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A Climate Resilience Guide for Urban Forests in the Northwest

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Trees captivate us with their beauty and serve many important functions in the spaces where we live, work, and play. They offer privacy, improve scenic views, provide shade to cool buildings on hot days, contribute to mental well-being and public health, and mitigate climate change by absorbing carbon dioxide. Given the many benefits of urban forests, it is clear that thoughtful growth and management of a community tree canopy improves the quality of life for local residents while advancing environmental objectives.

Climate change is altering many aspects of our lives and the natural environment in the northwestern continental United States (hereafter, the Northwest)[1], with bigger changes expected in the future. The effects of climate change on natural forests are well documented. However, the effects of climate change on trees in urban areas—where 80% of the population of Idaho, Oregon, and Washington live—are less clear. In this guide, we examine the potential effects of climate change on Northwest urban forests and discuss strategies that planners, foresters, and arborists can implement to ensure the long-term sustainability of community tree canopies.

[1] The guide refers to the states Idaho, Oregon, and Washington collectively as the "Northwest." Other sources may refer to it as the "Pacific Northwest" region of the United States.

Trees and Climate in Urban Landscapes

Urban forests encompass trees and associated vegetation growing within and near urban areas: trees along roads and sidewalks, trees in parks and public spaces, trees in residential yards, trees adjacent to businesses, remnant patches of native forest within urban boundaries, and planted forests in cities. Urban forests are typically near dense human populations. These forests often include many different species and are both publicly and privately owned.

Trees modify climate and conserve energy in cities through (1) shading, which reduces energy absorbed and stored by built surfaces, (2) transpiration, which converts moisture to water vapor and thus cools the air, and (3) lowered wind speed, which reduces transmission of outside air into interior spaces. This moderates the phenomenon of urban heat islands in areas that experience high temperatures accentuated by absorption and retention of heat by asphalt, concrete, and buildings. Heat islands contribute to increased use of air conditioning, heightened health risks during heat waves, and poor air quality. The net cooling effect of a large, healthy tree is equivalent to 10 window-size air conditioners operating 20 hours a day. Community tree canopies can lower local temperatures by 5°F or more, reducing the risk of heat-related illness.

Urban forests can reduce atmospheric carbon dioxide in two ways. First, trees directly take up carbon dioxide and incorporate carbon in roots, wood, and leaves. Second, trees near buildings reduce demand for heating and air conditioning, thereby reducing emissions associated with electric power production. A tree can absorb around 50 pounds of carbon dioxide per year, so by the time that the tree is 40 years old, that can add up to 2 tons of carbon (the amount of carbon emitted by driving a gasoline-powered car 5,000 miles). Trees also absorb gaseous pollutants (e.g., ozone, nitrogen oxides, sulfur dioxide) through leaf surfaces, intercept particulate matter (e.g., dust, pollen, and smoke), and release oxygen through photosynthesis.

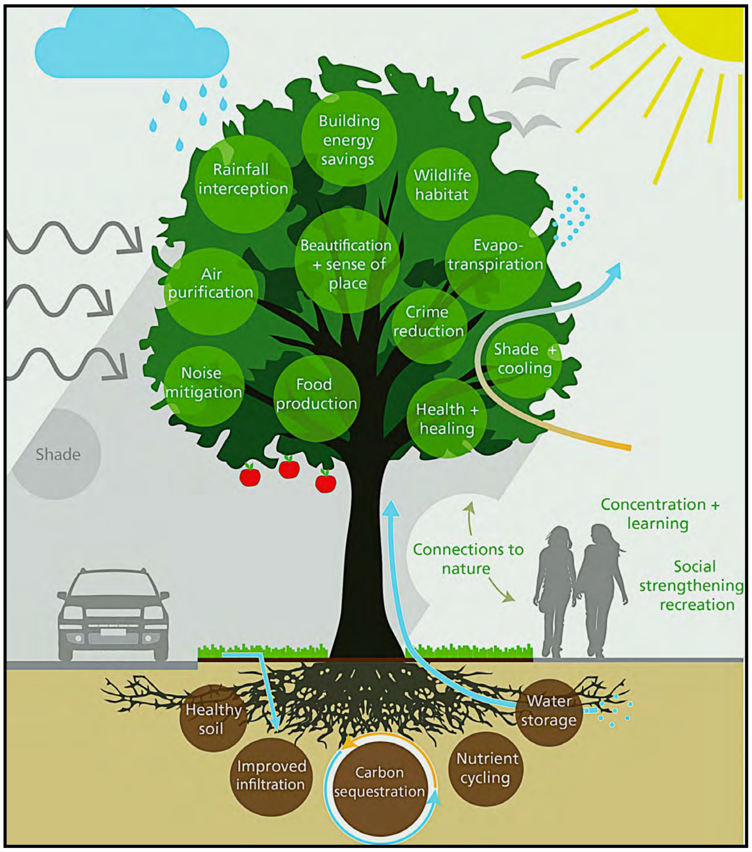


Figure 1: Urban forests provide many benefits that contribute to community well-being. (From the Bellingham State of the Urban Forest Report)

Stormwater runoff is a major problem in urban areas and may worsen if climate change increases high-intensity rainfall as expected. When rain hits surfaces—roads, parking lots, and building roofs—some of the rainfall becomes runoff. The runoff picks up sediment, fertilizers, pesticides, and oils that eventually make their way to streams and lakes, creating hazards for fish and other aquatic life. Trees reduce runoff and pollutants by intercepting and storing water, increasing the rate of soil infiltration, and reducing soil erosion caused by intense rainfall. Urban forests can be considered "green infrastructure" that moderates the environmental impacts of stormwater and reduces risks.

Climate in the Northwest

Climate in the Northwest is influenced by proximity to the Pacific Ocean and the presence of mountainous topography. This results in contrasting climates on the west and east sides of Oregon and Washington, whereas temperature in Idaho differs from north to south. In addition, average temperature and growing-season length differ across the region. Precipitation varies by latitude and elevation, depending on how atmospheric systems move from the ocean inland along river valleys.

Oregon

Western Oregon

Western Oregon has a Mediterranean climate characterized by wet winters and dry summers. The Coast Range heavily influences weather patterns in the region by enhancing precipitation on the western slopes through large-scale movement of air masses. The area west of the Coast Range is the wettest location in Oregon, receiving 150 inches of annual rainfall in some places, with 70% falling between November and March. During these months, average daily temperatures in western Oregon range from freezing to the low 50s, depending on location. During the summer, average daily temperatures range from the 60s to the 80s. Summers in southwest Oregon are much hotter and drier than the rest of western Oregon. Around 75% of precipitation falls during the winter rainy season.

Eastern Oregon

Eastern Oregon has a dry climate with high variability in seasonal temperatures. Precipitation during the winter months is substantially lower than most of western Oregon. Mean annual precipitation averages 10–20 inches, with much of the precipitation falling as snow. Summers are hot and dry, with average daily temperatures climbing into the mid 90s.

Washington

Western Washington

The climate west of the Cascade Range is influenced by its proximity to Puget Sound and the Pacific Ocean, creating a maritime climate. The region experiences mild, wet winters, with most annual precipitation falling from November through March. Western Washington receives around 40–60 inches of precipitation, but the coastal and mountainous regions can receive double that amount. The summer is mild and dry, with high temperatures typically ranging from 65°F to 80°F. The climate is further influenced by the marine layer that blankets the region, contributing to foggy and overcast conditions, especially during winter.

Eastern Washington

The Cascade Range influences the climate in eastern Washington by forcing air masses to rise over the crest, causing heavy precipitation and snow in the mountains and low precipitation (a rain shadow) east of the crest. This broad-scale pattern results in a climate marked by substantial weather variability across eastern Washington. The Columbia River Basin experiences semi-arid conditions with desert-like characteristics, whereas the mountainous northern region receives more precipitation. Summers are hot and dry, with some areas experiencing average daily temperatures in the 90s and above. Winters are cold, and sub-freezing temperatures are common. Winter precipitation varies by location, with heavy snowfall in high-elevation areas.

Idaho

The climate in Idaho varies throughout the state due to its diverse topography, which includes low valleys and rugged mountains. Southern Idaho has hot summers with average daily temperatures over 90°F, whereas northern Idaho typically experiences milder summers with highs in the 80s. The winter months are cold, with temperatures dropping well below 20°F in some parts of northern Idaho. Most precipitation falls between November and May, and total precipitation varies by elevation. Semi-arid areas at lower elevations receive low precipitation due to the rain-shadow effect created by the mountains. Higher-elevation areas in northern and central Idaho receive more precipitation, much of it in the form of snow.

Projected Climate

Climate projections for the Northwest indicate significant changes by mid- to late-21st century. These projections are based on representative concentration pathways (RCP)—climate change scenarios used to project future greenhouse gas concentrations. Large temperature increases are projected for both moderate (RCP 4.5) and high (RCP 8.5) emission scenarios, with greater warming in the summer. Winter precipitation is projected to increase across all states, whereas summer precipitation is projected to decrease everywhere except southern Idaho.

Western Oregon and Western Washington

Annual temperatures are projected to increase 3.6°F (RCP 4.5) to 4.7°F (RCP 8.5) by the 2050s, and 4.5°F to 7.5°F by the 2080s. Warming will be greatest during the summer, with temperature increases as high as 9.0°F by the 2080s. Although precipitation projections are less certain, most models project that winters will be wetter (+4.3% to +7.0%) and summers will be drier (–9.9% to –13.0%) by the 2050s, with summers up to 15.9% drier by the 2080s.

Eastern Oregon and Eastern Washington

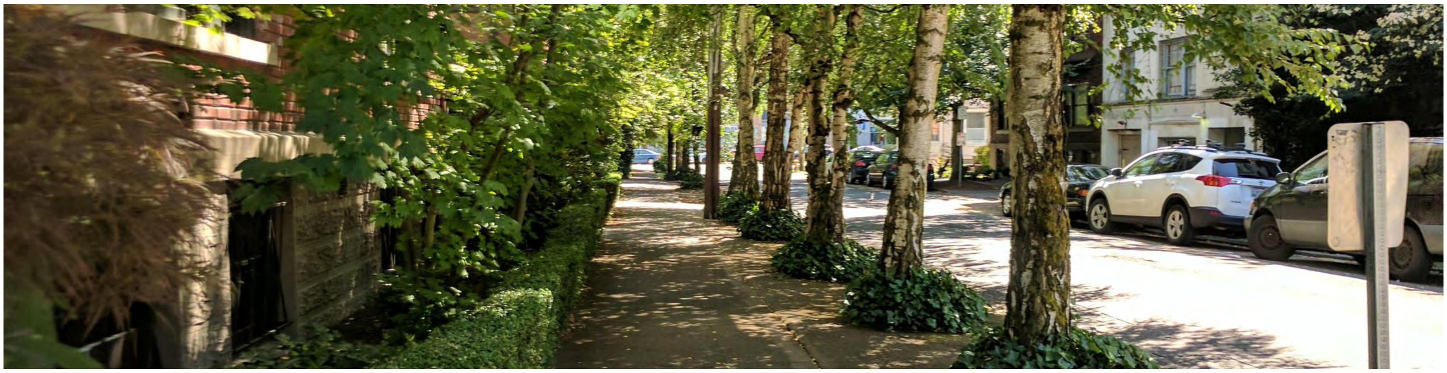
Annual temperatures are projected to increase 4.4°F to 5.7°F by the 2050s, and 5.5°F to 9.1°F by the 2080s. Warming will be greatest during the summer, with temperature increases as high as 10.9°F by the 2080s. Although precipitation projections are less certain, most models project that winters will be wetter (+5.1% to +8.6%) and summers will be drier (-4.7% to -6.3%) by the 2050s, with summers up to 9.9% drier by the 2080s.

Northern Idaho

Annual temperatures are projected to increase 4.5°F to 6.1°F by the 2050s, and 5.9°F to 9.6°F by the 2080s. Warming will be greatest during the summer, with temperature increases as high as 11.3°F by the 2080s. Although precipitation projections are less certain, most models project that winters will be wetter (+6.6% to +8.5%) and summers will be drier (-5.9% to -6.7%) by the 2050s; summers will be only 2.5% drier by the 2080s.

Southern Idaho

Annual temperatures are projected to increase 4.7°F to 6.3°F by the 2050s, and 5.9°F to 10.1°F by the 2080s. Warming will be greatest during the summer, with temperature increases as high as 11.3°F by the 2080s. Although precipitation projections are less certain, most models project that winters will be wetter (+7.3% to +8.9%), and summers will be slightly wetter (1.2% to 2.8%) by the 2050s; winters will be up to 21.5% wetter by the 2080s.



	Annual temperature increase (°F)		Summer temperature increase (°F)		Winter precipitation change (%)		Summer precipitation change (%)	
2050s	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Western Oregon & Western Washington	3.6	4.7	4.2	5.6	+4.3	+7.0	-9.9	-13.0
Eastern Oregon & Eastern Washington	4.4	5.7	5.0	6.7	+5.1	+8.6	-4.7	-6.3
Northern Idaho	4.5	6.1	5.0	6.9	+6.6	+8.5	-5.9	-6.7
Southern Idaho	4.7	6.3	5.1	7.1	+7.3	+8.9	+1.2	+2.8
2080s								
Western Oregon & Western Washington	4.5	7.5	5.3	9.0	+5.9	+10.4	-12.6	-15.9
Eastern Oregon & Eastern Washington	5.5	9.1	6.3	10.9	+7.5	+14.6	-6.1	-9.9
Northern Idaho	5.6	9.6	6.2	11.3	+8.2	+8.2	-4.5	-2.5
Southern Idaho	5.9	10.1	6.3	11.3	+10.5	+10.5	+4.5	+3.6

Projected temperature and precipitation for the mid 21st century (2050s) and late 21st century (2080s) for moderate (RCP 4.5) and high (RCP 8.5) greenhouse gas emission scenarios. Projections for Oregon and Washington are from global climate models in the Coupled Model Intercomparison Project (CMIP5; Pacific Northwest Climate Projection Tool, University of Washington, Climate Impacts Group; https://cig.uw.edu/resources/analysis-tools/pacific-northwest-climate-projection-tool). Projections for Idaho are from global climate models in the Climate Mapper tool (CMIP5; https://climatetoolbox.org).

Extreme Weather

Extreme temperatures and precipitation are important drivers of change in all forests, including urban forests. Consistent with mean temperatures increasing in the future, as described above, the frequency of very high temperatures is also expected to increase. These extremes can be stressful for trees, especially when they occur for days to weeks at a time. Precipitation intensity is also projected to increase but with longer periods of time between precipitation events than has occurred historically. Periods of low precipitation that co-occur with high temperatures are especially stressful for trees, causing prolonged periods of low soil moisture and high evaporative demand.

The extent to which extreme weather events will occur in the coming decades is uncertain, but their frequency and severity in the Northwest may be on the rise. For example, the six-day heatwave in June 2021 brought record-breaking temperatures throughout the Northwest, jeopardizing the health of both urban forests and people. That same year, Idaho and Oregon endured their second-driest summer on record, and Washington its fourth driest. But heat events are not the only challenge. In 2024, the region faced a “bomb cyclone” that brought heavy rainfall and high winds, leading to widespread damage in urban forests. Portland, Oregon suffered major tree loss during this event, with the city recording 750 reports of downed trees.

If extreme weather becomes more frequent, it will exacerbate drought stress and flooding, leading to reduced tree vigor, increased physical damage, and potentially higher mortality. Urban forest managers will need to prepare for how trees will respond to extreme weather combined with the usual challenges of growing trees in an urban environment.

Effects of Climate Change on Urban Forests

Climate change poses challenges for urban trees, affecting their health, survival, and ability to provide environmental benefits to city residents. Chronic stressors like poor drainage and soil compaction can build up over time and slowly weaken trees, whereas extreme weather (intense storms, floods, extreme heat, etc.) can rapidly damage trees. Climate-related challenges can intensify existing stressors, further compromising urban tree health. The primary effects of climate change on urban trees are summarized below.

Temperature Variability

High temperatures can increase respiration and decrease photosynthesis, creating stress in some tree species and reducing their vigor. A period of high temperature when leaves are young or not fully emerged can damage or kill the leaves, which reduces growth during that year. This can occur in both conifers and hardwoods. Urban heat islands can elevate ambient temperature to a harmful level, damaging the vascular system of trees and, in some cases, killing them. Sun scalding caused by magnified reflection of sunlight from windows in urban areas can exacerbate heat-related stress. Mild winter temperatures can shorten the dormancy period of some trees. Then, early spring warming can cause buds to open early, making them susceptible to freezing. An early cold period can kill bark and sapwood tissues through rapid formation of internal ice that ruptures cells.

Drought Stress

Reduced availability of soil water is the biggest concern for most urban trees in a warmer climate. Long drought periods make it difficult for trees to move water from the roots into the crown, which reduces growth and can cause leaf mortality, in some cases killing the upper crown or the tree itself. Drought stress is especially common in cities, where limited soil volume and compacted soil restrict water storage and hinder root growth. Many species, especially Northwest natives, are tolerant of low soil moisture in late summer. However, low soil moisture in spring and early summer can reduce photosynthesis and weaken trees.

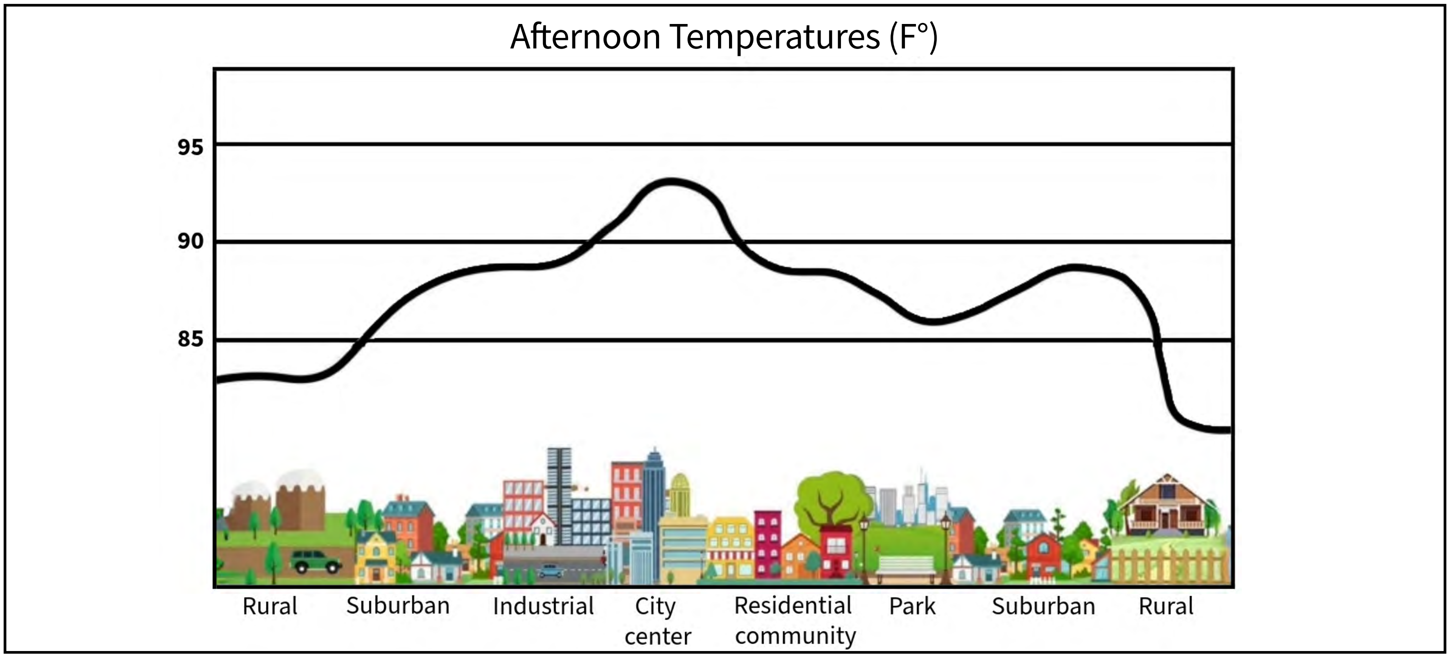


Figure 2: In urban areas, the retention of heat by buildings, concrete, and asphalt makes afternoon temperatures much hotter than surrounding rural areas. (Graphic by Elyse Doerr).

Figure 3: Diseases, higher temperatures, and lower water availability can cause crown thinning in western redcedar trees, eventually leading to mortality, as shown here in Tacoma, Washington. (Photo by Joey Hulbert)

Extreme Weather

Extreme weather can be particularly harmful to urban trees. As mentioned earlier, even short periods of extreme heat can rapidly increase water loss through transpiration, leading to leaf wilting or dieback. Sudden cold snaps following gradual spring warming can kill emerging buds and freeze vascular tissue. More intense precipitation can also increase runoff, leading to flooding that endangers both trees and surrounding infrastructure.

Multiple Stresses

Trees become vulnerable to climate-related stress when multiple interacting factors combine to weaken them—a condition known as a stress complex. For example, bark beetles preferentially attack trees that are already weakened from drought stress. Armillaria (root rot) most commonly exploits trees whose natural defenses have been compromised. Urban trees generally suffer more during heat waves and drought compared to their rural counterparts, because the urban environment is hotter and drier than natural habitat. Trees planted in areas with compacted or shallow soils, air pollution, and other growth-limiting conditions—which are common in urban environments—are more prone to additional stress during drought.

Insects and Disease

Higher temperatures stimulate many insect species, increasing their reproductive rate and allowing them to overwinter in locations where a cold climate would normally kill eggs or larvae. This includes bark beetles that feed on phloem (e.g., pines and Douglas-fir [*Pseudotsuga menziesii*]) and some defoliators that feed in tree canopies. Insects are more successful in attacking a host tree if the tree is already weakened by drought stress or other causes. Fungal pathogens like root rot, sooty bark disease (*Cryptostroma corticale*), and anthracnose can weaken, disfigure, and ultimately kill affected trees. This is especially true for older, less vigorous trees and those growing in marginal soil conditions. Some fungal pathogens can take advantage of drought-stressed trees, whereas other fungi will not grow as well under drier conditions.

Figure 4: Insects such as the California fivespined ips (*Ips paraconfusus*) can weaken and kill trees, especially those that are already weakened by environmental factors such as drought or heat stress. (Photo by Savannah Swanson)

Adapting Urban Forests to Climate Change

Expansion of urban areas elevates the need for landscapes that conserve energy and water, reduce stormwater runoff, sequester carbon, attract wildlife, and provide other aesthetic, social, and economic benefits. As Northwest communities continue to grow, using forests to enhance the urban environment, increase community attractiveness and livability, and promote civic pride is taking on greater significance. The simple act of planting trees connects residents with nature and with each other. Large citywide projects such as community gardens, food forests, and neighborhood tree plantings encourage collaboration among citizens, businesses, and government in the betterment of communities.

Approaches to sustainability and urban forest stewardship are as diverse as the settings in which they occur. Different tree species and forest structures are needed for a wide variety of urban spaces—cities, suburbs, parks, community forests, rural areas, and tribal lands. As a result, careful planning is essential when creating strategies for planting and maintenance. And the potential effects of climate change must be considered in planning to ensure resilience and long-term sustainability.

This section describes a general strategy that will help urban forests—and urban forest management organizations—adapt to a warmer climate. This strategy should be feasible for agencies and municipalities with sufficient budget and staff to conduct the necessary evaluations and planning. Urban foresters, arborists, and landscapers may have sufficient capacity and time to address some components of the strategy. It will be unrealistic for most homeowners to implement a detailed strategy, although they can consult with organizations and practitioners with urban forestry expertise.

Figure 5: Engaging community members in tree planting fosters a sense of stewardship towards urban trees. (Photo of WWU LEAD volunteers by Brandon McWilliams)

Engage with Local Communities on Objectives and Stewardship

Community engagement and public outreach are essential components of successful urban forest planning. Including a cross-section of people from different economic classes, age groups, and cultural backgrounds helps ensure that multiple perspectives are considered in urban forest stewardship. It also empowers local communities to partner with their cities in the long-term care of urban trees. A community-based urban forest team that meets periodically, not just at the planning stage, can enhance continuity and commitment.

City governments, businesses, and residents often have distinct concerns that should be addressed during urban forest planning. Open discussions can help build awareness of differing perspectives, foster shared understanding, and lead to clear objectives—such as choosing appropriate species, determining planting locations, and assigning maintenance responsibilities. Although a municipality may set broad planting goals, individual neighborhoods may

Highlight: Urban Food Forests

Urban food forests are a creative approach to integrating trees and other plants into the built environment while simultaneously enhancing local food security. By replicating the structure of natural forest ecosystems with edible trees, shrubs, and herbaceous plants, underutilized urban spaces can be transformed into productive landscapes. Food forests also help promote community resilience through collaborative stewardship and provide environmental-education opportunities focused on sustainable agricultural practices. By allowing residents to take an active part in the food-production cycle, communities can become more aware of where their food comes from while improving connections with nature.

Food forests address food-security challenges in urban "food deserts," areas that lack or have limited access to nutritious food options due to the absence of grocery stores or farmers markets. Residents in these areas often lack reliable transportation and have low income, preventing them from traveling to distant grocery stores that have healthier food options. By establishing food forests in these areas, communities gain improved access to fresh produce and have the opportunity to develop practical growing skills.

Several communities in the Northwest are exploring food forests as a strategy to boost local food security. One notable example is the Beacon Food Forest in Seattle, Washington—one of the largest public food forests in the United States. Its mission is to expand food access and empower residents to grow and harvest their own food. Modeled after the layered structure of a natural forest, the site features an upper canopy of fruit and nut trees, with berry bushes, edible perennials, and annuals in the understory. This approach demonstrates how urban forestry can play a vital role in addressing food security while enriching the quality of life in urban settings.

Figure 6: Created in partnership with the City of Seattle, the Beacon Food Forest demonstrates how urban forestry can promote food sovereignty and community health. (Photo from Beacon Food Forest)

have specific needs and preferences. For instance, if stormwater runoff is a concern, tree species and planting designs should focus on reducing surface flow and flooding. If public safety is a priority, then high-canopy trees, low-growing shrubs, and consistent maintenance may be more appropriate.

Urban forest plans and projects must adhere to local laws and ordinances concerning approved tree species, permits, property access, and liability. Although city and county employees may navigate these requirements with relative ease, they can pose challenges for those who are less familiar with local government structures and regulations. Factors such as housing-density regulations, wildfire mitigation strategies, and long-term environmental planning must also be considered when determining the appropriate density, species composition, and adaptability of an urban forest.

When urban forest designs incorporate diverse community input, they are more likely to meet multiple objectives. In areas with existing forest vegetation, a phased transition plan may be necessary to introduce new species and cultivars over time. This approach supports the gradual development of more resilient vegetation, where the health of current plantings is declining due to climate-related stress.

The history of land use and vegetation management provides valuable context for urban forest planning and projects. For example, have past activities such as soil removal, grading, or construction degraded site conditions? Which tree species have historically thrived or struggled in a proposed project site? Investigating previous tree plantings and maintenance practices can help avoid repeating past mistakes and increase the chances of long-term success.

Understanding how climate change will affect specific neighborhoods is essential for effective planning and tree planting. Citywide climate projections may not provide the detail needed for local decision making. For instance, how might the density of buildings and infrastructure in a neighborhood intensify temperatures through the urban heat island effect? Are the soils deep and fine-textured enough to retain moisture through the summer? Could rising temperatures lead to increases in local insect populations that threaten certain tree species? In the absence of detailed data, qualitative assessments and expert insights can offer valuable direction. Although not all climate-related stressors can be anticipated, reducing known risks improves the likelihood of establishing a resilient urban forest.

Create a Long-term Management Plan

Long-term care and maintenance are essential components of every urban forest plan and project. Unfortunately, trees in urban areas often die from inadequate watering during dry summers, leading to both ecological and financial losses. The initial investment is wasted, long-term benefits are forfeited, and in some cases, this can erode community trust. As climate change increases stress on urban vegetation, having a clear, committed management plan becomes even more critical to ensure tree survival and project success.

Urban forest management is often straightforward in public areas like city parks, where municipal staff are typically responsible for maintenance. Ensuring consistent care in rights-of-way or on private property can be more challenging. Homeowners may be reluctant to plant new trees if they lack the knowledge or confidence to care for them properly. In such cases, support from municipalities and local organizations, such as university extension programs and county conservation districts, can be crucial. These organizations can offer guidance, resources, and consultations to help ensure that newly planted trees thrive.

Highlight: Case Studies of Climate-resilient Urban Forestry

Across the Northwest, local governments are recognizing the important role that trees play in mitigating the effects of climate change, while also planning for how trees will adapt to climate-related stressors. The examples below demonstrate how cities are preparing urban forests to face the challenges of a changing climate.

Ashland — Climate and Energy Action Plan

The city of Ashland, Oregon (population 21,000) is taking proactive steps to address climate change risks by implementing strategies to strengthen and adapt its urban forest. As part of its Climate and Energy Action Plan, Ashland aims to expand its urban tree canopy and update its street-tree guide to include species better suited to a warming climate. The city has prioritized tree species that can tolerate higher temperatures and reduced water availability while providing long-term canopy cover.

Ashland also intends to revise the urban forest guidelines outlined in its 2016 forest plan, with an emphasis on increasing species diversity. Priority is being given to drought-tolerant pines, hardwoods, and shrubs that are well-suited to warmer, drier conditions. To support this effort, the city is promoting community involvement in climate-resilient landscaping through education, outreach, and technical assistance, thus empowering residents to strengthen tree resilience on their own properties.

Seattle — 2020 Urban Tree Management Plan

The City of Seattle (population 755,000) recognizes that although urban trees help mitigate the effects of climate change, they are also vulnerable to its impacts. The 2020 Urban Forest Management Plan (UFMP) provides a comprehensive strategy for preserving and enhancing Seattle's urban forests while emphasizing their critical role in building the city's resilience to climate change. The UFMP outlines key objectives and actionable strategies to sustain urban forests in the future.

A primary goal is to increase the city's tree canopy cover to 30% by 2037, with a focus on planting diverse species, particularly those that tolerate drought and heat. Recognizing that many of Seattle's existing trees are nearing the end of their lifespans, the plan highlights the importance of planting trees of varying ages to ensure the long-term health and continuity of the urban forest. In addition, the UFMP underscores the value of public engagement, aiming to educate and involve residents in urban forestry to foster community awareness and stewardship.

Boise — Elaine Clegg City of Trees Challenge

The city of Boise, Idaho (population 235,000), is addressing climate change through a collaborative tree-focused initiative. In partnership with the Treasure Valley Canopy Network and The Nature Conservancy, Boise launched the Elaine Clegg City of Trees Challenge. This initiative aims to plant a tree for every household in Boise (100,000 trees), and one seedling in an Idaho forest per Boise resident (235,000 seedlings). By prioritizing neighborhoods with sparse tree coverage, this collaborative effort aims to increase the average canopy coverage to 30%.

To achieve these goals, the city partnered with local businesses and nonprofits to reach community members. Local plant nurseries participated in a program called "The Nursery Coupon Program" that gave residents a discount on trees and supplied trees for giveaways at the weekly Boise farmers market. Businesses and nonprofits in the region also provided support by hosting volunteer events, tree plantings, and educational programs. This collaborative approach demonstrates how urban forestry can mitigate the effects of climate change while improving community well-being and forest stewardship.

Figure 7: Boise is working to expand its urban tree canopy as a climate change mitigation strategy, combining public and private partnerships with active community involvement. (Photo by Click Sluice/Unsplash)

Summary

These case studies demonstrate that, despite the differences between cities, universal strategies exist for improving the sustainability of urban forests. For example, all plans prioritize diversification of tree species and ages. Drought and heat tolerance are emphasized in creating or updating approved street-tree lists. Proactive planning, including updates to management guidelines and urban canopy expansion, are also emphasized. Each city is striving to educate neighborhoods about why trees are important and how climate change will affect urban ecosystems. Finally, all these cities acknowledge the vital role of public participation in the long-term resilience and sustainability of urban forests.

Long-term maintenance involves all the activities necessary to keep trees healthy—such as watering, mulching, protecting against herbivores, and preventing damage from human activity. Although climate-related factors may influence certain maintenance practices, they should still be grounded in established best practices. For instance, additional mulch may be needed to retain soil moisture during hot, dry summers, but it should be kept away from the root flare. Young trees require regular inspections until they are well established. Clearly defined work specifications and maintenance schedules help ensure that tasks are carried out effectively. Maintenance crews should be provided with detailed instructions (translated into other languages when necessary) and encouraged to participate in training and continuing-education opportunities.

Clearly identifying and communicating who is responsible for specific tasks such as pruning, general maintenance, hazard reduction, and care of trees near sidewalks is essential. On public land, maintenance is typically carried out by city staff or private contractors, whereas homeowners usually perform the work themselves or hire professionals. Maintenance costs—often highest during a tree's early years and again when trees are old—should be estimated in advance and incorporated into urban forest plans and budgets. This is especially important for trees on public land, where responsibility falls on municipal agencies. Private property owners, including homeowners, apartment managers, and businesses, must also commit to long-term care to ensure tree health. Although climate-resilient maintenance may involve slightly higher costs (e.g., extra mulch or more frequent watering), these additional expenses are generally modest and well worth the investment.

Evaluate Information on Best Practices and Climate-Resilient Management

Science-based practices in arboriculture, horticulture, and landscaping are well established and widely documented in books, reports, and professional publications. Today, this information is more accessible than ever through online platforms. University extension programs and county conservation districts regularly offer resources to both professionals in arboriculture and the public, including classes and hands-on training. Professional organizations also play a key role in promoting best practices among those who plant and maintain trees, such as arborists, landscapers, and garden designers.

Urban forest managers, arborists, and landscapers should consistently apply these best practices when planting and managing trees in urban environments. These guidelines are grounded in decades of field experience and research. One of the primary sources for industry standards is the *ANSI A300 Care Standards for Trees, Shrubs, Palms, and Other Woody Landscape Plants* (2023), published by the Tree Care Industry Association. This document outlines comprehensive best management practices and serves as a benchmark for professionals in the arboricultural field.

Recent publications have begun to highlight best practices that incorporate climate considerations into urban forest management. A notable example is the book *Climate-Wise Landscaping: Practical Actions for a Sustainable Future* (2023), which outlines a wide range of strategies for climate-conscious landscaping, including tree care. Another valuable resource is the online publication *Urban Forest Management: A Primer to Strategic Planning for Municipal Governments*, which integrates climate-resilient tree selection and planning standards into municipal strategies. Together, these resources offer a solid foundation for adopting climate-resilient practices in urban forest planning and management.

Adapting to climate change will often involve only minor adjustments to existing practices, and in some cases, no changes may be necessary. However, older management plans may require updates to reflect current conditions—for instance, replacing traditionally planted species with more drought-tolerant alternatives. Useful resources identified during our search for climate-resilient practices are listed in the Information Sources section at the end of this guide.

Climate-Resilient Management Plans For Urban Forests

Climate-resilient urban forest management focuses on adapting individual trees and the broader urban forest ecosystem to changing climate conditions. This work is guided by individuals and organizations who plan and manage with future climate impacts in mind. Although urban forest managers should continue to apply proven knowledge and practices, they must also integrate new insights related to climate change. International standards for forest management provide a foundation of general guidelines for developing initial management plans. These broad frameworks can then be customized by incorporating location-specific needs and climate considerations to create tailored management strategies.

A science-based plan is essential for effective climate-resilient urban forest management, whether for large-scale initiatives or smaller projects. A citywide plan may require a detailed, multi-page document, whereas a residential landscape plan might fit on a single page. In both cases, the plan serves as a roadmap, describing clear objectives and actions. The approach and topics presented here are geared primarily toward large-scale planning but are also applicable to smaller efforts. Incorporating a tree inventory can greatly enhance the effectiveness of the planning process.

Identify Objectives

Clear objectives are essential for effective urban forest management. They should be defined at the outset in both (1) strategic plans, which offer broad guidance, and (2) project plans, which describe specific on-the-ground actions. All objectives should account for the short- and long-term effects of climate change on urban landscapes and vegetation in order to achieve desired outcomes.

Comprehensive strategic plans address a wide range of topics, including shade and cooling, stormwater runoff reduction, erosion control, carbon sequestration, and how trees will function in a broader system of plants, animals, and people. All these factors will be affected by climate change. Relying on historical conditions is no longer adequate for addressing these issues. Instead, projections generated by climate models are essential to understand how these factors will change in response to future climate patterns.

Project plans should account for site-specific conditions such as microclimate, proximity to buildings and infrastructure, soil characteristics, and tree species or cultivars selected for planting. Although it may be tempting to begin by choosing species and cultivars, it is critical to first assess the key environmental factors that influence plant growth and health. This ensures the project is both effective and sustainable. For instance, a site with heavily compacted soil will limit viable species options unless soil conditions are improved. Incorporating a diverse mix of species, cultivars, genetic backgrounds, and in some cases, age classes, can enhance resilience to climate-related stressors.

Identify Roles and Responsibilities

Clear expectations are needed for which individuals, teams, and organizations have responsibility and accountability for implementing a plan. This includes review of site conditions, permits, notifications, safety concerns, and other logistics before the work starts. A specific individual or organization should have the lead on communication, especially if the plan is administered by a municipality. In addition, someone with knowledge of climate-related issues

Highlight: Sustainable Forestry Initiative Urban and Community Forest Sustainability Standard

The Sustainable Forestry Initiative has developed the world's first forest standard for communities (https://forests.org/sfi-urban forestry-standard). The standard promotes nature-based solutions and resilience to climate change, including 16 objectives for urban and community forest certification, all of which are addressed in this Guide. Applicable to cities and towns of all sizes, the standard helps maintain and enhance the many values of urban trees.

Objective 7 of the standard—*climate-smart management*—promotes climate-change resilience and addresses environmental, social, and economic concerns using tree-related adaptation and mitigation strategies. Organizations that want to accomplish this objective are guided by the following performance measures and indicators:

Performance Measure 7.1: Monitors and strives to maximize the ecosystem services provided by the urban or community forest, such as carbon sequestration and storage, stormwater reduction, improved air quality, reduced urban heat island effect, stabilized temperature, and more.

- *Indicator 7.1.1*: Quantifies and tracks ecosystem services, economic, and/or aesthetic benefits.
- *Indicator 7.1.2*: Utilizes tree planning and management efforts to maximize ecosystem services.
- *Indicator 7.1.3*: Incentivizes the use of trees and green infrastructure to minimize greenhouse gas emissions and stormwater runoff and flooding, while maximizing carbon sequestration.

Performance Measure 7.2: Monitors and takes steps to minimize the carbon footprint of urban or community forestry operations.

- *Indicator 7.2.1*: Demonstrates that strategies are utilized to minimize carbon footprints and maximize urban wood utilization to minimize the release of greenhouse gases into the atmosphere, and to help promote a circular economy.

Performance Measure 7.3: Assesses and works to address vulnerabilities within their jurisdictions related to climate change and extreme weather.

- *Indicator 7.3.1*: Implements strategies to mitigate the effects of urban heat islands, ecological disruption, and social/economic disruption caused by climate change.
- *Indicator 7.3.2*: Promotes tree preservation and planting to maximize the provision of various ecosystem services, prioritizing areas with historically disadvantaged and vulnerable populations and low tree equity.

can play a key role. Supervisory roles need to be clear, and workers should be trained on project specifications. This is especially important if climate-resilient practices are new or unfamiliar. Individuals should be designated for post-project monitoring, both immediately after implementation and in the long term.

Describe Climate in the Built Landscape

A quantitative summary of expectations for future climatic change and variability are needed in the plan. This includes climate projections and how they may affect future weather (available from the University of Washington Climate Impacts Group and the Oregon State University Oregon Climate Change Research Institute). The influence of climate and weather on the biophysical environment for trees and people (soils, hydrology, and infrastructure) provides an important context for urban forest management.

Climate descriptions require a multi-decadal perspective connecting site conditions with specific tree species and management practices. In some cases, such as a large community forest, coarse-scale data will be sufficient to guide management. In other cases, such as urban areas with tall buildings, fine-scale data will be needed on light conditions, soil characteristics, and drainage patterns. Although compiling fine-scale information can require additional time and expense, it is a good investment for climate-resilient plans and projects.

Identify Climate-Related Stressors

A clear description of how climate will affect tree growth and vigor will inform plan implementation and long-term stewardship. In most cases, climate change will create conditions that negatively affect trees, but potential positive effects (e.g., a longer growing season) can also be considered. The primary climate-related stressors in the Northwest include the following:

- Average and extreme **temperatures are expected to increase** greatly from the 2050s onward. Higher temperature will increase evapotranspiration in trees, especially during the summer. This will be especially prominent in cities with large buildings and extensive pavement, accentuating the urban heat island phenomenon.
- Larger **fluctuations in temperature** are expected. Very cold temperatures in late winter or early spring, especially after a warm spell, can damage or kill newly emerged leaves. Sudden drops in temperature can also cause bark and sapwood tissues to crack—a phenomenon known as frost cracking—due to rapid freezing following expansion during warmer conditions.

- Higher temperature and lower summer rainfall will cause **soil moisture deficits during the growing season**. This will be especially damaging if soil moisture is low during spring and persists through summer. Moisture retention is largely controlled by soil volume and texture. Well-drained soils lose moisture to ground water, leaving less water for uptake by trees.
- **More winter precipitation and high-rainfall events** (e.g., atmospheric rivers) will create longer periods of time when the soil is saturated, especially in urban areas with lots of impervious surfaces and high surface runoff. Saturated soils with anaerobic (low oxygen) conditions can have negative physiological effects on trees and provide favorable conditions for root rot.
- Higher temperatures will stimulate **larger populations of insects**, especially bark beetles that damage conifers. Higher temperatures will also increase physiological stress in trees through low soil moisture, making trees more susceptible to insect attacks. Large outbreaks of insects can damage and kill trees and are difficult to control.
- Higher temperatures and drier summers will cause **long periods of low soil moisture** that weaken trees and make them more susceptible to some fungal pathogens. Conversely, drought will make trees less susceptible to pathogens that require high soil moisture. Unfortunately, little scientific information is available on how specific pathogens respond to different climatic conditions.
- A **longer growing season** is expected in the future. This can be measured with growing-degree days and by observing tree phenology (e.g., the number of days from bud break to leaf drop in deciduous trees). A longer growing season may increase growth and productivity of some trees, but only if sufficient soil moisture and nutrients are available.

Identify Suitable Trees and Forest Structure

Selecting appropriate trees for a specific location is only one part of urban forest planning. As noted earlier, accounting for climate-related stressors adds complexity to this process but improves the chances of accomplishing planning goals. Urban forest planning also intersects with other areas such as parks and open space, transportation, and infrastructure, all of which should inform tree selection. The choice of species and cultivars may differ depending on whether the goal is to restore an existing urban forest or establish a new one.

Selecting tree species and cultivars requires some research, partly because trees that were planted in the past may no longer be suitable in a warmer climate, and partly because there are so many species and cultivars to consider. Using criteria guided by information on climate change effects will constrain the selection to a reasonable number of choices. The Northwest Urban Tree List (see Appendix) linked to this guide provides a summary of tree species and cultivars to support the tree selection process. It is also recommended to consult with forestry professionals and municipalities with experience implementing climate-resilient plans and plantings.

Most plans contain at least some components of an established urban forest. Therefore, current trees and other vegetation should be incorporated into the plan. Older trees can be removed if they create unacceptable risks, introducing new trees as appropriate, with plan objectives guiding the spatial design over time. In addition to using two-dimensional maps, including a vertical dimension will encompass multiple vegetation layers, much as one would think of forest structure in a natural (non-urban) forest. The maturation and potential mortality of existing and new trees over time must be considered. In some cases, it might be advisable to plant at high densities, then remove less vigorous trees over time. In addition, trees with high allergenic potential should not be planted in areas with high human activity (e.g., schools, workplaces, and homes).

Some adjustment of species/cultivars, forest structure, and tree densities may be needed when going from a plan in the office to management on the ground. Flexibility is needed in climate-resilient planning, but diversions from the plan should be justified and documented.

Develop a Schedule

A schedule provides a roadmap and accountability for the planning team to communicate internally and externally. Implementation of plans typically requires a sequence of events that are interdependent. For example, plans often consist of different phases—site selection, site assessment, plan development, permitting, plant selection and procurement, etc. Planting is often the focus of urban forest planning, but planting cannot occur until other preparations are complete. Planting is best done in late fall or early spring in most locations, so acquisition of plants, hiring of crews, and notifications to people affected by planting activities must be accomplished in a timely manner.

Develop a Monitoring Plan

Monitoring tree health is an essential component of long-term stewardship. This can be as simple as taking occasional photos, or as complex as developing a detailed inventory of trees and periodically collecting data. A monitoring plan focuses data collection on topics such as (1) trees (survival, growth, damage, phenology, foliar color), (2) insects and diseases (presence, absence, severity), and (3) soils (water-holding capacity, chemistry).

Monitoring can also identify the effectiveness of different management strategies, informing revised strategies over time (adaptive management). Sharing monitoring data provides valuable information to the broader community of urban forest managers and property owners. The publications *Urban Tree Monitoring: A Field Guide* and *Urban Tree Monitoring: A Resource Guide* provide detailed guidance on the monitoring process.

Some municipalities have completed large inventories of trees (e.g., 330,000 trees in Portland, Oregon), providing a foundation for monitoring and future management. If funding for a large inventory is unavailable, a representative subsample can be used to characterize urban forest conditions; even minimal data can be helpful. Time and funding targeted for monitoring ensure a commitment to adaptive management. Community members and local organizations can often provide valuable support for data collection and monitoring activities.

Highlight: Forest Health Watch—Using Community Science to Understand Climate Change

Addressing climate change impacts on urban forests calls for collaboration across multiple areas of expertise. Scientists, arborists, and resource managers must work together to create strategies that build climate resilience in urban forests. At the same time, local residents—who have firsthand knowledge of their communities—play a crucial role in identifying local priorities and needs, ensuring that solutions are tailored to each city's unique context.

Community science is essential to fostering climate-resilient urban forests by promoting collaboration and local engagement. When residents participate in forest health research and planning, they bring valuable perspectives on local conditions. Involving the community in activities such as data collection and tree monitoring helps uncover otherwise overlooked information while encouraging personal connections and a sense of ownership. This shared stewardship strengthens long-term forest resilience by ensuring that the community is invested in the care and success of urban trees.

Western redcedar (*Thuja plicata*), a relatively common tree in Northwest urban areas, has been negatively affected by recent droughts. In response to concerns about a decline in the health of the species, the Forest Health Watch program, led by Washington State University, launched a project on western redcedar dieback. Using the iNaturalist app, community members, scientists, and trained professionals monitored the health of western redcedar (1,258 trees) in Tacoma and King County, Washington and in Portland, Oregon. In addition to data collected on tree health, urban heat data and air temperatures for all three locations were analyzed.

For both King County and Portland, a strong correlation was found between afternoon temperatures and tree health, with the probability of top-dieback increasing with afternoon temperatures. There was no correlation between afternoon heat and cedar dieback in Tacoma. Although all communities faced similar challenges, the underlying causes of cedar dieback may differ. The results of this study show the value of community contributions for addressing tree health issues.

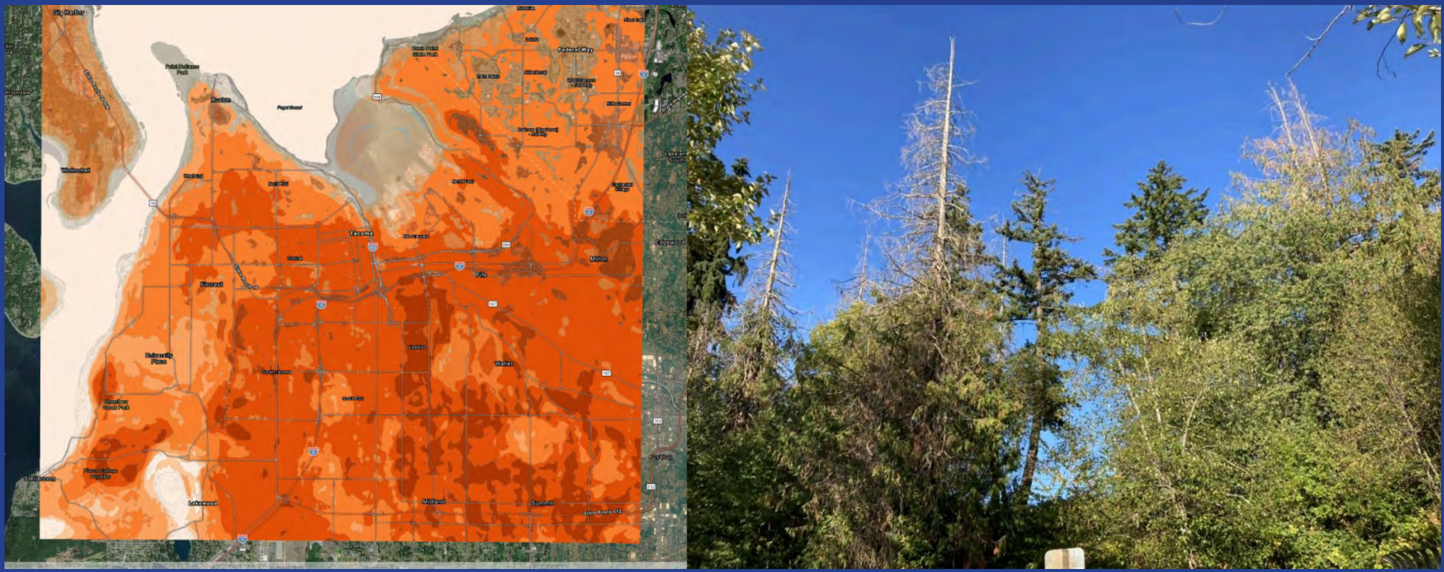


Figure 8: An urban heat island map for Tacoma, Washington, where extensive western redcedar dieback has been documented. Dark-orange colors indicate temperatures as high as 92°F, and light-orange areas indicate temperatures of 83° F and lower. (Photo and map from Joey Hulbert)

Climate-Resilient Practices For Urban Forests

The potential effects of climate change must be considered to ensure the long-term resilience of trees in urban forests. In most cases, this means adjusting existing best practices, rather than making big changes in planting, growing, and tending trees. In many areas, hotter and drier summers will increasingly limit tree survival and growth due to insufficient soil moisture. This will trigger adjustments in traditional maintenance practices. For example, additional water is needed for trees less than 10 years old during the summer (depending on species, size, and location) with emphasis on deep soaking and mulching.

Climate-resilient practices are especially important in cities where temperatures are higher than surrounding areas, impermeable surfaces are widespread, and soils may be compacted or infertile. In locations where non-climatic stressors exist, elevated temperature and drought can intensify those stressors. Climate-resilient practices are essential in areas where trees receive little ongoing care, such as portions of large parks or underserved neighborhoods.

Tree species and cultivars from all over the world are present in urban areas, and some have been in their current location for a century or more. This provides an opportunity to observe how a wide range of trees have performed in an urban environment over a long period of time. Documenting tree performance, especially in warmer microclimates in cities, can inform species and cultivar choices when considering how trees will be affected by climate-related stressors in the future.

The **climate-resilient practices** (**CRP**s) summarized below are based on current best practices and standards, as discussed above. These practices are more suited to urban forests in city environments than to individual residential trees, but the underlying principles are broadly applicable across most types and locations of urban forests.

CRP 1: Minimize the effects of low soil moisture on trees

Accounting for low soil moisture during the summer is a primary consideration for tree selection, planting, and maintenance. Therefore, match a tree species or cultivar with expected soil-moisture conditions. Pay special attention to the microsite in which a tree is planted, especially soil characteristics that affect water retention. Soils that are excessively well drained (sandy soils, coarse texture) will not retain water for long, whereas soils that are moderately well drained (loamy soils, intermediate texture) are better suited for water retention and tree growth. Although poorly drained soils (clayey soils, fine texture) retain water, they are an unsuitable growth medium for most trees. Pay attention to microtopography as well; depressions and drainages retain more water than hills, even at small spatial scales.

In areas with well-drained soils or limited summer irrigation, prioritize planting drought-tolerant species. Consider replacing high-water-use trees with more drought-resilient alternatives, which will need to make up a larger share of urban forests in the future. To streamline maintenance and improve tree survival, group species with similar water needs. Align tree maintenance requirements with the level of care they are likely to receive—this approach is both climate resilient and practical.

Apply mulch generously to retain soil moisture and suppress weeds, particularly around seedlings and saplings. Mature trees can also benefit from mulch—just be sure to keep it away from the root flare. Although mulching is highly effective, it may not be practical for large areas such as community forests and parks. If using fertilizer, apply it directly to the soil rather than mixing it with mulch to ensure it reaches the tree roots. Reapply mulch annually as needed—this is a cost-effective investment in tree health. When water is available and within budget, irrigate regularly, especially young trees. Watering methods can include hoses, drip irrigation systems, or slow-release watering bags. Use deep watering techniques to promote strong root development deeper in the soil.

CRP 2: Minimize the effects of extreme temperature on trees

Cold tolerance (per USDA Plant Hardiness Zones) is a traditional consideration for tree planting. It will still be an important tree characteristic in the future, because extreme temperatures (both cold and hot) are projected to occur more frequently as average temperatures increase. Extreme temperatures are especially important for small trees, because extremes are higher near the ground and can vary greatly within a single day.

Highlight: Right Tree, Right Place

Finding the best tree for a specific planting site requires time, research, and often some data. Collecting information on conditions at the site is the first step. You can ask the following questions to guide your evaluation:

- How much soil volume is available for roots, and how much aboveground space is available for branches? How much space will be available in the future?
- What are the drainage properties of the soil? Is the soil compacted? Is information available on soil chemistry and possible contamination?
- What is the microclimate—temperature, precipitation, humidity, wind—at the planting site?
- Is water available at the planting site?
- Will aboveground or belowground utilities constrain planting and tree growth?
- What kinds of activities are expected near the tree (e.g., foot traffic, parking, recreation)?

With the exception of activities like mulching, it is usually too expensive to alter site conditions to make them more suitable for a tree species or cultivar. Instead, identify trees with characteristics that best match existing site conditions, with special attention to factors that are expected to be most limiting to growth. Climate-related stress is important, but so are microclimatic conditions that influence disease susceptibility (e.g., root rot), and recreational uses that compact soil and damage tree trunks (e.g., adjacent athletic fields). If native trees are planted, use assisted migration concepts to identify appropriate climate-resilient trees and genotypes.

Whenever possible, group trees with similar water and maintenance needs. These groupings can function as mini-ecosystems, enhancing vegetation health, ecosystem services, and overall functionality. Also, plan for long-term care, including watering, pruning, fertilization, weed management, and disease control to support plant health and reduce maintenance costs. Collaborate with other urban forest managers to learn about successful species and cultivar combinations, as well as climate-resilient designs that can inform future plans. Finally, routinely monitor planting sites to assess the effectiveness of plantings and maintenance practices, using those insights to improve future projects.

The USDA Plant Hardiness Zone map tracks average annual extreme minimum temperature. When selecting trees by hardiness zone, consider going one zone lower to hedge your bets against a hard freeze. As winter approaches, mulch with leaves or similar material around the base of trees and other plants that may be on the margin of cold tolerance. Late freezes after buds have opened are more difficult to guard against. Drape tarps or cloth around smaller trees if budget permits, or spray water on trees or leave sprinklers on to slow cooling and create a protective ice layer.

Extreme heat can quickly elevate drought stress in trees. Even a few days of extreme heat can damage or kill leaves that have recently emerged and are not fully formed. Reflected heat from buildings and pavement (especially on the south and west sides of buildings), as well as heat from air conditioning and other sources, can further increase local temperature. Although reducing extreme heat is difficult, using shade cloth to protect the canopy of small trees can help, if the budget allows.

The American Horticultural Society's heat zone map assesses trees based on the average number of days above 86°F. However, because it assumes adequate watering and does not account for drought tolerance, this rating system is not used in the Northwest Urban Tree List (see Appendix).

CRP 3: Increase the availability of climate-resilient tree species and cultivars

Tree selection in urban settings is a compromise among proposed functions of the tree, its adaptation to the site, and the amount of care it will receive. Cities, organizations, and homeowners often face challenges in find climate-resilient (also called climate-ready) trees. Some commercial nurseries may have a big inventory, but the suitability of nursery stock for climate resilience in an urban environment may not be listed. Furthermore, the geographic source and genotype of plant materials are often unknown, and many nurseries are only beginning to take note of climate change. Some plant suppliers—state tree nurseries, county conservation districts, and commercial native-plant nurseries—may provide some of this information, but it is more difficult to find for non-native plants and cultivars.

Assisted migration is the intentional human-assisted movement of tree populations or species to locations that are expected to become climatically suitable in the future due to climate change. This process includes planting seeds or seedlings in new locations (1) within the current range of a species, (2) just outside the current range, or (3) far outside the current range. The primary objective is to increase genetic or species diversity to enhance resilience to heat and drought. Diversifying genotypes is usually a good idea and has low risk.

If species are moved outside their current range, it should be only a short distance and a small percentage of a planting project. This will reduce risks associated with (1) moving insects and pathogens on the trees, and (2) being exposed to insects and pathogens to which the planted trees have little resistance. This topic is less applicable to urban forests, which are usually dominated by species that may be thousands of miles outside their native ranges. However, be aware of the climate zone and native habitat of all tree species to help ensure a good match in a warmer climate.

Some organizations have begun to develop collaborations with plant suppliers to ensure a supply of trees (typically native) from known geographic sources. This facilitates planting of trees that are more likely to be resilient to climate-related stressors. If you are associated with a municipality or other organization with an ongoing need for climate-resilient trees, nurseries can be a partner in long-term planning and projects. For example, a "grow contract" is an agreement in which a grower commits to producing specific trees for a buyer, who in turn agrees to purchase them at a set price. Alternatively, municipalities can establish their own nurseries to provide climate-resilient trees on a continuing basis. Consider developing partnerships with neighborhoods and homeowner associations to assist them in finding climate-resilient trees.

CRP 4: Retain forest canopy and biomass, and increase them where possible

Maintain and gradually increase the amount of forest canopy and vegetative biomass over time. At a minimum, move towards no net loss of cover and biomass in urban areas. If it is necessary to remove trees, they should be replaced with one or more trees. Some cities have policies that enforce this approach. Although maintaining a robust number of trees is useful, it is more important to (1) select tree species and cultivars that will remain climate resilient for decades, and (2) choose trees with a high leaf area to maximize shade and cooling.

Retaining forest canopy and biomass requires a strategic approach, especially in areas where development may disrupt vegetation and infrastructure. First, preserve existing trees in the urban landscape through proper care and maintenance. Verify that existing trees are suitable in the long run, accomplish objectives of the urban forest plan, and have few liabilities (e.g., falling dead branches). Second, develop a transition plan for replacing existing trees with new plantings. If possible, use a geographic information system (GIS) combined with drone imagery to identify canopy gaps and optimize tree planting. Consider multiple canopy layers where appropriate, using shade-tolerant, climate-resilient nursery stock. Multiple layers help maximize leaf area per square foot, which increases both shade and photosynthesis. Higher photosynthetic capacity increases productivity and biomass, thus sequestering more carbon.

CRP 5: Increase diversity of tree species, genetics, and forest structure

High species diversity in urban forests generally enhances resilience to climate-related stressors. Although monocultures can be aesthetically pleasing, they are more susceptible to insects and diseases that target specific species—and higher

Figure 9: Geospatial analysis and imagery are increasingly used to inform planning and management in urban forests. LiDAR, aerial photography, and color infrared (from left to right) were used to measure tree canopy in a Seattle, Washington neighborhood; the final LiDAR-based tree canopy is shown on the far right. (Photo from the City of Seattle)

Highlight: Strategic Shade—Choosing Trees Near Your Home

Planting suitable trees that are well-matched to a home site provides cooling (summer) and heat retention (winter) for individual homeowners and the local community, saving energy and reducing the cost of tree care. The ideal shade tree has a dense crown with branches broad enough to partially shade the roof, and wood that can resist storms, insects, and disease. For narrow spaces, trees with a columnar or upright growth form are a good choice.

Location is critical for maximizing the cooling benefits of shade trees. To reduce heat gain, trees should be planted on the west and east sides of buildings, where the sun has the greatest impact—especially in the afternoon, when temperatures peak. Morning sun from the east can also quickly warm buildings, depending on window placement and orientation. Strategically placed shade trees in these areas can help keep homes cooler during the hottest parts of the day. Although trees on the south side also provide shade, they can block beneficial winter sunlight and increase heating costs. A practical solution is to plant deciduous trees on the south side, allowing sunlight to filter through bare branches in winter while providing shade in summer.

Tree placement requires careful consideration to balance benefits with potential risks. Trees should not be planted near power lines, sewer systems, and water lines. Before planting, contact your local utility provider to identify the location of underground infrastructure and to select tree species that are suitable for areas beneath or near overhead power lines. To provide effective shade, trees should be planted within 30 to 50 feet of a building, but maintain a minimum distance of 5 to 10 feet to reduce the risk of root damage to foundations and branch interference with structures.

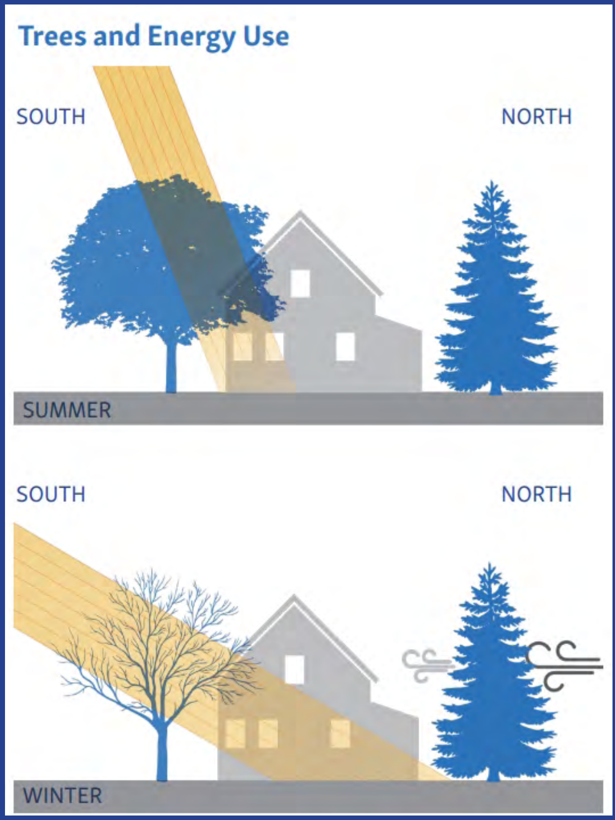


Figure 10: Strategically placed trees can facilitate cooling and heat retention, thus reducing energy use and cost. Deciduous trees on the west and south side cool a building in summer, allowing sunlight to warm the building in winter. Evergreen trees on the north side help block cold winter winds. (From the Brookline Urban Forest Climate Resiliency Master Plan)

temperatures can increase this vulnerability. If a monoculture fails, the entire planting may be lost, forcing the property owner to replant from scratch. Given the added pressures from climate change, monocultures are even less advisable unless there is an ongoing commitment to watering and maintenance.

Diversity in urban forests can be addressed in multiple ways. First, increase the number of tree species and cultivars in most locations. There are many possible choices, so this needs to be done thoughtfully, ensuring that climate-resilient species are selected. Second, increase the genetic diversity of tree species if possible. Using different cultivars of the same species increases genetic diversity, but climate resilience must be a criterion for selection. Obtaining genetic information on nursery stock can be difficult, but ask suppliers about this. Identify species and cultivars that are sourced from locations similar to or warmer than your location. Genotype information is starting to improve for native species and will hopefully improve for non-natives in the future. In any case, this is an opportunity to eliminate species that are poorly adapted to the current and future climate.

Third, diversify the forest structure to reduce the risk of widespread damage from insects and diseases that target specific species. You can design an urban forest as a novel mini-ecosystem, mirroring ecological features of a natural forest stand while including both native and non-native species. Native species may be particularly desirable in large community forests and exurban locations adjacent to natural forests. The specific design depends on objectives at a given location. Include large trees (where space permits) and multiple layers to maximize shade and enhance bird habitat. Use trees with different growth rates and a range of shade tolerance to contribute to a layered structure over time, providing replacement trees as others die. For this approach to work, ensure that sufficient space is available for both branches and roots.

When selecting trees for a given site, take into account the species and cultivars already present in surrounding areas. Maintaining diversity at multiple spatial scales is essential, so avoid overplanting any one species. Some guidelines recommend limiting any single genus to no more than 20% and any single species to no more than 10% of the total population, but such thresholds can be difficult to achieve in areas with limited climate-resilient options. Looking ahead, focus on incorporating drought-tolerant species along with a mix of experimental selections, using diversity as a guiding principle across the landscape.

CRP 6: Maintain resilience to insects and disease

Keeping urban forests healthy will help maintain resilience to insects and disease. This may seem simplistic, but it requires a long-term commitment to maintenance, ensuring that trees have sufficient water, nutrients, and light, and are not damaged significantly. Diversify tree species, with emphasis on climate-resilient species, to reduce the risk of widespread damage from insects and diseases that target specific species. Broad genetic diversity also enhances adaptability to climate stressors. Never use tree species that are known to be highly sensitive to certain insects and diseases (e.g., Oregon ash [*Fraxinus latifolia*] is not resistant to the non-native emerald ash borer [*Agrilus planipennis*]).

Regularly monitor urban forests for signs of harmful insects and diseases to enable early detection/rapid response, which can help limit damage. Although professional input from an entomologist or pathologist may be needed for accurate diagnosis, trained volunteers can also play a valuable role in monitoring efforts. Where feasible, apply integrated pest management (IPM) strategies that emphasize biological controls and selective pesticide use to address outbreaks. Reducing soil compaction can improve tree health and increase resistance to root diseases.

CRP 7: Reduce risk of damage from storms

Climate change is likely to bring more frequent and intense rainstorms, which can damage tree canopies and lead to flooding in urban forests. These negative impacts are sometimes called “disservices.” Reduce such risks and improve resilience through proactive maintenance: (1) prune young trees to promote strong, storm-resistant branching structures, (2) remove dead or hazardous trees to lower the risk of storm-related failures, and (3) selectively thin tree crowns, where appropriate, to decrease wind sail and potential damage.

Consistent with CRP 5, diversify tree species, genetics, and forest structure, making sure to include trees that are resistant to wind and flooding. Where appropriate, position trees to optimize the creation of windbreaks (e.g., where winds are funneled between structures). In addition, use climate-resilient infrastructure to improve the functionality of local hydrology—permeable pavement, bioswales, and adaptive tree pits can retain water temporarily. Finally, use GIS, remote sensing, and drone overflights to map and monitor areas that are vulnerable to storm damage, then implement interventions as needed.

CRP 8: Increase carbon sequestration

Urban forests in the United States store approximately 740 million tons of carbon and sequester (take from the atmosphere) 27 million tons of carbon annually. This means that urban forests account for 3% of total carbon storage in U.S. forestlands and 10% of annual sequestration compared to all U.S. forests. Although urban forests play a smaller role in carbon storage than natural forests, they play a key role in lowering the amount of carbon dioxide in the atmosphere. Many urban areas have the potential to support far more trees, which would increase carbon sequestration and storage.

To optimize carbon sequestration, make sure that trees are well-suited to the site and resilient to climate and other stressors. Consistent with CRP 3, increase the number of trees, forest cover, and biomass where possible. When trees die, replace them quickly so that carbon sequestration by new trees can begin to compensate for carbon lost through the removal of dead trees. Note that dense forest cover may not be advisable near structures in fire-prone areas (see CRP 12).

Young trees have a higher rate of carbon uptake than old trees, whereas old trees store more carbon than young trees. Therefore, maintain a mix of age classes to help optimize the carbon cycle in an urban forest. Although fast-growing trees sequester more carbon than slow-growing trees, fast-growing trees may not live as long. Consider all these factors when managing carbon over a long period of time. Maintain a diversity of habitats, species, and ages to maximize carbon sequestration while maintaining resilience to climate stressors.

Finally, seek opportunities to reduce carbon emissions in landscape maintenance. Use tree litter and wood waste (e.g., chipped branches) as mulch to maintain carbon on site while retaining soil moisture for tree growth. When applying mulch around trees, use coarse-textured material made from species and plant parts that decompose slowly (e.g., western redcedar wood chips, Douglas-fir bark). If high-quality logs are generated through tree removal, they can be repurposed into products such as furniture and lumber, providing long-term carbon storage for decades. This practice diverts waste from landfills, supports local jobs, and generates economic and environmental benefits for communities. Use efficient power implements for maintenance and minimize travel distances for maintenance crews to reduce carbon emissions.

CRP 9: Promote healthy soils

Promote healthy soils in urban forests by using practices that improve soil volume, structure, and nutrient availability. Apply mulch, compost, biochar, and mycorrhizae, as appropriate, to increase organic matter, retain soil moisture, improve nutrient content, and reduce compaction. Use sub-soiling or aeration to improve root penetration and water infiltration in compacted soils. Increasing the soil depth and volume is especially helpful. Replace contaminated soil with clean soil and/or compost to reduce heavy metal concentrations and enhance soil quality.

In suburban and exurban locations, preserve native vegetation and undisturbed soil where possible. Implement low-impact development practices during construction to keep the soil profile intact, minimize soil compaction, and reduce erosion. Finally, periodically test soil properties such as organic matter content, bulk density, and pH to monitor soil health.

CRP 10: Protect special sites

Old, large trees in urban forests are attractive, have value for animal habitat, and store large amounts of carbon. Some large trees may have cultural or historical value. Retaining these trees in the urban landscape may require extra care, especially if they are not considered climate resilient. First, determine if zoning and municipal codes provide long-term protection for these trees. Second, invest extra time in maintenance to ensure they are healthy. This includes pruning, inspection for insects and disease, and periodic deep watering in the summer. Watering is especially important in coarse-textured soils. In addition, develop a transition plan for when the vigor of old trees declines and they need to be removed. Replace them with climate-resilient trees that will also be large when mature if this meets planning objectives for the site.

Healthy trees need healthy soils. However, most urban soils are less functional than undisturbed native soils, and some are severely compromised, creating a source of stress for trees and other vegetation. An exception to this general trend may be large community parks that have a high proportion of native soils that have not been greatly altered. In addition, some sites receive runoff from adjacent impermeable surfaces, providing extra water to tree roots.

Urban areas typically constrain the spatial extent and biomass of roots. Compacted soil reduces the physiological health of roots, and low levels of organic matter and nutrients inhibit the health of mycorrhizae and the microbial community. All these factors limit the potential for growth and productivity, restricting the capacity for resilience to climate-related stressors.

CRP 11: Improve hydrologic processes

Improve hydrologic processes in urban forests with strategies that support water management, mitigate stormwater runoff, and adapt to changing climatic conditions. Ensure that a mature tree canopy is present to intercept rainfall, reduce the volume and speed of stormwater runoff, delay water reaching impervious surfaces, facilitate infiltration, and reduce erosion. An evergreen tree canopy is especially effective at reducing runoff during the winter rainy season. Trees also transpire water, freeing up soil pore space and improving soil water-holding capacity, thus moderating hydrologic extremes.

Consistent with CRP 8, reduce soil compaction to facilitate water infiltration. Minimize heavy foot traffic around trees and maintain permeable surfaces. Allow leaf litter to remain on the soil to enhance water absorption and reduce surface runoff. Treat stormwater at its source by integrating urban forests with green stormwater infrastructure, such as rain gardens, bioswales, and vegetative buffers. This approach directs runoff to permeable surfaces for infiltration.

In addition, educate communities about the hydrologic benefits of urban forests, thus encouraging conservation and support for trees in urban landscapes. Look for opportunities to

integrate urban forest protection and sustainable water-management practices within the broader context of urban planning. This will improve the hydrologic resilience of urban areas to climate change while enhancing water quality and reducing flood risks.

CRP 12: Reduce risk of damage from wildfire

Climate change is projected to greatly increase the frequency and extent of wildfires in the coming decades. Although wildfires are not usually linked to urban forests, they pose a growing risk in suburban and exurban areas, especially within the wildland-urban interface, including community forests and residential landscapes. Although most large wildfires have historically occurred in the wildlands of Idaho, eastern Oregon, and eastern Washington, the September 2020 fires that burned 840,000 acres in western Oregon highlighted the vulnerability of westside urban forests to wildfire as well.

The amount and arrangement of fuels—both live and dead vegetation—play a key role in determining wildfire risk in urban forests. Fine fuels (less than 3 inches in diameter) on the ground contribute most of the energy in a fire, and the potential for fire spread depends on how continuous these fuels are across the landscape. To reduce fire hazards near homes and structures, remove fine fuels and ensure trees are spaced widely enough that their crowns do not touch. Reduce understory vegetation and prune lower tree branches to prevent fire from climbing into the canopy. Although these practices may reduce carbon sequestration (a tradeoff with CRP 8), they are essential for minimizing wildfire hazards in fire-prone areas.

Low-stature plants (e.g., mowed grass) or hardscaping (e.g., gravel) can be used near structures to create fuel breaks. Recommended spacing between shrubs and trees varies by location; local conservation agencies can assist with guidelines. Fire-resistant trees (e.g., ponderosa pine [*Pinus ponderosa*], Douglas-fir [*Pseudotsuga menziesii*]) are a priority in fire-prone landscapes. It has been suggested that some plant species limit fire spread near structures, but in fact this is rarely the case, and some shrubs and smaller trees can actually accelerate fire spread.

A final important step is to fireproof homes and other buildings using fire-resistant materials, barriers to embers, and other design features. See the Firewise USA website (https://www.nfpa.org/education-and-research/wildfire/firewise-usa) for details on increasing fire resistance in buildings, infrastructure, and landscapes.

Figure 11: Trees adjacent to homes in suburban and exurban locations in fire-prone areas of the Northwest can increase risk to residential property, as in this wildfire in Spokane, Washington in 2016. (Photo by Colin Mulvany, The Spokesman-Review)

CRP 13: Increase resilience to invasive plants

Higher temperatures and more droughts (and more wildfires in some locations) will favor the establishment and spread of invasive plants in urban forests. Some invasives (typically non-native species) spread aggressively, reducing the availability of soil water for trees and native plants. For example, Scotch broom (*Cytisus scoparius*; western Oregon and Washington) and cheatgrass (*Bromus tectorum*; dry interior regions of Idaho, Oregon, and Washington) can quickly dominate a disturbed area and inhibit tree regeneration. This is relevant primarily in exurban areas, because invasive and horticultural plants are so common in heavily urbanized areas that it is rarely feasible to eliminate them.

Actively manage invasive species using early detection/rapid response strategies to prevent their establishment and spread. Regularly remove aggressive invasives like English ivy (*Hedera helix*) and Himalayan blackberry (*Rubus bifrons*), which can quickly degrade ecosystems. Following removal, replant the site with appropriate trees and other vegetation suited to local conditions, and ensure proper maintenance to support their growth. To build resilience to climate change, include a mix of species with varied ecological functions, such as drought tolerance and pest resistance. Use simple survey methods to monitor for new invasions, and engage volunteers to support ongoing monitoring efforts.

CRP 14: Reduce the effects of heat exposure and hazardous weather on people and infrastructure

Some urban forests were intentionally designed to achieve specific goals and benefits, whereas others have developed more haphazardly. Most urban forests would benefit from improved design and functionality. New designs need to consider how climate-driven heat exposure and hazardous weather can be addressed, making urban environments safer and more comfortable.

Promote energy-efficient urban planning by integrating thoughtfully designed urban forests alongside energy-conscious buildings and infrastructure. Trees help reduce building temperatures by shading structures and cooling the air through evapotranspiration. Deciduous trees offer natural climate controls for buildings, keeping them cool in summer by providing shade, and warmer in winter by letting sunlight through bare branches. Where feasible, replace hard surfaces with trees and vegetation, especially on the south and southwest sides of structures and public spaces. Expand tree cover through strategies such as removing pavement and transforming former industrial and commercial sites into parks and green spaces.

Design (or retrofit) urban spaces to support mental well-being by integrating built environments with safe, accessible urban forests and other elements of large-scale green infrastructure. This is particularly important for disadvantaged communities and vulnerable populations where these features are uncommon. Encourage the use of green roofs, living walls, permeable pavement, rain gardens, bioswales, constructed wetlands, and connected greenways. This type of infrastructure will increase urban cooling and reduce stormwater runoff, providing a more comfortable environment.

Implementing the climate-resilient practices described above is an ambitious task. The “workforce” for long-term management of urban forests can be expanded by engaging residents and community organizations. Identifying neighborhood leaders and organizations can motivate citizens to contribute time and labor to planning, maintenance, and data collection. Municipalities can often support homeowners and businesses by providing trees for yards and rights-of-way, conducting education and outreach, and streamlining permitting (and perhaps cost sharing) for removal and replacement of dead trees.

Urban Forests In A Warming World

Most urban forests can benefit from increased tree cover, more equitable distribution across neighborhoods, the use of better-adapted species, and enhanced maintenance. By integrating technology, ecological science, and inclusive planning, cities can safeguard their infrastructure and environment against the escalating impacts of climate change. Collaborative partnerships among governments, communities, and local organizations can attain resilient urban ecosystems that support sustainable development and economic goals.

Implementation of urban forest strategies often encounters challenges, including:

- Limited long-term funding for planning, project implementation, and maintenance.
- Underserved neighborhoods with sparse tree canopies that have historically been overlooked in urban forest management and socioeconomic investment.
- Absence of proactive planning and tree-protection policies and regulations.
- Gaps in technical skills for effective urban forest management, and insufficient knowledge about climate change effects.

Addressing these barriers requires a multi-faceted approach that includes adequate funding, community education, equitable access to resources, supportive policies, and innovative solutions tailored to local contexts. Building on urban forestry as essential infrastructure, progress can be advanced through climate-resilient planting and maintenance and through public engagement that emphasizes clear communication and community science.

Innovation will be essential for effective urban forest management in the future. Technological advances, including tools driven by artificial intelligence (AI), can improve the effectiveness of urban forest planning and projects. For example, systems like Tree-D Fusion use AI to create three-dimensional models of urban trees, enabling city planners to simulate tree growth, monitor environmental stresses, and optimize tree placement. GIS and

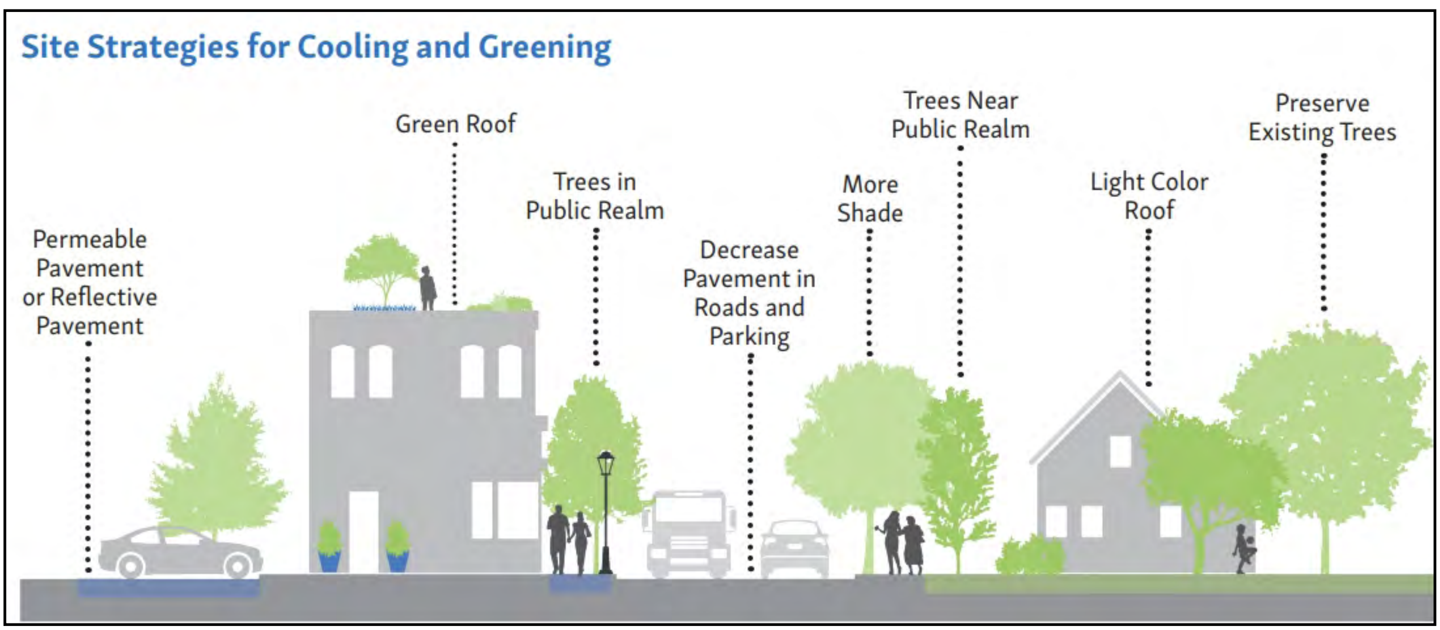


Figure 12: Multiple site and exterior-building strategies can be implemented to enhance cooling during the summer. (From the Brookline Urban Forest Climate Resiliency Master Plan)

web-based mapping tools support strategic tree planting by identifying priority areas based on canopy gaps, flood risk, and demographic information. Drones are increasingly being used to monitor tree condition and identify planting locations.

Aligning urban forestry plans across housing, transportation, and public health sectors will maximize the benefits of urban forest cover. Aligning these plans with disaster-response plans will address the increased risk of heat waves, storms, and flooding. In addition, climate-resilient urban forestry needs to be integrated with climate-resilient urban design. For example, integrating vegetation into building designs, such as green roofs and vertical forests, expands green spaces in densely populated areas while improving stormwater management, reducing heat absorption, and enhancing air quality. Using biodiversity corridors to connect fragmented green spaces enhances ecosystem function and provides wildlife habitat.

Climate-resilient urban forestry is expanding in the Northwest. We are optimistic that climate-informed planning and the adoption of climate-resilient practices will continue to advance in urban forestry. We anticipate that the following will be accomplished within the next decade:

- Urban forest management will be a standard component of urban planning in most cities and counties. Collaboration among municipalities, other organizations, and stakeholders will become the norm.
- Policies that incentivize tree planting, preservation, and integration of community tree canopies in private-development projects will facilitate the expansion of urban tree canopies.
- Tree canopy cover will become more equitable as cities, neighborhoods, and organizations work together to expand urban forests and address climate risks.
- Collaborations among agencies, private developers, and non-profits will expand green infrastructure.
- Climate-resilient nursery stock will become more readily available.
- Carbon sequestration will increase as urban forests transition to more climate-resilient trees.
- Urban forest conditions and effectiveness of climate-resilient practices will be monitored on the ground and with advanced technology.
- Carbon sequestration in urban areas will increase as more wood products are used in construction of buildings, replacing fossil fuel-intensive materials like steel.

This *Climate Resilience Guide* provides a foundation for understanding potential climate change effects in urban forests and implementing climate-resilient planning and management. We anticipate that users of the *Guide* will refine the climate-resilient practices described here and develop new ones. Sharing information, including both successes and failures, among cities and regions will help spread and improve climate-resilient urban forestry throughout the Northwest.

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Key Terms

Adaptation	The process of adjusting to actual or projected climate and its associated effects, including with human intervention to facilitate the adjustment.
Adaptive management	A structured, iterative process of decision making that aims to manage resources effectively while simultaneously learning about the system being managed and adjusting management as needed.
Adaptive tree pit	A planting system engineered to create a sustainable environment for trees by integrating features that adapt to the needs of the tree and adjacent urban infrastructure. It supports tree growth while addressing stormwater management, soil compaction, and limited space in urban environments.
Assisted migration	The intentional human-assisted movement of tree populations or species to new locations that are expected to be climatically suitable in the future as the climate changes.
Best practices	Science-based strategies and techniques designed to sustainably manage forest resources while minimizing adverse environmental impacts, preserving biodiversity, and supporting economic and social benefits.
Biochar	Charcoal produced by heating of biomass (e.g., wood waste, crop residue) in a low-oxygen environment. Biochar sequesters and stores carbon. Its porous structure enhances water retention, nutrient availability, and microbial activity in the soil.
Biodiversity	The variety and variability of living organisms in a particular area, including genetic diversity within species, diversity among species, and diversity across ecosystems.
Biomass	Organic material derived from living or recently living organisms, including plants, animals, and their waste products.
Bioswale	A shallow, vegetated channel designed to manage stormwater runoff by slowing its flow, filtering out pollutants, and promoting infiltration into the soil.
Carbon sequestration	The process of capturing atmospheric carbon dioxide and storing carbon in solid (e.g., plants, soil) or liquid (e.g., oceans) form, thus helping to mitigate climate change.
Carbon storage	The retention of carbon in a reservoir—biological, geological, or technological—after it has been sequestered.
Circular economy	An economic model focused on minimizing waste and maximizing the use of resources by keeping materials, products, and systems in circulation for as long as possible.

Climate	Average weather conditions over multiple years.
Climate change	Long-term alterations in the average weather patterns and conditions on Earth, including changes in temperature, precipitation, wind patterns, and other atmospheric phenomena. Although these shifts can naturally occur over geological timescales, they are now being accelerated by human-induced greenhouse gas emissions from fossil fuel use.
Climate-resilient practice	Science-based strategic and on-the-ground activity that maintains or improves the conditions needed to ensure healthy urban forests. Climate-resilient practices build on current best practices and standards for urban forest management.
Community forest	A forest managed collectively by local communities in urban or rural areas, often with the goal of balancing environmental conservation, sustainable resource use, and community benefits.
Community science	The process by which scientists and city residents collaborate to advance one or more community priorities.
Cultivar	Short for "cultivated variety," it is a plant that has been selected and bred by humans for specific traits, such as improved yield, disease resistance, unique appearance, or adaptability to certain conditions.
Ecological restoration	The process of assisting the recovery of ecosystems that have been damaged or destroyed. It aims to reestablish structure, function, and biodiversity, enabling ecosystems to provide services such as clean water and animal habitat.
Ecosystem service	Ecological process or function that provides benefits or values to individuals and society (e.g., cooling buildings, flood reduction, carbon storage).
Evapotranspiration	The process by which water is transferred from the Earth's surface to the atmosphere through evaporation and transpiration. Evaporation is movement of water as vapor directly from soil, water, or other surfaces into the air. Transpiration is the release of water vapor by plants into the atmosphere through their leaves.
Genotype	The genetic makeup of a plant, specifically the set of genes or alleles inherited from its parents. The genotype determines the hereditary information encoded in the plant DNA, serving as a blueprint for its characteristics.
Global climate model	A computer simulation used to represent and project the behavior of Earth's climate system. It incorporates mathematical equations based on physical, chemical, and biological processes to simulate interactions between major components of the climate system (atmosphere, oceans, land surface, and ice-covered regions).

Greenhouse gas — Gas (e.g. carbon dioxide, water vapor, methane, nitrous oxide) that absorbs heat in the atmosphere near the Earth's surface, preventing it from escaping into space. As the atmospheric concentration of these gases rises, the average temperature of the lower atmosphere gradually increases, a phenomenon known as the greenhouse effect.

Microclimate — A local atmospheric zone where the climate differs from the surrounding area due to terrain, vegetation, water bodies, or urban structures, ranging from a few square feet to a few square miles.

Mitigation — A human intervention to reduce emissions or enhance the storage of greenhouse gases, especially carbon dioxide.

Nursery stock — Trees that are propagated, grown, and prepared for planting or sale in a public or commercial facility. This includes seedlings, saplings, bare-root trees, container-grown trees, and grafted trees.

Pathogen — A disease-causing organism in trees, most commonly fungi but also bacteria, viruses, and other organisms.

Permeable pavement — A pavement system that allows water and air to pass through its surface and into the soil beneath. This improves tree health in urban environments by facilitating root growth, soil aeration, and water infiltration.

Phenology — The study of cyclic and seasonal patterns in the natural world, mostly related to climate, plant, and animal life.

Photosynthesis — The biological process by which plants convert light energy from the sun into chemical energy stored in glucose. This process provides the primary energy source for most living organisms and produces oxygen as a byproduct.

Productivity — The rate at which plants produce biomass through photosynthesis and growth. It is a measure of how efficiently plants convert sunlight, water, carbon dioxide, and nutrients into usable energy and structural components (stems, leaves, roots, and fruits).

Resilience — The capacity of an environmental or human system to cope with and recover from a disturbance or extreme event to provide essential functions and structure.

Representative Concentration Pathway (RCP) — A climate change scenario used to project future greenhouse gas concentrations and their associated radiative forcing (increased energy received by the Earth). These pathways were developed for climate modeling and research, specifically for the Intergovernmental Panel on Climate Change. The radiative forcings RCP 4.5 Watts m^{-2} and RCP 8.5 Watts m^{-2} are often used as standard climate change scenarios.

Respiration	The biochemical process by which plants break down sugars (produced during photosynthesis) in the presence of oxygen to release energy that is essential for plant growth, reproduction, and repair.
Transpiration	The release of water vapor by plants into the atmosphere through their leaves, specifically small openings called stomata.
Tree vigor	The health and productivity of a tree, including its resilience to stressors.
Urban heat island	A phenomenon in which urban areas experience higher temperatures than surrounding rural areas. This temperature difference is caused by replacement of natural landscapes with heat-absorbing materials like asphalt, concrete, and buildings, and by reduced vegetation and water bodies. Waste heat from human activities (e.g., transportation, industrial processes, air conditioning) contributes to the effect.
Vertical forestry	An urban greening approach that integrates dense vegetation into the architectural design of buildings. Approaches can range from green facades and living walls to complex vertical ecosystems built into high-rise structures.
Water-holding capacity	The amount of water that soil can retain and hold against the force of gravity, making it available for plant use. This capacity depends primarily on soil texture, soil structure, organic matter content, and porosity.
Watershed	An area of land where water from rainfall, snowmelt, and runoff drains into a common outlet, such as a river, stream, lake, or ocean. It is defined by topography, with high points directing water flow toward the lowest point.
Weather	Short-term atmospheric conditions that are measured for minutes, hours, or days.
Wind sail	The tree surface area that intercepts wind—determined by leaves, branches, and canopy structure. A tree with a dense canopy has a larger wind sail, which increases wind resistance and can make it more vulnerable to breakage or uprooting during storms.

Appendix

The Northwest Urban Tree List

The *Northwest Urban Tree List* is an online database that accompanies *A Climate Resilience Guide for Urban Forests in the Northwest*. The *Tree List* is comprised of tree species and cultivars available from tree nurseries, agencies, municipalities, and other organizations in Idaho, Oregon, and Washington. The *Tree List* represents a large proportion of the trees currently in use and available for purchase in these states. The climate resilience of trees in the *Tree List* differs greatly. Trees with different levels of climate resilience are included, recognizing that some individuals and organizations may choose to grow species that are not inherently climate adapted but are willing to provide the maintenance (e.g., irrigation) needed to support tree health and vigor.

Characteristics summarized in the *Tree List* can be used to select trees for different objectives and locations. These characteristics were derived from scientific and arboricultural sources. For consistency, most information was obtained from the Gardenia, Missouri Botanical Garden, and USDA NRCS PLANTS Database websites. These sources were supplemented with information from other knowledge bases as needed, especially for the categories “insects and diseases” and “suitable within 10 miles of the coast.” The amount of information available for individual species and cultivars differs greatly; some cultivars have relatively little information. Entries in the *Tree List* were reviewed by practitioners and scientists with expertise in urban forestry and arboriculture.

Descriptors in the *Northwest Urban Tree List*

Scientific name

The Integrated Taxonomic Information System (ITIS) was the primary taxonomic authority for scientific names (Latin binomial). If a species was not listed in ITIS, then World Flora Online was a secondary taxonomic authority. When cultivar scientific names were inconsistent or difficult to verify, multiple sources were consulted to identify the name used most frequently.

Common name

The Integrated Taxonomic Information System (ITIS) was the primary taxonomic authority for common names. If a species was not listed in ITIS, or if there were multiple common names, other sources were consulted to determine the most frequently used common name. When common names of cultivars were inconsistent or difficult to verify, multiple sources were consulted to identify the name used most frequently.

Family

A category in plant taxonomy that aggregates related genera sharing common structural features, reproductive traits, and evolutionary ancestry. Trees within a family often have similar flower structures, fruit types, leaf arrangements, and genetic characteristics, reflecting their descent from a common ancestor.

Native?

Trees are considered natives if the current natural range of the tree includes any portion of Idaho, Oregon, or Washington. All other trees are considered non-natives. Cultivars developed from native species are considered non-native due to their altered genetic composition relative to wild native populations. Indicated as *yes* or *no*.

Evergreen/Deciduous

Evergreen trees keep their leaves year round, remaining green (or other colors) through all seasons. They do not shed all their foliage at once, even during winter or dry periods. *Deciduous trees* lose all their leaves for part of the year, typically in autumn, although some species retain their leaves over the winter (e.g., many oak species). After shedding leaves, deciduous trees remain bare until new leaves grow in the spring and summer. *Semi-evergreen trees* fall between evergreen and deciduous types, retaining some foliage year round while shedding some of it seasonally.

Broadleaf/Conifer

Broadleaf trees are characterized by wide, flat leaves. Most broadleaf trees are angiosperms (flowering plants) and are sometimes called hardwoods. Most broadleaf trees are deciduous, and a few are evergreen. *Conifer trees* have needle-like or scale-like leaves. All conifers are gymnosperms, with seeds borne on cones. Most conifers are evergreen.

Growth rate

Fast growth = height growth is more than 2 feet per year. *Medium growth* = height growth is 1–2 feet per year. *Slow growth* = height growth is less than 1 foot per year. These are general guidelines; actual growth varies as a function of soil conditions, moisture, and light. Many trees grow faster when they are young.

Height

The expected highest point of a fully mature tree. Indicated in *feet*.

Spread

The expected crown width of a fully mature tree. Indicated in *feet*.

Powerline friendly?

A tree is considered compatible with powerlines if its mature height does not exceed 35 feet, ensuring it will not grow into or require frequent pruning near overhead powerlines. This minimizes safety hazards, power outages, and maintenance needs. Local powerline height and regulations need to be considered when planting trees. Indicated as *yes* or *no*.

USDA Plant Hardiness Zone

The USDA Plant Hardiness Zone Map is a widely used geographic classification based on the average annual extreme minimum winter temperature, divided into 10-degree Fahrenheit zones. A lower number indicates more cold tolerance. This helps determine which trees are most likely to survive and thrive at a specific location relative to low temperatures of the local climate. The most recent map (2023), accounts for recent temperature increases associated with climate change. Local microclimates (e.g., in a drainage where cold air persists) may have an *actual* hardiness zone that differs from the mapped hardiness zone. Indicated as an *individual* or *range of hardiness zones*.

Drought tolerance

Tolerance of dry soil over weeks to months, especially during the primary growing season, is essential for the productivity and vigor of trees. Drought frequency and magnitude will increase as the climate warms, so drought tolerance is a key factor in identifying climate-resilient trees. This trait refers to *mature* trees. Seedlings have smaller root systems than mature trees and are usually less drought tolerant, often requiring considerable maintenance (e.g., irrigation). Indicated as *low* to *high*.

Shade tolerance

The degree of tolerance to low light is a physiological trait that differs greatly among tree species. Although some trees can survive in shade for long periods, shade typically slows growth by limiting photosynthesis below optimal levels and, in some cases, can reduce tree vigor. Indicated as *low* to *high*.

Compacted-soil tolerance

Soil compaction in urban areas is common, limiting the movement of air and water that tree roots need to function. When roots are shallow and unable to penetrate dense layers, restricted access to moisture and nutrients can reduce tree vigor, making trees more vulnerable to drought, insects, and diseases. Indicated as *low* to *high*.

Saturated-soil tolerance

Saturated soil is common in urban areas, where water fills pore spaces and limits oxygen availability to tree roots (anaerobic conditions). Oxygen-deprived roots cannot respire effectively, so water and nutrient uptake decline, leading to reduced growth and vigor. Prolonged saturation can lower resistance to soil pathogens, weakening root-soil anchorage and increasing windthrow. Indicated as *low* to *high*.

Frost tolerance

Tolerance of very low temperatures is a physiological trait that differs among tree species. Frost tolerance is the ability of a tree to survive and resist damage from freezing temperatures, primarily through cold acclimation and mechanisms that avoid or tolerate ice formation in plant tissues. A cold period following initiation of budbreak and sap flow can be especially damaging. Indicated as *low* to *high*.

Air pollution tolerance

Air pollution can reduce tree growth and vigor by damaging foliage, which impairs photosynthesis and respiration and lowers carbohydrate production needed for wood and root development. Gaseous pollutants (e.g., tropospheric ozone, sulfur dioxide) can weaken trees by injuring foliage and causing chlorosis and premature leaf drop. Chronic exposure to air pollution can reduce tree resistance to insects, diseases, and drought. Indicated as *low* to *high*. Intermediate ratings (low-moderate, moderate-high) often indicate uncertainty based on a low amount of scientific information.

Suitable within 10 miles of the coast?

This descriptor identifies trees that can withstand high wind and salt spray in coastal environments, without experiencing significant stress or branch damage. High resistance to both high wind and salt spray were required for a tree to be considered suitable. Indicated as *yes* or *no*.

Insects and diseases

Insects and diseases (primarily fungal pathogens) can create stress for trees, especially in urban environments where additional stressors can affect tree health. Although many insect and disease species can affect trees, only a small number typically cause significant damage. Multiple knowledge bases were searched to identify organisms that pose a moderate to high threat to tree vigor and survival. *Insects* are listed first, followed by *diseases* (after the semicolon), in approximate order of severity (from higher to lower). *None* is indicated for trees with no prominent insect or disease threats.

Additional comments

This descriptor includes characteristics—both desirable and undesirable—that may affect decisions about growing a specific tree in urban environments. Characteristics include growth form, morphological and aesthetic features (leaves, flowers, fruits, roots), and special concerns such as invasiveness, short lifespan, resistance to high-impact diseases (e.g., Dutch elm disease), and potential safety and maintenance issues (e.g., toxic fruits, high production of nuts).

Climate resilience

Climate resilience for trees is rated for northern Idaho, southern Idaho, eastern Oregon, western Oregon, eastern Washington, and western Washington. Climate resilience is based mostly on drought tolerance and temperature in the context of projected climatic conditions in the late 21st century. Indicated as *low* to *high*.

Climate resilience refers to the long-term health of *established trees*; resilience ratings assume that minimal maintenance (e.g., irrigation) will be provided for mature trees. Seedlings and saplings of all species and cultivars have small root systems, typically requiring extra care to ensure survival and growth. Some cultivars have been developed to be more resilient than their parent species. Site conditions (topography, drainage, soil volume, and proximity to buildings), as well as stress from insects and diseases, influence tree growth and vigor. These factors should be evaluated alongside climate resilience when selecting trees.

The scientific understanding of climate resilience continues to advance. Integrating field experience from urban foresters and arborists with *Tree List* ratings can help identify species and cultivars that are likely to be resilient in a changing climate.

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