# Climate Adaptation Plan for the Washington Park Arboretum

**Prepared for the Washington Park Arboretum by the University of Washington Botanic Gardens and the Arboretum Foundation**

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University of Washington Botanic Gardens

Arboretum Foundation

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# Arboretum Climate Adaptation Plan

## Foreword

Dr. Christina Owen, Director of UW Botanic Gardens

Seattle's temperate climate is the envy of the horticultural world. The historically mild wet winters and warm dry summers has allowed for the cultivation of a wide variety of ornamental plant species from around the world. However, in recent years, the impact of climate change has been increasingly impacting the diverse plant collections in the Washington Park Arboretum, presenting a major threat to the Arboretum's collection of ornamental plants and its conservation collections. Drought and heat stress, and the resulting pressure from pests and disease, are having a lethal impact on many of our plant collections and tree species including Western Red Cedar, Western Hemlocks, and Pines.

The Washington Park Arboretum's plant collections contain over 15,000 individual specimens, representing nearly 5,000 unique taxa. The work presented in this Climate Adaptation Plan is intended to help us better understand the impacts of climatic changes on these vast and diverse collections. This plan provides predictions of what to expect and recommendations for how we can adapt. Most critically, it identifies the investments and changes we can start making now in order to provide the appropriate horticultural interventions that will allow our plants to continue to thrive in spite of these challenges.

Botanical Gardens and Arboreta like ours operate on the front lines of the biodiversity crisis. We seek to preserve plant species in living collections for future generations. The effects of climate change will undoubtedly impact our ability to execute on that mission. This is long-term work and we are determined to be as prepared as possible. This Climate Adaptation Plan is a first step in helping us do just that.

# Introduction

## Statement of Need

The Washington Park Arboretum is the largest botanic garden in Washington State and is among the most diverse temperate woody plant collections in North America. The climate of the maritime Pacific Northwest has long been among the best in the world for growing temperate plants, historically having been neither “too hot” or “too cold,” and as a result displays a tremendous number of species from around the globe. The original mission of the Arboretum was to grow every plant species that could survive and thrive in our climate. This led to the great diversity of collections today and the Arboretum has been a source of introduction, research, education and inspiration for over 90 years.

Our local climate and the diversity of long-established collections make the Arboretum one of the best places to study climate effects on plant species over time. The Arboretum’s location within Seattle, the largest city in the Northwest, also offers an opportunity to study the effects of urbanization and urban heat effects on plants, as conditions in cities are typically warmer and more stressful than in suburban or rural situations – offering a preview of expected climate impacts on the region’s native and cultivated flora.

But the landscape is changing and there are increasing impacts on plants and gardens. Over the last decades the impacts of additional heat, drought and extreme weather events have started to manifest in noticeable stresses to the Arboretum’s plant collections. Species that once thrived with minimal care are exhibiting increased signs of stress. Large scale decline and die-off in species that are both native and exotic have become impossible to ignore. The dry season has become longer and hotter and we need to understand how best to safeguard our existing plant collections and plan for a sustainable future.

This plan is the first attempt to assess the current challenges for the Arboretum plant collections and discuss some ways in which we can mitigate current and future climate impacts. It includes analyses of landscape character and climate predictions for the Washington Park Arboretum under multiple scenarios. It assess the risks to the Arboretum’s plant collections, and then provides recommendations for mitigating those risks. In addition to offering strategies for our collections, we hope this plan can assist other gardens in starting to address climate challenges.

Woodland Garden in autumn

## Local Climate and Future Challenges

Seattle is known for its moderate climate with mild wet winters and warm dry summers. When the Arboretum was first developed as a plant collection in the 1930s, Seattle was a much smaller place, and the surrounding area was far less developed. The sprawl of concrete and density was far less and the temperature and rainfall patterns were more typical of the overall Puget Sound region. Summers were dry between early July and mid-September, but temperatures were less extreme and rarely exceeded 85 degrees Fahrenheit for most of the summer. Winters were colder, with rainfall that was generally drizzly and diffuse. Winter temperatures rarely dropped into the low 20s during the winter and extreme lows were less common.

However, in recent decades temperatures have warmed in the city by several degrees compared to outlying, rural areas. The proximity to Puget Sound and Lake Washington mitigated these effects, but the combination of urbanization and climate change means that Seattle and the Washington Park Arboretum are experiencing warming temperatures compared to historical baselines and is projected to see a rapid increase in temperature throughout the rest of the 21st century. The Pacific Northwest Climate Project Tool developed by University of Washington's Climate Impact Group projects that in all cases the mean annual temperature in the greater Seattle area is projected to increase by the end of the century (Figure 1) with changes estimated from 4.5-8.0 °F [1] for areas west of the Cascade Mountains.

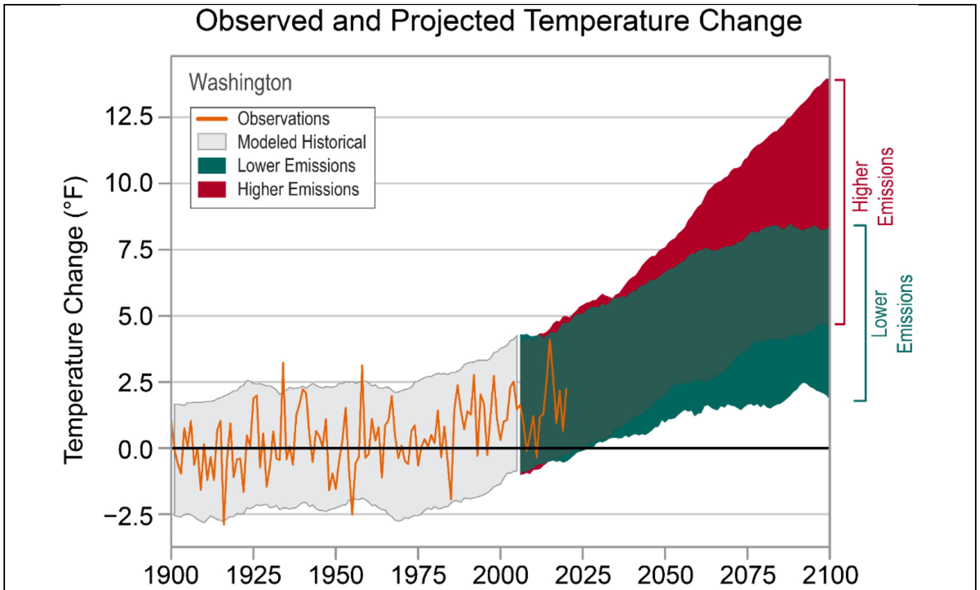



**Figure 1.** Change in mean annual temperature from historical baseline for Washington state for two potential emission scenarios[1].

The increase in mean annual temperature reflects not just the warming summer conditions, but also warming winter conditions, including decreased number of days below freezing. Seasonally, the average temperature for winter is predicted to increase less, 4.3-7.0°F [1], compared to summer, 5.5-9.0°F [1] (Table 1). In addition to increased average temperature, there will be more days of extreme heat , with climate models predicting around 45 days per year of extreme heat for Western Washington if emissions continue without mitigation[2].

**Table 1.** Estimated changes in precipitation for the maritime Pacific Northwest for 2080 compared to the 1950-1999 normals. Each value represents an average of several different climate models. *High emission scenario represents RCP 8.5 and the low emissions scenario represents RCP 4.5. Data extracted from PNW Climate Projection Tool by Matthew Rogers[1].

| | Annual | | Summer | | Fall | | Winter | | Spring | |
|---|---|---|---|---|---|---|---|---|---|---|
| Emissions Scenario* | High | Low | High | Low | High | Low | High | Low | High | Low |
| Temperature Change (°F) | 7.5 | 4.5 | 9.0 | 5.3 | 7.7 | 4.4 | 7.0 | 4.3 | 6.5 | 4.1 |
| Precipitation Change (%) | 5.2 | 3.0 | -15.9 | -12.6 | 5.7 | 4.1 | 11.4 | 5.9 | 2.7 | 1.7 |

Changes in precipitation are also predicted for the Seattle area. Overall, the mean annual precipitation may increase slightly. However, the distribution of precipitation across seasons will likely result in drier summer and wetter winter and spring[3]. Increased precipitation during winter and spring, and more extreme precipitation events, such as larger atmospheric rivers, will continue to increase flooding and storm conditions like heavy winds[3]. With warming temperatures, more precipitation in the region will fall as rain, which will result in decreased snowpack in the Cascades[4]. Decreased snowpack and earlier snow melt will result in increased regional drought, especially during summer, and potentially impact local water availability for irrigation in Seattle.

Along with increased temperatures and decreased precipitation during the summer, an increase in the vapor pressure deficit (VPD) is projected. Higher VPD is an indicator of drier air and increased evapotranspiration and is a major factor in drought severity, that is important to consider in addition to precipitation and soil water availability. High VPD is also documented to be an important driver of wildfire conditions. VPD increases are projected to occur across winter, spring, and summer and across multiple emission scenarios[5]. Projections of VPD changes are harder to estimate because they are calculated based on both temperature and relative humidity. As temperature increases, the VPD also increases under the same humidity conditions. Model projections of future humidity are more variable and sensitive to microclimates, but the overall increase in temperature and likely similar humidity levels indicate overall higher VPD projections into the future. When operating in combination, the challenges facing plants and landscapes—changes in temperature, precipitation levels, and humidity—become even more pronounced. Summer temperature increases combined with significantly decreased precipitation totals and drier air during those months exacerbate an already stressful combination of heat and dryness during the time of most active plant growth and longest days of the year.

So what does this mean for the Arboretum, and how can we maintain existing collections and plan for a sustainable future? What are the risks of inaction? What steps can be taken now, and in the decades to come, to mitigate climate effects and build more resilient collections? This plan seeks to answer these questions.

1: Projection for west of the cascades for 2080 using scenarios RCP 4.5 and RCP 8.5:
https://public.tableau.com/app/profile/matthew.rogers6435/viz/PNWClimateProjectionTool/StorySheet?publish=yes
2: Extreme heat days defined as days exceeding the 99th percentile using the 1971-2000 baseline. Estimated extreme heat days based on Intergovernmental Panel on Climate Change (IPCC) scenario RCP8.5. From: Vogel, J., J. Hess, Z. Kearl, K. Naismith, K. Bumbaco, B.G. Henning, R. Cunningham, N. Bond. 2023. In the Hot Seat: Saving Lives from Extreme Heat in Washington State.
3: USDA Climate Hubs Northwest Climate Hubs Climate Change Impacts in the Northwest
https://www.climatehubs.usda.gov/hubs/northwest/topic/climate-change-impacts-northwest
4. Kunkel, K.E., R. Frankson, J. Runkle, S.M. Champion, L.E. Stevens, D.R. Easterling, B.C. Stewart, A. McCarrick, and C.R. Lemery (Eds.), 2022: State Climate Summaries for the United States 2022. NOAA Technical Report NESDIS 150. NOAA/NESDIS, Silver Spring, MD.
5: Brey, S. J., Barnes, E. A., Pierce, J. R., Swann, A. L. S., & Fischer, E. V. (2021). Past Variance and Future Projections of the Environmental Conditions Driving Western U.S. Summertime Wildfire Burn Area. *Earth's Future*, *9*(2), e2020EF001645. https://doi.org/10.1029/2020EF001645


Azalea Way in spring

## Landscape Character

### Historical Factors

The landscape within the Arboretum has changed extensively in the last 200 years. Today's Arboretum has been greatly influenced by various large-scale and comprehensive plans of the last 90 years, and in particular the original Olmsted Brothers master plan in 1936. But the site was also shaped by human uses as well as long-scale natural changes in vegetation, hydrology and soils going back millennia.

The Washington Park Arboretum is on land that is part of the traditional homelands of the Coast Salish tribes and bands therein. Since at least the last ice age, the local landscape saw both seasonal and permanent use by indigenous peoples that live around the greater Lake Washington and Lake Union watersheds and adjacent areas of central Puget Sound.

The Arboretum lies within a valley and a larger watershed, historically drained by springs, seeps and groundwater into Arboretum Creek. The creek runs along the valley floor, emptying into Lake Washington at the north end of the Arboretum. Historically this drained a much larger area of land to the south, though most of the headwaters were diverted into pipes and sewers by the early part of the 20th century. The soils are relatively young having been shaped by the last ice age.

The shoreline at the north part of the Arboretum is part of Union Bay, an arm of Lake Washington. Where the creek meets Union Bay, the mouth or outlet of Arboretum Creek was historically known in Lushootseed as Stałał (stáhLahL), or "fathom". As a unit of measure, fathom meant that the width of the stream where it reached the lake was equivalent to 6 feet—notably wide. This matches what Government Land Office surveyors measured in their original surveys in 1855. The Lushootseed name for what is now called Foster (or Foster's) Island at the northeastern side of the Arboretum is sti't'[1]tci (stéétcHee) or "little island." The land was well known and well used by native people.

The landscape was a mix of forests of different ages, dominated by conifers in the uplands and deciduous trees closer to the creek, wetlands and lake. Some areas may have been kept more open of trees due to historical indigenous practices, but the landscape was in a state of rapid change by the time Euro-American settlement began in earnest in the mid-19th century.

By the early 1770s, European explorers and traders had introduced infectious diseases that spread through Coast Salish populations in waves over the next century. The resulting population decline and fragmentation lead to signification changes in land use and community cohesion. Longstanding use of the landscape changed with population upheaval and loss, and the character of the land changed. In the Arboretum itself, this change in vegetation was reflected by remarks in 1855 surveys notes of early successional growth in lowlands and the high percentage of younger trees present.

By the late 1880s as the Seattle area was being rapidly settled by Euro-Americans, the largest of the forest trees were cut. Logging was generally more selective than the clearcutting of the 1900s, with many smaller or more difficult to access trees left. The more valuable timber was cut first, but in time many of the middle and smaller sizes would be felled too.

In the Arboretum much of the land was logged twice before the area was set aside as a park in 1900 on the outskirts of the rapidly growing city of Seattle. Within Washington Park, a more extensive tree survey was undertaken along the route of the proposed Lake Washington Boulevard. In 1935, when the Olmsted Brothers firm were developing the first plan for the new Arboretum, they extensively surveyed the land and recorded the sizes of all the existing trees. Some larger remnant trees were noted at the time, but most were not more than 80-100 years old. The percentage of young trees was very high, and the mix had tilted to a higher percentage of deciduous species than would have been present 100 years earlier.

**Soil Types**

For any cultivated landscape, understanding of the soil types and properties and how they are distributed is essential for managing plant growth and health. Different types of soils support different types of plants, and soil composition, depth, drainage, chemical makeup and many other aspects are all limiting factors in plant growth. Different species have different preferences and requirements, and how fertile or well-drained a soil is critical in determining plant success or failure. Furthermore, as the Arboretum is primarily concerned with woody plants, and trees and shrubs in particular, soils must be able to support decades or centuries of growth of large, well-rooted plants. Critically, soil moisture must be sufficient to allow for healthy growth throughout the year. Even small changes in rainfall or temperature can limit available soil moisture when plants need it. This is especially true for some soil types that are unable to store water during longer dry periods, or conversely, become waterlogged due to more extreme rainfall events and therefore inhospitable to root growth.

The Arboretum's northern boundary is Lake Washington along Union Bay, where much of the near shore area was former lake-bottom until 1916. When the Lake Washington Ship Canal and locks were developed, the lake level dropped nine feet when Lake Washington was connected by canal to the lower Lake Union to the west. These newly dry lands were later filled in some places and dredged in others to form lagoons. At the extreme northwest of the Arboretum, a portion was used as sanitary landfill (Miller Street Dump) during the early part of the 20$^{th}$ century.

While some areas within the Arboretum—especially along the lake, the Washington Park playfield and the limited areas with buildings—have been extensively modified in the last 120 years, much of the underlying soils retain their historical characteristics. Soils in the Arboretum are typically "heavy" with a higher clay content. They are not very deep, especially in the lower areas in the larger creek watershed. Some of the higher ridges and hills have relatively sandier soils and better drainage, but even in places like the hill in the Pinetum, the soil layer is shallow and poorly drained.

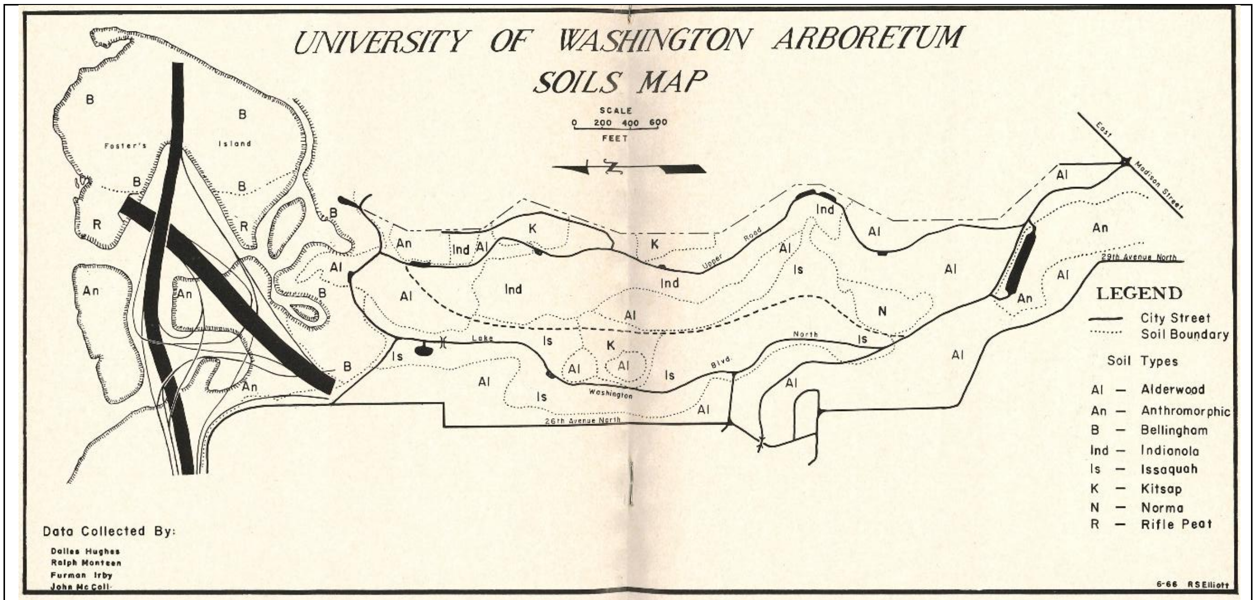



**Figure 2.** Soils map of the Arboretum (1966). Map of various soil types in the Washington Park Arboretum. Produced by Dr. Stanley Gressel and graduate students published in Arboretum Bulletin, Fall 1966.

Much of the Arboretum has soils in the Alderwood and Issaquah series. Alderwood soils are predominant in the Pinetum and west of Lake Washington Boulevard above the creek, on the hilltops of Yew and Honeysuckle Hill, the north end of Azalea Way and the Oak family section, a large band above and east of Azalea Way extending to the north side of Rhododendron Glen, and much of the south end of the Arboretum around the Japanese Garden and Pacific Connections. This soil developed on glacial till and drift material and contains a wide variety of rocks of varying sizes with the till becoming compacted and cemented at varying depths below the surface. If dry the till is often impermeable to the roots of plants. Surface drainage is decent, but subsoil drainage is slow and the soil can become water saturated at shallow depths during the rainy season. Layers can be cemented in thin plates, though some root penetration can occur, but usually not very deeply. Water moves downward with difficulty even on hills. This has led to water pooling even on the hillsides of the Pinetum, and led to loss of a large Coulter pine, which fell over when soils became too saturated. The lack of available soil for adequate root growth has otherwise stressed deeper rooted trees like pines and oaks as they age.

The Issaquah series is found along much of Azalea Way and the areas around Arboretum Creek, as well as the creek drainage in Rhododendron Glen. This is characterized by lake or stream deposits over a poorly drained substratum. The uppers layer Is silty loam and generally good for plant growth. However, at 18 inches or more it shifts to layers of sandy clay, clay loam and clay sand with reddish brown and gray layers of anaerobic soil. Some layers of gravel can be found between clay layers. The soil at this depth is very poorly drained and can restrict plant growth, including for most trees and large shrubs.

The soil maps are very useful for planning for future plantings and in determining which areas may need amending or alteration. Unfortunately, the Olmsted Brothers firm didn't have this kind of detailed information when they designed the original 1936 plan, and the planners time on site was very limited. In the years that followed it became increasingly clear that soils were a limiting factor in implementing the design as contemplated, and many collections were later re-sited to better conform to existing soil and hydrological conditions.

**Plant Collections**

When the first large scale plantings began in the 1930s, the Arboretum set about requesting seeds from all of the major botanical gardens in the United States. The original mission for the Arboretum was to grow and display every kind of woody plant that could be cultivated outdoors in the maritime Northwest. As planting began, the Olmsted plan, with its taxonomic layout sequence, was followed as closely as possible. Other than Azalea Way, with its designation as a central walk displaying spring flowering plants such as azaleas, cherries, magnolias and dogwoods, much of the collection remains grouped by taxonomic relationships and similar characteristics. However, it soon became clear that existing site and ground conditions were not appropriate to support the genera specified for those sites. The original Olmsted plan failed to account for topography and existing second and third growth forest trees, and some sites required extensive cultivating and improvement of soil or other modifications.

More recent planting areas were developed for theme and landscape function – the Woodland Garden, Winter Garden, Mediterranean Beds and Loderi Valley are a few examples. Collecting and acquisition continued through the 1940s and 50s, with more than 1,500 accessions adding during many years. In the 1990s the first Eco-Geographic garden, the New Zealand High Country Exhibit was installed and more and larger examples followed after the 2001 Master Plan was approved.

These extensive plant acquisions and garden development—along with Seattle's moderate climate—led to the development of a broad and comprehensive collection focused on woody plants: trees, shrubs, groundcovers and vines. By the 1970s the Arboretum was home to one of the most diverse woody plant collections of temperate plants in North America. Today the Arboretum has over 40,000 plants, comprising over 13,000 different living accessions and nearly 5,000 distinct taxa. In addition to a wide variety of species and cultivars present throughout the collections, the Arboretum features several plant collections of special depth, breadth and importance. Currently the Arboretum features four

Nationally Accredited Plant Collections as part of the Plant Collection Network of the American Public Gardens Association (APGA): maples (*Acer* species (spp.)), holly (*Ilex* spp.), magnolia (*Magnolia* spp.), and oaks (*Quercus* spp. and other members of the Fagaceae).

The Arboretum also has many "core collections," or those genera, families or eco-geographical regions with a particularly broad range of species represented. These include:

- *Rhododendron* species and cultivars
- Heather family (Ericaceae other than *Rhododendron*, including *Vaccinium*, *Kalmia*, *Pieris*, *Gaultheria* spp., etc.)
- Witch Hazel family (Hamamelidaceae including witch hazel (*Hamamelis* spp.), winter hazel (*Corylopsis* spp.) etc.)
- *Viburnum* species
- Mountain ash (*Sorbus*, *Aria* spp.)
- Tea Family (Theaceae including *Camellia*, *Stewartia* spp.)
- Conifer genera (species of pine (*Pinus* spp.), true fir (*Abies* spp.), hemlock (*Tsuga* spp.), true cedar (*Cedrus* spp.), red cedar (*Thuja* spp.), spruce (*Picea* spp.), cypress (*Cupressus* spp.), false cypress (*Chamaecyparis* spp., *Callitropsis*), Douglas-fir (*Pseudotsuga* spp.), larch (*Larix* spp.), giant redwood (*Sequoia sempervirens*), coast redwood (*Sequoiadendron giganteum*), and others)
- Birch (*Betula* spp.-though greatly reduced due to climate and related insect impacts)
- New Zealand (South Island Interior)
- Chile (south-central)
- Australia (southeast mountains)
- China (Emei Shan (Mt. Omei) and Sichuan mountains)
- Japan (Japanese Garden and broadly throughout collections)

The Arboretum has always been a testing and introduction site for newly cultivated species and cultivars for gardens and landscapes. Throughout its history the Arboretum has often been the initial regional or national location of plant introduction thanks to the work of curators and collections managers utilizing networks of gardens, collectors, seed exchange programs and botanical institutions throughout the temperate world. As a result of these connections, many species or selections from other areas of the world have been tested and trialed over many years to determine suitability for cultivation in the region, including modeling for potential invasiveness. Many of the Arboretum's plants have been trialed under different conditions throughout variable weather conditions for many years to test their suitability for local gardens and landscapes. Of particular value for assessment, plant collections are carefully documented, and records of performance and health are kept throughout their lives. The Arboretum has and continues to offer great value as a venue in testing plant performance over time, providing a valuable research space to learn more about climate effects as well as more traditional studies in botany, biology, landscape design, horticulture and many related disciplines.

The Arboretum's location in a large and growing city also means that it offers a preview of conditions in a warming world.  The Urban Heat Island Effect is pronounced in large urban areas, including Seattle, with hotter local temperatures than surrounding areas as well as increased temperatures for longer periods as the concrete surfaces absorb and radiate heat. Conditions generally stay warmer at night and take much longer to cool down compared to rural areas.  These effects increase stress on urban plants and can be used to predict how species will perform as surrounding areas also experience warmer baseline temperatures due to climate change.  The diversity of the Arboretum's plantings provides a living laboratory for the study of these effects.

The Arboretum is a particularly important site for ex-situ conservation, or preservation of species outside of their native range.  Currently the Arboretum's Conservation Collection contains over 230 species that are threatened or endangered in the wild, from many countries around the world.  The collection not only helps safeguard species from further losses in the wild, but is also a means of preserving genetic diversity within species to help build redundancy and resilience for their preservation and potential re-introduction.

The ecosystem services the Arboretum provides are also vast.  The plantings are a major means of carbon sequestration, and provide diverse, layered and rich habitat that supports ecosystem biodiversity.  The gardens provide food, animal and insect habitat, air quality, climate regulation, water regulation and quality in addition to enhancing public health through engagement with the natural world, connection with cultural landscapes, gatherings and celebrations, and providing countless opportunities for learning at all levels and for all ages.


New Zealand Forest in the Pacific Connections Garden

## Risk Assessment of Existing Collections

We employed a variety of tools to assess the potential climate impact risks to existing collections in the Arboretum.  These included species assessment tools using data on their natural and cultivated range, local and international climate maps and weather data. Foremost for looking at species specific information was the Climate Assessment Tool (CAT), which was developed through collaboration between the Royal Botanic Gardens Victoria (Australia), the Botanic Gardens Conservation International (BCGI) and the University of Tasmania, with support from the International Association of Botanic Gardens.

**Methods**

The Climate Assessment Tool (CAT) was used to analyze the Washington Park Arboretum collection, comparing the current and future climate at the site. The CAT uses observation records from several sources to determine the observed climatic range for an individual taxon, then uses climate models to generate an estimate for the selected site (in this case, the Washington Park Arboretum in Seattle, WA).

For each of the included taxa, five bioclimatic metrics based on current observed distribution were generated by the CAT. These metrics are: mean annual temperature (MAT, BIO1), maximum hottest month temperature (MHMT, BIO5), minimum temperature of the coldest quarter (MTCQ, BIO11), annual precipitation (MAP, BIO12), and precipitation of the driest quarter (PDQ, BIO17) (https://www.worldclim.org/data/bioclim.html).

The CAT then provided projections of these same five bioclimatic metrics for the Arboretum, based on three possible scenarios:

## The Climate Assessment Tool

The Climate Assessment Tool (CAT), hosted by the Botanic Gardens Conservation International (BGCI), predicts the suitability of plant species for future climates by analyzing datasets of current occurrences in the natural, botanic gardens, and cultivated environments. By comparing the climates of these occurrences with future projections, CAT generates suitability scores, aiding in informed plant selection and evaluation for sustainable landscapes. This approach addresses the challenges posed by climate change, which is introducing unprecedented conditions that will redefine horticultural landscapes traditionally managed based on past knowledge and observations. The suitability of taxa to locations where they currently grow will vary in the future based on the impact of climate change to those locations, the sensitivity of taxa to these changes, and the ability of the taxa to adapt or acclimate to the novel conditions.

1. **Current Conditions.** This projection uses current conditions as a basis of interpretation for how species would be expected to fare under current local conditions based on observations in their natural ranges as well as under garden conditions in botanical gardens worldwide.
2. **Intermediate Scenario.** This projection predicts climate 30 years into the future based on some slowing of the current rate of emissions in the coming decades. This uses the RCP4.5 (Representative Concentration Pathway for climate scenarios where greenhouse gas concentrations increase by 4.5 W/m$^2$ (watts per square meter) and then start to level off). In other words, greenhouse gas concentrations are curtailed over time but still increase. This is considered an intermediate scenario and assumes measures are taken to reduce greenhouse gas emissions.
3. **Worst Case/Business as Usual.** The third scenario is a “business as usual” model where greenhouse gasses increase at their current rate into the future through 2090.

This scenario uses the RCP8.5 extreme heat projections for 2090 from the Intergovernmental Panel on Climate Change (IPCC)[6]. This is considered a worst-case scenario in which emissions are not curtailed and limited to no steps are taken to address greenhouse gas emissions.

The projections were then evaluated in relation to the growing range of the taxon of interest to indicate how resilient or vulnerable they are to climate change based on the current distribution of the taxon. The CAT focuses on trees and other woody plants and does not include cultivars (cultivated varieties), forms, varieties, or subspecies, so herbaceous plants were excluded and only straight species and hybrids of woody plants included.

While the CAT database is large and diverse, it does not cover all possible woody species – or even all those that are currently growing in the Arboretum. The current cataloged collection at the Arboretum includes 15,281 individual entries, representing nearly 5,000 unique taxa including all plant forms, cultivars, varieties, and plants with uncertain taxonomy. Of these, 967 taxa were matched with existing records in the CAT. The majority of Arboretum taxa missing records in CAT are uncommonly grown species or hybrids, or are varieties, subspecies, forms or cultivars (cultivated varieties), and therefore out of scope for the tool. Some taxa have undergone recent taxonomic changes and this likely also led to other omissions or duplications. Using the observation data and the three site-specific projection scenarios, the CAT then generated a rating based on mean annual temperature (MAT) indicating where a taxon occurs, is on the edge of adaptability, or is unlikely to occur.

To better understand the potential impacts to the Arboretum's Nationally Accredited Plants Collection, a core group of taxa in this collection were analyzed in CAT as a subset. These taxa include species in the genera *Acer*, *Ilex*, *Magnolia,* and *Quercus*. For cultivars and varieties in the core taxa the straight species was run through CAT. In total there were 197 core taxa in CAT, including 62 *Acer* taxa, 33 *Ilex* taxa, 37 *Magnolia* taxa, and 65 *Quercus* taxa. In the collection in total, core taxa include 85 *Acer* species, 52 *Ilex* taxa, 48 *Magnolia* taxa, and 79 *Quercus* taxa. The difference between what is represented in the CAT results and the collection is primarily subspecies, forms, varieties and cultivars and varieties within each genus that were out of scope for CAT.

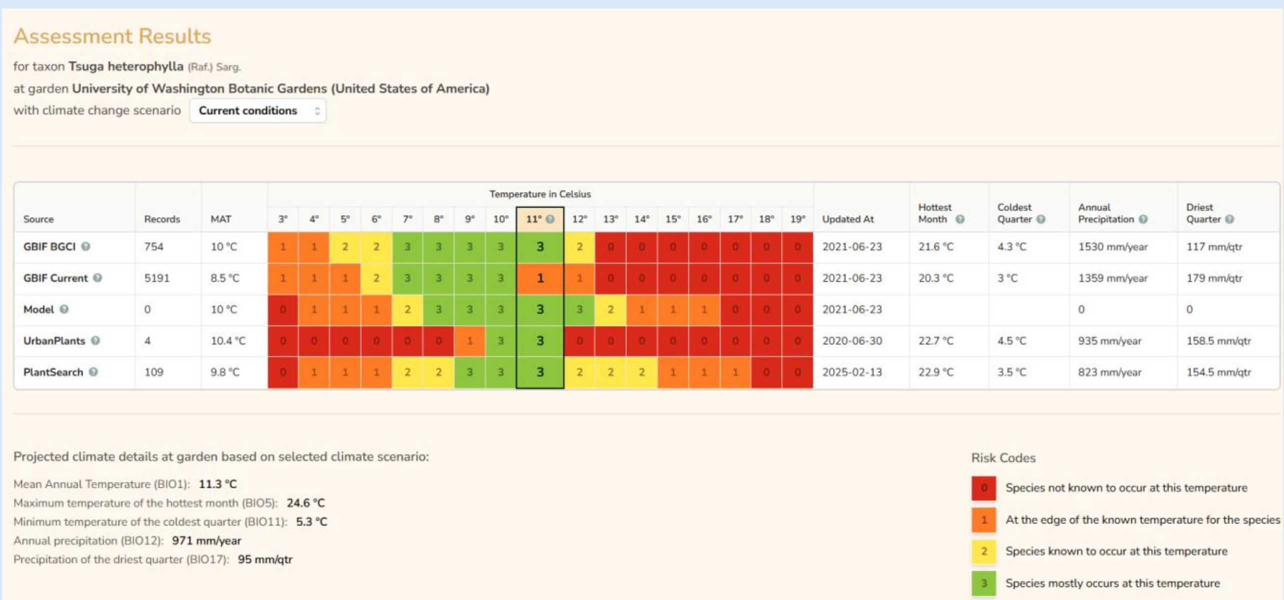
6: Climate Change Alliance of Botanic Gardens. [2024]. Climate Assessment Tool v1. Botanic Gardens Conservation International. Richmond, U.K. Available at https://cat.bgci.org. Accessed on 11/2024

## Native Species Under Stress

Western hemlock (*Tsuga heterophylla*) death in the Washington Park

An important native species that is currently under stress in the Arboretum is the western hemlock (*Tsuga heterophylla*). This is the state tree of Washington and a major component of coniferous forests in the western side of the state. It is considered a "climax" species of old growth forests in many habitats, meaning it will be a dominant tree in those habitats.

Currently, western hemlocks and western red cedars are experiencing decline and death in many areas of the Arboretum. Observationally, this has corresponded with increasing heat and summer aridity in the last decade. Our assessment confirms that. For current conditions, the assessment shows that the species is within it's current heat tolerances at the Arboretum, but is getting closer to the edge of its range:



Assessment Results

for taxon **Tsuga heterophylla** (Raf.) Sarg.

at garden **University of Washington Botanic Gardens (United States of America)**

with climate change scenario **Current conditions**

| Source | Records | MAT | 3° | 4° | 5° | 6° | 7° | 8° | 9° | 10° | 11° | 12° | 13° | 14° | 15° | 16° | 17° | 18° | 19° | Updated At | Hottest Month | Coldest Quarter | Annual Precipitation | Driest Quarter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GBIF BGCI | 754 | 10 °C | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2021-06-23 | 21.6 °C | 4.3 °C | 1530 mm/year | 117 mm/qtr |
| GBIF Current | 5191 | 8.5 °C | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2021-06-23 | 20.3 °C | 3 °C | 1359 mm/year | 179 mm/qtr |
| Model | 0 | 10 °C | 0 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 2021-06-23 | | | 0 | 0 |
| UrbanPlants | 4 | 10.4 °C | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2020-06-30 | 22.7 °C | 4.5 °C | 935 mm/year | 158.5 mm/qtr |
| PlantSearch | 109 | 9.8 °C | 0 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 2025-02-13 | 22.9 °C | 3.5 °C | 823 mm/year | 154.5 mm/qtr |

(Temperature in Celsius: 3°–19°)

Projected climate details at garden based on selected climate scenario:

Mean Annual Temperature (BIO1): **11.3 °C**
Maximum temperature of the hottest month (BIO5): **24.6 °C**
Minimum temperature of the coldest quarter (BIO11): **5.3 °C**
Annual precipitation (BIO12): **971 mm/year**
Precipitation of the driest quarter (BIO17): **95 mm/qtr**

Risk Codes

- 0 Species not known to occur at this temperature
- 1 At the edge of the known temperature for the species
- 2 Species known to occur at this temperature
- 3 Species mostly occurs at this temperature

However, under a "business as usual" emissions scenario, the results were very different:

## Assessment Results

for taxon **Tsuga heterophylla** (Raf.) Sarg.
at garden **University of Washington Botanic Gardens (United States of America)**
with climate change scenario **Business as Usual in 2090 (SSP3)**

| Source | Records | MAT | Temperature in Celsius 7° | 8° | 9° | 10° | 11° | 12° | 13° | 14° | 15° | 16° | 17° | 18° | 19° | 20° | 21° | 22° | 23° | Updated At | Hottest Month | Coldest Quarter | Annual Precipitation | Driest Quarter |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GBIF BGCI | 754 | 10 °C | 3 | 3 | 3 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2021-06-23 | 21.6 °C | 4.3 °C | 1530 mm/year | 117 mm/qtr |
| GBIF Current | 5191 | 8.5 °C | 3 | 3 | 3 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2021-06-23 | 20.3 °C | 3 °C | 1359 mm/year | 179 mm/qtr |
| Model | 0 | 10 °C | 2 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2021-06-23 | | | 0 | 0 |
| UrbanPlants | 4 | 10.4 °C | 0 | 0 | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2020-06-30 | 22.7 °C | 4.5 °C | 935 mm/year | 158.5 mm/qtr |
| PlantSearch | 109 | 9.8 °C | 2 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2025-02-13 | 22.9 °C | 3.5 °C | 823 mm/year | 154.5 mm/qtr |

Projected climate details at garden based on selected climate scenario:
Mean Annual Temperature (BIO1): **15.4 °C**
Maximum temperature of the hottest month (BIO5): **30.1 °C**
Minimum temperature of the coldest quarter (BIO11): **9.2 °C**
Annual precipitation (BIO12): **1021 mm/year**
Precipitation of the driest quarter (BIO17): **84 mm/qtr**

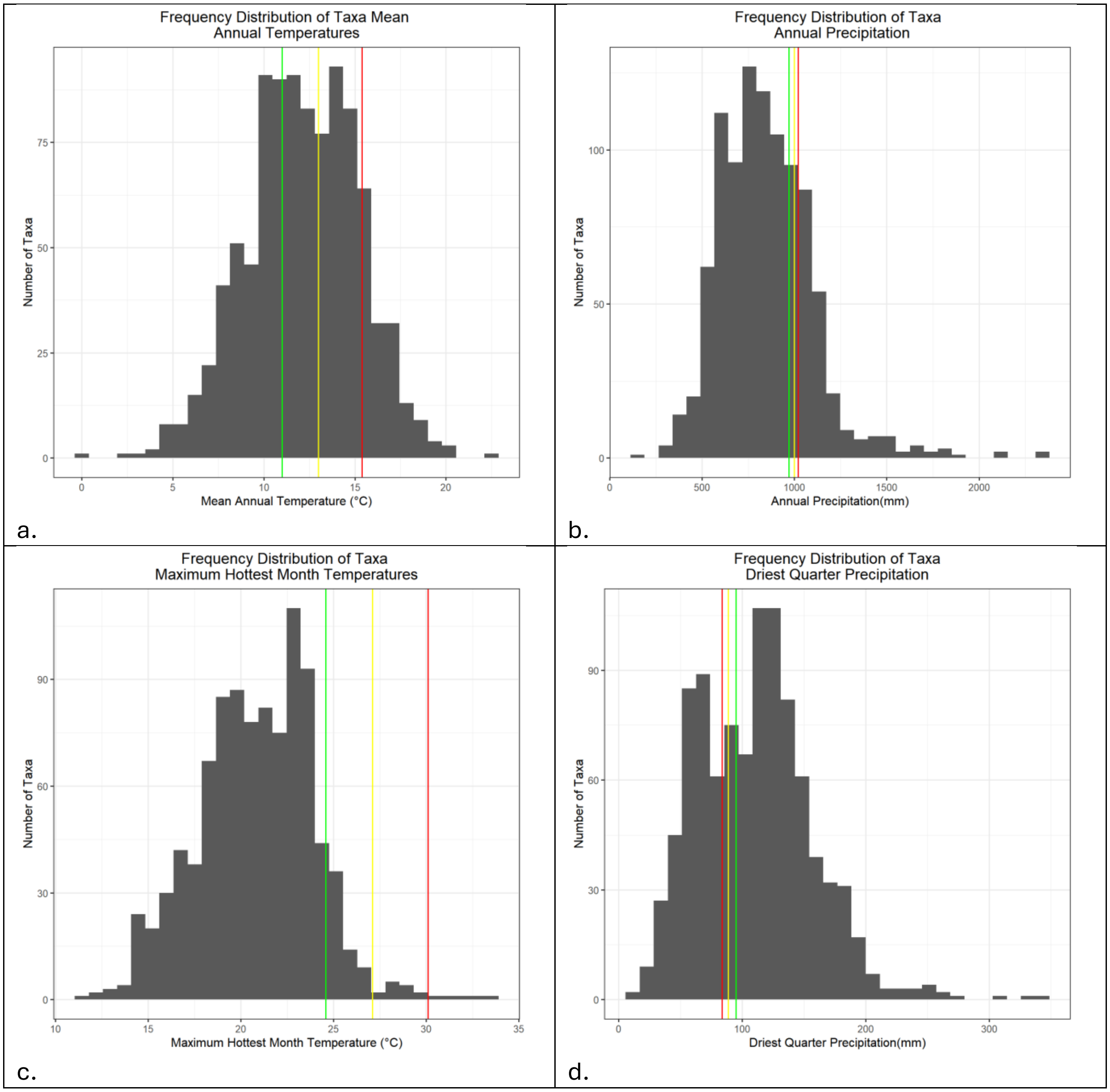
Risk Codes
- 0 Species not known to occur at this temperature
- 1 At the edge of the known temperature for the species
- 2 Species known to occur at this temperature
- 3 Species mostly occurs at this temperature

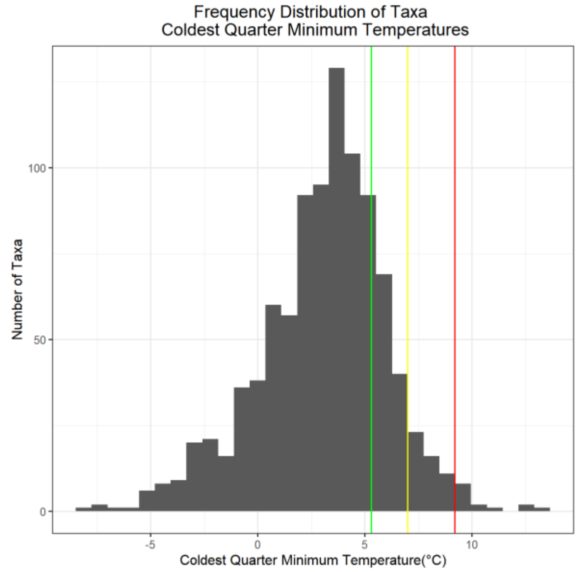
In this scenario, the species is beyond or at the very edge of its heat tolerances, both in the wild and in gardens. This is just a heat consideration, without accounting for predicted changes to annual precipitation or the extended dry periods during summer months, which are expected to be exacerbated under all climate models.

### Results

Taxa in the Arboretum's collection originate from a broad range of environments from around the world. Specific taxa are from environments with both higher and lower annual temperatures, and the Arboretum's current mean annual temperature (MAT, fig. 3a.) shows that the collection is relatively centralized around mean taxa preferences.

The Arboretum has annual precipitation (MAP) rates higher than the average of the majority of the collection, and annual precipitation is projected to increase slightly due to climate change (fig. 3b). However, the precipitation is highly concentrated in the October-May period, and the annual precipitation rate does not reflect needs for those species that are from summer rain climates and must have additional water during our arid summers.


Frequency Distribution of Taxa Mean Annual Temperatures
Number of Taxa
0
25
50
75
0
5
10
15
20
Mean Annual Temperature (°C)
a.
Frequency Distribution of Taxa Annual Precipitation
Number of Taxa
0
50
100
0
500
1000
1500
2000
Annual Precipitation(mm)
b.
Frequency Distribution of Taxa Maximum Hottest Month Temperatures
Number of Taxa
0
30
60
90
10
15
20
25
30
35
Maximum Hottest Month Temperature (°C)
c.
Frequency Distribution of Taxa Driest Quarter Precipitation
Number of Taxa
0
30
60
90
0
100
200
300
Driest Quarter Precipitation(mm)
d.




e.

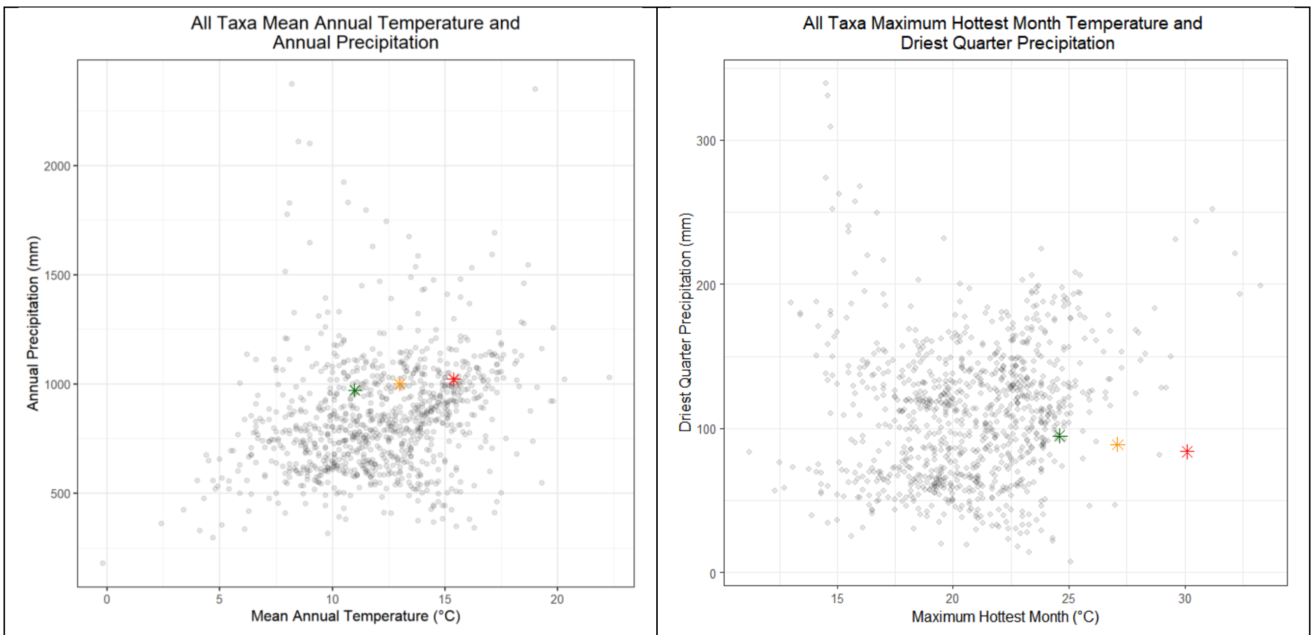
**Figure 3:** Distribution of taxa at Washington Park Arboretum, for climate variables based on current distribution records and derived from the Climate Assessment Toll. Green line shows current conditions for the Arboretum. Yellow line shows 2050 projection for the Arboretum based on a moderate emissions scenario (Intermediate Scenario, RCP 4.5). Red line shows 2090 projection for the Arboretum based on a business-as-usual emissions scenario (Worst Case Scenario, RCP 8.5).

The current maximum hottest month temperature (MHMT) at the Arboretum is equal to the upper end of the distribution of MHMT for the collection and will increase in the future with projections for 2090 exceeding almost all MHMT temperatures for the current collection (fig. 3c). Driest quarter precipitation (DQP) for the Arboretum is fairly centered for current levels compared to the collection; however, this is likely to shift later in the century with the driest quarter being dryer than typical for the majority of the collection (fig. 3d). The Arboretum is warmer during the coldest quarter of the year than most of the collection's distribution. This suggests that the majority of the collection is adapted to or able to acclimate to colder temperatures than the Arboretum, which can indicate a low risk for cold damage. This disparity increases with climate change, however, and the interpretation of risk should also include aspects of plant phenology and cold hardiness, as timing and development are crucial aspects of low temperature tolerance in temperate plant taxa.

Thus, cold temperatures are generally not going to be a limiting factor in ability to grow existing species but will increasingly affect certain taxa that depend on temperature cues to flower and set fruit. Necessary chilling days may no longer occur to produce flowers or seed/fruit for many taxa, including Syringa, Malus and others. Earlier flowering or inability to develop typical flowers will also affect insect populations and disrupt the food web. Of most concern is figure 3d. This shows that most taxa on the Arboretum will increasingly be beyond their aridity tolerances during the dryest part of the year – summer, which is also when water is needed most.

In addition to temperature and precipitation independently, visualizing these climate traits in combination underscored that the largest area of concern is during the warmest and driest part of the year. The MAT and MAP visualization shows that the Arboretum is and will continue to be within the distribution of current taxa in the collection for these traits (fig. 4a), however when looking at the MHMT and PDQ, the Arborteum appears to already be on the edge of the distribution of the taxa in the current collection, and is likely to be outside of the distribution of these traits, except for a few taxa, by mid-century (fig. 4b). These plots highlight the importance of looking not just at annual averages, but at the periods of highest stress.

While annual rainfall is projected to increase somewhat, it will not address water deficits in existing dry periods from late June-early October.  This is also the time of maximum temperatures and longer days.  Higher temperatures will exacerbate water deficits and the ability of plants to access water and remain turgid, greatly increasing stresses and decreasing viability.  Available soil moisture will further decline from existing levels.  An increasing number of existing species—projected to be well over half of existing taxa—will require additional summer moisture through irrigation in order for them to survive.




a. b.

**Figure 4.** Temperature by Precipitation plots for all taxa for a) Mean Annual Temperature and Mean Annual Precipitation and b) Maximum Hottest Month Temperature and Driest Quarter Precipitation. Green stars show current value for the Arboretum. Yellow stars show 2050 projection for the Arboretum based on a moderate emissions scenario (RCP 4.5). Red stars show 2090 projection for the Arboretum based on a business-as-usual emissions scenario (RCP 8.5).

The CAT rates taxa on a 0-11 scale (Table 2) based on the MAT of the site (the Arboretum) compared to each taxon's climatic distribution. As mentioned above, summer will be the period of highest stress for the Arboretum collections, and probably the limiting factor for taxa suitability to the site. So, interpretation of these ratings must consider how they may differ from the summer conditions in Seattle, notability our long period of aridity.

Another caveat of these results is that taxa with few observation records may not be accurately represented by CAT in terms of bioclimatic distribution, and as a result the vulnerability rating may be biased. The 0-11 vulnerability scale is based on four categories derived from taxa distribution: unknown to occur, near edge of range, shoulder of range, and middle of range, and the vulnerability can be conceptualized as high, moderate, low, and minimal, respectively. The observations that determine species distribution are grouped into three categories: natural, urban, and botanic garden. Based on this rating system, by 2090, 421 taxa in the Arboretum's collections show minimal vulnerability, 265 show low vulnerability, 232 show moderate vulnerability, and 43 show high vulnerability (Table 2).

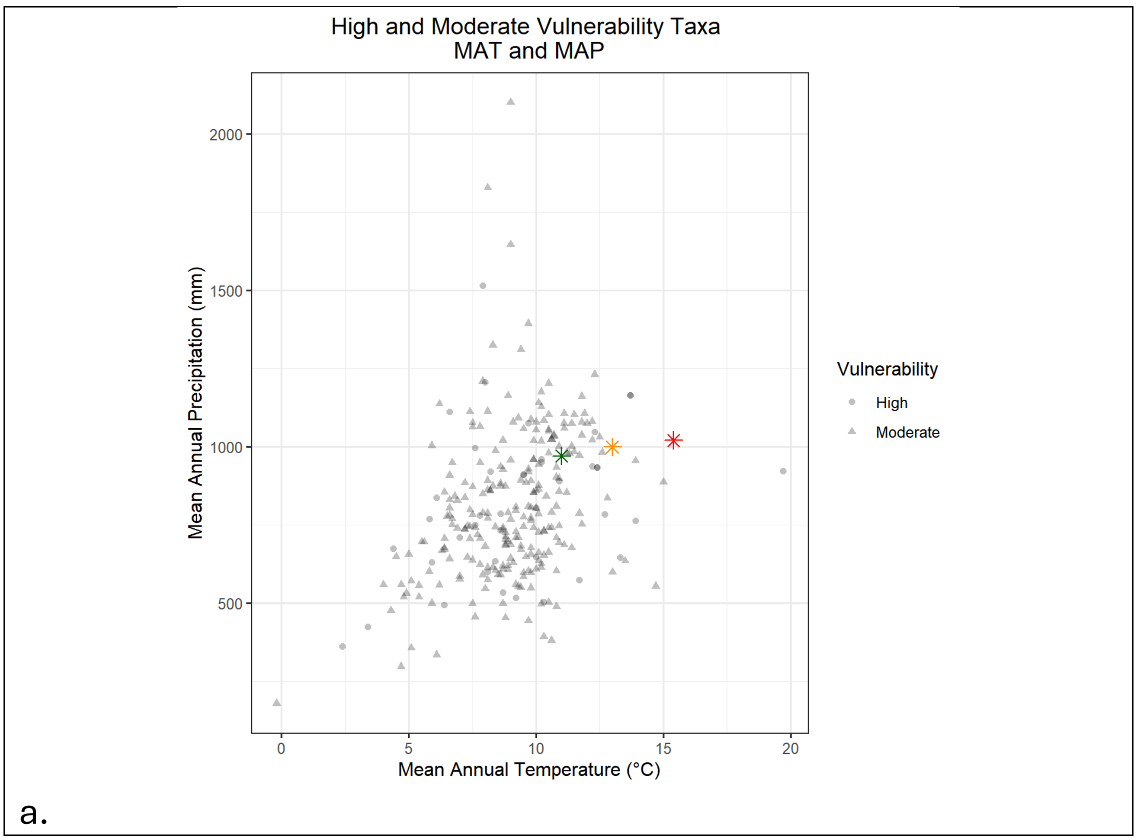
**Table 2.** The Climate Assessment Tool (CAT) rating system based on taxa observed distribution across natural populations, urban populations, and botanic garden collections.

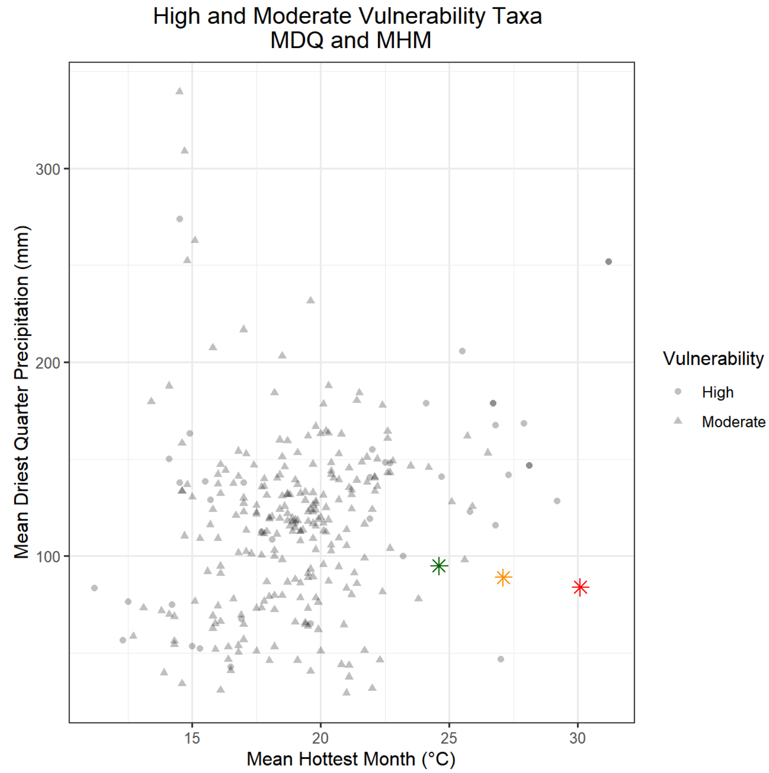
| Rating | Rating Meaning | Number of Taxa | Vulnerability |
|---|---|---|---|
| 0 | Not known and not likely | 20 | High – 43 Taxa |
| 1 | Not know but possible | 0 | |
| 2 | Not known but likely | 23 | |
| 3 | Near edge of botanic garden range | 133 | Moderate – 232 Taxa |
| 4 | Near edge of urban range | 0 | |
| 5 | Near edge of natural range | 99 | |
| 6 | Shoulder of botanic garden range | 133 | Low – 265 Taxa |
| 7 | Shoulder of urban range | 0 | |
| 8 | Shoulder of natural range | 132 | |
| 9 | Middle of botanic garden range | 92 | Minimal – 421 Taxa |
| 10 | Middle of urban range | 0 | |
| 11 | Middle of natural range | 329 | |

Figure 5 visualizes how the high and moderate vulnerability taxa compare to the temperature and precipitation projections for the Arboretum for MAT and MAP (a) and MHMT and PDQ (b). Annual means (fig. 5a) show that Arboretum conditions for 2090 are outside of the range of the vulnerable taxa and distinct from the collection as a whole. However, this pattern is not clear when looking at the summer period, where the distribution of bioclimate traits for vulnerable species reflects the results for all taxa (fig. 4b, fig. 5b). This indicates that MAT and

MAP may not be good predictors in this data set for vulnerability during the hottest and driest period. Rating of taxa in relation to the hottest and driest period may provide better indication of vulnerability to future climates.

Thus, most species in core collections will be increasingly vulnerable to hotter, drier summers without interventions (fig 5a). Water deficits in summer are increasingly the limiting factor. Increasing heat during dry summer months will greatly diminish available water, suggesting that the timing of precipitation remains the limiting factor for many species in all scenarios.



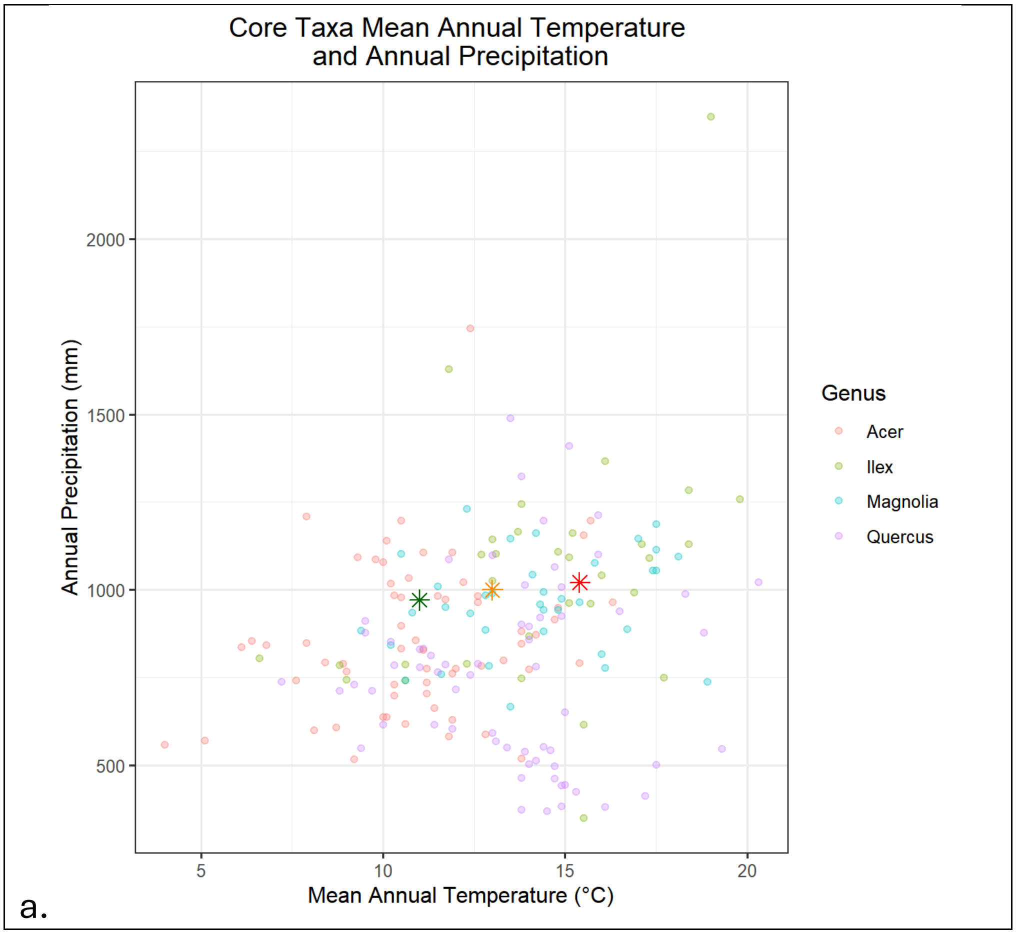



b.

**Figure 5.** High and moderate vulnerability taxa temperature by precipitation plots for a) Mean Annual Temperature and Mean Annual Precipitation and b) Maximum Hottest Month Temperature and Driest Quarter Precipitation. Green stars show current value for the Arboretum. Yellow stars show 2050 projection for the Arboretum based on a moderate emissions scenario (RCP 4.5). Red stars show 2090 projection for the Arboretum based on a business-as-usual emissions scenario (RCP 8.5).

### Core Taxa

The bioclimatic distribution pattern of the core taxa from the national collection is consistent with that of the entire collection. Overall, *Acer* and *Quercus* taxa are generally distributed in cooler areas of the world than *Ilex* and *Magnolia* taxa. *Quercus* taxa are generally more suited to low precipitation during dry periods than the other core taxa, and *Acer* has the most taxa that are primarily distributed in cool wet areas but, as a genus, is distributed across the range of temperature and precipitation traits.  Figure 6 shows the distribution of core taxa across temperature and precipitation variables compared to current and projected conditions for the Arboretum. One troubling feature of this visualization is the 2090 projection for our taxa in figure 6b. This emphasizes the risk of high temperature and low precipitation in the summer for this component of the collection. Across the entire Arboretum collections, only five taxa have maximum hottest month temperature (MHMT) greater than the projection for the Arboretum and these taxa are all from the core collection: *Ilex attenuata*, *Ilex opaca*, *Ilex* *cassine*, *Ilex vomitoria*, and *Quercus texana*. Thus, only a handful of existing taxa remain within their heat and water tolerances under the combination of increased heat during our arid summers. Most existing taxa will require intervention to remain viable in the long term.



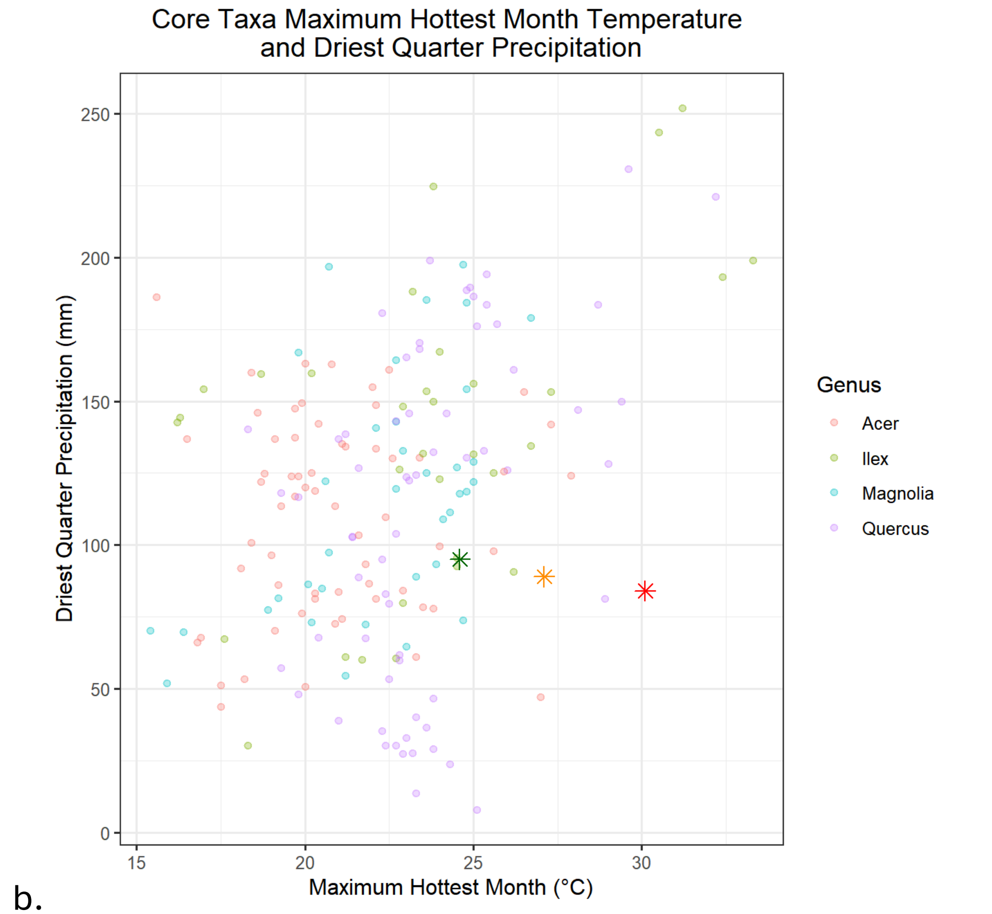



**Figure 6.** Core taxa temperature by precipitation plots for A) Mean Annual Temperature and Mean Annual Precipitation and B) Maximum Hottest Month Temperature and Driest Quarter Precipitation. Green stars show current value for the Arboretum. Yellow stars show 2050 projection for the Arboretum based on a moderate emissions scenario (RCP 4.5). Red stars show 2090 projection for the Arboretum based on a business-as-usual emissions scenario (RCP 8.5).

Analysis of the Arboretum collection using the CAT demonstrates which taxa are most vulnerable to local climate change conditions. However, this is a coarse approach that uses current and historic observational data to infer suitability for the future. This approach provides a tool for identifying taxa within the Arboretum collection that are most vulnerable to climate change but does not encompass the nuance of individual taxa or individual plants abilities to acclimate or adapt to these changes or site-specific variability like microclimate and ground water availability. Thus, this analysis serves as an initial step to coarsely categorize taxa vulnerability but additional investigation into taxa ecophysiology, site variability, and mitigation measures is necessary to provide a more precise understanding of the vulnerability of the Arboretum collection under climate change.

For a complete list of taxa by vulnerability rating, see Appendix A.

## Recommendations for Collections Management

### Climate Adaptive Collections

If climate trends continue, it is expected that the Seattle area will have longer, drier periods of summer aridity as well as more frequent, higher intensity rain events during the fall, winter and early spring. Overall precipitation is projected to increase, but this will only occur during the already rainy months and in more severe events. While overall temperatures will warm, it is unclear if winter temperatures will evenly warm or if extremes will still be present. For example, the Arboretum experienced its deepest cold snap in 34 years in January 2024, when temperatures dropped to 13 degrees F two weeks after temperatures were near 60 degrees F. The result was substantial losses in many collections even of plants that were well-established over the last two decades.

Some of the existing species in the collection may have a range of tolerances for hotter or drier places due to their wide natural range. Securing examples from these genetically variable species offers some promise for climate-adapted traits and should be pursued. For example, European beech, *Fagus sylvatica*, occurs over a very large area in Europe, from southern Scandinavia to the steppes of southeastern Europe. Researchers are testing trees from different areas to find examples that promise to be more adaptable to heat and drought stress and urban environments (Popovic et al, 2015). For other species that occur in widely variable natural conditions, there are also likely to be populations that can tolerate our locally changing climate.

It is also very useful to look at which climate regions are most similar to what is expected and then curate collections to include species from these areas thereby expanding the plant palette for future success. The CityApp tool, developed by the University of Maryland Center for Environmental Science, is a climate planning model that allows users to select a city in the United States and forecast what the climate will be like in 60 years, by showing what place or places in the country currently match those future conditions. For Seattle, CItyApp shows the closest analog to be Three Rivers, California, a town in the foothills of the Sierra Nevada at the eastern side of the Central Valley of California. This region is much more sparsely vegetated, with far fewer trees, more grass and scrub-shrub land, and a more typical Mediterranean climate. Summers are hotter and drier, but it is still cold in the winter due to elevation. Similar climate areas are along the western side of the Sierra Nevada range in northern California.

Other resources are available for determining additional regions analogous to our predicted climate. The Sunset Climate Zones—defined horticultural zones developed over many decades for the western region of the United States—rely on more than just cold temperatures or number of hot days to group zones. Currently, the Sunset Zone for the western foothills of the Sierra Nevada and the town of Three Rivers, is Sunset 7. This suggests that over the next 60 years, Seattle's zone will shift from it's current Sunset 5 to a Sunset 7. In such a scenario, the climate analogs we can look to today are the Rogue River Valley in southwest Oregon, the California gray pine belt and southern California mountains. These areas are characterized by hot summers and mild, pronounced winters. Winters would not have severe cold but would still range from lows of 26 degrees F to 34 degrees F. Gray pines (*Pinus sabiniana*) define this zone around California's Central Valley but incense cedars (*Calocedrus decurrens*) and more adaptable conifers replace them further north and in some other areas. Rainfall averages are projected to increase, primarily due to higher intensity storms.

We can use this and other information to further compare climate regions from around the world, and identify other areas that may have appropriate flora for our projected future climate. Using Walter-Lieth climate charts, more commonly called Walter climate diagrams, we can compare the climate information for specific sites with other areas throughout the world. Developed in the 1950s by Heinrich Walter and Helmut Lieth, Walter diagrams visualize the typical annual climate conditions and patterns in different localities, combining measures of average monthly temperature, precipitation, and historical temperature extremes. The power of these diagrams is that locations are directly comparable and can be created for any area where weather records have been kept, allowing for highly localized and accurate depictions. The diagrams show the temperature and precipitation averages for each month during the year, making it easy to visualize the conditions present. They map how precipitation and temperate change seasonally over the year and when dry or wet periods typically occur and how they relate to heat or cold. For instance, if there were high temperatures and low precipitation during a season, the overlap of the curves visually show the periods of aridity. The same would be true for periods of high precipitation.

Seattle's future climate is likely to mirror today's climate in southern Oregon and the foothills of the Sierra Nevada in California. Comparing Walter diagrams from Seattle (fig. 7a) and Cedar Grove, California (fig. 7b), in the Three Rivers region, we see a longer and more pronounced summer aridity period along with increased summer temperatures. Regions that show similar patterns offer the promise for finding plant species that will be suitable for the Washington Park Arboretum in the long term. Seed collections from species in those areas should be grown and trialed in the Arboretum to examine performance and for inclusion in future collections and garden spaces. But these are not the only regions with potentially suitable flora.

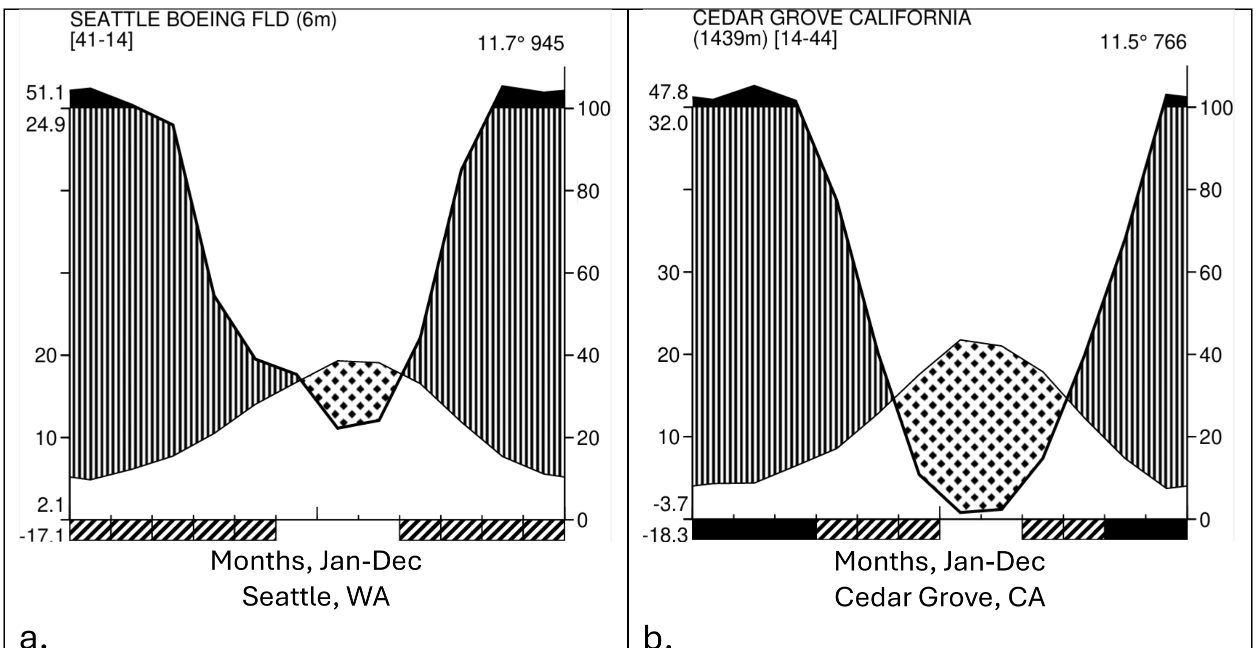



**Figure 7.** Walter diagrams showing the average climate at Boeing Field in Seattle (a.) and Cedar Grove, California (b.). The months are at the bottom of the chart, starting with January. The left side shows average monthly temperature in degrees Celsius, mapped along the lower curve. The right side shows the average monthly precipitation in mm, mapped along the higher curve.

Summer aridity periods are shown in the dotted area. The dark areas at the top in the early and later months show times of high rainfall.

In the mid-1980s Dr. Clem Hamilton at the UW Center for Urban Horticulture (now UW Botanic Gardens) utilized Walter diagrams to compare Seattle with other winter rain regions around the world and found that central Chile, the South African cape, south Australia and the Mediterranean offered a promising range of species for further trialing for the Seattle area. His work helped shape the future development of certain Arboretum collections, and recommendations for eco-geographic garden development were included in the Arboretum's 2001 Master Plan. Since that time, however, our region's climate has warmed, with more pronounced dry periods extending into spring and fall. Conditions now are different than they were 40 years ago and the pace of that change has accelerated. Any future curation decisions must be informed by these changes and robust future climate projections.

For our current planning, we compared Walter diagrams of various locations around the world (Figure 8) with future climate analogs for Seattle (e.g. Cedar Grove, CA, fig. 7b). We found good matches with current climates in multiple countries across the globe including central Chile (fig. 8a), parts of southwest Greece (fig. 8b) and the Balkans, higher elevation areas of Portugal (fig. 8c), parts of the Caucasus region bordering the southwest Caspian Sea, the extreme southwest of South Africa, and areas west of Perth in southwestern Australia (fig. 8d). These areas and other localities offer opportunities to identify additional species that may be highly suitable and resilient in our future climate.

The Arboretum should focus on obtaining seed from climate-suitable, non-invasive species in these regions and trialing multiple collections sourced from different microclimates within the species local range for inclusions in the collections. This approach will allow the Arboretum to tailor our collections for future climate conditions in the Pacific Northwest, ensuring the long-term sustainability of the Arboretum's plants and trees while thoughtfully expanding its current collections.

The trialing of these species will require space in the Arboretum, but trials also offer a wonderful opportunity for communicating with the public about the challenges and reality of climate change. Incorporating trial gardens and displays into the Arboretum will visibly demonstrate this important facet of research of botanical gardens and clearly communicate how we are responding to climate challenges.

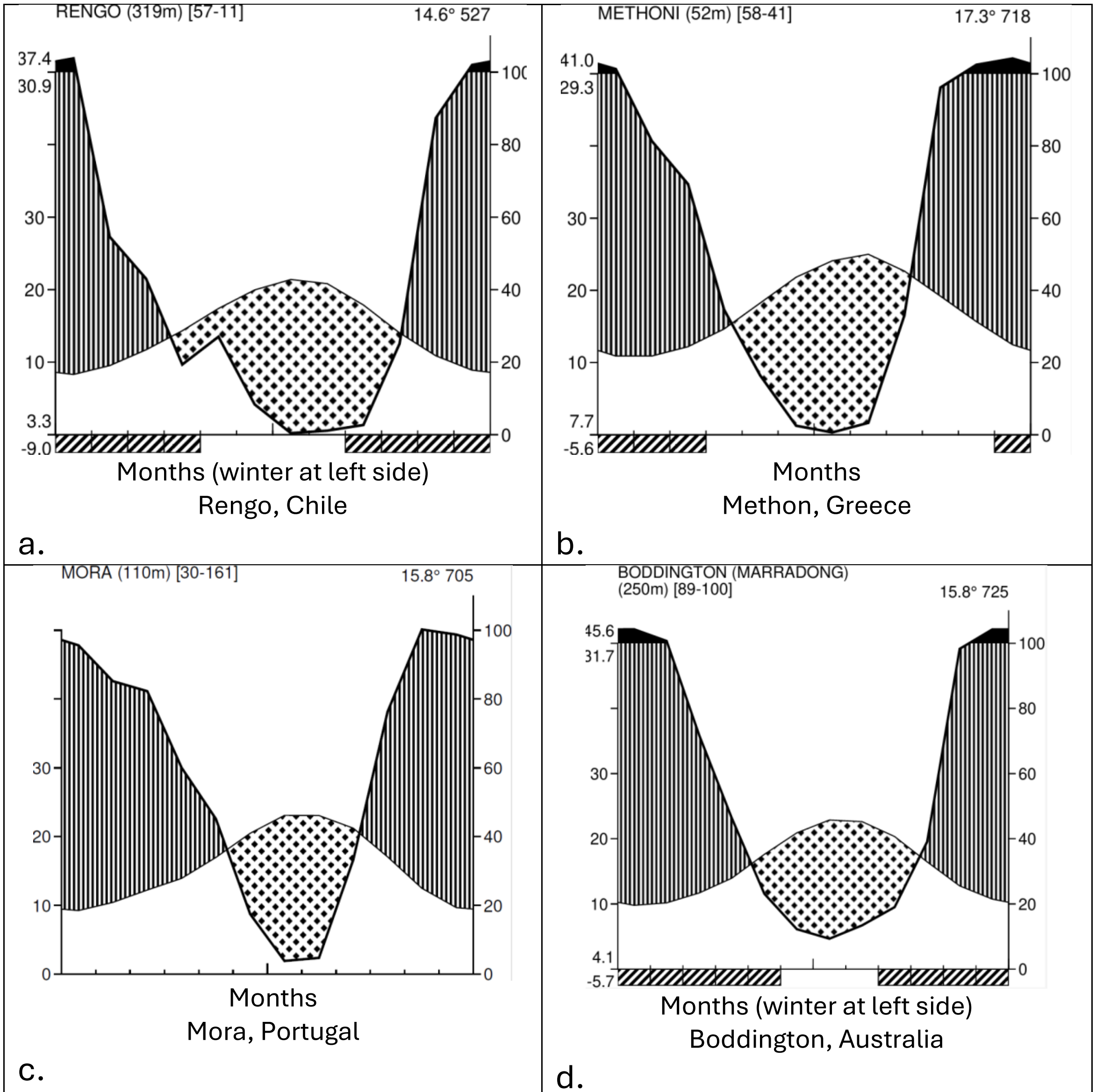



**Figure 8.** Walter diagrams showing the average climate at Rengo, Chile (a.), Methon, Greece (b.), Mora, Portugal (c.), and Boddington, Australia (d.). The months are at the bottom of the chart, with southern hemisphere cities adjusted to show winter monts at the edges.

## Management of Existing Collections

Our analysis indicates that water availability during the growing season is one of the main challenges facing the existing collections. However, a variety of actions can be taken to help mitigate impacts, including targeted irrigation for the most vulnerable taxa, and appropriate planting location selection in relationship to soil type, water table depth, and proximity to surface water. We will first look at how we can mitigate dry season water stress for existing collections and then will discuss factors that should be considered for future collections development and adaptation of the local plant palette.

For existing collections, it is critical to safeguard and sustain what we can, with a special focus on collections of high conservation and horticultural value. The most critical means of sustaining current collections is making sure that our landscape and systems can efficiently protect against water and heat stresses.

**Irrigation**

While regular irrigation has always been necessary for the establishment of any planting (native or exotic), mitigating longer-term needs due to increased heat and dryness cannot be ignored. Today, the pace of specimen loss has greatly accelerated due to increasing climate stresses, compounded by insect and pathogen pressures on water and heat-stressed plants. As this study helps demonstrate, water availability will be an increasingly important factor for collection sustainability.

In the immediate term, soil moisture should be regularly checked in garden beds with soil probes and other measuring devices. Individual horticultural staff can do this as part of their regular routine and should do so at least once a month during the growing season with a manual soil probe. This will ensure that soil moisture is better understood so adjustments can be made to make sure moisture reaches far enough in the soil for healthy root growth. To the extent possible, it is even more critical that species with similar water needs be planted in proximity to each other within themed or genera-based garden

## Irrigation in the Arboretum

In the early days of the Arboretum, water availability was less of a limiting factor. Milder summers and more predictable rainfall could allow more plants to be placed in broader conditions with minimal irrigation support, typically during extreme dry periods and during initial plant establishment. Manual watering, while time-consuming and requiring staff time, was possible for most areas. This allowed for a great diversity of plantings and the Arboretum collections grew to one of the most diverse temperate collections in North America.

Beginning in the early 1970s, decreased staffing left much of the Arboretum unirrigated, with only limited water provided in times of extreme dry periods. Over time collections in many areas suffered and were lost. Recognizing this limitation, some irrigation systems were installed in older collection areas, such as parts of Rhododendron Glen, Azalea Way, and the Camellia Family collection. Many of these towers were over 10' tall and while they could cover wide areas with high-volume spray, they didn't effectively reach the ground level through larger plantings, and were hard to maintain.

Fortunately, irrigation systems are vastly more efficient and adjustable today than even 10 or 20 years ago. Sophisticated computer-controlled systems and adjustable irrigation heads can be increasingly fine-tuned and better tailored to specific conditions. While drip irrigation can be an option in some areas, in places that are regularly cultivated and weeded, drip systems remain susceptible to routine damage from hand tools and require constant patching.

areas.  For those that require some regular summer water, high efficiency irrigation should be installed in these areas.

Some of the Arboretum's newer gardens, such as Pacific Connections and recently expanded areas in Rhododendron Glen,, do have efficient and easily measured systems, but most of the Arboretum's irrigation infrastructure is decades old and inefficient in terms of coverage and water use.  These should be audited and upgraded to maximize efficiency.

While much of the Arboretum has in-ground mainlines that can allow for expansion of irrigation systems, most of these areas only have widely spaced, in-ground valves (quick couplers) that must be manually operated and connected to hoses to reach plants.  As expanding these systems is costly and can be overly disruptive to root systems of older and densely planted tree collection, this must be planned for maximum benefit and value.  For existing plants from summer rain climates, adding high-efficiency systems will be necessary to keep these species healthy or alive.  While some existing areas of the Arboretum, such as the Magnolia collection and older parts of Rhododendron Glen and the Camellia section, will require additional or improved irrigation systems, other areas should have irrigation installed in ways that are most resource efficient.  For example, the Woodland Garden and Holly collection may need supplemental water in some areas more than others and new plantings should be grouped accordingly.

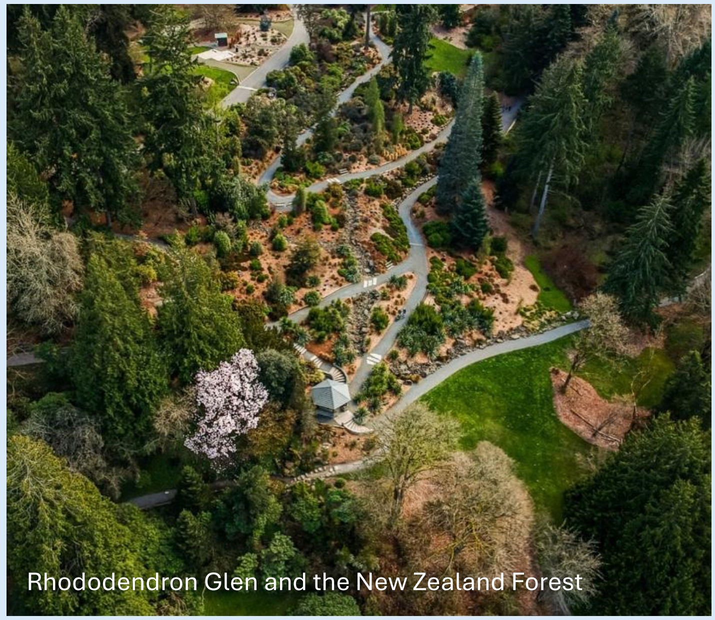
Through upgrades and better monitoring it is now possible to expand irrigated areas while also reducing total water use in the Arboretum from current levels.  But investments in infrastructure and monitoring, as well as staff to manage these systems is necessary to achieve these gains.  Upgrading is not inexpensive, but the water savings are substantial and the value of protecting species in the Arboretum is immeasurable.

**Soil improvement**

Soil management and improvement is a long-term process and should be carefully considered. It is especially critical for larger garden areas and new garden development.  As discussed earlier, many underlying and native soils in the Arboretum have less than adequate conditions for a wide array of tree and shrub species to perform well.  Some areas can be improved over time with mulching, composting and aeration.  For many years, lawn areas in the Pinetum were aerated and top dressed with a thin layer of amendments on an annual basis to try to improve soil health and drainage.  This practice stopped in the last twenty years due to reduced staffing levels and shifting priorities for lawn and turf care.  But it should be considered for poor soil areas such as the Pinetum to help keep the soil aerated and better suited for long-term woody plant growth.  Healthy, stress-free trees are resilient and are better able to tolerate stressful periods.

For new garden areas, special care needs to be taken to make sure soils are improved or amended during construction to allow for optimal growth. In smaller areas the use of berms to add drainage or improved soils can be helpful. This has been achieved with great success in areas with compaction and little topographical change. Adaptive planting can only go so far to mitigate initial problems caused by poor soil. Optimal conditions for sustained plant growth of selected collection types must be provided for any new gardens if they are to succeed. Too often this is an afterthought in construction and capital projects.

### Cautionary Tale: New Zealand Forest


Rhododendron Glen and the New Zealand Forest

In the early 2010s, the poorly drained soils of the New Zealand Forest were insufficiently mitigated to allow for successful long-term growth of many of the species that were planted at the site. Imported well drained soil was specified in the construction documents, but was non uniformly applied during construction. Many areas were not sufficiently amended and heavy clay was just under the mulch layer. These types of soils dry out excessively in summer and are waterlogged in the winter, and this resulted in the death of many of the species specified in the plans and planted.

The Arboretum has had an active system of mulching new planting areas for the last several decades using arborist wood chips for weed suppression, soil improvement and to aid in mitigating water loss during the drier season. This has been beneficial to many existing and newly planted individual trees. Upper layers of soil can improve over many years as the chips break down. While arborist chips are an effective mulch for the majority of species, mulching should be tailored as much as possible to species preferences, including leaf litter and pine straw. While beneficial in most areas, it is just one tool for improving soil health.

**Propagation of Existing Collections**

Given the stressors that face the collections, preservation of existing germplasm from Arboretum taxa is of critical importance. It will be necessary to move some of the plants to more suitable locations in some cases, and it is important to have more than one example of a taxon to ensure long term survival. Propagation of existing collections and especially those of high conservation or collection value is important for long term preservation.

Having a well-resourced propagation program will enable the Arboretum to have a reserve of plants to replant in the gardens if existing specimens fail due to climate stress as well as extreme weather events. Having a supply of plants of different ages is important in managing a resilient collection.

An additional benefit of a strong propagation program is having plants and germplasm to share with other gardens and botanical institutions. This is true for gardens regionally and further afield in different climate zones. Climate stresses will differ by varying factors and degrees in different locations. Vancouver, Canada is expected to shift to a climate more similar to Seattle's current climate, and ours will become more like Portland and that of areas further south. Species that are successful in those areas currently may not be in the future. Sharing collections between gardens is critical for genetic preservation and resiliency, and the Washington Park Arboretum must play a role in that.

The Arboretum has been without a permanent plant propagator since 2010 when university funding was cut during the Great Recession. This past year, the Arboretum Foundation began funding a half-time position, an important first step to ensuring long-term collection sustainability. Fortunately, we have adequate greenhouse and nursery facilities available at the Center for Urban Horticulture site, but much work needs to be done to build the program to what it needs to be. We must invest in this critical program to ensure resiliency for our collections as well as the genetic diversity we hold. The scale and diversity of our collections requires a commitment to both sustaining our collection and trialing new species for our changing climate.

**Green Infrastructure**

The Arboretum has many future opportunities to capture rain from buildings and garden displays for storage and use for summer irrigation. This is another effective means in which the Arboretum can decrease overall water use and costs associated with the city's potable (tap) water system while increasing irrigated areas.

Cisterns are one tool that can reduce reliance on city water while increasing water availability during the growing season. Precipitation during the rainy season can be stored in both underground and above ground tanks and cisterns for use during arid months. Cisterns can be expensive, especially large in-ground systems, and the size needed to store water has to be weighed with benefits and overall cost of construction, but there are a lot of opportunities for efficient applications. While existing facilities can be retrofitted to some extent, substantial investment will still be required to achieve the needed scale to both store and distribute water to needed areas. Buildings with large roof areas such as equipment sheds, greenhouses and other buildings provide many opportunities for projects large and small. While the amount of rain that falls during the rainy season exceeds what cisterns can realistically store for drier months, including cisterns and water catchment infrastructure in future projects may help offset dry season watering needs.

New facility and garden construction offers an opportunity to take a more comprehensive and holistic approach. Capturing water from roofs and hardscapes such as patios, walkways and parking lots is an increasingly common approach. In winter months, this captured water can be stored in cisterns and also used in the landscape for water features and water gardens. Beside providing teaching and demonstration opportunities for using water seasonally in the landscape, this stored water can be used as needed for surrounding landscapes in dryer months, significantly decreasing water use from city systems.

There are also some future stormwater projects that could be considered for gray water uses. In addition to potential use in buildings for flushing toilets and non-potable applications, it is possible to use above ground and landscape areas to clean runoff for use

## Project Potential: Woodland Meadow

Saturated soil and root failure, April

Large landscape projects in open areas, such as those considered for the Arboretum's Woodland Meadow, offer the chance to address existing drainage challenges, showcase water efficient solutions to wet areas, and store water for use in surrounding landscapes during drier months. Some of these areas pose hazards for large tree growth due to poorly draining soil. The meadow is typically muddy and wet for most of the year, with a high water table during the rainy months, only drying out typically in late May or early June. This space is mostly turfgrass with a few large trees surrounding the open lawn.

In spring of 2025 a healthy-appearing oak over 100 feet tall fell over on a calm morning, crushing the picnic tables nearby. During the day and especially during summer, this area is often well-used for classes, summer camps and passive recreation. Fortunately, no one was hurt. The large hole under the root ball was entirely filled with water. The soil had become too saturated to support a tree of this size, even during a atypically dry spring, as its roots could not growth well or deeply in the wet soils. Several other oaks of similar size and age, (planted in the 1950s and 60s) that may be concealing similar issues. This area offers an opportunity to address drainage in this large, open and flat area while also utilizing appropriate water storage to supply irrigation for drier months. Plantings can be added to increase diversity, structure and canopy, and connections can be made to the Woodland Garden ponds and stream to the west. Care should be taken not to divert groundwater needed to support streams and ponds, but there are many opportunities to work in conjunction with the landscape to support year-round water needs in the Arboretum's drying climate.

in irrigation. A large opportunity for this exists for North Entry projects after the Washington State Department of Transportation (WSDOT) vacates their large construction staging area at the north end of the Arboretum. Currently large pipes run from streets in the adjacent neighborhood underground through the Arboretum into combined sewer pipes to the lake. Some of these may be used for stormwater treatment in Arboretum for use during dryer months after cleaning in settlement ponds and related landscape treatments.

## Next Steps

This Climate Adaptation Plan is not only useful for the Washington Park Arboretum, but also offers lessons for other gardens and landscapes in Seattle and beyond. The tools used to assess climate challenges can be applied widely. The Climate Assessment Tool, local climate data and projections and climate diagrams are all useful in helping to set the baseline for appropriate action. Going forward, this plan will inform all aspects of the future development of the gardens and spaces within the Arboretum and the Botanic Gardens. This plan will also inform future updates to the Collections Policy and Living Collections Plan, with a focus on the coming decades and associated climate challenges.

Addressing the challenges plants and gardens face also requires engagement with horticultural audiences and the public at large. The next step for the Arboretum team is to prepare an executive summary and share findings with other regional gardens, stakeholders and the community. Regional garden networks such as Puget Sound Gardens, local agencies and community organizations can help share findings and information. We will also prepare additional materials for the website, in-garden interpretation, visitors and larger outreach efforts. We also hope to present these results at the American Public Gardens Association meeting in 2026.

Climate challenges are the biggest threat to plants and gardens today. But there are many ways we can respond and adapt to ensure a sustainable, green future where current collections and future gardens can benefit everyone.

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