	Winged elm	Moderate
Ulmus americana	American elm	Moderate
Betula papyrifera	Paper birch	Moderate-high
Carya cordiformis	Bitternut hickory	Moderate-high
Carya glabra	Pignut hickory	Moderate-high
Cercidiphyllum japonicum	Katsura tree	Moderate-high
Fagus grandifolia	American beech	Moderate-high
Picea abies	Norway spruce	Moderate-high
Picea omorika	Serbian spruce	Moderate-high
Pinus taeda	Loblolly pine	Moderate-high

Plantanus x acerifolia	London planetree	Moderate-high
Populus tremuloides	Quaking aspen	Moderate-high
Quercus alba	White oak	Moderate-high
Quercus laevis	Turkey oak	Moderate-high
Quercus macrocarpa	Bur oak	Moderate-high
Salix babylonica v. matsudana	Corkscrew willow	Moderate-high
Sassafras albidum	Sassafras	Moderate-high
Tilia tomentosa	Silver linden	Moderate-high
Liriodendron tulipifera	Tuliptree	High
Platanus occidentalis	American sycamore	High
Quercus palustris	Pin oak	High
Quercus phellos	Willow oak	High

Air Quality

Climate change is contributing to reduced air quality by modifying weather patterns that increase and concentrate pollutants, enhancing storm and disturbance events that raise particulate levels, and elevating the release of pollen and volatile organic compounds. These impacts, compounded with proximity to industrial areas, traffic corridors, construction, and other sources of air pollution, can all contribute to compromised air quality in urban areas. Air pollution is now the biggest environmental risk for early death; it can hinder lung development in children, and contribute to the development of emphysema, asthma, and other respiratory diseases, such as chronic obstructive pulmonary disease (COPD) and chronic bronchitis (National Institute of Environmental and Health Services, 2022). According to the American Lung Association's 2020 "State of the Air" report, the Boston metro area ranked as the 38th most polluted city in the nation for ozone, with an increase in unhealthy days compared to results in last year's report.

Neighborhoods adjacent to major roadways are particularly vulnerable to the negative effects of air pollution. Research out of the Boston Metropolitan Area Planning Council has shown that ultrafine particulates are at their highest concentrations near highways, and drop off considerably between 150 and 200 meters from roadways (Metropolitan Area Planning Council, 2021). Higher levels of this kind of air pollution are associated with respiratory conditions such as asthma, cardiovascular diseases, and neurological conditions. Low-income communities and communities of color within the Boston area and Massachusetts more broadly are at greater risk of exposure to high levels of air pollution; a study conducted over eight years and published in 2017 found that in Massachusetts, annual-average population-weighted particulate matter 2.5 and nitrogen dioxide concentrations were highest for urban non-Hispanic black populations and urban Hispanic populations (Rosofsky et al. 2017). Within Boston city limits, the Chinatown area in particular is bordered by interstates 90 and 93 and is subject to some of the highest ultra-fine particle concentrations in the city (Thayer et al. 2022).

Exposure to natural areas and biodiversity has been associated with positive health responses, including reduced asthma in both adults and children (Donovan et al. 2018, Hartley et al. 2020). In some cases, trees can intercept particles on their leaf and limb surfaces, reducing the amount of respiratory irritants in the air. Trees can also absorb and remove polluting gases, such as ozone and nitrous oxide. Careful planning of plant selection, planting density and location, and management can increase health benefits while reducing risks. For instance, planting trees near major emissions sources, such as industrial or manufacturing sites, and along transportation corridors, can protect people from the drift of particulate matter.

It is also important to consider the role that trees can sometimes play in exacerbating respiratory conditions. Allergies due to pollen are a seasonal health concern that interacts with broader environmental conditions, such as temperature, humidity, and other air pollutants, to negatively influence human health. Although tree pollen may contribute to illness, some household allergens and other plants (such as ragweed, which produces highly allergenic pollen) pose equal or greater risk. All of these conditions can disproportionately harm older people and children. However, efforts can be made to reduce locally recognized sources of plant-based allergens; for instance, using fewer male trees to reduce pollen, or avoiding species that cause increased allergic response.

Table 10.—Allergenicity of tree species in the Boston region.

Scientific Name	Common Name	Allergenicity Rating
Abies balsamea	Balsam fir	No allergy reported
Acer buergerianum	Trident maple	Moderate allergen
Acer campestre	Hedge maple	Moderate allergen
Acer ginnala	Amur maple	No allergy reported
Acer griseum	Paperbark maple	Moderate allergen
Acer miyabei	Miyabei maple	Moderate allergen
Acer pensylvanicum	Striped maple	Moderate allergen
Acer platanoides	Norway maple	Moderate allergen
Acer rubrum	Red maple	Moderate allergen
Acer saccharinum	Silver maple	Moderate allergen
Acer saccharum	Sugar maple	Moderate allergen
Aesculus hippocastanum	European horsechesnut	No allergy reported
Amelanchier spp	Serviceberry spp.	Mild allergen
Asimina triloba	Pawpaw	Mild allergen
Betula alleghaniensis	Yellow birch	Moderate allergen
Betula lenta	Sweet birch	Moderate allergen
Betula nigra	River birch	Moderate allergen
Betula papyrifera	Paper birch	Moderate allergen
Betula populifolia	Gray birch	Moderate allergen
Carpinus caroliniana	American hornbeam	Moderate allergen
Carya alba	Mockernut hickory	Severe allergen
Carya cordiformis	Bitternut hickory	Severe allergen
Carya glabra	Pignut hickory	Severe allergen
Carya illinoinensis	Pecan	Severe allergen
Carya laciniosa	Shellbark hickory	Severe allergen
Carya ovata	Shagbark hickory	Severe allergen
Carya texana	Black hickory	Severe allergen
Castanea dentata	American chestnut	Mild allergen
Celtis laevigata	Sugarberry	Moderate allergen
Celtis occidentalis	Hackberry	Moderate allergen
Cercidiphyllum japonicum	Katsura tree	Moderate allergen
Cercis canadensis	Eastern redbud	Mild allergen
Chamaecyparis thyoides	Atlantic white-cedar	Moderate allergen

Scientific Name	Common Name	Allergenicity Rating
Cladrastis kentukea	Yellowwood	No allergy reported
Cornus Florida	Flowering dogwood	Mild allergen
Cornus kousa	Kousa dogwood	Moderate allergen
Crataegus	Hawthorn spp.	Mild allergen
Diospyros virginiana	Common persimmon	Mild allergen
Fagus grandifolia	American beech	Mild allergen
Fraxinus americana	White ash	Severe allergen
Fraxinus pennsylvanica	Green ash	Severe allergen
Ginkgo biloba	Ginkgo	Mild allergen
Gleditsia triacanthos	Honeylocust	Mild allergen
Gymnocladus dioicus	Kentucky Coffeetree	Mild allergen
Ilex opaca	American holly	Mild allergen
Juglans nigra	Eastern black walnut	Severe allergen
Juniperus virginiana	Eastern redcedar	Severe allergen
Koelreuteria paniculata	Golden Raintree	No allergy reported
Liquidambar styraciflua	American Sweetgum	Mild allergen
Liriodendron	Tulip tree	Mild allergen
Maackia amurensis	Amur maackia	Mild allergen
Maclura pomifera	Osage-orange	Moderate allergen
Malus	Crabapple	Mild allergen
Metasequoia	Dawn Redwood	Mild allergen
Morus rubra	Red mulberry	Severe allergen
Nyssa aquatica	Water tupelo	Mild allergen
Nyssa biflora	Swamp tupelo	Mild allergen
Nyssa sylvatica	Blackgum/Black tupelo	Mild allergen
Nyssa sylvatica	Blackgum	Mild allergen
Ostrya virginiana	Eastern hophornbeam/ironwood	Moderate allergen
Oxydendrum arboreum	Sourwood	Mild allergen
Parrotia persica	Persian Ironwood	No allergy reported
Picea abies	Norway Spruce	No allergy reported
Picea glauca	White spruce	No allergy reported
Picea rubens	Red spruce	No allergy reported
Pinus clausa	Sand pine	No allergy reported
Pinus echinata	Shortleaf pine	No allergy reported
Pinus palustris	Longleaf pine	No allergy reported
Pinus resinosa	Red pine	No allergy reported
Pinus rigida	Pitch pine	No allergy reported
Pinus serotina	Pond pine	No allergy reported
Pinus strobus	Eastern white pine	No allergy reported
Pinus taeda	Loblolly pine	No allergy reported
Pinus virginiana	Virginia pine	No allergy reported
Platanus occidentalis	American Sycamore	Moderate allergen
Populus deltoides	Eastern cottonwood	Moderate allergen
Populus grandidentata	Bigtooth aspen	Moderate allergen
Populus tremuloides	Quaking aspen	Moderate allergen
Prunus × yedoensis	Yoshino Cherry	Mild allergen
Prunus pensylvanica	Pin cherry	Mild allergen

Scientific Name	Common Name	Allergenicity Rating
Prunus persica	Peach	Mild allergen
Prunus sargentii	Sargent Cherry	Mild allergen
Prunus serotina	Black cherry	Mild allergen
Prunus serrulata	Kwansan Cherry	Mild allergen
Prunus 'Snowgoose'	Snowgoose Cherry	Mild allergen
Prunus virginiana	Chokecherry	Mild allergen
Prunus x incamp 'Okame'	Okame Cherry	Mild allergen
Pyrus calleryana	Callery Pear	Mild allergen
Quercus alba	White oak	Severe allergen
Quercus bicolor	Swamp White Oak	Severe allergen
Quercus coccinea	Scarlet oak	Severe allergen
Quercus falcata	Southern red oak	Severe allergen
Quercus ilicifolia	Scrub oak	Severe allergen
Quercus imbricaria	Shingle oak	Severe allergen
Quercus laevis	Turkey oak	Severe allergen
Quercus macrocarpa x robur	Heritage Oak	Severe allergen
Quercus marilandica	Blackjack oak	Severe allergen
Quercus michauxii	Swamp chestnut oak	Severe allergen
Quercus muehlenbergii	Chinkapin oak	Severe allergen
Quercus nigra	Water oak	Severe allergen
Quercus pagoda	Cherrybark oak	Severe allergen
Quercus palustris	Pin Oak	Severe allergen
Quercus phellos	Willow oak	Severe allergen
Quercus prinus	Chestnut oak	Severe allergen
Quercus robur	English Oak	Severe allergen
Quercus rubra	Northern red Oak	Severe allergen
Quercus shumardii	Shumard oak	Severe allergen
Quercus stellata	Post oak	Severe allergen
Quercus velutina	Black oak	Severe allergen
Robinia pseudoacacia	Black locust	Mild allergen
Salix babylonica	Weeping willow	Severe allergen
Salix nigra	Black willow	Severe allergen
Sassafras albidum	Sassafras	Mild allergen
Styphnolobium japonicum	Japanese Pagoda Tree	Mild allergen
Syringa reticulata	Japanese Tree Lilac	No allergy reported
Taxodium distichum	Baldcypress	No allergy reported
Thuja occidentalis	Northern white-cedar	Moderate allergen
Tilia americana	American basswood/linden	Moderate allergen
Tilia cordata	Littleleaf linden	Moderate allergen
Tilia tomentosa	Silver linden	Moderate allergen
Tsuga canadensis	Canadian hemlock	No allergy reported
Ulmus alata	Winged elm	Moderate allergen
Ulmus americana	American elm	Moderate allergen
Ulmus crassifolia	Cedar elm	Moderate allergen

Scientific Name	Common Name	Allergenicity Rating
Ulmus parvifolia	Chinese elm	Moderate allergen
Ulmus rubra	Slippery elm	Moderate allergen
Zelkova serrata	Japanese zelkova	Moderate allergen

Overview of Carbon Benefit, Health Benefits & Health Disservices

Trees provide benefits by reducing greenhouse gases in the atmosphere by directly storing carbon in their leaves, wood, and roots, and by helping to reduce energy use for heating and cooling. Carbon benefits provided by each species were modeled for the Boston region and binned into categories based on their relative benefits to one another using data from the i-Tree Species Selector. This tool, available through i-Tree's state-of-the-art, peer-reviewed software suite, helps users select the most appropriate tree species based on potential tree benefits and geographic area.

The following factors were combined to assess carbon benefits:

• **Carbon storage:** the total of all carbon stored during the average lifespan for the species. Larger trees tend to store more carbon.
• **Carbon sequestration rate:** carbon absorption per year. Species that gain a lot of growth per year will have higher sequestration rates.
• **Carbon savings from energy use:** the total amount of carbon saved from reduced heating and cooling energy use. Large shade trees tend to reduce cooling energy use and large conifers tend to reduce heating energy use.

Trees can reduce risks to human health that may be faced under a changing climate, such as heat stress and reduced air quality, by providing shade, cooling through transpiration, and absorption of pollutants. Benefits provided by each species were modeled for the Boston region using data from the i-Tree Species Selector, and binned into categories relative to one another.

The following factors were combined to assess human health benefits:
• **Leaf area:** the maximum leaf area reached over the species' lifespan. Trees with greater leaf area provide more shade and can typically absorb more pollutants.
• **Transpiration:** average transpiration rate per year, which is influenced in part by tree size and differences in water use efficiency. Trees that transpire more can be better at evaporative cooling and mitigating flooding.
• **Pollutants removed:** weighted sum of the pollutants NO_3, O_3 , $PM_{2.5}$ and SO_2 removed over a species' lifespan.

Some trees may need to be considered for their potential negative effects on human health. In particular, some trees produce allergenic pollen or volatile organic compounds such as isoprene or monoterpenes that can reduce air quality. Isoprene and monoterpene emissions for each species were modeled and binned into categories based on their relative health benefits to one another using methods developed for the i-Tree Species Selector. Allergenicity was obtained from pollenlibrary.com.

The following factors were combined to assess human health disservices:
• **Allergenicity**: how likely the tree is to cause allergies. Wind-pollinated trees tend to be more allergenic.
• **Isoprene emissions:** total emissions of isoprene over a species' lifespan. Certain species of broadleaved trees, such as oaks, are known for high isoprene emissions.
• **Monoterpene emissions:** total emissions of monoterpenes over a species' lifespan. Some species, and many conifers in particular, can be high emitters of monoterpenes.

Table 11. Summary of carbon benefit, health benefit, and health disservices for assessed species in the Boston region.

Scientific Name	Common Name	Carbon Benefit	Health Benefit	Health Disservices
Abies balsamea	Balsam fir	Low	Low-moderate	Low-moderate
Abies concolor	White fir	Low	Low-moderate	Low-moderate
Acer buergerianum	Trident maple	Low	Low-moderate	Moderate-high
Acer campestre	Hedge maple	Low	Low-moderate	Moderate-high
Acer griseum	Paperbark maple	Low	Low-moderate	Moderate-high
Acer pensylvanicum	Striped maple	Low	Low-moderate	Moderate-high
Acer platanoides	Norway maple	Moderate	Low-moderate	Moderate-high
Acer rubrum	Red maple	High	Moderate	Moderate-high
Acer saccharinum	Silver maple	Moderate-high	Moderate	Moderate-high
Acer saccharum	Sugar maple	Moderate-high	Low-moderate	Moderate-high
Acer tataricum ginnala	Amur maple	Low	Moderate	Low-moderate
Acer truncatum	Shantung maple, Purpleblow maple	Low	Low-moderate	Moderate-high
Aesculus hippocastanum	European horsechestnut	Moderate-high	Moderate	Moderate
Aesculus x carnea	Red horsechestnut	High	Low-moderate	Moderate
Amelanchier laevis	Allegheny serviceberry	Low	Low	Low
Asimina triloba	Pawpaw	Low	Low-moderate	Low
Betula alleghaniensis	Yellow birch	Moderate-high	Moderate	Moderate
Betula lenta	Sweet birch	High	Moderate	Moderate
Betula nigra	River birch	Moderate-high	Moderate	Moderate
Betula papyrifera	Paper birch	Moderate	High	Moderate
Betula populifolia	Gray birch	Low	Moderate	Moderate
Carpinus betulus	Common hornbeam, European hornbeam	Low	Low-moderate	Moderate
Carpinus caroliniana	Musclewood, American hornbeam	Low	Low-moderate	Moderate

Scientific Name	Common Name	Carbon Benefit	Health Benefit	Health Disservices
Carya cordiformis	Bitternut hickory	Moderate	Moderate-high	Moderate-high
Carya glabra	Pignut hickory	Moderate	Moderate-high	Moderate-high
Carya illinoinensis	Pecan	Moderate	Low-moderate	Moderate-high
Carya laciniosa	Shellbark hickory	Moderate	Moderate	Moderate-high
Carya ovata	Shagbark hickory	Moderate	Moderate	Moderate-high
Carya texana	Black hickory	Moderate-high	Moderate	Moderate-high
Castanea dentata	American chestnut	Moderate	Moderate	Moderate
Catalpa speciosa	Northern catalpa	Moderate	Low-moderate	Low-moderate
Celtis laevigata	Sugarberry	Low	Low-moderate	Moderate
Celtis occidentalis	Common hackberry	Low	Moderate	Moderate
Cercidiphyllum japonicum	Katsura tree	Low-moderate	Moderate-high	Moderate-high
Cercis canadensis	Eastern redbud	Low-moderate	Low-moderate	Low-moderate
Chamaecyparis thyoides	Atlantic white cedar	Low	Moderate	Moderate
Chionanthus virginicus	White fringetree	Low	Low-moderate	Low-moderate
Cladrastis kentukea	Yellowwood	Moderate	Low-moderate	Low-moderate
Cornus florida	Flowering dogwood	Low	Low	Low-moderate
Cornus kousa	Kousa dogwood	Low	Low	Moderate
Cornus mas	Cornelian cherry dogwood	Low	Low	Low-moderate
Corylus colurna	Turkish filbert	High	Moderate	Low-moderate
Cotinus obovatus	American smoketree	Low	Low	Low
Crataegus crus-galli	Cockspur hawthorn	Low	Low	Low-moderate
Crataegus laevigata	English hawthorn	Low	Low	Low-moderate
Crataegus monogyna	Common hawthorn	Low	Low	Low-moderate
Diospyros virginiana	Common persimmon	Moderate	Low	Low-moderate
Eucommia ulmoides	Hardy Rubber Tree	Moderate	Moderate	Low-moderate
Fagus grandifolia	American beech	Moderate-high	Moderate-high	Low-moderate
Fraxinus americana	White ash	High	Low-moderate	Moderate
Fraxinus pennsylvanica	Green ash	Moderate	Moderate	Moderate
Ginkgo biloba	Ginkgo	Low-moderate	Moderate	Moderate
Gleditsia triacanthos	Honeylocust	Moderate	Low-moderate	Low

Scientific Name	Common Name	Carbon Benefit	Health Benefit	Health Disservices
Gymnocladus dioicus	Kentucky coffeetree	Low-moderate	Low-moderate	Low
Halesia tetraptera, Halesia carolina	Carolina silverbell	Low	Moderate	Low
Ilex opaca	American holly	Low	Moderate	Low
Juglans cinerea	Butternut	Low-moderate	Moderate	Low
Juglans nigra	Black walnut	Moderate	Moderate	Moderate-high
Juniperus virginiana	Eastern redcedar	Low	Moderate	Moderate-high
Koelreuteria paniculata	Goldenrain tree	Moderate	Low-moderate	Low-moderate
Liquidambar styraciflua	Sweetgum	Moderate	Moderate	Moderate
Liriodendron tulipifera	Tuliptree	Moderate-high	High	Low-moderate
Maackia amurensis	Amur maackia	Moderate	Low	Moderate
Maclura pomifera	Osage-orange	Low	Low-moderate	Low-moderate
Magnolia acuminata	Cucumbertree	High	Moderate	Moderate
Magnolia virginiana	Sweet bay magnolia	High	Low-moderate	Moderate
Malus sylvestris	Crabapple	Moderate	Moderate	Moderate
Metasequoia glyptostroboides	Dawn redwood	Low-moderate	Moderate	Low
Morus rubra	Red mulberry	Low	Moderate	Moderate-high
Nyssa sylvatica	Black tupelo, Black gum	High	Moderate	Moderate
Ostrya virginiana	Ironwood	Low-moderate	Moderate	Low-moderate
Oxydendrum arboreum	Sourwood	Low	Low	Low-moderate
Parrotia persica	Persian ironwood	Low	Low-moderate	Moderate-high
Picea abies	Norway spruce	Low-moderate	Moderate-high	Low-moderate
Picea glauca	White spruce	Low-moderate	Moderate	Low-moderate
Picea omorika	Serbian spruce	High	Moderate-high	Low-moderate
Picea rubens	Red spruce	Moderate	Moderate	Low-moderate
Pinus cembra	Swiss stone pine	Moderate-high	Low-moderate	Low-moderate
Pinus clausa	Sand pine	Low-moderate	Low-moderate	Low-moderate
Pinus echinata	Shortleaf pine	Low-moderate	Low-moderate	Low-moderate
Pinus palustris	Longleaf pine	Low-moderate	Low-moderate	Low-moderate
Pinus resinosa	Red pine	Moderate	Low-moderate	Low-moderate
Pinus rigida	Pitch pine	Moderate	Low-moderate	Low-moderate
Pinus serotina	Pond pine	Low-moderate	Low-moderate	Low-moderate
Pinus strobus	Eastern white pine	Low-moderate	Moderate	Low-moderate
Pinus taeda	Loblolly pine	Moderate	High	Low-moderate

Scientific Name	Common Name	Carbon Benefit	Health Benefit	Health Disservices
Pinus virginiana	Virginia pine	Moderate	Low-moderate	Low-moderate
Plantanus x acerifolia	London planetree	Moderate-high	High	Low-moderate
Platanus occidentalis	American sycamore	Moderate	High	Low-moderate
Populus deltoides	Eastern cottonwood	High	Moderate	Moderate-high
Populus grandidentata	Bigtooth aspen	High	Moderate	Moderate-high
Populus tremuloides	Quaking aspen	Moderate-high	Moderate-high	Moderate-high
Prunus persica	Peach	Moderate	Moderate	Low-moderate
Prunus sargentii	Sargent cherry	Moderate-high	Moderate	Low-moderate
Prunus serotina	Black cherry	High	Moderate	Low-moderate
Prunus serrulata	Japanese cherry	Low	Low	Low-moderate
Prunus virginiana	Chokecherry	Low	Moderate	Low-moderate
Prunus x yedoensis	Yoshino cherry	Low	Low-moderate	Low-moderate
Pyrus calleryana	Callery pear	Moderate	Moderate	Low-moderate
Quercus alba	White oak	Moderate-high	Moderate	High
Quercus bicolor	Swamp white oak	Moderate	Moderate	High
Quercus coccinea	Scarlet oak	High	Moderate	High
Quercus falcata	Southern red oak	Moderate	Moderate	High
Quercus imbricaria	Shingle oak	Low-moderate	Moderate-high	High
Quercus laevis	Turkey oak	Low-moderate	Moderate-high	High
Quercus macrocarpa	Bur oak	Moderate-high	Moderate	High
Quercus marilandica	Blackjack oak	Low	Moderate	High
Quercus michauxii	Swamp chestnut oak	Moderate	Moderate-high	High
Quercus muehlenbergii	Chinkapin oak	Moderate	Moderate	High
Quercus nigra	Water oak	Moderate	Moderate	High
Quercus pagoda	Cherrybark oak	Moderate	Moderate	High
Quercus palustris	Pin oak	Moderate	High	High
Quercus phellos	Willow oak	High	High	High
Quercus prinus	Chestnut oak	Moderate-high	Moderate	High
Quercus robur	English oak	Moderate	Moderate	High
Quercus rubra	Northern red oak	High	Low-moderate	High
Quercus shumardii	Shumard oak	Moderate	Moderate	High
Quercus stellata	Post oak	Moderate	Moderate	High
Quercus velutina	Black oak	High	Moderate	High
Robinia pseudoacacia	Black locust	Moderate	Low	Moderate

Scientific Name	Common Name	Carbon Benefit	Health Benefit	Health Disservices
Salix babylonica v. matsudana	Corkscrew willow	Moderate	Moderate-high	High
Salix nigra	Black willow	High	Moderate	High
Sassafras albidum	Sassafras	High	Moderate	Moderate
Taxodium distichum	Bald cypress	Moderate	Moderate	Low
Thuja occidentalis	Northern white cedar, Arborvitae	Low	Moderate	Moderate-high
Tilia americana	American linden, Basswood	Moderate	Moderate	Low-moderate
Tilia cordata	Littleleaf linden	Moderate	Low-moderate	Low-moderate
Tilia tomentosa	Silver linden	Low-moderate	Moderate	Low-moderate
Tsuga canadensis	Eastern hemlock	Low-moderate	Moderate	Low-moderate
Ulmus alata	Winged elm	High	Moderate	Moderate
Ulmus americana	American elm	Moderate-high	Moderate	Moderate
Ulmus crassifolia	Cedar elm	High	Low-moderate	Moderate
Ulmus parvifolia	Chinese elm	High	Low-moderate	Moderate
Ulmus rubra	Slippery elm	High	Low-moderate	Moderate
Zelkova serrata	Japanese zelkova	Moderate	Low-moderate	Moderate
Abies balsamea	Balsam fir	Low	Low-moderate	Low-moderate
Abies concolor	White fir	Low	Low-moderate	Low-moderate
Acer buergerianum	Trident maple	Low	Low-moderate	Moderate-high
Acer campestre	Hedge maple	Low	Low-moderate	Moderate-high
Acer griseum	Paperbark maple	Low	Low-moderate	Moderate-high
Acer pensylvanicum	Striped maple	Low	Low-moderate	Moderate-high
Acer platanoides	Norway maple	Moderate	Low-moderate	Moderate-high
Acer rubrum	Red maple	High	Moderate	Moderate-high
Acer saccharinum	Silver maple	Moderate-high	Moderate	Moderate-high
Acer saccharum	Sugar maple	Moderate-high	Low-moderate	Moderate-high
Acer tataricum ginnala	Amur maple	Low	Moderate	Low-moderate
Acer truncatum	Shantung maple, Purpleblow maple	Low	Low-moderate	Moderate-high
Aesculus hippocastanum	European horsechestnut	Moderate-high	Moderate	Moderate
Aesculus x carnea	Red horsechestnut	High	Low-moderate	Moderate
Amelanchier laevis	Allegheny serviceberry	Low	Low	Low
Asimina triloba	Pawpaw	Low	Low-moderate	Low
Betula alleghaniensis	Yellow birch	Moderate-high	Moderate	Moderate
Betula lenta	Sweet birch	High	Moderate	Moderate

Scientific Name	Common Name	Carbon Benefit	Health Benefit	Health Disservices
Betula nigra	River birch	Moderate-high	Moderate	Moderate
Betula papyrifera	Paper birch	Moderate	High	Moderate
Betula populifolia	Gray birch	Low	Moderate	Moderate
Carpinus betulus	Common hornbeam, European hornbeam	Low	Low-moderate	Moderate
Carpinus caroliniana	Musclewood, American hornbeam	Low	Low-moderate	Moderate
Carya cordiformis	Bitternut hickory	Moderate	Moderate-high	Moderate-high
Carya glabra	Pignut hickory	Moderate	Moderate-high	Moderate-high
Carya illinoinensis	Pecan	Moderate	Low-moderate	Moderate-high
Carya laciniosa	Shellbark hickory	Moderate	Moderate	Moderate-high
Carya ovata	Shagbark hickory	Moderate	Moderate	Moderate-high
Carya texana	Black hickory	Moderate-high	Moderate	Moderate-high
Castanea dentata	American chestnut	Moderate	Moderate	Moderate
Catalpa speciosa	Northern catalpa	Moderate	Low-moderate	Low-moderate
Celtis laevigata	Sugarberry	Low	Low-moderate	Moderate
Celtis occidentalis	Common hackberry	Low	Moderate	Moderate
Cercidiphyllum japonicum	Katsura tree	Low-moderate	Moderate-high	Moderate-high
Cercis canadensis	Eastern redbud	Low-moderate	Low-moderate	Low-moderate
Chamaecyparis thyoides	Atlantic white cedar	Low	Moderate	Moderate
Chionanthus virginicus	White fringetree	Low	Low-moderate	Low-moderate
Cladrastis kentukea	Yellowwood	Moderate	Low-moderate	Low-moderate
Cornus florida	Flowering dogwood	Low	Low	Low-moderate
Cornus kousa	Kousa dogwood	Low	Low	Moderate
Cornus mas	Cornelian cherry dogwood	Low	Low	Low-moderate
Corylus colurna	Turkish filbert	High	Moderate	Low-moderate
Cotinus obovatus	American smoketree	Low	Low	Low
Crataegus crus-galli	Cockspur hawthorn	Low	Low	Low-moderate
Crataegus laevigata	English hawthorn	Low	Low	Low-moderate
Crataegus monogyna	Common hawthorn	Low	Low	Low-moderate
Diospyros virginiana	Common persimmon	Moderate	Low	Low-moderate

Scientific Name	**Common Name**	**Carbon Benefit**	**Health Benefit**	**Health Disservices**
Eucommia ulmoides	Hardy Rubber Tree	Moderate	Moderate	Low-moderate
Fagus grandifolia	American beech	Moderate-high	Moderate-high	Low-moderate
Fraxinus americana	White ash	High	Low-moderate	Moderate
Fraxinus pennsylvanica	Green ash	Moderate	Moderate	Moderate
Ginkgo biloba	Ginkgo	Low-moderate	Moderate	Moderate
Gleditsia triacanthos	Honeylocust	Moderate	Low-moderate	Low
Gymnocladus dioicus	Kentucky coffeetree	Low-moderate	Low-moderate	Low
Halesia tetraptera, Halesia carolina	Carolina silverbell	Low	Moderate	Low
Ilex opaca	American holly	Low	Moderate	Low
Juglans cinerea	Butternut	Low-moderate	Moderate	Low
Juglans nigra	Black walnut	Moderate	Moderate	Moderate-high
Juniperus virginiana	Eastern redcedar	Low	Moderate	Moderate-high
Koelreuteria paniculata	Goldenrain tree	Moderate	Low-moderate	Low-moderate
Liquidambar styraciflua	Sweetgum	Moderate	Moderate	Moderate
Liriodendron tulipifera	Tuliptree	Moderate-high	High	Low-moderate
Maackia amurensis	Amur maackia	Moderate	Low	Moderate
Maclura pomifera	Osage-orange	Low	Low-moderate	Low-moderate
Magnolia acuminata	Cucumbertree	High	Moderate	Moderate
Magnolia virginiana	Sweet bay magnolia	High	Low-moderate	Moderate
Malus sylvestris	Crabapple	Moderate	Moderate	Moderate
Metasequoia glyptostroboides	Dawn redwood	Low-moderate	Moderate	Low
Morus rubra	Red mulberry	Low	Moderate	Moderate-high
Nyssa sylvatica	Black tupelo, Black gum	High	Moderate	Moderate
Ostrya virginiana	Ironwood	Low-moderate	Moderate	Low-moderate
Oxydendrum arboreum	Sourwood	Low	Low	Low-moderate
Parrotia persica	Persian ironwood	Low	Low-moderate	Moderate-high
Picea abies	Norway spruce	Low-moderate	Moderate-high	Low-moderate
Picea glauca	White spruce	Low-moderate	Moderate	Low-moderate
Picea omorika	Serbian spruce	High	Moderate-high	Low-moderate
Picea rubens	Red spruce	Moderate	Moderate	Low-moderate
Pinus cembra	Swiss stone pine	Moderate-high	Low-moderate	Low-moderate

Scientific Name	Common Name	Carbon Benefit	Health Benefit	Health Disservices
Pinus clausa	Sand pine	Low-moderate	Low-moderate	Low-moderate
Pinus echinata	Shortleaf pine	Low-moderate	Low-moderate	Low-moderate
Pinus palustris	Longleaf pine	Low-moderate	Low-moderate	Low-moderate
Pinus resinosa	Red pine	Moderate	Low-moderate	Low-moderate
Pinus rigida	Pitch pine	Moderate	Low-moderate	Low-moderate
Pinus serotina	Pond pine	Low-moderate	Low-moderate	Low-moderate
Pinus strobus	Eastern white pine	Low-moderate	Moderate	Low-moderate
Pinus taeda	Loblolly pine	Moderate	High	Low-moderate
Pinus virginiana	Virginia pine	Moderate	Low-moderate	Low-moderate
Plantanus x acerifolia	London planetree	Moderate-high	High	Low-moderate
Platanus occidentalis	American sycamore	Moderate	High	Low-moderate
Populus deltoides	Eastern cottonwood	High	Moderate	Moderate-high
Populus grandidentata	Bigtooth aspen	High	Moderate	Moderate-high
Populus tremuloides	Quaking aspen	Moderate-high	Moderate-high	Moderate-high
Prunus persica	Peach	Moderate	Moderate	Low-moderate
Prunus sargentii	Sargent cherry	Moderate-high	Moderate	Low-moderate
Prunus serotina	Black cherry	High	Moderate	Low-moderate
Prunus serrulata	Japanese cherry	Low	Low	Low-moderate
Prunus virginiana	Chokecherry	Low	Moderate	Low-moderate
Prunus x yedoensis	Yoshino cherry	Low	Low-moderate	Low-moderate
Pyrus calleryana	Callery pear	Moderate	Moderate	Low-moderate
Quercus alba	White oak	Moderate-high	Moderate	High
Quercus bicolor	Swamp white oak	Moderate	Moderate	High
Quercus coccinea	Scarlet oak	High	Moderate	High
Quercus falcata	Southern red oak	Moderate	Moderate	High
Quercus imbricaria	Shingle oak	Low-moderate	Moderate-high	High
Quercus laevis	Turkey oak	Low-moderate	Moderate-high	High
Quercus macrocarpa	Bur oak	Moderate-high	Moderate	High
Quercus marilandica	Blackjack oak	Low	Moderate	High
Quercus michauxii	Swamp chestnut oak	Moderate	Moderate-high	High
Quercus muehlenbergii	Chinkapin oak	Moderate	Moderate	High
Quercus nigra	Water oak	Moderate	Moderate	High
Quercus pagoda	Cherrybark oak	Moderate	Moderate	High
Quercus palustris	Pin oak	Moderate	High	High
Quercus phellos	Willow oak	High	High	High

Scientific Name	Common Name	Carbon Benefit	Health Benefit	Health Disservices
Quercus prinus	Chestnut oak	Moderate-high	Moderate	High
Quercus robur	English oak	Moderate	Moderate	High
Quercus rubra	Northern red oak	High	Low-moderate	High
Quercus shumardii	Shumard oak	Moderate	Moderate	High
Quercus stellata	Post oak	Moderate	Moderate	High
Quercus velutina	Black oak	High	Moderate	High
Robinia pseudoacacia	Black locust	Moderate	Low	Moderate
Salix babylonica v. matsudana	Corkscrew willow	Moderate	Moderate-high	High
Salix nigra	Black willow	High	Moderate	High
Sassafras albidum	Sassafras	High	Moderate	Moderate
Taxodium distichum	Bald cypress	Moderate	Moderate	Low
Thuja occidentalis	Northern white cedar, Arborvitae	Low	Moderate	Moderate-high
Tilia americana	American linden, Basswood	Moderate	Moderate	Low-moderate
Tilia cordata	Littleleaf linden	Moderate	Low-moderate	Low-moderate
Tilia tomentosa	Silver linden	Low-moderate	Moderate	Low-moderate
Tsuga canadensis	Eastern hemlock	Low-moderate	Moderate	Low-moderate
Ulmus alata	Winged elm	High	Moderate	Moderate
Ulmus americana	American elm	Moderate-high	Moderate	Moderate
Ulmus crassifolia	Cedar elm	High	Low-moderate	Moderate
Ulmus parvifolia	Chinese elm	High	Low-moderate	Moderate
Ulmus rubra	Slippery elm	High	Low-moderate	Moderate
Zelkova serrata	Japanese zelkova	Moderate	Low-moderate	Moderate

Management Considerations

A changing climate presents both challenges and opportunities for urban forest management. Increases in temperature, drought, and extreme precipitation events can impact tree species planting lists and current management of existing trees—both native and nonnative species—as well as alter public outreach and engagement efforts. Management considerations may include topics such as, but not limited to: wildlife, biodiversity, street trees, public health, municipal parks, private properties, the nursery industry, landscaping features and green infrastructure, equity and environmental justice, planning and partnerships, and businesses and institutions. Perhaps most critically, ongoing care and maintenance of both existing and newly planted urban trees will be needed to support trees as they cope with the stressors associated with climate change.

When assessing the *vulnerability* of an entire urban forest or ecosystem, you will want to consider how physical factors like elevation or soil type may affect your susceptibility to drought or flooding. You will also want to consider how biological factors like a high proportion of vulnerable trees or the presence of particular pests or diseases may make your impacts more pronounced, as well as human-influenced factors such as the amount of impervious surface, the influence of the urban heat island, or past management in your particular site. When considering the *adaptive capacity* of your urban forest, you will want to consider biological factors such as the amount of biological or genetic diversity of urban forest, economic factors such as the amount of funding available to support urban forestry efforts, organizational factors such as policies and the number of trained staff to do the work, and social factors such as support from the community to assist with tree care and planting. Ecological adaptive capacity factors, such as species diversity, connectivity, age class diversity, and genetic diversity are also important to consider.

To further explore climate adaptation approaches related to the intersection of urban forests, human health, and social equity, browse the full *Climate Adaptation Actions for Urban Forests and Human Health* report (Janowiak et al. 2021). This report is intended to serve a broad audience, including but not limited to: urban forest managers, urban planners, public health professionals, landscape architects, non-profit organizations, and anyone seeking tools and information to help reduce climate risks to urban forests and promote their beneficial functions. It synthesizes adaptation actions to address climate change in urban forest management and promote human health and well-being through nature-based solutions. The report compiles and organizes information from a wide range of peer-reviewed research and evidence-based reports on climate change adaptation, urban forest management, carbon sequestration and storage, and the relationship between human health and urban nature. It does not provide specific recommendations or guidance for any particular place, but offers a range of potential actions for urban forest-based climate adaptation at different scales.

Please note that this assessment is not considered a recommended planting guide. While this report was reviewed by experts in the region and feedback was Incorporated to adjust the adaptability scores as necessary, it is important to take on-the-ground observations into account as decisions are made. We do not make recommendations as to how management should be adjusted for projected changes, but a separate document, *Forest Adaptation Resources: Climate Change Tools* *and Approaches for Land Managers, 2nd edition* (Swanston et al. 2016), has been developed to assist forest managers in a decision-making process to adapt their land management to projected impacts.

Appendices

Appendix 1. Factors for Planted Trees in Developed Areas

We created separate scores for trees planted in developed areas. Factors, scores, and weighting were modified from naturally occurring trees to account for the different environments experienced by trees in more developed areas. Many biological factors were also altered to account for the fact that dispersal and natural reproduction are not typically factors for planted trees. Most information for native species was derived from Burns and Honkala (1990a and 1990b) with supplementary material relevant to cultivated environments from Gilman and Watson (1993). Most information for cultivars and nonnatives was taken from Gilman and Watson (1993). Additional information for wind and ice storm susceptibility were taken from Hauer et al. (2006) and Duryea et al. (2007).

Factors that received a weighted score of less than -4.5 or greater than 4.5 were listed as contributing negatively or positively to the species' overall adaptability score in tables. Weighted scores between these two values were not listed.

Disturbance Factors:
Disease - Accounts for the number and severity of known pathogens that attack a species. If a species is resistant to many pathogens, it is assumed that it will continue to be so in the future. If the mortality rate is low, it is assumed that the species is not greatly affected by diseases. Thus, those species would receive positive scores. Defaults for all species: -1 Score, 0.75 Uncert, and 2 FutureRelevance.

Insect Pests - Accounts for the number and severity of insects that may attack the species. If a species is resistant to attacks from known insect pests now or is adapted to cope with them, then it is assumed to be at least partially resistant in the future. This factor, although highly uncertain in overall effects, is likely to be very important over the next 50 years. Defaults for all species: -1 Score, 0.5 Uncert, and 4 FutureRelevance.

Browse - The extent to which browsing (by deer or other herbivores) has an effect on the species, either positive by promoting growth or by effective strategies for herbivory avoidance, or negative by over-browsing. Defaults for all species: -1 Score (+1 if promoted by browsing), 0.75 Uncert, and 1 FutureRelevance.

Invasive Plants - The effects of invasive plants on the species, either through competition for nutrients or as a pathogen. This factor is not yet well researched as to effects on individual tree species but could be very important in the future as invasives are usually more readily adapted to changing environments and can form monotypic stands that restrict regeneration. Defaults for all species: 0 Score, 0.5 Uncert, and 4 FutureRelevance.

Drought - Extended periods without sufficient access to water. Certain species are better adapted to drier conditions, allowing them to survive more frequent or prolonged droughts. Defaults for all species: -1 Score, 0.75 Uncert, and 3 FutureRelevance.

Flood - Frequent or prolonged periods of standing water. Species adapted to sustained flooding will be positively affected while species vulnerable to flooding will be negatively affected by the assumed greater flooding exposures under climate change. Defaults for all species: -1 Score, 0.75 Uncert, and 4 FutureRelevance.

Ice - The damaging effects of ice storms and potential for ice heaving on a species. Defaults for all species: -1 Score, 0.5 Uncert, and 2 FutureRelevance.

Wind - The damaging effects of windstorms and uprooting potential (and top breakage) of a species: -1 Score, 0.75 Uncert, and 2 FutureRelevance. If a species is susceptible to windthrow, the standard default is -2 (Score); if resistant to windthrow, Score is +1.

Temperature Gradients - The effects of variations in the temperature gradient associated with a species. Species that currently occupy regions with a diverse range of temperatures are assumed to be better adapted to warmer and highly variable climates than species occupying regions with a small range of temperatures. Defaults for all species: 1 Score, 0.75 Uncert, and 3 FutureRelevance.

Air Pollution - Airborne pollutants that affect, mostly negatively, a species' growth, health, and distribution. Includes acid rain, ozone. Defaults for all species: -3 Score, 0.75 Uncert, and 3 FutureRelevance.

Soil/Water Pollution - Pollutants in the soil and water that affect, mostly negatively, a species' growth, health, and distribution. Defaults for all species: -2 Score, 0.5 Uncert, and 1 FutureRelevance.

Biological Factors:
Competition-Light - The tolerance of a species toward light. Does the species grow better in shade, partial shade, or full sun? Default values depend on species tolerance level, and all with FutureRelevance of 3. Species intolerant to shade receive -3 (Score) 0.75 (Uncert), Intermediate either -1, 0, 1 (Score) 0.5 (Uncert). Intermediate default is 0, with flexibility to go +1 or -1. Tolerant species have scores of +3 (Score) 0.75 (Uncert).

Edaphic Specificity - The specific soil requirements (e.g., pH, texture, organic content, horizon thickness, permeability) for a species to survive in a suitable habitat. Includes long-term soil moisture capacities of the soil. Species with general requirements have positive scores, and species with specific requirements have negative defaults. Unsuitable soils north of the current range of a species can be a barrier to migration. Defaults for all species: 0 Score, 0.75 Uncert, and 2 FutureRelevance.

Land-Use/Planting Site Specificity - The ability for the species to be planted in a variety of site types (street, residential, park, campus). Also considers the range of non-edaphic environmental characteristics (e.g., slope, aspect, topographic position, climatic modulation, specific associates) that the species requires. Defaults for all species: 0 Score, 0.75 Uncert, and 3 FutureRelevance.

Restricted Rooting Conditions and Soil Compaction - The ability of a species to grow and survive in narrow boulevards and other constrained spaces. Defaults for all species: -1 Score, 0.75 Uncert, and 3 FutureRelevance.

Nursery Propagation - The ease and/or cost of producing the species in a nursery. Also relates to how widely available it is. Future Relevance is high for this factor because it will largely determine the extent to which the species is widely propagated and planted. For all species: 0.75 Uncert, and 4 FutureRelevance. If stock is widely available, Score is +2. If not currently available, Score is -2.

Planting Establishment - The ease with which the species establishes itself after planting. Also relates to the amount of care required to establish. Defaults for all species: 1 Score, 0.75 Uncert, and 2 FutureRelevance. -1 Score if not easily established.

Maintenance Required - The degree to which pruning or other maintenance is needed after establishment. Negative score indicates that maintenance is required. Defaults for all species: -1 Score, 0.75 Uncert, and 2 FutureRelevance. 1 Score if minimal maintenance required.

Invasive Potential - Likelihood the species could become invasive if planted. Applies to both native and nonnative species. Negative score indicates that a species is known to be or has the potential to be invasive. Defaults for all species: 0 Score, 0.75 Uncert, and 3 FutureRelevance. -3 Score if species is known to be invasive.

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