PUGET SOUND REGION: TREE SPECIES VULNERABILITY ASSESSMENT

Annamarie Rutledge and Leslie Brandt

ABSTRACT

As the climate changes over the 21st century, the Puget Sound region's urban forest will be impacted by changing temperatures and precipitation regimes, leading to implications for the people who depend on its ecosystem services. This report summarizes climate change projections for the Puget Sound region and provides an assessment of tree species vulnerability in the region. We used projected shifts in plant hardiness and heat zones to understand how tree species of interest are projected to tolerate future conditions. We also assessed the adaptability of planted trees to stressors such as drought, flooding, wind damage, and air pollution, as well as environmental conditions such as shade, soils, and restricted rooting using "modification factors"—an adaptability scoring system for planted environments. The region has been warming at a rate of about 0.4°F per decade since 1960, and the average temperature is projected to increase by 5.0°F to 8.6°F by the end of the century compared with the 1971-2000 historical average. Precipitation in the region has been increasing by over 0.5 inches per decade since 1960 and is projected to increase by 2.1 to 3.2 inches by the end of the century compared with the 1971-2000 historical average. By the end of the century, the Puget Sound region is projected to shift from hardiness zones 8-9 to zone 9 completely, and from heat zone 2 to heat zone 3 (RCP4.5) or 6 (RCP8.5), depending on the climate change scenario. Of the evaluated tree species, 27% were rated as having high adaptability, 59% were rated as having medium adaptability, and 14% were rated as having low adaptability. Given that the hardiness zone range is projected to remain within the historical (1980-2009) range, we considered both heat zones alone as well as heat and hardiness zones. Considering heat zones only, most of the assessed tree species fell into the low-moderate vulnerability category (57%), followed by low vulnerability (26%) and moderate vulnerability (17%) under both low and high climate change scenarios. The vulnerability ratings remain the same between low and high climate change scenarios because all assessed tree species are considered suitable under both sets (low and high) of heat zone projections through the end of the century. Considering both heat and hardiness zones, most of the assessed tree species fell into the moderate-high vulnerability category (34%), followed by low-moderate (25%), moderate (18%), low (14%), and high (9%). The vulnerability ratings are the same between low and high climate change scenarios because the projected hardiness zone is the same under both scenarios through the end of the century. The vulnerability of individual species is not the only factor to consider when making urban forestry decisions, and this assessment also contains species diversity and human health as additional factors. 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.

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INTRODUCTION

Context

This assessment was created as part of the Urban Forestry Climate Change Response Framework project (www.forestadaptation.org/urban). The Climate Change Response Framework is a collaborative, cross-boundary approach among scientists, managers, and landowners to incorporate climate change considerations into natural resource management. The Urban Forestry Framework efforts were first developed in Chicago and have since been expanded to other regions and metropolitan areas to help address urban forest vulnerability for cities in the United States and create tools to help local managers adapt to the effects of climate change.

Scope and Goals

The overarching goal of the Urban Forestry Climate Change Response Framework project is to incorporate climate change considerations into forest management to ensure that urban forests will continue to provide benefits to the people who live in urban communities as the climate changes. 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 Puget Sound Tree Species Vulnerability Assessment 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) to provide an overview of climate observations and projections, as well as tree species vulnerability and additional considerations for the urban forest. The tools and approaches developed in the Urban Forestry Framework project were originally designed to be applied to areas in the Midwest and Northeast. This report expands that work to the Pacific Northwest and focuses on the tree species vulnerability component of previous climate vulnerability assessments (Brandt et al. 2017, 2020).

The assessment focuses on three components: climate observations and projections, tree species vulnerability, and additional considerations. We designed the assessment to be a synthesis of the best available scientific information on tree species that are in the region or under consideration for planting. Its primary goal is to summarize the potential changes to the urban forest of the Puget Sound region under a range of future climates and determine the vulnerability of trees in planted landscapes to those changes. The assessment was developed to inform those that work, study, recreate, and care about the urban forests and natural areas in the Puget Sound region to ensure that urban forests will continue to provide benefits to the people who live in urban communities as the climate changes. As new scientific information arises, we expect that new 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 applied to decision-making.

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Chapter 1: Climate Observations and Projections

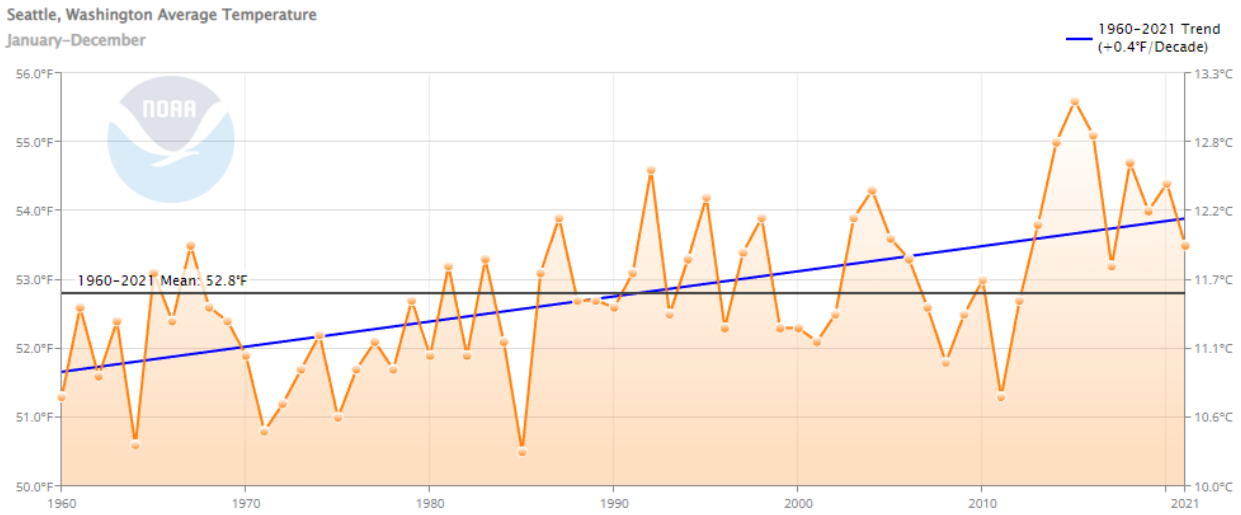
Climate, the average weather over a long-term period for a particular location, can change substantially over hundreds and thousands of years. Precipitation and temperature are changing at a global scale, and the rate is projected to increase in the coming decades. However, these changes will impact different locations 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 Seattle, Washington.

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 Temperature Trends

The average annual temperature in Seattle has increased by 0.4°F per decade since 1960, and the average annual minimum (+0.3°F/decade) and maximum (+0.4°F/decade) temperatures follow a similar trend (Figure 1; NOAA, 2022). The trend varies by season, increasing the most in March to May (+0.5°F/decade) and June to August (+0.5°F/decade). Temperature has increased by 0.3°F per decade from September to November and by 0.2°F per decade from December to February.



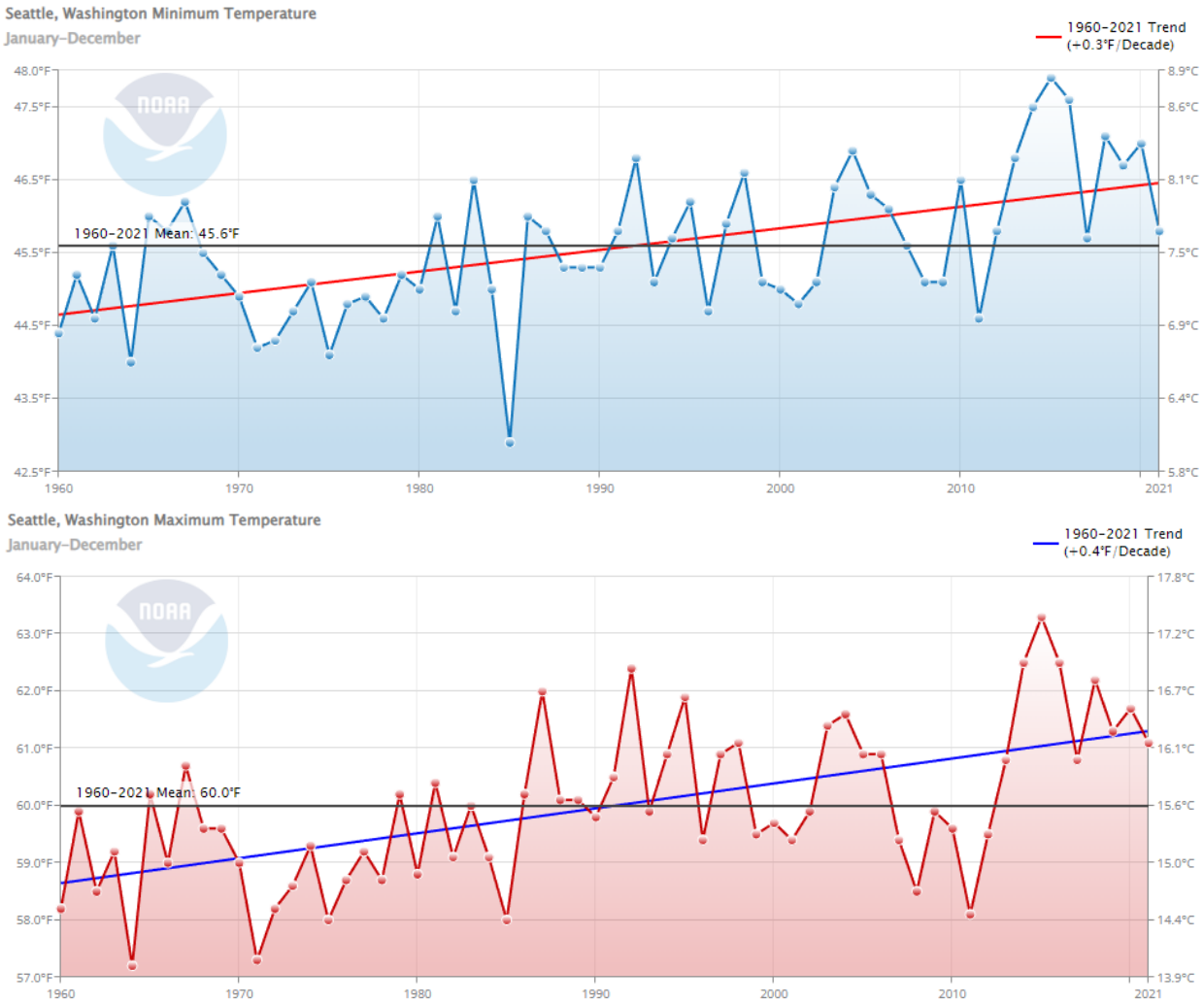


Figure 1.—Changes in annual (January to December) temperature over the observational record from 1960 to 2020 for Seattle, Washington, including average (top), minimum (middle), and maximum (bottom) temperatures. The gray line indicates the 1960 to 1990 average, and the blue line shows the trend over the observational record (NOAA, 2022).

Observed Precipitation Trends

Annual precipitation in Seattle has increased by over 0.5 inches per decade since 1960 (Figure 2; NOAA, 2022). This trend varies by season. Precipitation has increased the greatest in September to November (+0.41 inches/decade) followed by March to May (+0.35 inches/decade). Precipitation has decreased overall from June to August (-0.16 inches/decade) as well as December to February (-0.04 inches/decade).

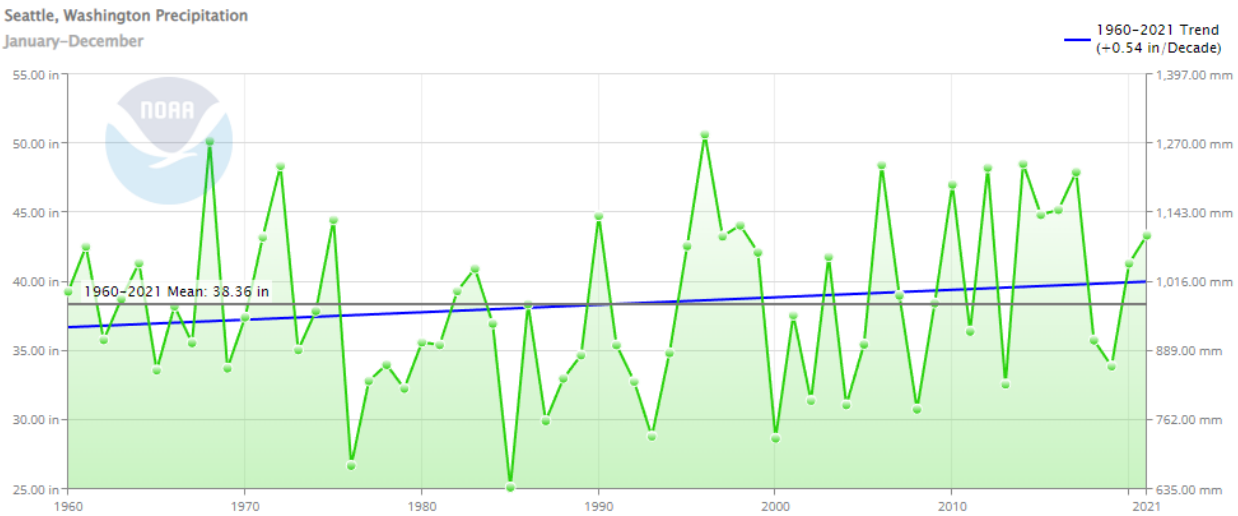


Figure 2.—Changes in annual (January to December) precipitation over the observational record from 1960 to 2020 for Seattle, Washington, including average, minimum, and maximum temperatures. The gray line indicates the 1960 to 1990 average, and the blue line shows the trend over the observational record (NOAA, 2022).

Snowfall on street trees in the Ballard Neighborhood of Seattle, Washington. Photo by amidfallenleaves, Flickr.

Climate Projections

Temperature and precipitation projections were obtained from the Climate Toolbox's Climate Mapper (https://climatetoolbox.org/tool/climate-mapper), which provides future projections of climate conditions for locations across the United States. Values presented in this section indicate the multi-model mean derived from 20 downscaled CMIP5 models for Seattle, Washington (47.6062°N, 122.3321°W).

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 (Figure 3, Appendix 1). Annual mean temperature is projected to increase by 5.0°F by the end of the century under a low climate change scenario and by as much as 8.6°F by the end of the century under a high climate change scenario.

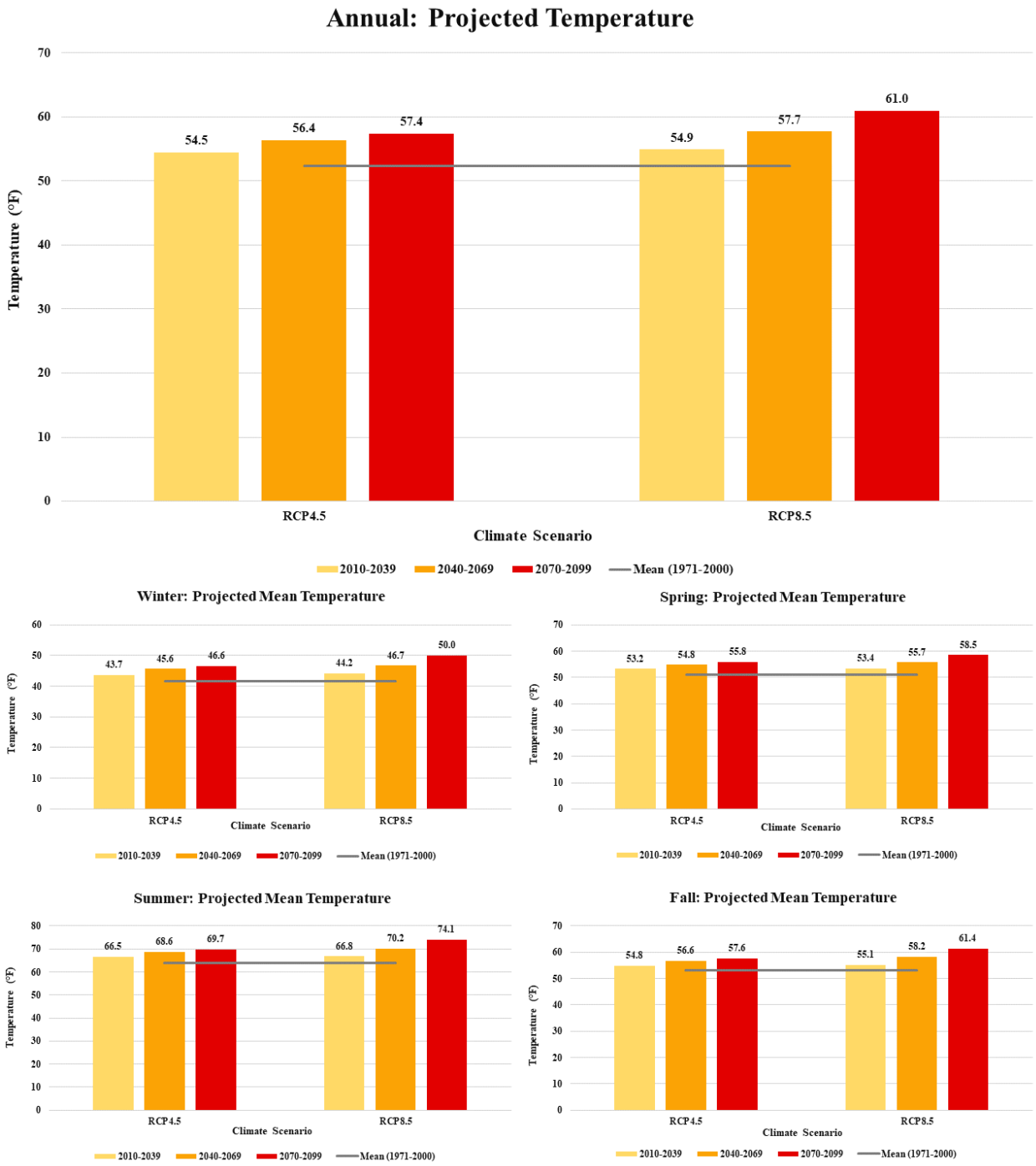


Figure 3.—Projected temperature in Seattle, Washington under RCP 4.5 and RCP 8.5 climate change scenarios. Values indicate the multi-model mean derived from 20 downscaled CMIP5 models. The gray line represents the mean (1971-2000). Data retrieved from https://climatetoolbox.org/tool/climate-mapper

Precipitation Projections

Precipitation is projected to increase under both low (RCP 4.5) and high (RCP 8.5) climate change scenarios through the end of the century in the winter, spring, and fall, while decreasing in the summer by

as much as -0.6 inches (Figure 4, Appendix 1). Annual precipitation is projected to increase by 2.1 inches by the end of the century under a low climate change scenario, and by as much as 3.2 inches by the end of the century under a high climate change scenario.

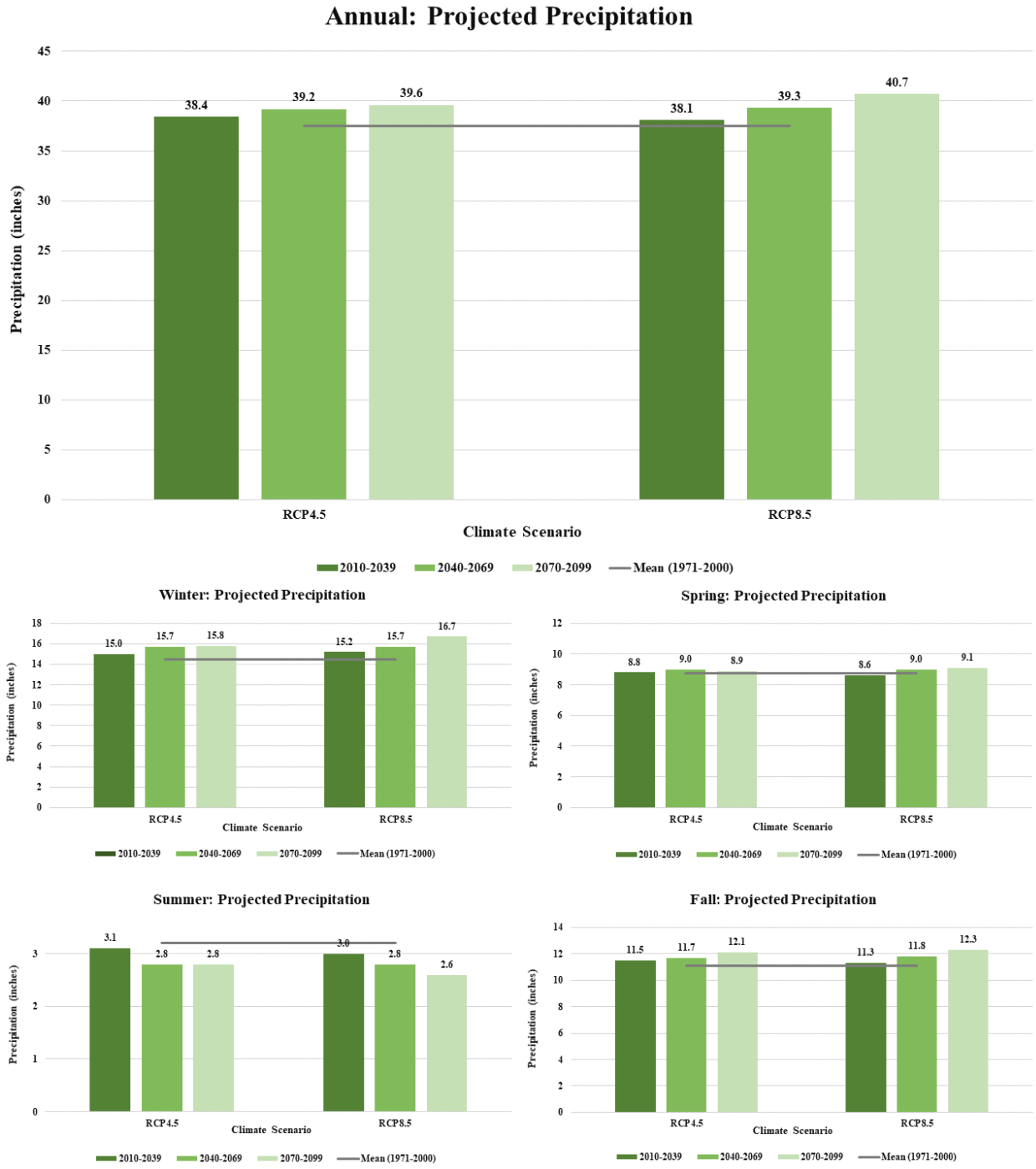


Figure 4.—Projected precipitation in Seattle, Washington under RCP 4.5 and RCP 8.5 climate change scenarios. Values indicate the multi-model mean derived from 20 downscaled CMIP5 models. The gray line represents the mean (1971-2000). Data retrieved from https://climatetoolbox.org/tool/climate-mapper.

Chapter 2: Tree Species Vulnerability

Changes in climate have the potential to profoundly affect the Puget Sound Region's trees. 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. 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 document summarizes expected changes in habitat suitability and the adaptive capacity of different species in the region's developed areas. A complete list of tree species assessed can be found in Appendix 2.

Trees in Parsons Gardens Park in Seattle, Washington. Photo by Steve Ginn, Flickr.

Shifts in Heat and Hardiness Zones

Heat zones and plant 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, plant 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. The plant hardiness zone map is based on minimum annual temperature and helps to identify plants that may or may not be adapted to withstand winter cold temperatures. It was published in 1990 (Cathey 1990) and updated in 2003 (Ellis 2003) and 2010 (Daly et al. 2012). 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, 2020).

The American Horticultural Society established heat zones for determining the upper temperature limits that trees are able to tolerate (Cathey 1997). The heat zone map is based on the number of days exceeding 86°F (30°C) and is used to determine heat stress on plants. The Puget Sound Region is historically (1980-2009) in heat zone 2 (1 to 7 days exceeding 30°C). Under the low climate change scenario, RCP 4.5, which assumes a reduction in global emissions of greenhouse gases, the heat zone is projected to stay in heat zone 2 through 2039 and shift to zone 3 (>7 to 14 days exceeding 30°C) by 2040-2069, remaining in zone 3 through 2099 (Table 1). Under the high climate change scenario, RCP 8.5, the heat zone is projected to shift to zone 3 by 2039, zone 4 (>14-30 days exceeding 30°C) by 2040-2069, and zone 6 (>45-60 days exceeding 30°C) by 2070-2099.

The Puget Sound Region is historically (1980-2009) in plant hardiness zones 8 (-12.2°C to -6.7°C) to 9 (-6.7°C to -1.1°C). Future hardiness and heat zones were obtained from Matthews et al. (2018). Under the RCP 4.5 scenario, which assumes a reduction in global emissions of greenhouse gases, the hardiness zone is projected to stay in zones 8-9 in the Puget Sound Region by 2039 and shift completely to zone 9 by 2040-2069 (Table 1). Under the high climate change scenario, RCP 8.5, the hardiness zone is projected to shift completely to zone 9 by 2039 and remain in zone 9 through 2099. See Appendix 3 for additional information on heat and hardiness zones.

Table 1.—Heat and hardiness zone shifts by climate change scenario (RCP4.5 and RCP8.5) and time period (2010-2039, 2040-2069, and 2070-2099) compared with the 1980-2009 ranges. Future heat and hardiness zones were obtained from Matthews et al. (2018).

Time Period	**Heat Zone Range**		**Hardiness Zone Range**	
1980-2009	Zone 2		Zones 8-9	
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
2010-2039	Zones 2	Zone 3	Zones 8-9	Zone 9
2040-2069	Zone 3	Zone 4	Zone 9	Zone 9
2070-2099	Zone 3	Zone 6	Zone 9	Zone 9

Projected Habitat Suitability from Heat and Hardiness Zones

Model information is not available for all species and cultivars that are found in the Puget Sound region nor for some of the species being considered for future planting. These species usually either are 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 and hardiness zone ranges of the species to see how they compare with 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 consider changes in precipitation, seasonal climate changes, and other habitat requirements such as soil texture. This analysis is meant to provide only a coarse estimate of potential changes in habitat

suitability based on temperature extremes. Although the defined heat and hardiness zones for each species were used in this analysis, it is possible that species can survive in zones above the defined maximum, as the viability of individual trees are impacted by local variations. In addition, some species not currently present in the region could potentially be planted as hardiness zones shift slightly in the Puget Sound region, and approach called assisted migration (Handler et al. 2018).

Blooming cherry tree under the clouds in Portage Bay, Seattle, Washington. Photo by amidfallenleaves, Flickr.

Heat zones were primarily obtained from Gardenia.net and hardiness zones were obtained from a variety of resources including the U.S. Forest Service, Arbor Day Foundation, Morton Arboretum, and university websites. Hardiness zones for Pacific Northwest species were obtained from Washington State University (Board of Regents, Washington State University 2022). For this assessment, we assessed trees based on heat zone suitability alone, as well as combined heat and hardiness zone suitability. We evaluated heat zones separately because the region is already above the minimum hardiness requirements for most temperate tree species and because hardiness zones were not projected to change considerably (Table 1). Zone suitability was determined by the current and projected heat zones for the Puget Sound region through the end of the century. Trees were considered suitable if the following criteria are met for the species:

- minimum hardiness zone tolerance is less than or equal to the current hardiness zone,
- maximum hardiness zone tolerance greater than or equal to the projected hardiness zone, and
- heat zone tolerance is greater than or equal to the projected heat zone.

For some species, heat zone data were not available and hardiness zone data were used alone.

For heat zone suitability, tree species were considered suitable under the low climate change scenario if its maximum heat zone was 3 or greater, indicating it can tolerate the projected average yearly number of 7 to 14 days with temperatures over 86 °F (Table 2). Tree species were considered suitable under the high climate change scenario if its maximum heat zone was 6 or greater, indicating it can tolerate the projected average yearly number of 45 to 60 days with temperatures over 86 °F. Using only the heat zone projections, all tree species assessed for the Puget Sound region were considered suitable under both low and high climate change scenarios through the end of the century.

For combined heat and hardiness zone suitability (Table 2), tree species were considered suitable under the low climate change scenario if:

- Its maximum heat zone was 3 or greater, indicating it can tolerate the projected average yearly number of 7 to 14 days with temperatures over 86 °F,
- its minimum hardiness zone was 9 or lower, indicating it can tolerate average annual minimum winter temperatures of 20 °F to 30 °F or lower, and
- its maximum hardiness zone was 9 or greater, indicating that average annual minimum winter temperatures of 20 °F to 30 °F or greater are sufficient to meet any physiological requirements for chilling or cold temperatures.

For example, with a hardiness range of 4-8 and maximum heat zone of 7, Douglas fir was considered "Not Suitable" because its maximum hardiness zone (8) is not 9 or greater. Western red cedar was considered "Suitable" with a hardiness range of 6-9 and maximum heat zone of 8 because its maximum heat zone (8) is greater than 3, its minimum hardiness zone (6) is less than 9, and its maximum hardiness (9), is 9 or greater.

The species was considered suitable under the high climate change scenario if:

- Its maximum heat zone was 6 or greater, indicating it can tolerate the projected average yearly number of 45 to 60 days with temperatures over 86 °F,
- its minimum hardiness zone was 9 or lower, indicating it can tolerate average annual minimum winter temperatures of 20 °F to 30 °F or lower, and
- its maximum hardiness was 9 or greater, indicating it that average annual minimum winter temperatures of 20 °F to 30 °F or greater are sufficient to meet any physiological requirements for chilling or cold temperatures (Table 2).

These minima and maxima were determined by the current and projected heat and hardiness zones for the Puget Sound region through the end of the century (Table 1).

For the Puget Sound region, the heat and hardiness zone suitability results were the same under the low and high climate change scenarios because all species were considered suitable given the projected changes in heat zones and there is little projected change in plant hardiness zones. Under both scenarios, 101 (56%) of the assessed tree species are not expected to be suitable and 84 (44%) of the assessed tree species are expected to be suitable through the end of the century.

Table 2.—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 Puget Sound region or are being considered for planting in the area. PNW = native to Pacific Northwest, NA = native to North America, No = not native to North America. If the heat zone was not defined for a species, suitability was based solely on hardiness zone.

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Abies concolor	White fir	PNW	3-9	1-7	Suitable	Suitable	Suitable	Suitable
Abies grandis	Grand fir	PNW	4-8	5-6	Suitable	Suitable	Not Suitable	Not Suitable
Abies procera	Noble fir	PNW	5-9	5-6	Suitable	Suitable	Suitable	Suitable
Acer buergerianum	Trident maple	No	5-9	5-9	Suitable	Suitable	Suitable	Suitable
Acer circinatum	Vine maple	PNW	6-9	4-9	Suitable	Suitable	Suitable	Suitable
Acer freemanii	Freeman maple	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Acer griseum	Paperbark maple	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Acer macrophyllum	Big leaf maple	PNW	5-9	4-9	Suitable	Suitable	Suitable	Suitable
Acer miyabei	Miyabe's maple	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Acer negundo	Boxelder	NA	2-10	3-8	Suitable	Suitable	Suitable	Suitable
Acer nigrum	Black maple	NA	4-8	3-8	Suitable	Suitable	Not Suitable	Not Suitable
Acer palmatum	Japanese maple	No	5-9	2-8	Suitable	Suitable	Suitable	Suitable
Acer platanoides	Norway maple	No	4-7	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Acer pseudoplatanus	Sycamore maple	No	5-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Acer rubrum	Red maple	NA	3-9	1-9	Suitable	Suitable	Suitable	Suitable
Acer saccharinum	Silver maple	NA	3-9	1-8	Suitable	Suitable	Suitable	Suitable
Acer saccharum	Sugar maple	NA	3-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Acer tataricum	Tatarian maple	No	3-8	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Acer triflorum	Three-flower maple	No	5-7	5-7	Suitable	Suitable	Not Suitable	Not Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Acer truncatum	Shantung maple	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Aesculus flava	Yellow buckeye	NA	3-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Aesculus hippocastanum	Horse chestnut	No	3-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Ailanthus altissima	Tree of heaven	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Albizia julibrissin	Persian silk tree	No	6-9	6-9	Suitable	Suitable	Suitable	Suitable
Alnus rubra	Red alder	PNW	5-8	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Amelanchier arborea	Downy serviceberry	NA	4-9	1-9	Suitable	Suitable	Suitable	Suitable
Amelanchier laevis	Allegheny serviceberry	NA	3-9	3-9	Suitable	Suitable	Suitable	Suitable
Arbutus menziesii	Pacific madrone	PNW	7-9	7-9	Suitable	Suitable	Suitable	Suitable
Arbutus unedo	Strawberry tree	NA	6-9	6-9	Suitable	Suitable	Suitable	Suitable
Betula alleghaniensis	Swamp birch	NA	3-7	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Betula nigra	River birch	NA	4-9	1-9	Suitable	Suitable	Suitable	Suitable
Betula papyrifera	Paper birch	PNW	2-9	1-7	Suitable	Suitable	Suitable	Suitable
Betula pendula	Silver birch	No	2-7	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Betula populifolia	Gray birch	NA	3-6	1-6	Suitable	Suitable	Not Suitable	Not Suitable
Carpinus betulus	European hornbeam	No	4-9	1-8	Suitable	Suitable	Suitable	Suitable
Carpinus caroliniana	American hornbeam	NA	3-9	1-9	Suitable	Suitable	Suitable	Suitable
Castanea mollissima	Chinese chestnut	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Castanea sativa	Sweet chestnut	No	6-7	5-7	Suitable	Suitable	Not Suitable	Not Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Catalpa bignonioides	Southern catalpa	NA	5-9	5-9	Suitable	Suitable	Suitable	Suitable
Catalpa speciosa	Northern catalpa	NA	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Celtis occidentalis	Common hackberry	NA	2-9	1-9	Suitable	Suitable	Suitable	Suitable
Cercidiphyllum japonicum	Katsura tree	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Cercis canadensis	Eastern redbud	NA	4-9	6-9	Suitable	Suitable	Suitable	Suitable
Chamaecyparis lawsoniana	Lawson's cypress	NA	5-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Chamaecyparis nootkatensis	Nootka cypress	PNW	4-8	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Chamaecyparis obtusa	Hinoki cypress	No	5-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Chamaecyparis pisifera	Sawara cypress	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Chionanthus retusus	Chinese fringetree	No	5-9	3-9	Suitable	Suitable	Suitable	Suitable
Cladrastis kentukea	Yellowwood	NA	4-8	1-9	Suitable	Suitable	Not Suitable	Not Suitable
Cornus florida	Flowering dogwood	NA	6-9	3-9	Suitable	Suitable	Suitable	Suitable
Cornus kousa	Kousa dogwood	No	5-8	5-8	Suitable	Suitable	Not Suitable	Not Suitable
Cornus mas	Cornelian cherry	No	4-8	5-8	Suitable	Suitable	Not Suitable	Not Suitable
Cornus nuttallii	Pacific dogwood	PNW	7-9	3-8	Suitable	Suitable	Suitable	Suitable
Corylus avellana	Common hazel / European filbert	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Corylus colurna	Turkish filbert	No	4-7	4-7	Suitable	Suitable	Not Suitable	Not Suitable
Cotinus coggygria	Smoke tree	No	4-8	3-9	Suitable	Suitable	Not Suitable	Not Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Cotinus obovatus	American smoke tree	NA	5-8	1-9	Suitable	Suitable	Not Suitable	Not Suitable
Crataegus crus-galli	Cockspur hawthorn	NA	3-7	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Crataegus laevigata	Midland hawthorn / English hawthorn	No	4-8	3-8	Suitable	Suitable	Not Suitable	Not Suitable
Crataegus monogyna	Common hawthorn	No	5-7	4-7	Suitable	Suitable	Not Suitable	Not Suitable
Crataegus phaenopyrum	Washington hawthorn	NA	3-9	1-8	Suitable	Suitable	Suitable	Suitable
Cupressus sempervirens	Mediterranean cypress	No	7-11	3-9	Suitable	Suitable	Suitable	Suitable
Elaeagnus angustifolia	Russian olive	No	3-7	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Eucommia ulmoides	Hardy rubber tree	No	4-7	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Fagus grandifolia	American beech	NA	4-9	1-9	Suitable	Suitable	Suitable	Suitable
Fagus sylvatica	Green beech	No	5-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Ficus carica	Common fig	No	6-10	6-9	Suitable	Suitable	Suitable	Suitable
Fraxinus americana	White ash	NA	4-9	1-10	Suitable	Suitable	Suitable	Suitable
Fraxinus angustifolia	Narrow-leafed ash	No	5-8	4-9	Suitable	Suitable	Not Suitable	Not Suitable
Fraxinus excelsior	European ash	No	5-7	3-8	Suitable	Suitable	Not Suitable	Not Suitable
Fraxinus latifolia	Oregon ash	PNW	6-8	6-8	Suitable	Suitable	Not Suitable	Not Suitable
Fraxinus pennsylvanica	Green ash	NA	3-9	1-9	Suitable	Suitable	Suitable	Suitable
Ginkgo biloba	Ginkgo / Maidenhair	No	4-8	3-9	Suitable	Suitable	Not Suitable	Not Suitable
Gleditsia triacanthos	Honey locust	NA	4-8	1-9	Suitable	Suitable	Not Suitable	Not Suitable
Gymnocladus dioicus	Kentucky coffeetree	NA	4-8	2-9	Suitable	Suitable	Not Suitable	Not Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Hamamelis virginiana	American witch-hazel	NA	3-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Hesperocyparis arizonica	Arizona cypress	NA	7-9	2-9	Suitable	Suitable	Suitable	Suitable
Hibiscus syriacus	Common hibiscus	No	5-8	1-9	Suitable	Suitable	Not Suitable	Not Suitable
Ilex aquifolium	Common holly	No	7-9	7-9	Suitable	Suitable	Suitable	Suitable
Juglans nigra	Black walnut	NA	4-9	3-9	Suitable	Suitable	Suitable	Suitable
Juglans regia	English walnut	NA	4-8	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Juniperus chinensis	Chinese juniper	No	4-9	1-9	Suitable	Suitable	Suitable	Suitable
Juniperus virginiana	Eastern red cedar	NA	3-9	1-9	Suitable	Suitable	Suitable	Suitable
Koelreuteria paniculata	Goldenrain tree	No	5-9	1-9	Suitable	Suitable	Suitable	Suitable
Laburnum anagyroides	Common laburnum	No	5-7	5-8	Suitable	Suitable	Not Suitable	Not Suitable
Lagerstroemia indica	Crepe myrtle	No	7-9	6-9	Suitable	Suitable	Suitable	Suitable
Larix decidua	European larch	No	3-6	1-6	Suitable	Suitable	Not Suitable	Not Suitable
Ligustrum japonicum	Wax-leaf privet / Japanese privet	No	7-10	7-10	Suitable	Suitable	Suitable	Suitable
Ligustrum lucidum	Glossy privet	No	8-10	8-10	Suitable	Suitable	Suitable	Suitable
Liquidambar styraciflua	Sweetgum	NA	5-9	1-10	Suitable	Suitable	Suitable	Suitable
Liriodendron tulipifera	Tulip tree	NA	5-7	2-9	Suitable	Suitable	Not Suitable	Not Suitable
Maackia amurensis	Amur maackia	No	3-7	4-7	Suitable	Suitable	Not Suitable	Not Suitable
Magnolia grandiflora	Southern magnolia	NA	7-10	1-11	Suitable	Suitable	Suitable	Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Magnolia kobus	Kobus magnolia	No	5-8	Not Defined	—	—	Not Suitable	Not Suitable
Malus domestica	Edible apple	No	3-8	1-9	Suitable	Suitable	Not Suitable	Not Suitable
Malus spp.	Crabapple	No	3-8	1-9	Suitable	Suitable	Not Suitable	Not Suitable
Metasequoia glyptostroboides	Dawn redwood	No	4-10	5-10	Suitable	Suitable	Suitable	Suitable
Morus alba	White mulberry	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Nyssa sylvatica	Tupelo	NA	3-9	7-9	Suitable	Suitable	Suitable	Suitable
Olea europaea	European olive	No	8-10	8-10	Suitable	Suitable	Suitable	Suitable
Ostrya virginiana	Ironwood	NA	3-9	5-9	Suitable	Suitable	Suitable	Suitable
Oxydendrum arboreum	Sourwood	NA	5-9	3-9	Suitable	Suitable	Suitable	Suitable
Parrotia persica	Persian parrotia	No	5-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Paulownia tomentosa	Empress tree	No	5-9	4-8	Suitable	Suitable	Suitable	Suitable
Picea abies	Norway spruce	No	3-7	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Picea glauca	White spruce	NA	2-6	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Picea omorika	Serbian spruce	No	4-7	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Picea pungens	Colorado spruce	NA	2-7	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Pinus banksiana	Jack pine	NA	2-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Pinus halepensis	Aleppo pine	No	8-11	1-10	Suitable	Suitable	Suitable	Suitable
Pinus mugo	Sweet mountain pine	No	3-8	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Pinus nigra	Austrian pine	No	4-7	1-8	Suitable	Suitable	Not Suitable	Not Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Pinus parviflora	Japanese white pine	No	6-9	1-9	Suitable	Suitable	Suitable	Suitable
Pinus pinea	Italian stone pine	No	7-11	9-12	Suitable	Suitable	Suitable	Suitable
Pinus ponderosa	Ponderosa pine	PNW	3-8	4-8	Suitable	Suitable	Not Suitable	Not Suitable
Pinus sabiniana	Foothill pine	NA (Endemic to CA)	8-10	Not Defined	—	—	Suitable	Suitable
Pinus strobus	Eastern white pine	NA	3-8	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Pinus sylvestris	Scots pine	No	3-8	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Pistacia chinensis	Chinese pistachio	No	6-9	6-9	Suitable	Suitable	Suitable	Suitable
Platanus occidentalis	American sycamore	NA	4-9	3-9	Suitable	Suitable	Suitable	Suitable
Populus alba	White poplar	No	4-9	1-9	Suitable	Suitable	Suitable	Suitable
Populus nigra	Black poplar	No	3-9	Not Defined	—	—	Suitable	Suitable
Populus tremuloides	Quaking aspen	PNW	1-10	1-8	Suitable	Suitable	Suitable	Suitable
Prunus armeniaca	Apricot	No	5-7	1-9	Suitable	Suitable	Not Suitable	Not Suitable
Prunus avium	Sweet cherry	No	3-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Prunus cerasifera	Cherry plum	No	4-9	1-9	Suitable	Suitable	Suitable	Suitable
Prunus cerasus	Sour cherry	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Prunus domestica	Common plum	No	4-9	3-8	Suitable	Suitable	Suitable	Suitable
Prunus laurocerasus	English laurel	No	6-9	6-10	Suitable	Suitable	Suitable	Suitable
Prunus pendula	Weeping higan cherry	No	5-8	6-8	Suitable	Suitable	Not Suitable	Not Suitable
Prunus persica	Peach	No	5-9	1-9	Suitable	Suitable	Suitable	Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Prunus sargentii	Sargent cherry	No	5-8	5-9	Suitable	Suitable	Not Suitable	Not Suitable
Prunus serotina	Black cherry	NA	3-9	1-9	Suitable	Suitable	Suitable	Suitable
Prunus serrula	Birch bark cherry	No	6-8	6-8	Suitable	Suitable	Not Suitable	Not Suitable
Prunus serrulata	Japanese cherry	No	5-6	4-9	Suitable	Suitable	Not Suitable	Not Suitable
Prunus subhirtella	Higan cherry	No	5-8	6-8	Suitable	Suitable	Not Suitable	Not Suitable
Prunus virginiana	Common chokecherry	NA	2-7	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Pseudotsuga menziesii	Douglas fir	PNW	4-8	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Pyrus calleryana	Callery pear	No	5-9	3-8	Suitable	Suitable	Suitable	Suitable
Pyrus communis	Common pear	No	5-9	5-9	Suitable	Suitable	Suitable	Suitable
Quercus acutissima	Sawtooth oak	No	5-9	3-8	Suitable	Suitable	Suitable	Suitable
Quercus agrifolia	Coast live oak	NA	8-10	9-11	Suitable	Suitable	Suitable	Suitable
Quercus alba	White oak	NA	3-9	1-8	Suitable	Suitable	Suitable	Suitable
Quercus bicolor	Swamp white oak	NA	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Quercus coccinea	Scarlet oak	NA	4-9	4-9	Suitable	Suitable	Suitable	Suitable
Quercus garryana	Oregon oak	PNW	7-9	3-8	Suitable	Suitable	Suitable	Suitable
Quercus imbricaria	Shingle oak	NA	4-8	4-8	Suitable	Suitable	Not Suitable	Not Suitable
Quercus palustris	Pin oak	NA	4-8	3-7	Suitable	Suitable	Not Suitable	Not Suitable
Quercus phellos	Willow oak	NA	6-9	3-9	Suitable	Suitable	Suitable	Suitable
Quercus robur	English oak	No	3-8	3-8	Suitable	Suitable	Not Suitable	Not Suitable
Quercus rubra	Red oak	NA	4-8	5-9	Suitable	Suitable	Not Suitable	Not Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Quercus shumardii	Shumard oak	NA	5-9	1-9	Suitable	Suitable	Suitable	Suitable
Quercus virginiana	Live oak	NA	8-11	6-11	Suitable	Suitable	Suitable	Suitable
Robinia pseudoacacia	Black locust	NA	4-8	3-9	Suitable	Suitable	Not Suitable	Not Suitable
Salix matsudana	Corkscrew willow	No	5-9	Not Defined	—	—	Suitable	Suitable
Sequoia sempervirens	Coast redwood	NA	7-10	8-9	Suitable	Suitable	Suitable	Suitable
Sequoiadendron giganteum	Giant sequoia	NA	6-9	4-9	Suitable	Suitable	Suitable	Suitable
Sorbus alnifolia	Korean mountain ash	No	3-8	1-10	Suitable	Suitable	Not Suitable	Not Suitable
Sorbus aucuparia	Rowan	No	3-6	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Stewartia pseudocamellia	Japanese stewartia	No	5-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Styrax japonicus	Japanese snowbell	No	5-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Syringa pekinensis	Chinese tree lilac / Peking lilac	No	3-7	3-8	Suitable	Suitable	Not Suitable	Not Suitable
Syringa reticulata	Japanese tree lilac	No	3-7	3-8	Suitable	Suitable	Not Suitable	Not Suitable
Syringa vulgaris	Common lilac	No	4-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Taxodium distichum	Bald cypress	NA	4-11	5-12	Suitable	Suitable	Suitable	Suitable
Thuja occidentalis	Northern white cedar	NA	2-7	1-7	Suitable	Suitable	Not Suitable	Not Suitable
Thuja plicata	Western red cedar	PNW	6-9	6-8	Suitable	Suitable	Suitable	Suitable
Tilia americana	American basswood	NA	3-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Tilia cordata	Littleleaf linden	No	3-7	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Tilia platyphyllos	Large leaf linden	No	2-6	1-6	Suitable	Suitable	Not Suitable	Not Suitable

Scientific Name	Common Name	Native Status (PNW, NA, No)	Hardiness Zone	Heat Zone	Heat Zone Suitability - Low	Heat Zone Suitability - High	Heat and Hardiness Zone Suitability - Low	Heat and Hardiness Zone Suitability - High
Tilia tomentosa	Silver linden	No	4-7	1-9	Suitable	Suitable	Not Suitable	Not Suitable
Trachycarpus fortunei	Windmill palm	No	8-11	8-12	Suitable	Suitable	Suitable	Suitable
Tsuga canadensis	Eastern hemlock	NA	3-8	1-8	Suitable	Suitable	Not Suitable	Not Suitable
Tsuga heterophylla	Western hemlock	PNW	5-8	6-8	Suitable	Suitable	Not Suitable	Not Suitable
Tsuga mertensiana	Mountain hemlock	PNW	5-8	Not Defined	—	—	Not Suitable	Not Suitable
Ulmus americana	American elm	NA	3-9	1-9	Suitable	Suitable	Suitable	Suitable
Ulmus parvifolia	Chinese elm	No	5-9	1-9	Suitable	Suitable	Suitable	Suitable
Ulmus procera	English elm	No	5-8	2-8	Suitable	Suitable	Not Suitable	Not Suitable
Ulmus propinqua	Emerald sunshine elm	No	5-8	Not Defined	—	—	Not Suitable	Not Suitable
Ulmus pumila	Siberian elm	No	4-9	1-9	Suitable	Suitable	Suitable	Suitable
Zelkova serrata	Japanese zelkova	No	5-8	5-9	Suitable	Suitable	Not Suitable	Not Suitable

Adaptability Scores: Planted Environments

The results presented above use heat and plant hardiness zone data to provide information on potential changes in tree species habitat suitability across a range of projected extreme high and low temperatures. However, those analyses do not account for other climate-related impacts that may affect trees such as changes in flood regime, extreme weather events, insect pests, diseases, 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" to determine adaptability scores. Other scoring systems have been developed (Roloff et al. 2009), but we found the system developed by Matthews et al. (2011) 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 3). To arrive at a numerical score (see Appendix 3), these factors can be weighted by their intensity, the level of uncertainty about their impacts, and relative importance to future changes to tree mortality and survival. 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 many positive modification factors would have a high adaptive capacity, while a species with many negative modification factors would have a low adaptive capacity.

The modification factors were used in the Chicago Wilderness vulnerability assessment to capture the unique environment of urban areas (Brandt et al. 2017) and were refined by Brandt et al. (2021). We developed modification factor scores for 181 species and varieties in the Puget Sound region. Scores were then converted to categories of high, medium, and low 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.

Of the 181 tree species scored for adaptability, 25 species (14%) were found to have low adaptability, while the majority (107 species, 59%) were found to have moderate adaptability, and 49 species (27%) were found to have high adaptability. Common species in the Puget Sound region with high adaptability scores include red maple, Norway maple, kousa dogwood, littleleaf linden, and American hornbeam. Common species with low adaptability scores include sweetgum, paperbark maple, silver birch, and katsura tree. Tree species that received low vulnerability ratings tended to be susceptible to pests or diseases, were intolerant of a variety of disturbances and conditions (e.g., floods, wind, droughts, air pollution, restricted rooting conditions, temperature gradients), and had a narrow range in terms of urban sites and soil and temperature requirements. None of the listed species are native to the Pacific Northwest, and kousa dogwood, Norway maple, littleleaf linden, paperbark maple, silver birch, and katsura tree are not native to North America.

Table 3.—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 3 for more information.

Modification Factor	Trait Code	Type (Natural or Planted Environments)	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 is thus disfavored for planting
Land-use and planting site specificity	LPS	P	Can be planted on a wide variety of sites	Can be planted only 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

Vegetation surrounding Olympic Sculpture Park in Seattle, Washington. Photo by Daniel Lobo, Flickr.

Table 4.—Adaptability scores for trees in planted areas. See Table 3 for trait codes.

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Abies concolor	White fir	PNW	3.87	Moderate	—	FLO AIP
Abies grandis	Grand fir	PNW	4.14	Moderate	NUP	AIP
Abies procera	Noble fir	PNW	3.76	Moderate	—	DRO FLO TEM AIP
Acer buergerianum	Trident maple	No	4.21	Moderate	RRC	FLO LPS
Acer circinatum	Vine maple	PNW	5.0	High	TEM	—
Acer freemanii	Freeman maple	No	4.91	High	TEM ESP LPS NUP	—

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Acer griseum	Paperbark maple	No	3.28	Low	—	DRO TEM AIP NUP
Acer macrophyllum	Big leaf maple	PNW	3.75	Moderate	TEM NUP	RRC
Acer miyabei	Miyabe's maple	No	5.10	High	SAL	AIP
Acer negundo	Boxelder	NA	4.30	Moderate	DRO FLO TEM	INS AIP INPO ICE
Acer nigrum	Black maple	NA	3.69	Moderate	TEM	INS AIP SAL NUP
Acer palmatum	Japanese maple	No	3.92	Moderate	NUP	DRO AIP LPS
Acer platanoides	Norway maple	No	5.10	High	DRO FLO ESP LPS RRC NUP	INS INPO
Acer pseudoplatanus	Sycamore maple	No	4.25	Moderate	NUP	INS AIP INPO
Acer rubrum	Red maple	NA	4.70	High	—	AIP
Acer saccharinum	Silver maple	NA	3.80	Moderate	FLO TEM NUP	INS RRC MAR
Acer saccharum	Sugar maple	NA	4.40	Moderate	NUP MAR COL	INS FLO AIP RRC SAL
Acer tataricum	Tatarian maple	No	3.92	Moderate	DRO	AIP INPO
Acer triflorum	Three-flower maple	No	3.56	Moderate	—	DRO AIP
Acer truncatum	Shantung maple	No	5.41	High	DRO TEM LPS RRC NUP	INS
Aesculus flava	Yellow buckeye	NA	4.1	Moderate	—	DRO AIP

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Aesculus hippocastanum	Horse chestnut	No	4.20	Moderate	TEM	INPO
Ailanthus altissima	Tree of Heaven	No	4.94	High	DRO TEM AIP ESP LPS RRC	LPS NUP INPO ESP
Albizia julibrissin	Persian silk tree	No	2.88	Low	DRO FLO TEM ESP	AIP LPS INPO
Alnus rubra	Red alder	PNW	3.46	Low	FLO SAL	DISE INS BRO DRO ICE WIN TEM SWP AIP COL ESP
Amelanchier arborea	Downy serviceberry	NA	5.00	High	TEM NUP	AIP
Amelanchier laevis	Allegheny serviceberry	NA	4.66	High	LPS	DRO AIP
Arbutus menziesii	Pacific madrone	PNW	3.63	Moderate	DRO	FLO
Arbutus unedo	Strawberry tree	NA	4.57	High	LPS	—
Betula alleghaniensis	Swamp birch	NA	4.58	High	—	—
Betula nigra	River birch	NA	3.65	Moderate	TEM LPS NUP	DISE DRO PLE
Betula papyrifera	Paper birch	PNW	3.65	Moderate	NUP	DISE INS DRO TEM AIP
Betula pendula	Silver birch	No	3.22	Low	—	INS AIP
Betula populifolia	Gray birch	NA	3.22	Low	—	DISE INS AIP LPS
Carpinus betulus	European hornbeam	No	4.42	Moderate	—	SAL
Carpinus caroliniana	American hornbeam	NA	4.75	High	FLO TEM NUP COL	DRO AIP

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Castanea mollissima	Chinese chestnut	No	3.59	Moderate	TEM	—
Castanea sativa	Sweet chestnut	No	3.07	Low	—	TEM
Catalpa bignonioides	Southern catalpa	NA	4.46	Moderate	TEM LPS	—
Catalpa speciosa	Northern catalpa	NA	4.26	Moderate	DISE LPS INS PLE	AIP RRC
Celtis occidentalis	Common hackberry	NA	4.55	High	DRO TEM LPS NUP ESP	MAR WIN
Cercidiphyllum japonicum	Katsura tree	No	3.31	Low	DISE NUP	DRO WIN AIP RRC
Cercis canadensis	Eastern redbud	NA	3.90	Moderate	FLO TEM NUP	AIP LPS
Chamaecyparis lawsoniana	Lawson's cypress	NA	4.03	Moderate	—	DISE DRO AIP
Chamaecyparis nootkatensis	Nootka cypress	PNW	3.46	Low	TEM	FLO
Chamaecyparis obtusa	Hinoki cypress	No	3.41	Low	TEM	FLO AIP MAR
Chamaecyparis pisifera	Sawara cypress	No	3.95	Moderate	TEM	AIP
Chionanthus retusus	Chinese fringetree	No	4.77	High	LPS RRC	—
Cladrastis kentukea	Yellowwood	NA	4.33	Moderate	TEM RRC	AIP DRO
Cornus florida	Flowering dogwood	NA	3.84	Moderate	TEM NUP	DRO FLO AIP RRC LPS
Cornus kousa	Kousa dogwood	No	4.63	High	NUP	DRO AIP

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Cornus mas	Cornelian cherry	No	4.06	Moderate	TEM	AIP
Cornus nuttallii	Pacific dogwood	PNW	3.77	Moderate	NUP	DRO TEM
Corylus avellana	Common hazel / European filbert	No	3.71	Moderate	NUP	AIP RRC
Corylus colurna	Turkish filbert	No	4.27	Moderate	DRO TEM LPS RRC	SAL NUP
Cotinus coggygria	Smoke tree	No	4.90	High	DRO RRC LPS NUP	FLO
Cotinus obovatus	American smoke tree	NA	3.86	Moderate	DRO LPS RRC	AIP
Crataegus crus-galli	Cockspur hawthorn	NA	4.47	Moderate	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	NA	4.32	Moderate	DRO TEM RRC NUP	DISE INS
Cupressus sempervirens	Mediterranean cypress	No	5.15	High	DRO TEM	DISE
Elaeagnus angustifolia	Russian olive	No	4.95	High	DRO TEM NUP SAL PLE LPS ESP	INPO WIN ICE DISE
Eucommia ulmoides	Hardy rubber tree	No	4.69	High	DRO	FLO
Fagus grandifolia	American beech	NA	3.55	Moderate	TEM NUP	FLO AIP LPS RRC
Fagus sylvatica	Green beech	No	3.80	Moderate	NUP	DRO RRC LPS

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Ficus carica	Common fig	No	2.84	Low	FLO	DRO AIP
Fraxinus americana	White ash	NA	3.22	Low	NUP	INS AIP RRC
Fraxinus angustifolia	Narrow-leafed Ash	No	4.20	Moderate	TEM LPS RRC	DRO INPO
Fraxinus excelsior	European ash	No	3.83	Moderate	FLO	INS LPS
Fraxinus latifolia	Oregon ash	PNW	4.15	Moderate	—	—
Fraxinus pennsylvanica	Green ash	NA	3.90	Moderate	FLO LPS NUP	INS MAR
Ginkgo biloba	Ginkgo / Maidenhair	No	5.97	High	DRO TEM LPS RRC NUP	FLO
Gleditsia triacanthos	Honey locust	NA	4.26	Moderate	DRO TEM RRC NUP	—
Gymnocladus dioicus	Kentucky coffeetree	NA	4.60	High	DRO LPS NUP	AIP
Hamamelis virginiana	American witch-hazel	NA	4.06	Moderate	TEM	INS AIP
Hesperocyparis arizonica	Arizona cypress	NA	3.75	Moderate	DRO	FLO LPS
Hibiscus syriacus	Common hibiscus	No	4.55	High	NUP	—
Ilex aquifolium	Common holly	No	4.21	Moderate	LPS NUP	FLO RRC
Juglans nigra	Black walnut	NA	2.73	Low	DRO	AIP LPS RRC DISE MAR NUR
Juglans regia	English walnut	NA	3.66	Moderate	—	—

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Juniperus chinensis	Chinese juniper	No	4.50	High	—	—
Juniperus virginiana	Eastern red cedar	NA	4.71	High	DRO TEM LPS RRC	AIP
Koelreuteria paniculata	Goldenrain tree	No	4.71	High	DRO TEM LPS RRC NUP	INPO
Laburnum anagyroides	Common laburnum	No	3.40	Low	—	MAR
Lagerstroemia indica	Crepe myrtle	No	4.71	High	DRO TEM LPS RRC NUP	FLO AIP
Larix decidua	European larch	No	3.67	Moderate	—	DRO TEM AIP
Ligustrum japonicum	Wax-leaf Privet / Japanese Privet	No	4.14	Moderate	TEM NUIP	INPO
Ligustrum lucidum	Glossy privet	No	4.92	High	TEM AIP SWP ESP LPS RRC NUP PLE	DISE INS BRO MAR INPO
Liquidambar styraciflua	Sweetgum	NA	3.49	Low	FLO	INS DRO RRC LPS
Liriodendron tulipifera	Tulip tree	NA	3.47	Low	NUP	DRO AIP RRC
Maackia amurensis	Amur maackia	No	4.85	High	DRO TEM RRC NUP	FLO
Magnolia grandiflora	Southern magnolia	NA	3.97	Moderate	NUP	RRC
Magnolia kobus	Kobus magnolia	No	3.61	Moderate	—	—
Malus domestica	Edible apple	No	4.01	Moderate	TEM LPS RRC NUP	DISE INS AIP
Malus spp.	Crabapple	No	4.01	Moderate	DRO ICE TEM LPS RRC NUP	DISE INS BRO FLO WIN AIP SWP SAL COL ESP PLE MAR

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Metasequoia glyptostroboides	Dawn redwood	No	4.10	Moderate	TEM FLO	AIP COL
Morus alba	White mulberry	No	4.06	Moderate	TEM NUP SAL	LPS INPO
Nyssa sylvatica	Tupelo	NA	4.72	High	RRC	AIP
Olea europaea	European olive	No	3.85	Moderate	DRO LPS	—
Ostrya virginiana	Ironwood	NA	5.41	High	DRO TEM LPS RRC NUP	FLO AIP
Oxydendrum arboreum	Sourwood	NA	4.60	High	—	—
Parrotia persica	Persian parrotia	No	5.47	High	DRO TEM LPS RRC NUP	SAL
Paulownia tomentosa	Empress tree	No	5.55	High	NUP	INPO
Picea abies	Norway spruce	No	3.61	Moderate	NUR	INS FLO AIP
Picea glauca	White spruce	NA	4.15	Moderate	—	INS
Picea omorika	Serbian spruce	No	4.06	Moderate	NUP	INS
Picea pungens	Colorado spruce	NA	3.95	Moderate	NUP	INS FLO AIP
Pinus banksiana	Jack pine	NA	3.40	Low	—	—
Pinus halepensis	Aleppo pine	No	4.4	Moderate	DRO LPS	AIP
Pinus mugo	Sweet mountain pine	No	4.35	Moderate	WIN AIP RRC	FLO

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Pinus nigra	Austrian pine	No	3.91	Moderate	DRO TEM RRC	DISE INS
Pinus parviflora	Japanese white pine	No	4.00	Moderate	—	LPS
Pinus pinea	Italian stone pine	No	4.01	Moderate	DRO TEM	—
Pinus ponderosa	Ponderosa pine	PNW	3.45	Low	DRO TEM ESP NUP PLE	DISE INS BRO FLO ICE WIN AIP SWP SAL COL LPS MAR
Pinus sabiniana	Foothill pine	NA (Endemic to CA)	3.35	Low	DRO	LPS
Pinus strobus	Eastern white pine	NA	2.90	Low	NUP	DISE INS DRO TEM AIP LPS RRC
Pinus sylvestris	Scots pine	No	4.42	Moderate	TEM RRC NUP	INS
Pistacia chinensis	Chinese pistachio	No	4.86	High	INS DRO ICE WIN TEM AIP SWP ESP LPS RRC NUP	DISE BRO FLO PLE MAR INPO
Platanus occidentalis	American sycamore	NA	4.11	Moderate	TEM NUP FLO SAL	DRO
Populus alba	White poplar	No	3.59	Moderate	DRO TEM ESP NUP	—
Populus nigra	Black poplar	No	3.56	Moderate	TEM	—
Populus tremuloides	Quaking aspen	PNW	3.92	Moderate	TEM WIN MAR PLE	INS DRO AIP RRC INPO
Prunus armeniaca	Apricot	No	3.7	Moderate	LPS	—
Prunus avium	Sweet cherry	No	4.01	Moderate	TEM	FLO INPO DISE
Prunus cerasifera	Cherry plum	No	3.82	Moderate	NUP	AIP INS

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Prunus cerasus	Sour cherry	No	3.8	Moderate	TEM ESP NUP PLE	INS BRO FLO ICE WIN AIP SWP SAL COL MAR
Prunus domestica	Common plum	No	4.25	Moderate	TEM ESP LPS RRC	NUP
Prunus laurocerasus	English laurel	No	4.10	Moderate	RRC	FLO NUP INPO
Prunus pendula	Weeping higan cherry	No	3.5	Moderate	—	AIP RRC NUP
Prunus persica	Peach	No	3.61	Moderate	NUP	—
Prunus sargentii	Sargent cherry	No	3.80	Moderate	DRO TEM RRC LPS	WN AIP
Prunus serotina	Black cherry	NA	2.10	Low	CRO TEM	FLO AIP LPS RRC DRO
Prunus serrula	Birch bark cherry	No	3.62	Moderate	—	AIP
Prunus serrulata	Japanese cherry	No	4.31	Moderate	TEM LPS NUP	—
Prunus subhirtella	Higan cherry	No	4.00	Moderate	SAL DRO	FLO AIP RRC
Prunus virginiana	Common chokecherry	NA	3.56	Moderate	NUP	DISE FLO AIP
Pseudotsuga menziesii	Douglas fir	PNW	3.50	Moderate	NUP	FLO TEM LPS ESP SAL INS DISE
Pyrus calleryana	Callery pear	No	4.20	Moderate	DRO TEM RRC NUP SAL AIP	INS INPO DISE
Pyrus communis	Common pear	No	3.52	Moderate	—	AIP
Quercus acutissima	Sawtooth oak	No	5.48	High	DRO FLO TEM LPS RRC NUP	INPO

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Quercus agrifolia	Coast live oak	NA	4.11	Moderate	—	DISE
Quercus alba	White oak	NA	3.34	Low	TEM NUP SAL DRO	FLO AIP ESP LPS RRC DISE PLE
Quercus bicolor	Swamp white oak	NA	5.15	High	TEM RRC NUP SAL LPS TEM FLO	AIP
Quercus coccinea	Scarlet oak	NA	3.82	Moderate	TEM LPS	AIP ESP FLO DISE
Quercus garryana	Oregon oak	PNW	3.85	Moderate	—	—
Quercus imbricaria	Shingle oak	NA	4.50	High	DRO NUP	AIP ESP DISE
Quercus palustris	Pin oak	NA	3.52	Moderate	FLO RRC NUP	AIP DRO SAL ESP DISE
Quercus phellos	Willow oak	NA	4.80	High	FLO LPS RRC NUP	—
Quercus robur	English oak	No	4.22	Moderate	DRO TEM	—
Quercus rubra	Red oak	NA	4.05	Moderate	TEM LPS NUP	DISE FLO RRC ESP
Quercus shumardii	Shumard oak	NA	3.99	Moderate	DRO FLO TEM LPS RRC NUP	DISE PLE ESP
Quercus virginiana	Live oak	NA	4.54	High	TEM LPS RRC NUP	DISE AIP
Robinia pseudoacacia	Black locust	NA	3.91	Moderate	DRO TEM ESP SAL PLE	INS FLO AIP LPS RRC INPO WIN
Salix matsudana	Corkscrew willow	No	3.66	Moderate	FLO SAL COL ESP	DISE INS BRO ICE WIN LPS RRC PLE MAR
Sequoia sempervirens	Coast redwood	NA	3.4	Low	—	DRO AIP LPS

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Sequoiadendron giganteum	Giant sequoia	NA	3.5	Moderate	TEM	LPS RRC
Sorbus alnifolia	Korean mountain ash	No	3.65	Moderate	NUP	AIP
Sorbus aucuparia	Rowan	No	3.72	Moderate	LPS RRC NUP	ESP DRO SAL AIP DISE INS
Stewartia pseudocamellia	Japanese stewartia	No	3.20	Low	—	DRO AIP
Styrax japonicus	Japanese snowbell	No	4.19	Moderate	DISE INS AIP COL LPS RRC	ICE TEM SAL ESP NUP PLE MAR
Syringa pekinensis	Chinese tree lilac / Peking lilac	No	4.67	High	LPS NUP	FLO TEM
Syringa reticulata	Japanese tree lilac	No	4.55	High	LPS RRC NUP ESP PLE	AIP FLO INPO DISE
Syringa vulgaris	Common lilac	No	3.88	Moderate	NUP	AIP
Taxodium distichum	Bald cypress	NA	4.90	High	FLO RRC NUP	AIP
Thuja occidentalis	Northern white cedar	NA	4.77	High	NUP ESP FLO	DRO AIP ICE BRO WIN
Thuja plicata	Western red cedar	PNW	5.00	High	FLO WIN LPS	AIP
Tilia americana	American basswood	NA	4.38	Moderate	TEM NUP LPS PLE	AIP RRC INS DRO WIN SAL
Tilia cordata	Littleleaf linden	No	5.18	High	LPS NUP PLE ESP AIP	INS SAL WIN
Tilia platyphyllos	Large leaf linden	No	4.25	Moderate	TEM LPS	FLO
Tilia tomentosa	Silver linden	No	4.15	Moderate	TEM NUP	AIP

Scientific Name	Common Name	Native Status (PNW, NA, No)	Planted Adaptability Score	Planted Adaptability Class	Positive Modification Factors for Trees in Planted Areas	Planted Negative Modification Factors for Trees in Planted Areas
Trachycarpus fortunei	Windmill palm	No	4.96	High	RRC NUP	—
Tsuga canadensis	Eastern hemlock	NA	2.68	Low	NUP	DRO AIP LPS INS MAR RRC SAL
Tsuga heterophylla	Western hemlock	PNW	3.19	Low	—	DRO TEM AIP LPS
Tsuga mertensiana	Mountain hemlock	PNW	3.54	Moderate	—	DRO AIP
Ulmus americana	American elm	NA	4.45	Moderate	TEM NUP DRO FLO LPS SAL	DISE INS MAR
Ulmus parvifolia	Chinese elm	No	5.50	High	DRO TEM ESP LPS RRC NUP	INPO
Ulmus procera	English elm	No	4.22	Moderate	ESP LPS NUP	RRC
Ulmus propinqua	Emerald sunshine elm	No	5.2	High	TEM ESP NUP RRC	—
Ulmus pumila	Siberian elm	No	3.76	Moderate	DRO TEM DISE	WIN INPO
Zelkova serrata	Japanese zelkova	No	4.87	High	TEM LPS RRC NUP SAL DRO	—

Overall Vulnerability of Trees in the Puget Sound 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 trees in the Puget Sound region 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 (adaptability class in Table 4) together in a matrix (Table 5).

Table 5.—Vulnerability scoring matrix based on Brandt et al. (2017).

Heat and Hardiness Zone Suitability (end of 21st century)	Adaptability Class		
	Low	**Medium**	**High**
Not suitable	High Vulnerability	Moderate-high Vulnerability	Moderate Vulnerability

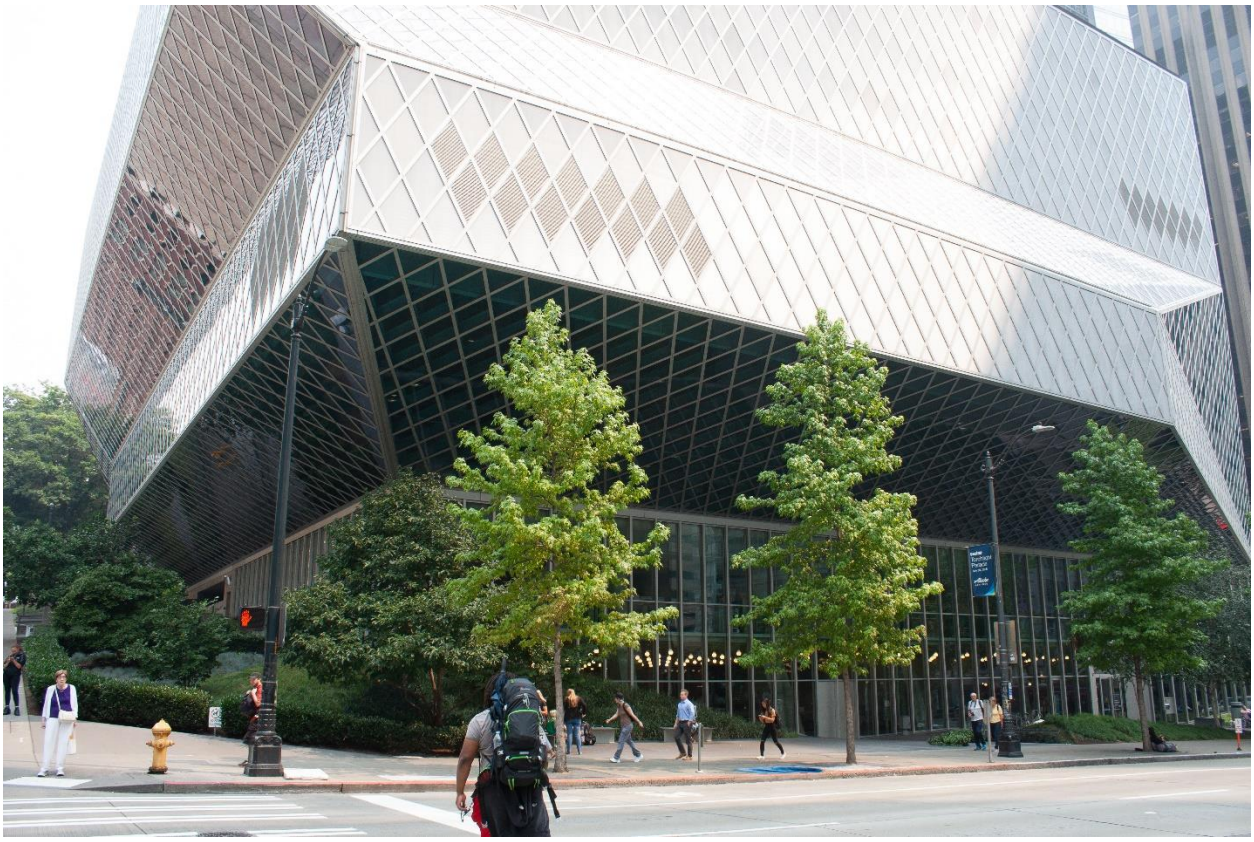
Suitable	Moderate Vulnerability	Low-moderate Vulnerability	Low Vulnerability

Tree species vulnerability is summarized in Table 6. Considering heat zones only, most tree species fell into the low-moderate (57%) vulnerability category, followed by low vulnerability (26%) and moderate vulnerability (17%) under both low and high climate change scenarios. The vulnerability ratings remain the same across both low and high climate change scenarios because all assessed tree species are considered suitable under the heat zone projections through the end of the century. Common species with low to low-moderate vulnerability considering heat zones include only red maple, Norway maple, crabapple, Japanese maple, cherry plum, Japanese cherry, midland hawthorn, callery pear, red oak, Japanese snowbell, and kousa dogwood. None of the assessed tree species fall into the moderate-high or high categories when considering heat zones only.

Considering combined changes in heat and hardiness zones, most tree species assessed fall into the moderate-high vulnerability category (34%), followed by low-moderate (25%), moderate (18%), low (14%), and high (9%). The vulnerability ratings are the same between low and high climate change scenarios because all species are considered suitable to projected future heat zones (see above paragraph) and because the projected hardiness zone is the same under both climate change scenarios through the end of the century.

Common species with low to low-moderate vulnerability considering both heat and hardiness zones include red maple, Norway maple, cherry plum, callery pear, big leaf maple, scarlet oak, green ash, American hornbeam, and European hornbeam. Common species with moderate-high to high vulnerability considering heat and hardiness zones include crabapple, Japanese maple, Japanese cherry, paperbark maple, red oak, Japanese snowbell, silver birch, katsura tree, rowan, and common hawthorn. Of these tree species, only big leaf maple is native to the Pacific Northwest. Norway maple, crabapple, Japanese maple, cherry plum, Japanese cherry, midland hawthorn, callery pear, Japanese snowbell, kousa dogwood, European hornbeam, paperbark maple, silver birch, katsura tree, rowan, and common hawthorn are not native to North America.

The tree species vulnerability list, including the adaptability scores and positive and negative traits, were reviewed by experts in the Puget Sound region. Expert notes were considered necessary to adjust tree species scores and reflect what has been observed on the ground in the region. Six experts reviewed the tree species, representing local arborists and ecologists across public, nonprofit, and private organizations. Reviewers were given instructions to review the tree species' scores, heat and hardiness zones, and positive and negative traits. Based on expert feedback, minimal changes were made to specific modification factor scores of some tree species. The changes to the modification factor scores rarely impacted the adaptability class of a tree species, but positive and negative traits were occasionally adjusted.



Street trees outside of the Seattle Public Library. Photo by Jessica Opalinski, Flickr.

Table 6.—Vulnerability ratings for trees in the Puget Sound region considering heat zones only and heat and hardiness zones under low and high climate change scenarios. Note: Because all species are suitable under the projected heat zone for both low and high climate change scenarios and the projected hardiness zone is the same under low and high climate change scenarios, the vulnerability ratings were the same between both low and high climate change scenarios and are not separated in the table below.

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
Abies concolor	White fir	16	Low-moderate	Low-moderate
Abies grandis	Grand fir	42	Low-moderate	Moderate-high
Abies procera	Noble fir	27	Low-moderate	Low-moderate
Acer buergerianum	Trident maple	166	Low-moderate	Low-moderate
Acer circinatum	Vine maple	646	Low-moderate	Low-moderate
Acer freemanii	Freeman maple	570	Low	Moderate
Acer griseum	Paperbark maple	2043	Moderate	High
Acer macrophyllum	Big leaf maple	1261	Low-moderate	Low-moderate

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
Acer miyabei	Miyabe's maple	89	Low	Moderate
Acer negundo	Boxelder	99	Low-moderate	Low-moderate
Acer nigrum	Black maple	-	Low-moderate	Moderate-high
Acer palmatum	Japanese maple	3630	Low-moderate	Low-moderate
*Acer platanoides***	Norway maple**	3988	Low	Moderate
*Acer pseudoplatanus***	Sycamore maple	879	Low-moderate	Moderate-high
Acer rubrum	Red maple	5374	Low	Low
Acer saccharinum	Silver maple	239	Low-moderate	Low-moderate
Acer saccharum	Sugar maple	611	Low-moderate	Moderate-high
Acer tataricum	Tatarian maple	181	Low-moderate	Moderate-high
Acer triflorum	Three-flower maple	-	Low-moderate	Moderate-high
Acer truncatum	Shantung maple	7	Low	Moderate
Aesculus flava	Yellow buckeye	7	Low-moderate	Moderate-high
*Aesculus hippocastanum***	Horse chestnut	639	Low-moderate	Moderate-high
*Ailanthus altissima***	Tree of heaven	52	Low	Moderate
Albizia julibrissin	Persian silk tree	96	Moderate	Moderate
Alnus rubra	Red alder	428	Moderate	High
Amelanchier arborea	Downy serviceberry	176	Low	Low
Amelanchier laevis	Allegheny serviceberry	106	Low	Low
Arbutus menziesii	Pacific madrone	249	Low-moderate	Low-moderate
Arbutus unedo	Strawberry tree	214	Low	Low
Betula alleghaniensis	Swamp birch	49	Low	Moderate
Betula nigra	River birch	123	Low-moderate	Low-moderate
Betula papyrifera	Paper birch	429	Low-moderate	Low-moderate

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
Betula pendula	Silver birch	1617	Moderate	High
Betula populifolia	Gray birch	16	Moderate	High
Carpinus betulus	European hornbeam	1073	Low-moderate	Low-moderate
Carpinus caroliniana	American hornbeam	1077	Low	Low
Castanea mollissima	Chinese chestnut	16	Low-moderate	Moderate-high
Castanea sativa	Sweet chestnut	44	Moderate	High
Catalpa bignonioides	Southern catalpa	268	Low-moderate	Low-moderate
Catalpa speciosa	Northern catalpa	97	Low-moderate	Moderate-high
Celtis occidentalis	Common hackberry	126	Low	Low
Cercidiphyllum japonicum	Katsura tree	1484	Moderate	High
Cercis canadensis	Eastern redbud	832	Low-moderate	Low-moderate
Chamaecyparis lawsoniana	Lawson's cypress	246	Low-moderate	Moderate-high
Chamaecyparis nootkatensis	Nootka cypress	96	Moderate	High
Chamaecyparis obtusa	Hinoki cypress	125	Moderate	High
Chamaecyparis pisifera	Sawara cypress	94	Low-moderate	Moderate-high
Chionanthus retusus	Chinese fringetree	7	Low	Low
Cladrastis kentukea	Yellowwood	33	Low-moderate	Moderate-high
Cornus florida	Flowering dogwood	545	Low-moderate	Low-moderate
Cornus kousa	Kousa dogwood	1676	Low	Moderate
Cornus mas	Cornelian cherry	107	Low-moderate	Moderate-high
Cornus nuttallii	Pacific dogwood	131	Low-moderate	Low-moderate
Corylus avellana	Common hazel / European filbert	56	Low-moderate	Moderate-high
Corylus colurna	Turkish filbert	48	Low-moderate	Moderate-high
Cotinus coggygria	Smoke tree	103	Low	Moderate

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
Cotinus obovatus	American smoke tree	18	Low-moderate	Moderate-high
Crataegus crus-galli	Cockspur hawthorn	109	Low-moderate	Moderate-high
Crataegus laevigata	Midland hawthorn / English hawthorn	2491	Low-moderate	Moderate-high
*Crataegus monogyna***	Common hawthorn	985	Low-moderate	Moderate-high
Crataegus phaenopyrum	Washington hawthorn	841	Low-moderate	Low-moderate
Cupressus sempervirens	Mediterranean cypress	97	Low	Low
*Elaeagnus angustifolia***	Russian olive	22	Low	Moderate
Eucommia ulmoides	Hardy rubber tree	77	Low	Moderate
Fagus grandifolia	American beech	26	Low-moderate	Low-moderate
Fagus sylvatica	Green beech	639	Low-moderate	Moderate-high
Ficus carica	Common fig	165	Moderate	Moderate
Fraxinus americana	White ash	209	Moderate	Moderate
Fraxinus angustifolia	Narrow-leafed Ash	163	Low-moderate	Moderate-high
Fraxinus excelsior	European ash	81	Low-moderate	Moderate-high
Fraxinus latifolia	Oregon ash	87	Low-moderate	Moderate-high
Fraxinus pennsylvanica	Green ash	1141	Low-moderate	Low-moderate
Ginkgo biloba	Ginkgo / Maidenhair	856	Low	Moderate
*Gleditsia triacanthos***	Honey locust	871	Low-moderate	Moderate-high
Gymnocladus dioicus	Kentucky coffeetree	20	Low	Moderate
Hamamelis virginiana	American witch-hazel	23	Low-moderate	Moderate-high
Hesperocyparis arizonica	Arizona cypress	-	Low-moderate	Low-moderate
Hibiscus syriacus	Common hibiscus	28	Low	Moderate
*Ilex aquifolium***	Common holly	298	Low-moderate	Low-moderate
Juglans nigra	Black walnut	70	Moderate	Moderate

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
Juglans regia	English walnut	80	Low-moderate	Moderate-high
Juniperus chinensis	Chinese juniper	26	Low	Low
Juniperus virginiana	Eastern red cedar	13	Low	Low
*Koelreuteria paniculata***	Goldenrain tree	358	Low	Low
Laburnum anagyroides	Common laburnum	147	Moderate	High
Lagerstroemia indica	Crepe myrtle	283	Low	Low
Larix decidua	European larch	14	Low-moderate	Moderate-high
Ligustrum japonicum	Wax-leaf Privet / Japanese Privet	8	Low-moderate	Low-moderate
Ligustrum lucidum	Glossy privet	23	Low	Low
Liquidambar styraciflua	Sweetgum	2742	Moderate	Moderate
Liriodendron tulipifera	Tulip tree	477	Moderate	High
*Maackia amurensis***	Amur maackia	86	Low	Moderate
Magnolia grandiflora	Southern magnolia	683	Low-moderate	Low-moderate
Magnolia kobus	Kobus magnolia	247	N/A	Moderate-high
Malus domestica	Edible apple	928	Low-moderate	Moderate-high
Malus spp.	Crabapple	3960	Low-moderate	Moderate-high
Metasequoia glyptostroboides	Dawn redwood	86	Low-moderate	Low-moderate
*Morus alba***	White mulberry	31	Low-moderate	Moderate-high
Nyssa sylvatica	Tupelo	625	Low	Low
Olea europaea	European olive	31	Low-moderate	Low-moderate
Ostrya virginiana	Ironwood	19	Low	Low
Oxydendrum arboreum	Sourwood	98	Low	Low
Parrotia persica	Persian parrotia	788	Low	Moderate
*Paulownia tomentosa***	Empress tree	33	Low	Low

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
Picea abies	Norway spruce	145	Low-moderate	Moderate-high
Picea glauca	White spruce	26	Low-moderate	Moderate-high
Picea omorika	Serbian spruce	3	Low-moderate	Moderate-high
Picea pungens	Colorado spruce	96	Low-moderate	Moderate-high
Pinus banksiana	Jack pine	-	Moderate	High
Pinus halepensis	Aleppo pine	5	Low-moderate	Low-moderate
Pinus mugo	Sweet mountain pine	35	Low-moderate	Moderate-high
Pinus nigra	Austrian pine	155	Low-moderate	Moderate-high
Pinus parviflora	Japanese white pine	-	Low-moderate	Low-moderate
Pinus pinea	Italian stone pine	9	Low-moderate	Low-moderate
Pinus ponderosa	Ponderosa pine	61	Moderate	High
Pinus sabiniana	Foothill pine	-	N/A	Moderate
Pinus strobus	Eastern white pine	46	Moderate	High
Pinus sylvestris	Scots pine	114	Low-moderate	Moderate-high
Pistacia chinensis	Chinese pistachio	65	Low	Low
Platanus occidentalis	American sycamore	154	Low-moderate	Low-moderate
Populus alba	White poplar	26	Low-moderate	Low-moderate
Populus nigra	Black poplar	59	N/A	Low-moderate
Populus tremuloides	Quaking aspen	259	Low-moderate	Low-moderate
Prunus armeniaca	Apricot	17	Low-moderate	Moderate-high
Prunus avium	Sweet cherry	469	Low-moderate	Moderate-high
Prunus cerasifera	Cherry plum	3203	Low-moderate	Low-moderate
Prunus cerasus	Sour cherry	119	Low-moderate	Moderate-high
Prunus domestica	Common plum	302	Low-moderate	Low-moderate

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
*Prunus laurocerasus***	English laurel	205	Low-moderate	Low-moderate
Prunus pendula	Weeping higan cherry	364	Low-moderate	Moderate-high
Prunus persica	Peach	118	Low-moderate	Low-moderate
Prunus sargentii	Sargent cherry	232	Low-moderate	Moderate-high
Prunus serotina	Black cherry	41	Moderate	Moderate
Prunus serrula	Birch bark cherry	123	Low-moderate	Moderate-high
Prunus serrulata	Japanese cherry	2572	Low-moderate	Moderate-high
Prunus subhirtella	Higan cherry	657	Low-moderate	Moderate-high
Prunus virginiana	Common chokecherry	5	Low-moderate	Moderate-high
Pseudotsuga menziesii	Douglas fir	609	Moderate	High
*Pyrus calleryana***	Callery pear	2202	Low-moderate	Low-moderate
Pyrus communis	Common pear	269	Low-moderate	Low-moderate
*Quercus acutissima***	Sawtooth oak	55	Low	Low
Quercus agrifolia	Coast live oak	42	Low-moderate	Low-moderate
Quercus alba	White oak	33	Moderate	Moderate
Quercus bicolor	Swamp white oak	228	Low	Moderate
Quercus coccinea	Scarlet oak	1199	Low-moderate	Low-moderate
Quercus garryana	Oregon oak	83	Low-moderate	Low-moderate
Quercus imbricaria	Shingle oak	121	Low	Moderate
Quercus palustris	Pin oak	715	Low-moderate	Moderate-high
Quercus phellos	Willow oak	192	Low	Low
Quercus robur	English oak	370	Low-moderate	Moderate-high
Quercus rubra	Red oak	1999	Low-moderate	Moderate-high
Quercus shumardii	Shumard oak	72	Low-moderate	Low-moderate

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
Quercus virginiana	Live oak	14	Low	Low
*Robinia pseudoacacia***	Black locust	481	Low-moderate	Moderate-high
Salix matsudana	Corkscrew willow	46	N/A	Low-moderate
Sequoia sempervirens	Coast redwood	50	Moderate	Moderate
Sequoiadendron giganteum	Giant sequoia	78	Moderate	Moderate
Sorbus alnifolia	Korean mountain ash	-	Low-moderate	Moderate-high
Sorbus aucuparia	Rowan	1055	Low-moderate	Moderate-high
Stewartia pseudocamellia	Japanese stewartia	341	Moderate	High
Styrax japonicus	Japanese snowbell	1712	Low-moderate	Moderate-high
Syringa pekinensis	Chinese tree lilac / Peking lilac	63	Low	Moderate
Syringa reticulata	Japanese tree lilac	239	Low	Moderate
Syringa vulgaris	Common lilac	116	Low-moderate	Moderate-high
Taxodium distichum	Bald cypress	37	Low	Low
Thuja occidentalis	Northern white cedar	447	Low	Moderate
Thuja plicata	Western red cedar	935	Low	Low
Tilia americana	American basswood	280	Low-moderate	Moderate-high
Tilia cordata	Littleleaf linden	1541	Low	Moderate
Tilia platyphyllos	Large leaf linden	298	Low-moderate	Moderate-high
Tilia tomentosa	Silver linden	-	Low-moderate	Moderate-high
Trachycarpus fortunei	Windmill palm	207	Low	Low
Tsuga canadensis	Eastern hemlock	13	Moderate	High
Tsuga heterophylla	Western hemlock	113	Low-moderate	Moderate-high
Tsuga mertensiana	Mountain hemlock	62	N/A	Moderate-high
Ulmus americana	American elm	302	Low-moderate	Low-moderate

Scientific Name	Common Name	Estimated Street Trees in Seattle	Vulnerability - Considering Heat Zones Only	Vulnerability - Considering Heat & Hardiness Zones
Ulmus parvifolia	Chinese elm	222	Low	Low
Ulmus procera	English elm	70	Low-moderate	Moderate-high
Ulmus propinqua	Emerald sunshine elm	44	N/A	Moderate
*Ulmus pumila***	Siberian elm	29	Low-moderate	Low-moderate
Zelkova serrata	Japanese zelkova	854	Low	Moderate

***Invasive Species*

Chapter 3: Additional Considerations

When assessing the vulnerability of an entire urban forest or ecosystem, additional factors beyond the vulnerability of individual tree species are also important to consider. Physical factors such as elevation or soil type may affect the susceptibility of the urban forest to drought or flooding. Biological factors such as a high proportion of vulnerable trees or the presence of particular pests or diseases may make impacts to a particular urban forest more pronounced. Human-influence factors such as the amount of impervious surface, the influence of the urban heat island, or past management in a particular site are also important considerations

When evaluating the adaptive capacity of a particular urban forest, considerations could include: 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.

Note that the heat and hardiness zone suitability analysis, which helps inform the overall vulnerability, is meant to provide an estimate of potential changes in habitat suitability based on temperature extremes and does not consider additional factors such as changes in precipitation or other habitat requirements. The adaptability scores provide a qualitative assessment that accounts for disturbance and biological factors as a complement to information provided by projected heat and hardiness zones. The tree species vulnerability list in the previous chapter is not a recommended planting guide and 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.

Tree Species Diversity

Tree species diversity is an important component of adaptive capacity. Areas with high taxonomic diversity (e.g., a small percentage of species in any one family, genus, or species) may be less vulnerable to pests and pathogens and other climate-related disturbances. Seattle's most recent street tree inventory provides information on tree diversity at the genus level. *Acer* and *Prunus* genera make up a significant portion of the city's street trees, followed by numerous other genera in smaller proportions (Table 7). The high proportions of species in the *Acer* and *Prunus* genera may reduce adaptive capacity to some extent, especially if species in these families are a preferred host to a specific pest or pathogen. Note that Table 7 does not contain an exhaustive list of all genera in the Puget Sound region; some municipalities and land cover types may have a very different species composition from this list.

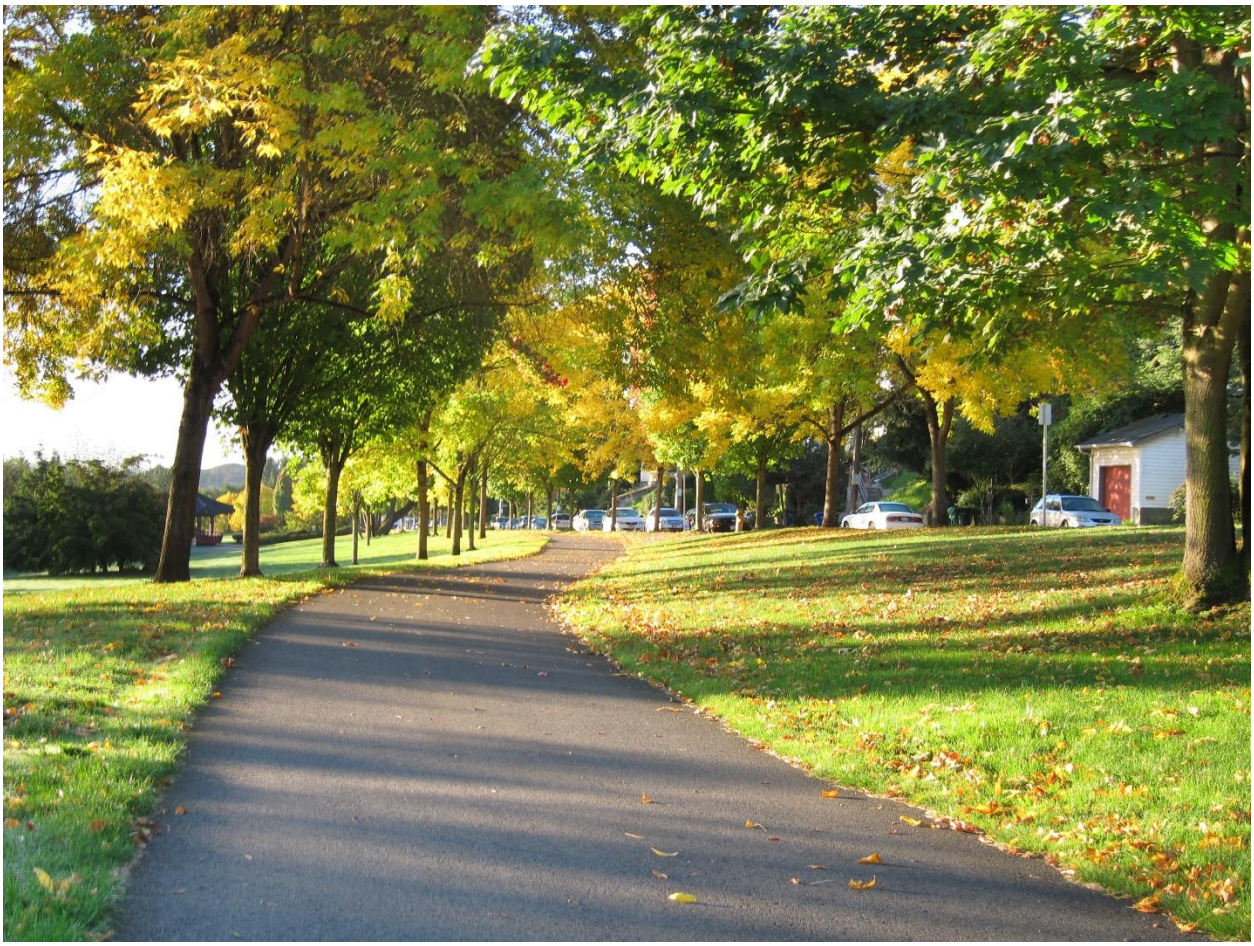
Table 7.—Seattle street tree diversity by genus. Note: This table is not an exhaustive list of all street trees in the Puget Sound region and may not be reflective of other municipalities.

Genus	Percentage of Street Trees	Genus	Percentage of Trees
Acer (maple)	21.5%	*Tilia* (linden)	2.6%
Prunus (cherry, plum, etc)	17.0%	*Betula* (birch)	2.5%
Malus (apple)	5.2%	*Carpinus* (hornbeam)	2.1%
Crataegus (hawthorn)	4.3%	*Amelanchier* (serviceberry)	2.1%
Quercus (oak)	3.5%	*Magnolia*	1.7%
Pyrus (pear)	3.2%	*Ulmus* (elm)	1.5%

Fraxinus (ash)	2.9%	*Thuja* (cedar)	1.3%
Cornus (dogwood)	2.7%		

Tree Species Allergenicity

Urban forests and their associated benefits have become more important for human health, as more than half of the nation's population resides in cities. Urban trees provide ecosystem services, such as cooling the air, absorbing rainfall, providing oxygen, intercepting UV light, storing carbon, and reducing air pollution. However, trees can also pose human health issues due to the presence and intensity of allergens. The interaction between trees and a changing climate will have important implications for protecting human health. The allergenicity levels (mild, moderate, severe, or no allergy reported) of the assessed tree species are included in Table 8 as an additional consideration.



Fall trees along the I-90 trail in Seattle, Washington. Photo by joshua_putnam, Flickr.

Table 8.—Allergenicity of Puget Sound tree species of interest.

Scientific Name	Common Name	Scientific Name	Common Name
Mild Allergen			

Castanea sativa	Sweet chestnut	*Magnolia grandiflora*	Southern magnolia
Ailanthus altissima	Tree of heaven	*Magnolia kobus*	Kobus magnolia
Albizia julibrissin	Persian silk tree	*Malus domestica*	Edible apple
Amelanchier arborea	Downy serviceberry	*Malus spp.*	Crabapple
Amelanchier laevis	Allegheny serviceberry	*Morus alba*	White mulberry
Arbutus unedo	Strawberry tree	*Ostrya virginiana*	Ironwood
Castanea mollissima	Chinese chestnut	*Populus tremuloides*	Quaking aspen
Catalpa bignonioides	Southern catalpa	*Prunus armeniaca*	Apricot
Catalpa speciosa	Northern catalpa	*Prunus avium*	Sweet cherry
Cercis canadensis	Eastern redbud	*Prunus cerasifera*	Cherry plum
Cornus florida	Flowering dogwood	*Prunus cerasus*	Sour cherry
Cornus kousa	Kousa dogwood	*Prunus domestica*	Common plum
Cornus mas	Cornelian cherry	*Prunus laurocerasus*	English laurel
Cornus nuttallii	Pacific dogwood	*Prunus pendula*	Weeping higan cherry
Crataegus crus-galli	Cockspur hawthorn	*Prunus persica*	Peach
Crataegus laevigata	Midland hawthorn / English hawthorn	*Prunus sargentii*	Sargent cherry
Crataegus monogyna	Common hawthorn	*Prunus serotina*	Black cherry
Crataegus phaenopyrum	Washington hawthorn	*Prunus serrula*	Birch bark cherry
Elaeagnus angustifolia	Russian olive	*Prunus serrulata*	Japanese cherry
Fagus grandifolia	American beech	*Prunus subhirtella*	Higan cherry
Fagus sylvatica	Green beech	*Pseudotsuga menziesii*	Douglas fir
Ginkgo biloba	Ginkgo / Maidenhair	*Pyrus calleryana*	Callery pear
Gleditsia triacanthos	Honey locust	*Pyrus communis*	Common pear
Gymnocladus dioicus	Kentucky coffeetree	*Robinia pseudoacacia*	Black locust

Hibiscus syriacus	Common hibiscus	*Sorbus alnifolia*	Korean mountain ash
Koelreuteria paniculata	Goldenrain tree	*Sorbus aucuparia*	Rowan
Laburnum anagyroides	Common laburnum	*Stewartia pseudocamellia*	Japanese stewartia
Ligustrum lucidum	Glossy privet	*Styrax japonicus*	Japanese snowbell
Liquidambar styraciflua	Sweetgum	*Trachycarpus fortunei*	Windmill palm
Maackia amurensis	Amur maackia		
Moderate Allergen			
Acer buergerianum	Trident maple	*Chamaecyparis lawsoniana*	Lawson cypress
Acer circinatum	Vine maple	*Chamaecyparis nootkatensis*	Nootka cypress
Acer freemanii	Freeman maple	*Chamaecyparis obtusa*	Hinoki cypress
Acer griseum	Paperbark maple	*Chamaecyparis pisifera*	Sawara cypress
Acer macrophyllum	Big leaf maple	*Corylus avellana*	Common hazel / European filbert
Acer miyabei	Miyabe's maple	*Corylus colurna*	Turkish filbert
Acer nigrum	Black maple	*Olea europaea*	European olive
Acer palmatum	Japanese maple	*Pistacia chinensis*	Chinese pistachio
Acer platanoides	Norway maple	*Platanus occidentalis*	American sycamore
Acer pseudoplatanus	Sycamore maple	*Populus alba*	White poplar
Acer rubrum	Red maple	*Populus nigra*	Black poplar
Acer saccharinum	Silver maple	*Sequoiadendron giganteum*	Giant sequoia
Acer saccharum	Sugar maple	*Thuja occidentalis*	Northern white cedar
Acer tataricum	Tatarian maple	*Thuja plicata*	Western red cedar
Acer triflorum	Three-flower maple	*Tilia americana*	American basswood
Acer truncatum	Shantung maple	*Tilia cordata*	Littleleaf linden
Alnus rubra	Red alder	*Tilia platyphyllos*	Large leaf linden

Betula alleghaniensis	Swamp birch	*Tilia tomentosa*	Silver linden
Betula nigra	River birch	*Ulmus americana*	American elm
Betula papyrifera	Paper birch	*Ulmus parvifolia*	Chinese elm
Betula pendula	Silver birch	*Ulmus procera*	English elm
Betula populifolia	Gray birch	*Ulmus propinqua*	Emerald sunshine elm
Carpinus betulus	European hornbeam	*Ulmus pumila*	Siberian elm
Carpinus caroliniana	American hornbeam	*Zelkova serrata*	Japanese zelkova
Celtis occidentalis	Common hackberry		
Severe Allergen			
Acer negundo	Boxelder	*Quercus alba*	White oak
Fraxinus americana	White ash	*Quercus bicolor*	Swamp white oak
Fraxinus excelsior	European ash	*Quercus coccinea*	Scarlet oak
Fraxinus latifolia	Oregon ash	*Quercus garryana*	Oregon oak
Fraxinus pennsylvanica	Green ash	*Quercus imbricaria*	Shingle oak
Ilex aquifolium	Common holly	*Quercus palustris*	Pin oak
Juglans nigra	Black walnut	*Quercus phellos*	Willow oak
Juglans regia	English walnut	*Quercus robur*	English oak
Juniperus chinensis	Chinese juniper	*Quercus rubra*	Red oak
Larix decidua	European larch	*Quercus shumardii*	Shumard oak
Ligustrum japonicum	Wax-leaf privet / Japanese privet	*Quercus virginiana*	Live oak
Metasequoia glyptostroboides	Dawn redwood	*Salix matsudana*	Corkscrew willow
Nyssa sylvatica	Tupelo	*Cercidiphyllum japonicum*	Katsura tree
Quercus acutissima	Sawtooth oak	*Chionanthus retusus*	Chinese fringetree
Quercus agrifolia	Coast live oak		

No Allergy Reported			
Abies concolor	White fir	*Picea glauca*	White spruce
Abies grandis	Grand fir	*Picea omorika*	Serbian spruce
Abies procera	Noble fir	*Picea pungens*	Colorado spruce
Aesculus flava	Yellow buckeye	*Pinus banksiana*	Jack pine
Aesculus hippocastanum	Horse chestnut	*Pinus halepensis*	Aleppo pine
Arbutus menziesii	Pacific madrone	*Pinus mugo*	Sweet mountain pine
Cladrastis kentukea	Yellowwood	*Pinus nigra*	Austrian pine
Cotinus coggygria	Smoke tree	*Pinus parviflora*	Japanese white pine
Cotinus obovatus	American smoke tree	*Pinus pinea*	Italian stone pine
Cupressus sempervirens	Mediterranean cypress	*Pinus ponderosa*	Ponderosa pine
Eucommia ulmoides	Hardy rubber tree	*Pinus sabiniana*	Foothill pine
Ficus carica	Common fig	*Pinus strobus*	Eastern white pine
Fraxinus angustifolia	Narrow-leafed ash	*Pinus sylvestris*	Scots pine
Hamamelis virginiana	American witch-hazel	*Prunus virginiana*	Common chokecherry
Hesperocyparis arizonica	Arizona cypress	*Sequoia sempervirens*	Coast redwood
Juniperus virginiana	Eastern red cedar	*Syringa pekinensis*	Chinese tree lilac / Peking lilac
Lagerstroemia indica	Crepe myrtle	*Syringa reticulata*	Japanese tree lilac
Liriodendron tulipifera	Tulip tree	*Syringa vulgaris*	Common lilac
Oxydendrum arboreum	Sourwood	*Taxodium distichum*	Bald cypress
Parrotia persica	Persian parrotia	*Tsuga canadensis*	Eastern hemlock
Paulownia tomentosa	Empress tree	*Tsuga heterophylla*	Western hemlock
Picea abies	Norway spruce	*Tsuga mertensiana*	Mountain hemlock

Source: http://www.pollenlibrary.com/

Climate and Health Tree Species List

In addition to the tree species vulnerability assessment, tree species were assessed for their carbon benefit, health benefits, and health disservices using i-Tree data for Seattle, Washington (i-Tree Team, n.d.). This tree species list was developed to visualize some of the climate and health benefits and concerns when selecting tree species and aid community forestry practitioners in selecting trees. The list is not considered a recommended planting list but demonstrates the complexity of tree species selection and provides insight into four categories: climate vulnerability, carbon benefit, health benefit, and health disservices. Methodology for determining these categories is described in Appendix 4.

Table 9.—Climate and health tree species list for Seattle, Washington.

Scientific Name	Common Name	Climate Vulnerability	Carbon Benefit	Health Benefit	Health Disservices
Abies concolor	White fir	Low-moderate	Low-moderate	Low-moderate	Low-moderate
Abies grandis	Grand fir	Moderate-high	Low-moderate	Low-moderate	Low-moderate
Abies procera	Noble fir	Low-moderate	Low-moderate	Low-moderate	Low-moderate
Acer buergerianum	Trident maple	Low-moderate	Low	Low-moderate	Moderate-high
Acer griseum	Paperbark maple	High	Low	Low-moderate	Moderate-high
Acer macrophyllum	Big leaf maple	Low-moderate	High	High	Moderate-high
Acer negundo	Boxelder	Low-moderate	Moderate-high	Moderate-high	High
Acer nigrum	Black maple	Moderate-high	High	Moderate	Moderate-high
Acer palmatum	Japanese maple	Low-moderate	Low	Low-moderate	Moderate-high
*Acer platanoides***	Norway maple**	Moderate	Moderate	Low-moderate	Moderate-high
*Acer pseudoplatanus***	Sycamore maple	Moderate-high	High	Moderate-high	Moderate-high
Acer rubrum	Red maple	Low	High	Moderate	Moderate-high
Acer saccharinum	Silver maple	Low-moderate	Moderate-high	Moderate	Moderate-high
Acer saccharum	Sugar maple	Moderate-high	Moderate-high	Low-moderate	Moderate-high
Acer tataricum ssp. Ginnala	Amur maple	Moderate-high	Low-moderate	Moderate	Moderate-high
Acer truncatum	Shantung maple	Moderate	Low	Low-moderate	Moderate-high
Aesculus flava	Yellow buckeye	Moderate-high	Moderate	Moderate	Low-moderate
*Aesculus hippocastanum***	Horse chestnut	Moderate-high	High	Moderate	Low-moderate
*Ailanthus altissima***	Tree of heaven	Moderate	Moderate	Low-moderate	Low
Albizia julibrissin	Persian silk tree	Moderate	Low	Low-moderate	Moderate
Alnus rubra	Red alder	High	Low	High	Moderate-high
Amelanchier laevis	Allegheny serviceberry	Low	Low	Low	Low
Arbutus menziesii	Pacific madrone	Low-moderate	High	Moderate	Low-moderate
Arbutus unedo	Strawberry tree	Low	Low	Low-moderate	Moderate
Betula alleghaniensis	Swamp birch	Moderate	Moderate-high	Moderate	Moderate
Betula nigra	River birch	Low-moderate	High	Moderate	Moderate
Betula papyrifera	Paper birch	Low-moderate	High	High	Moderate
Betula pendula	Silver birch	High	High	Moderate	Moderate
Betula populifolia	Gray birch	High	Low	Moderate	Moderate
Carpinus betulus	European hornbeam	Low-moderate	Low	Low-moderate	Moderate

Scientific Name	Common Name	Climate Vulnerability	Carbon Benefit	Health Benefit	Health Disservices
Carpinus caroliniana	American hornbeam	Low	Low	Low-moderate	Moderate
Castanea mollissima	Chinese chestnut	Moderate-high	Moderate	Moderate-high	Moderate
Castanea sativa	Sweet chestnut	High	Moderate-high	Moderate	Moderate
Catalpa bignonioides	Southern catalpa	Low-moderate	Moderate	Moderate	Low-moderate
Catalpa speciosa	Northern catalpa	Moderate-high	Moderate	Low-moderate	Low-moderate
Celtis occidentalis	Common hackberry	Low	Low	Low-moderate	Moderate
Cercidiphyllum japonicum	Katsura tree	High	Low-moderate	Moderate-high	High
Cercis canadensis	Eastern redbud	Low-moderate	Low	Low-moderate	Low-moderate
Chamaecyparis lawsoniana	Lawson's cypress	Moderate-high	Moderate	Moderate	Moderate
Chamaecyparis nootkatensis	Nootka cypress	High	Low	Moderate	Moderate
Chamaecyparis obtusa	Hinoki cypress	High	Moderate	Moderate	Moderate
Chamaecyparis pisifera	Sawara cypress	Moderate-high	Moderate-high	Moderate	Moderate
Chionanthus virginicus	White fringetree	Low	Low	Low-moderate	Low-moderate
Cladrastis kentukea	Yellowwood	Moderate-high	Moderate	Moderate	Low-moderate
Cornus florida	Flowering dogwood	Low-moderate	Low	Low	Low-moderate
Cornus kousa	Kousa dogwood	Moderate	Low	Low	Low-moderate
Cornus mas	Cornelian cherry	Moderate-high	Low	Low	Low-moderate
Cornus nuttallii	Pacific dogwood	Low-moderate	High	Moderate	Low-moderate
Corylus colurna	Turkish filbert	Moderate-high	High	Moderate	Low-moderate
Cotinus coggygria	Smoke tree	Moderate	Low	Low	Low
Cotinus obovatus	American smoke tree	Moderate-high	Low	Low	Low
Crataegus crus-galli	Cockspur hawthorn	Moderate-high	Low	Low-moderate	Low-moderate
Crataegus laevigata	Midland hawthorn / English hawthorn	Moderate-high	Low	Low-moderate	Low-moderate
*Crataegus monogyna***	Common hawthorn	Moderate-high	Low	Low	Low-moderate
Crataegus phaenopyrum	Washington hawthorn	Low-moderate	Low	Low	Low-moderate
Cupressus sempervirens	Mediterranean cypress	Low	Low	Low	Low
*Elaeagnus angustifolia***	Russian olive	Moderate	Low	Low	Low-moderate
Eucommia ulmoides	Hardy rubber tree	Moderate	Moderate-high	Moderate	Low-moderate
Fagus grandifolia	American beech	Low-moderate	Moderate-high	Moderate-high	Low-moderate
Fagus sylvatica	Green beech	Moderate-high	Moderate	High	Low-moderate
Ficus benjamina	Weeping fig	Moderate	Low	Low-moderate	Low-moderate
Fraxinus americana	White ash	Moderate	High	Low-moderate	Moderate
Fraxinus excelsior	European ash	Moderate-high	High	Low-moderate	Moderate
Fraxinus latifolia	Oregon ash	Moderate-high	Moderate-high	Low-moderate	Moderate
Fraxinus pennsylvanica	Green ash	Low-moderate	Moderate	Moderate	Moderate
Ginkgo biloba	Ginkgo / Maidenhair	Moderate	Moderate	Moderate	Moderate
*Gleditsia triacanthos***	Honey locust	Moderate-high	Moderate	Low-moderate	Low
Gymnocladus dioicus	Kentucky coffeetree	Moderate	Moderate	Low	Low
Ilex opaca	American holly	Low-moderate	Low-moderate	Moderate	Low
Juglans nigra	Black walnut	Moderate	Moderate	Moderate	Moderate-high

Scientific Name	Common Name	Climate Vulnerability	Carbon Benefit	Health Benefit	Health Disservices
Juglans regia	English walnut	Moderate-high	Moderate	Moderate-high	Moderate-high
Juniperus chinensis	Chinese juniper	Low	Moderate-high	Low-moderate	Moderate-high
Juniperus virginiana	Eastern red cedar	Low	Low	Moderate	Low
*Koelreuteria paniculata***	Goldenrain tree	Low	Moderate	Low-moderate	Low
Lagerstroemia indica	Crepe myrtle	Low	Low	Low	Low
Larix decidua	European larch	Moderate-high	Moderate	Moderate	High
Ligustrum lucidum	Glossy privet	Low	Low-moderate	Moderate	Low-moderate
Liquidambar styraciflua	Sweetgum	Moderate	Moderate-high	Moderate	Moderate
Liriodendron tulipifera	Tulip tree	High	High	High	Low
*Maackia amurensis***	Amur maackia	Moderate	Low	Low	Moderate
Magnolia grandiflora	Southern magnolia	Low-moderate	Moderate-high	Moderate-high	Moderate
Malus domestica	Edible apple	Moderate-high	Low	Low	Moderate
Malus sylvestris	Crabapple	Moderate-high	Moderate	Moderate	Moderate
Metasequoia glyptostroboides	Dawn redwood	Low-moderate	Low-moderate	Moderate	Moderate-high
*Morus alba***	White mulberry	Moderate-high	Low-moderate	Moderate	Low-moderate
Nyssa sylvatica	Tupelo	Low	High	Moderate	High
Olea europaea	European olive	Low-moderate	Low-moderate	Moderate	Moderate
Ostrya virginiana	Ironwood	Low	Low-moderate	Moderate	Low
Oxydendrum arboreum	Sourwood	Low	Low	Low	Low
Parrotia persica	Persian parrotia	Moderate	Low	Low-moderate	Low-moderate
*Paulownia tomentosa***	Empress tree	Low	Low-moderate	High	Low
Picea abies	Norway spruce	Moderate-high	Moderate	Moderate-high	Low-moderate
Picea glauca	White spruce	Moderate-high	Low-moderate	Moderate	Low-moderate
Picea omorika	Serbian spruce	Moderate-high	High	Moderate-high	Low-moderate
Picea pungens	Colorado spruce	Moderate-high	Moderate	Moderate	Low-moderate
Pinus banksiana	Jack pine	High	Low-moderate	Low-moderate	Low-moderate
Pinus halepensis	Aleppo pine	Low-moderate	Low-moderate	Moderate	Low-moderate
Pinus mugo	Sweet mountain pine	Moderate-high	Moderate-high	Low-moderate	Low-moderate
Pinus nigra	Austrian pine	Moderate-high	Moderate	Moderate	Low-moderate
Pinus parviflora	Japanese white pine	Low-moderate	Moderate	Moderate	Low-moderate
Pinus pinea	Italian stone pine	Low-moderate	Moderate	Moderate	Low-moderate
Pinus ponderosa	Ponderosa pine	High	Low-moderate	Low-moderate	Low-moderate
Pinus sabiniana	Foothill pine	Moderate	Moderate-high	Low-moderate	Low-moderate
Pinus strobus	Eastern white pine	High	Moderate	Moderate	Low-moderate
Pinus sylvestris	Scots pine	Moderate-high	Low-moderate	Moderate	Low-moderate
Pistacia chinensis	Chinese pistachio	Low	Low	Low-moderate	Moderate
Platanus occidentalis	American sycamore	Low-moderate	Moderate-high	High	Moderate-high
Populus alba	White poplar	Low-moderate	High	Moderate	Moderate-high
Populus nigra	Black poplar	Low-moderate	High	Moderate	Moderate-high
Populus tremuloides	Quaking aspen	Low-moderate	High	Moderate-high	Moderate

Scientific Name	Common Name	Climate Vulnerability	Carbon Benefit	Health Benefit	Health Disservices
Prunus armeniaca	Apricot	Moderate-high	Low	Low-moderate	Low-moderate
Prunus avium	Sweet cherry	Moderate-high	Low	Moderate	Low-moderate
Prunus cerasifera	Cherry plum	Low-moderate	Low	Moderate	Low-moderate
Prunus domestica	Common plum	Low-moderate	Low	Moderate	Low-moderate
*Prunus laurocerasus***	English laurel	Low-moderate	Low	Moderate	Low-moderate
Prunus persica	Peach	Low-moderate	Low	Moderate	Low-moderate
Prunus sargentii	Sargent cherry	Moderate-high	Moderate-high	Moderate	Low-moderate
Prunus serotina	Black cherry	Moderate	High	Moderate	Low-moderate
Prunus serrulata	Japanese cherry	Moderate-high	Low	Low	Low-moderate
Prunus virginiana	Common chokecherry	Moderate-high	Low	Moderate	Low
Pseudotsuga menziesii	Douglas fir	High	Low-moderate	Low-moderate	Low-moderate
*Pyrus calleryana***	Callery pear	Low-moderate	Moderate	Moderate	Low-moderate
Pyrus communis	Common pear	Low-moderate	Low	Low-moderate	Low-moderate
*Quercus acutissima***	Sawtooth oak	Low	Moderate-high	Moderate	High
Quercus agrifolia	Coast live oak	Low-moderate	Moderate-high	Low-moderate	High
Quercus alba	White oak	Moderate	High	Moderate	High
Quercus bicolor	Swamp white oak	Moderate	Moderate-high	Moderate	High
Quercus coccinea	Scarlet oak	Low-moderate	High	Moderate	High
Quercus garryana	Oregon oak	Low-moderate	Moderate	Low-moderate	High
Quercus imbricaria	Shingle oak	Moderate	Low-moderate	Moderate-high	High
Quercus palustris	Pin oak	Moderate-high	Moderate	High	High
Quercus phellos	Willow oak	Low	High	High	High
Quercus robur	English oak	Moderate-high	Moderate	Moderate	High
Quercus rubra	Red oak	Moderate-high	High	Low-moderate	High
Quercus shumardii	Shumard oak	Low-moderate	Moderate	Moderate	High
Quercus virginiana	Live oak	Low	Low-moderate	Moderate	High
*Robinia pseudoacacia***	Black locust	Moderate-high	Moderate	Low-moderate	Moderate
Salix babylonica v. matsudana	Corkscrew willow	Low-moderate	Moderate	Moderate-high	High
Sequoia sempervirens	Coast redwood	Moderate	Moderate	Moderate	Low
Sequoiadendron giganteum	Giant sequoia	Moderate	Moderate-high	Low-moderate	Moderate
Sorbus aucuparia	Rowan	Moderate-high	Moderate	Moderate	Moderate
Stewartia pseudocamellia	Japanese stewartia	High	Low	Low	Low
Styrax japonicus	Japanese snowbell	Moderate-high	Low	Low-moderate	Low-moderate
Taxodium distichum	Bald cypress	Low	Moderate	Moderate	Low
Thuja occidentalis	Northern white cedar	Moderate	Low	Moderate	Moderate-high
Thuja plicata	Western red cedar	Low	Low	Moderate	Moderate-high
Tilia americana	American basswood	Moderate-high	Moderate-high	Moderate	Low-moderate
Tilia cordata	Littleleaf linden	Moderate	High	Low-moderate	Low-moderate
Tilia platyphyllos	Large leaf linden	Moderate-high	High	Moderate-high	Low-moderate
Tilia tomentosa	Silver linden	Moderate-high	Low-moderate	Moderate	Low-moderate

Scientific Name	Common Name	Climate Vulnerability	Carbon Benefit	Health Benefit	Health Disservices
Tsuga canadensis	Eastern hemlock	High	Low-moderate	Moderate	Low-moderate
Tsuga heterophylla	Western hemlock	Moderate-high	Low	Moderate	Low-moderate
Tsuga mertensiana	Mountain hemlock	Moderate-high	Low-moderate	Moderate	Low-moderate
Ulmus americana	American elm	Low-moderate	High	Moderate	Moderate
Ulmus parvifolia	Chinese elm	Low	High	Low-moderate	Moderate
Ulmus procera	English elm	Moderate-high	High	Low-moderate	Moderate
*Ulmus pumila***	Siberian elm	Low-moderate	High	Moderate	Moderate
Zelkova serrata	Japanese zelkova	Moderate	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 future tree species selection and current management of existing trees—both native and nonnative species—as well as alter public outreach and engagement efforts. Management considerations when managing urban forests in a changing climate may include whether a species provides wildlife habitat, biodiversity goals, public health considerations, differences in decisions across ownerships and land uses, nursery supply, the contribution of urban trees to green infrastructure, impacts of urban forestry decisions on equity and environmental justice, and influences on planning and partnerships.

Although we do not make recommendations for how management should be adjusted for projected changes, 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. An additional report, *Climate Adaptation Actions for Urban Forests and Human Health* (Janowiak et al. 2021), provides information for optimizing the climate and health outcomes of urban forestry projects and provides professionals working at the intersection of climate, public health, and urban forestry with resources to support climate adaptation planning and actions.

APPENDIX 1.
Temperature and Precipitation Projections

Table A1.1—Temperature and precipitation projections for Seattle, Washington 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 *for Seattle, Washington (47.6062°N, 122.3321°W).*

	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	38.4 in (+0.9 in)	38.1 in (+0.7 in)	39.2 in (+1.7 in)	39.3 in (+1.8 in)	39.6 in (+2.1 in)	40.7 in (+3.2 in)	37.5 in
Winter (Dec - Feb)	15 in (+0.5 in)	15.2 in (+0.7 in)	15.7 in (+1.2 in)	15.7 in (+1.2 in)	15.8 in (+1.3 in)	16.7 in (+2.2 in)	14.5 in
Spring (Mar - May)	8.8 in (+0.1 in)	8.6 in (-0.1 in)	9 in (+0.3 in)	9 in (+0.3 in)	8.9 in (+0.2 in)	9.1 in (+0.4 in)	8.7 in
Summer (June - Aug)	3.1 in (-0.1 in)	3 in (-0.2 in)	2.8 in (-0.4 in)	2.8 in (-0.4 in)	2.8 in (-0.4 in)	2.6 in (-0.6 in)	3.2 in
Fall (Sept - Nov)	11.5 in (+0.4 in)	11.3 in (+0.2 in)	11.7 in (+0.6 in)	11.8 in (+0.7 in)	12.1 in (+1 in)	12.3 in (+1.2 in)	11.1 in
	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	54.5°F (+2.1°F)	54.9°F (+2.4°F)	56.4°F (+4°F)	57.7°F (+5.3°F)	57.4°F (+5°F)	61°F (+8.6°F)	52.4°F
Winter (Dec - Feb)	43.7°F (+2°F)	44.2°F (+2.5°F)	45.6°F (+3.9°F)	46.7°F (+5°F)	46.6°F (+4.9°F)	50°F (+8.3°F)	41.7°F
Spring (Mar - May)	53.2°F (+2.1°F)	53.4°F (+2.4°F)	54.8°F (+3.8°F)	55.7°F (4.7°F)	55.8°F (+4.7°F)	58.5°F (+7.4°F)	51°F
Summer (June - Aug)	66.5°F (+2.5°F)	66.8°F (+2.8°F)	68.6°F (+4.6°F)	70.2°F (+6.2°F)	69.7°F (+5.7°F)	74.1°F (+10.1°F)	64°F
Fall (Sept - Nov)	54.8°F (+1.8°F)	55.1°F (+2.1°F)	56.6°F (+3.6°F)	58.2°F (+5.2°F)	57.6°F (+4.6°F)	61.4°F (+8.4°F)	53°F
	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	47°F (+2°F)	47.3°F (2.3°F)	48.8°F (+3.8°F)	50.1°F (+5.1°F)	49.9°F (+4.9°F)	53.4°F (+8.4°F)	45°F
Winter (Dec - Feb)	38.2°F (+2°F)	38.8°F (+2.6°F)	40.2°F (+4.1°F)	41.3°F (+5.2°F)	41.2°F (+5.1°F)	44.8°F (+8.6°F)	36.1°F
Spring (Mar - May)	45.2°F (+2°F)	45.4°F (+2.2°F)	46.8°F (+3.6°F)	47.7°F (+4.5°F)	47.7°F (+4.5°F)	50.5°F (+7.3°F)	43.2°F
Summer (June - Aug)	56.9°F (+2.2°F)	57.2°F (+2.5°F)	58.9°F (+4.1°F)	60.5°F (+5.8°F)	60°F (+5.3°F)	64.2°F (+9.5°F)	54.7°F
Fall (Sept - Nov)	47.7°F (+1.8°F)	47.9°F (+2°F)	49.4°F (+3.6°F)	51°F (+2°F)	50.5°F (+4.6°F)	54.3°F (+8.4°F)	45.9°F
	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	62.1°F (+2.2°F)	62.4°F (+2.6°F)	64°F (+4.1°F)	65.3°F (+5.4°F)	65°F (+5.1°F)	68.6°F (+8.7°F)	59.9°F
Winter (Dec - Feb)	49.2°F (+1.9°F)	49.6°F (+2.4°F)	51°F (+3.7°F)	52°F (4.7°F)	52°F (+4.7°F)	55.2°F (+8°F)	47.3°F
Spring (Mar - May)	61.2°F (+2.3°F)	61.4°F (+2.5°F)	62.9°F (+4°F)	63.7°F (+4.8°F)	63.9°F (+5°F)	66.5°F (+7.6°F)	58.9°F
Summer (June - Aug)	76°F (+2.8°F)	76.4°F (+3.2°F)	78.3°F (+5°F)	80°F (+6.8°F)	79.4°F (+6.2°F)	83.9°F (+10.7°F)	73.2°F
Fall (Sept - Nov)	61.9°F (+1.8°F)	62.3°F (+2.2°F)	63.7°F (+3.6°F)	65.4°F (5.3°F)	64.8°F (+4.7°F)	68.6°F (8.5°F)	60.1°F
	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	2.5 days (+1.7 days)	3.2 days (+2.4 days)	6.6 days (+5.8 days)	11.6 days (+10.8 days)	9.8 days (+9 days)	31 days (+30.2 days)	0.8 days
	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	38.4 in (+0.9 in)	38.1 in (+0.7 in)	39.2 in (+1.7 in)	39.3 in (+1.8 in)	39.6 in (+2.1 in)	40.7 in (+3.2 in)	37.5 in
Winter (Dec - Feb)	15 in (+0.5 in)	15.2 in (+0.7 in)	15.7 in (+1.2 in)	15.7 in (+1.2 in)	15.8 in (+1.3 in)	16.7 in (+2.2 in)	14.5 in
Spring (Mar - May)	8.8 in (+0.1 in)	8.6 in (-0.1 in)	9 in (+0.3 in)	9 in (+0.3 in)	8.9 in (+0.2 in)	9.1 in (+0.4 in)	8.7 in

Summer (June - Aug)	3.1 in (-0.1 in)	3 in (-0.2 in)	2.8 in (-0.4 in)	2.8 in (-0.4 in)	2.8 in (-0.4 in)	2.6 in (-0.6 in)	3.2 in
Fall (Sept - Nov)	11.5 in (+0.4 in)	11.3 in (+0.2 in)	11.7 in (+0.6 in)	11.8 in (+0.7 in)	12.1 in (+1 in)	12.3 in (+1.2 in)	11.1 in

APPENDIX 2.

List of Assessed Tree Species

Scientific Name	Common Name	Scientific Name	Common Name
Abies concolor	White fir	*Cornus mas*	Cornelian cherry
Abies grandis	Grand fir	*Cornus nuttallii*	Pacific dogwood
Abies procera	Noble fir	*Corylus avellana*	Common hazel / European filbert
Acer buergerianum	Trident maple	*Corylus colurna*	Turkish filbert
Acer circinatum	Vine maple	*Cotinus coggygria*	Smoke tree
Acer freemanii	Freeman maple	*Cotinus obovatus*	American smoke tree
Acer griseum	Paperbark maple	*Crataegus crus-galli*	Cockspur hawthorn
Acer macrophyllum	Big leaf maple	*Crataegus laevigata*	Midland hawthorn / English hawthorn
Acer miyabei	Miyabe's maple	*Crataegus monogyna***	Common hawthorn
Acer negundo	Boxelder	*Crataegus phaenopyrum*	Washington hawthorn
Acer nigrum	Black maple	*Cupressus sempervirens*	Mediterranean cypress
Acer palmatum	Japanese maple	*Elaeagnus angustifolia***	Russian olive
*Acer platanoides***	Norway maple**	*Eucommia ulmoides*	Hardy rubber tree
*Acer pseudoplatanus***	Sycamore maple	*Fagus grandifolia*	American beech
Acer rubrum	Red maple	*Fagus sylvatica*	Green beech
Acer saccharinum	Silver maple	*Ficus carica*	Common fig
Acer saccharum	Sugar maple	*Fraxinus americana*	White ash
Acer tataricum	Tatarian maple	*Fraxinus angustifolia*	Narrow-leafed Ash
Acer triflorum	Three-flower maple	*Fraxinus excelsior*	European ash
Acer truncatum	Shantung maple	*Fraxinus latifolia*	Oregon ash
Aesculus flava	Yellow buckeye	*Fraxinus pennsylvanica*	Green ash
*Aesculus hippocastanum***	Horse chestnut	*Ginkgo biloba*	Ginkgo/Maidenhair
*Ailanthus altissima***	Tree of heaven	*Gleditsia triacanthos***	Honey locust
Albizia julibrissin	Persian silk tree	*Gymnocladus dioicus*	Kentucky coffeetree
Alnus rubra	Red alder	*Hamamelis virginiana*	American witch-hazel
Amelanchier arborea	Downy serviceberry	*Hesperocyparis arizonica*	Arizona cypress
Amelanchier laevis	Allegheny serviceberry	*Hibiscus syriacus*	Common hibiscus
Arbutus menziesii	Pacific madrone	*Ilex aquifolium***	Common holly
Arbutus unedo	Strawberry tree	*Juglans nigra*	Black walnut
Betula alleghaniensis	Swamp birch	*Juglans regia*	English walnut
Betula nigra	River birch	*Juniperus chinensis*	Chinese juniper
Betula papyrifera	Paper birch	*Juniperus virginiana*	Eastern red cedar
Betula pendula	Silver birch	*Koelreuteria paniculata***	Goldenrain tree
Betula populifolia	Gray birch	*Laburnum anagyroides*	Common laburnum
Carpinus betulus	European hornbeam	*Lagerstroemia indica*	Crepe myrtle
Carpinus caroliniana	American hornbeam	*Larix decidua*	European larch
Castanea mollissima	Chinese chestnut	*Ligustrum japonicum*	Wax-leaf Privet / Japanese Privet
Castanea sativa	Sweet chestnut	*Ligustrum lucidum*	Glossy privet
Catalpa bignonioides	Southern catalpa	*Liquidambar styraciflua*	Sweetgum
Catalpa speciosa	Northern catalpa	*Liriodendron tulipifera*	Tulip tree
Celtis occidentalis	Common hackberry	*Maackia amurensis***	Amur maackia
Cercidiphyllum japonicum	Katsura tree	*Magnolia grandiflora*	Southern magnolia
Cercis canadensis	Eastern redbud	*Magnolia kobus*	Kobus magnolia
Chamaecyparis lawsoniana	Lawson's cypress	*Malus domestica*	Edible apple
Chamaecyparis nootkatensis	Nootka cypress	*Malus spp.*	Crabapple
Chamaecyparis obtusa	Hinoki cypress	*Metasequoia glyptostroboides*	Dawn redwood
Chamaecyparis pisifera	Sawara cypress	*Morus alba***	White mulberry
Chionanthus retusus	Chinese fringetree	*Nyssa sylvatica*	Tupelo
Cladrastis kentukea	Yellowwood	*Olea europaea*	European olive
Cornus florida	Flowering dogwood	*Ostrya virginiana*	Ironwood
Cornus kousa	Kousa dogwood	*Oxydendrum arboreum*	Sourwood
Parrotia persica	Persian Parrotia	*Quercus alba*	White Oak

Scientific Name	Common Name	Scientific Name	Common Name
*Paulownia tomentosa***	Empress tree	*Quercus bicolor*	Swamp white oak
Picea abies	Norway spruce	*Quercus coccinea*	Scarlet oak
Picea glauca	White spruce	*Quercus garryana*	Oregon oak
Picea omorika	Serbian spruce	*Quercus imbricaria*	Shingle oak
Picea pungens	Colorado spruce	*Quercus palustris*	Pin oak
Pinus banksiana	Jack pine	*Quercus phellos*	Willow oak
Pinus halepensis	Aleppo pine	*Quercus robur*	English oak
Pinus mugo	Sweet mountain pine	*Quercus rubra*	Red oak
Pinus nigra	Austrian pine	*Quercus shumardii*	Shumard oak
Pinus parviflora	Japanese white pine	*Quercus virginiana*	Live oak
Pinus pinea	Italian stone pine	*Robinia pseudoacacia***	Black locust
Pinus ponderosa	Ponderosa pine	*Salix matsudana*	Corkscrew willow
Pinus sabiniana	Foothill pine	*Sequoia sempervirens*	Coast redwood
Pinus strobus	Eastern white pine	*Sequoiadendron giganteum*	Giant sequoia
Pinus sylvestris	Scots pine	*Sorbus alnifolia*	Korean mountain ash
Pistacia chinensis	Chinese pistachio	*Sorbus aucuparia*	Rowan
Platanus occidentalis	American sycamore	*Stewartia pseudocamellia*	Japanese stewartia
Populus alba	White poplar	*Styrax japonicus*	Japanese snowbell
Populus nigra	Black poplar	*Syringa pekinensis*	Chinese tree lilac / Peking lilac
Populus tremuloides	Quaking aspen	*Syringa reticulata*	Japanese tree lilac
Prunus armeniaca	Apricot	*Syringa vulgaris*	Common lilac
Prunus avium	Sweet cherry	*Taxodium distichum*	Bald cypress
Prunus cerasifera	Cherry plum	*Thuja occidentalis*	Northern white cedar
Prunus cerasus	Sour cherry	*Thuja plicata*	Western red cedar
Prunus domestica	Common plum	*Tilia americana*	American basswood
*Prunus laurocerasus***	English laurel	*Tilia cordata*	Littleleaf linden
Prunus pendula	Weeping higan cherry	*Tilia platyphyllos*	Large leaf linden
Prunus persica	Peach	*Tilia tomentosa*	Silver linden
Prunus sargentii	Sargent cherry	*Trachycarpus fortunei*	Windmill palm
Prunus serotina	Black cherry	*Tsuga canadensis*	Eastern hemlock
Prunus serrula	Birch bark cherry	*Tsuga heterophylla*	Western hemlock
Prunus serrulata	Japanese cherry	*Tsuga mertensiana*	Mountain hemlock
Prunus subhirtella	Higan cherry	*Ulmus americana*	American elm
Prunus virginiana	Common chokecherry	*Ulmus parvifolia*	Chinese elm
Pseudotsuga menziesii	Douglas fir	*Ulmus procera*	English elm
*Pyrus calleryana***	Callery pear	*Ulmus propinqua*	Emerald sunshine elm
Pyrus communis	Common pear	*Ulmus pumila***	Siberian elm
*Quercus acutissima***	Sawtooth oak	*Zelkova serrata*	Japanese zelkova
Quercus agrifolia	Coast live oak		

**Invasive Species

APPENDIX 3.
Modification Factors for Assessing Adaptive Capacity of Trees in Urban Areas

Modification Factors and Adaptability Scores, based on Matthews et al. (2011), were developed for 181 species that are either already present or considered for planting in the Puget Sound region. The purpose of these scores is to provide managers and policy-makers with regional information about individual species that will allow potential suitable habitat distribution models to be considered in a local context based on specific variables within their jurisdiction. This approach will assist interpretation of modeled outputs as published on the Climate Change Atlas and other species distribution models.

Scoring System

Each species was given individual scores for each Modification Factor, which were then weighted and converted into Disturbance, Biological, and Adaptability scores.

Below are the definitions for the scoring system:

FactorType - One of two influential Factor Types (Biological and Disturbance) that describe the variables used to modify the outputs of individual species distribution models.

ModFactor - A Modification Factor that is considered to affect the establishment, growth, mortality rate, and regeneration of a species and that could reduce or increase the habitat suitability or future abundance for that species. See below for specific details relating to each ModFactor for planted and naturally occurring trees.

Score - A score, given as an integer ranging from -3 (negative effect on reproduction, growth, or survival) to +3 (positive effect on reproduction, growth, or survival), that relates to the potential influence a ModFactor has on the species throughout its range at the present.

Uncert - A default score (multiplier on Score) of how uncertain the ModFactor is in influencing the distribution of the species. Scores are 0.5 = highly uncertain; 0.75 = somewhat uncertain; 1.0 = low uncertainty that the ModFactor will provide the influence. These values are also assigned preliminarily by the modeling team based on literature research. For example, if there is contradictory information in the literature, the score would be 0.5.

FutureRelevance - A value (also a multiplier to Score) referring to the likely potential Future Relevance that a particular ModFactor could have on the distribution of a species over the next 50 years in a changing climate. Values range from 1 = not highly relevant over next 50 years to 5 = likely to be an extremely important ModFactor.

Weighted - A weighted score based on multiplication of the three default values (ScoreX UncertX FutureRelevance) for the species throughout its range.

Average Disturbance Score - The average of all the Weighted Disturbance Factor Scores—relates to the relative overall impact of these factors.

Average Biological Score - The average of all the Weighted Biological Factor Scores—relates to the relative overall impact of these factors.

Converted Dist Score - The average of all Disturbance Factor Scores (unweighted) +3 to remove negative values. Values can range from 0 to 6.

Converted Bio Score - The average Biological Factor Scores (unweighted) +3 to remove negative values. Values can range from 0 to 6.

Adaptability Score - The hypotenuse of a right triangle created from the Converted Dist and Bio Score. Values can range from 0 to 8.5.

Adaptability Class - Categories assigned based on Adaptability Score. Low: less than 3.5. Moderate: 3.5-4.5. High: more than 4.5.

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 (1990), 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 has 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.

Below is an example planted score for *Abies grandis* (Table A3.1).

Table A3.1.—Example of planted modification factor scores generated for the species *Abies grandis*.

FactorType	ModFactor	Score	Uncert	FutureRelevance	Weighted
Disturbance	Disease	-2	0.75	2	-3.00
Disturbance	Insect Pests	-1	0.5	4	-2.00
Disturbance	Browse	0	0.75	1	0.00
Disturbance	Invasive Plants	-1	0.5	2	-1.00
Disturbance	Drought	1	0.75	3	2.25
Disturbance	Flood	0	0.75	3	0.00
Disturbance	Ice	-1	0.5	2	-1.00
Disturbance	Wind	0	0.75	2	0.00
Disturbance	Temperature Gradients	-1	0.75	3	-2.25
Disturbance	Air Pollution	-3	0.75	3	-6.75
Disturbance	Soil and Water Pollution	-1	0.5	1	-0.50
Disturbance	Salt	-3	0.5	2	-3.00
Biological	Competition-Light	0	0.5	1	0.00

Biological	Edaphic Specificity	2	0.75	2	3.00
Biological	Land Use and Planting Site Specificity	-1	0.75	3	-2.25
Biological	Restricted Rooting Conditions	0	0.75	3	0.00
Biological	Nursery Propagation	2	0.75	4	6.00
Biological	Planting Establishment	0	0.75	2	0.00
Biological	Maintenance Required	2	0.75	2	3.00
Biological	Invasive Potential	0	0.75	3	0.00
	Average Disturbance Score				-1.44
	Average Biological Score				1.22
	Converted Disturbance Score				2.00
	Converted Biological Score				3.63
	Adaptability Score				4.14
	Adaptability Class				Moderate

APPENDIX 4.

Methods: Climate and Health Tree Species List

Climate Vulnerability

Trees can be vulnerable to various climate-related stressors such as heat, drought, flooding, and pest and disease patterns. Climate vulnerability is a function of climate change impacts on a tree species and the species' adaptive capacity. Species that are projected to have negative impacts on habitat suitability and low adaptive capacity will have high vulnerability and vice versa. The following factors, explained further in "Chapter 2: Tree Species Vulnerability," were used to determine climate vulnerability:

- **Habitat Suitability:** Habitat suitability was determined by examining heat and hardiness zone ranges. The ranges were documented for each tree species and compared with current and projected heat and hardiness zones for Seattle using downscaled climate models.
- **Adaptability:** Each tree species was assessed for adaptability based on literature describing its tolerance to biological factors such as soil needs, shade tolerance, maintenance requirements, and nursery propagation, as well as disturbance factors such as drought, flooding, pests, and disease. Adaptability scores were assigned to Seattle tree species using methods developed in an urban forest vulnerability assessment for Chicago (Brandt et al. 2017).

Carbon Benefit

Trees store carbon in their wood, roots, and leaves and help reduce energy use for heating and cooling. Carbon benefits provided by each tree species were modeled for Seattle, Washington using i-Tree data (i-Tree Team, n.d.) and were binned into categories based on their relative carbon benefits to one another. The following factors were used to assess carbon benefits:

- **Carbon Storage:** The total of all carbon stored during the average lifespan of a tree species. Smaller trees tend to store less carbon, while larger trees tend to store more carbon.
- **Carbon Sequestration Rate:** The carbon absorption of a tree species per year. Species that have more growth per year will have higher carbon sequestration rates.
- **Carbon Savings from Energy Use:** The total amount of carbon saved from reduced heating and cooling energy use. Large conifer trees tend to reduce heating energy use, and large shade trees tend to reduce cooling energy use.

Health Benefit

Trees can reduce risks to human health such as heat stress and reduced air quality, which can increase under a changing climate. Trees provide shade and cooling through transpiration, as well as absorption of pollutants. Human health benefits provided by each tree species were modeled for Seattle, Washington using i-Tree data (i-Tree Team, n.d.) and were binned into categories based on their relative health benefits to one another. The following factors were used to assess human health benefits:

- **Leaf Area:** The maximum leaf area reached over a tree species' lifespan. Trees with greater leaf area provide more shade and tend to absorb more pollutants.
- **Transpiration:** The average transpiration rate per year. The rate can be influenced by tree size as well as differences in water-use efficiency. Tree species that transpire more tend to be better at evaporative cooling and flood mitigation.
- **Pollutants Removed:** The weighted sum of pollutants NO_3, O_3, $PM_{2.5}$, and SO_2 removed over a tree species' lifespan.

Health Disservices

Some trees can have negative effects on human health by producing allergenic pollen or volatile organic compounds such as isoprene or monoterpenes, which can reduce air quality. Isoprene and monoterpene emissions for each tree species were modeled for Seattle, Washington using i-Tree data (i-Tree Team, n.d.) and were binned into categories based on their relative health disservices to one another. Allergenicity for each tree species was determined from Pollen Library (IMC Health, 2022), which bins each tree species into an allergenicity category (none, low, moderate, severe). The following factors were used to assess health disservices:

- **Allergenicity:** The capacity of a tree species to cause an allergic reaction. Trees that are wind-pollinated tend to be more allergenic.
- **Isoprene Emissions:** The total emissions of isoprene compounds over a tree species' lifespan. Some tree species (particularly broadleaved trees such as oaks) can be high emitters of isoprene.
  Monoterpene Emissions: The total emissions of monoterpene compounds over a tree species' lifespan. Some tree species (particularly many conifers) can be high emitters of monoterpenes.

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As the climate changes over the 21st century, the Puget Sound region's urban forest will be impacted by changing temperatures and precipitation regimes, leading to implications for the people who depend on its ecosystem services. This report summarizes climate change projections for the Puget Sound region and provides an assessment of tree species vulnerability in the region. We used projected shifts in plant hardiness and heat zones to understand how tree species of interest are projected to tolerate future conditions. We also assessed the adaptability of planted trees to stressors such as drought, flooding, wind damage, and air pollution, as well as environmental conditions such as shade, soils, and restricted rooting using "modification factors"—an adaptability scoring system for planted environments. The region has been warming at a rate of about 0.4°F per decade since 1960, and the average temperature is projected to increase by 5.0°F to 8.6°F by the end of the century compared with the 1971-2000 historical average. Precipitation in the region has been increasing by over 0.5 inches per decade since 1960 and is projected to increase by 2.1 to 3.2 inches by the end of the century compared with the 1971-2000 historical average. By the end of the century, the Puget Sound region is projected to shift from hardiness zones 8-9 to zone 9 completely and from heat zone 2 to heat zone 3 (RCP4.5) or 6 (RCP8.5), depending on the climate change scenario. Of the evaluated tree species, 27% were rated as having high adaptability, 59% were rated as having medium adaptability, and 14% were rated as having low adaptability. Given that the hardiness zone range is projected to remain within the historical (1980-2009) range, we considered both heat zones alone as well as heat and hardiness zones. Considering heat zones only, most of the assessed tree species fell into the low-moderate vulnerability category (57%), followed by low vulnerability (26%) and moderate vulnerability (17%) under both low and high climate change scenarios. The vulnerability ratings remain the same between low and high climate change scenarios because all assessed tree species are considered suitable under both sets (low and high) of heat zone projections through the end of the century. Considering both heat and hardiness zones, most of the assessed tree species fell into the moderate-high vulnerability category (34%), followed by low-moderate (25%), moderate (18%), low (14%), and high (9%). The vulnerability ratings are the same between low and high climate change scenarios because the projected hardiness zone is the same under both scenarios through the end of the century. The vulnerability of individual species is not the only factor to consider when making urban forestry decisions, and this assessment also contains species diversity and human health as additional factors. 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.

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