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Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Preparing for the Future:

Climate Change and Western Redcedars at the David C. Lam Asian Garden, University of British Columbia Botanical Garden

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Preparing for the Future: Climate Change and Western Redcedars at the David C. Lam Asian Garden, University of British Columbia Botanical Garden

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Thuja plicata Donn ex D. Don
(Western redcedar)

Land Acknowledgement

The University of British Columbia Botanical Garden (UBCBG) is geographically located at the western tip of the Point Grey Peninsula, 100 metres above the Georgia Strait in Vancouver, British Columbia, Canada. The UBCBG lies on the traditional, ancestral, and unceded territory of the **xʷməθkʷəyəm** (Musqueam) people.

Western redcedar has significant cultural value as British Columbia's official provincial tree, with great spiritual significance to many Coastal First Nations people due to its utility for cultural belongings such as vessels, clothing, buildings, totem poles, and dugout canoes.

The Origin of the Red Cedar (Coast Salish)

"There was a real good man who has always helping others. Whenever they needed, he gave; when they wanted, he gave the food and clothing. When the great Spirit saw this, he said. 'That man has done his work; when he dies and where he is buried, a cedar tree will grow and be useful to the people – the roots for baskets, the bark for clothing, the wood for shelter.'"

Told by Bertha Peters to Wally Henry and reproduced in **Cedar Tree of Life to the Northwest Coast Indians** by Hiliary Stewart (2013).

Cover image of *Thuja plicata* branches adapted from photograph © Beryl Zhuang

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Executive Summary

For the University of British Columbia Botanical Garden (UBCBG), species such as western redcedar (*Thuja plicata* Donn ex D. Don) are predicted to be maladapted to their current environment by 2071 under a medium emissions scenario and by 2041 under a high emissions scenario. This report addresses several physiological and ecological traits of western redcedar and identifies several themes of management challenges that the University of British Columbia Botanical Garden will need to address. Changes in soil moisture, shifts in temperature and precipitation, and vulnerability to diseases and pests can influence the decline of western redcedar. Actions to enhance the future conservation of western redcedar include the development of an adaptive management program, assisted seed migration (seed provenance strategies), and a monitoring program that engages citizen scientists. Furthermore, future planting lists of species that are more suitable to the predicted future climates are explored to help facilitate the transition of the UBCBG to one that is better matched to the climates modelled for 2071 to 2100. Botanic gardens conserve plant diversity through in-situ and ex-situ conservation and are responsible for maintaining living plant collections for science and education. While plant collections change over time, climate change impacts to existing plant species require strategic approaches and adaptation planning to ensure a botanical garden's ongoing role in plant conservation.

The following key findings in this report describes both management challenges and opportunities for western redcedar:

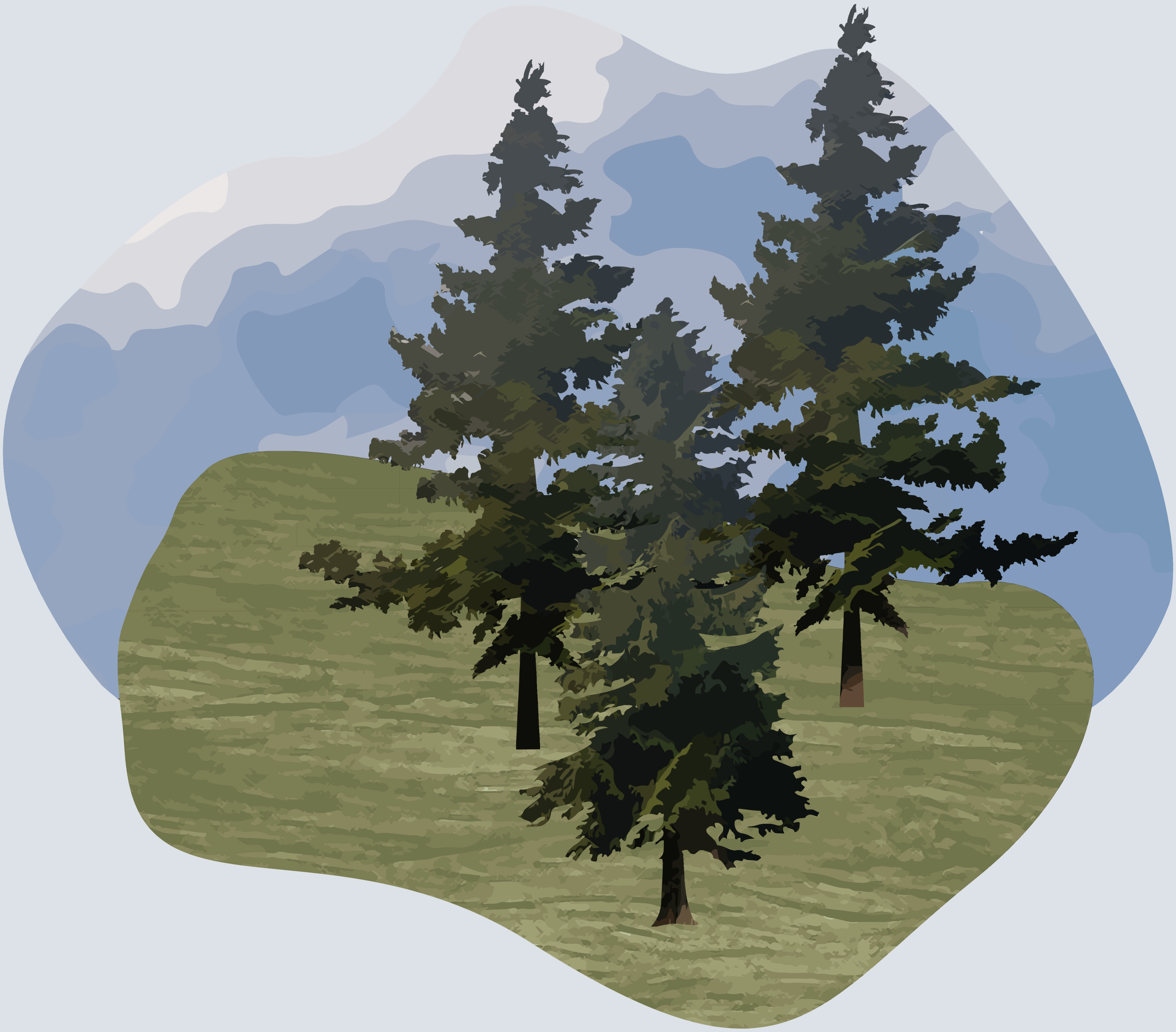
1. The Asian Garden in the UBCBG is expected to transition from a highly suitable location for western redcedars to one that has very low to no climate suitability to facilitate the growth of the species. Based on the results of the climate modelling projections and western redcedar distribution models, this species is not expected to survive in 2071 under both RCP 4.5 and 8.5 scenarios. The potential extirpation of this iconic species highlights the need to develop an adaptive management strategy to mitigate the loss of species involving seed migration and planting of species that are likely to succeed in future climates, monitor changes through longitudinal data management, and to design programs to engage the public in conservation.

2. Based on SSP2-4.5 and SSP5-8.5 scenarios, the key stressors that are considered important for western redcedar include abiotic and biotic factors. Abiotic factors include drier sites and moisture deficits due to warming temperatures and less precipitation during the summer growing season. Biotic factors include indirect damaging agents such as insect outbreaks linked to warming temperatures favouring the reproduction and proliferation of pests.

3. Western redcedar has an inability to occupy very dry sites and has better growth on moist sites in humid environments. It is expected that specific irrigation and water retention methods may be necessary as a climate adaptive measure to ensure that western redcedar will not be susceptible to water-deficit conditions.

4. An opportunity arises to plant western redcedar seeds from southern climates via assisted seed migration. Freeze and thaw damage to new seedlings from southern provenances may be minimized in the future as the frost-free period extends, the number of frost-free days increases, and minimum mean temperatures in the winter increase.

I. Background Information



1.0 Introduction

1.1 Climate Change and Trees

The world is experiencing an increasing loss of plant species due to climate change despite ongoing conservation efforts (Cibrian-Jaramillo et al., 2013). Since climate warming is accelerating at a rate that is much faster than previous climate shifts (McLachlan et al., 2005), the changes in climate can impact the preferred growing conditions in habitats and shift the environmental limits that trees can withstand (Burley et al., 2019). It is likely that warming regions will see poleward and upwards shifts in species range (Parmesan, 2006). Long-lived, slow-growing plants such as trees are limited by their dispersal abilities and will be unable to keep up with climate change unaided (Talluto et al., 2017). Unfortunately, post-glacial tree migration rates of 50 kilometres per century are slower than the estimated rate of climate change (Lemprière et al., 2008). Over one hundred North American tree species are expected to see an average northward shift of 700 kilometres in suitable climate by 2100 (McKenney et al., 2007). A species' genetic response to climatic variability, and phenotypic plasticity is essential to their capacity to adapt to changing climates (Jump and Peñuelas, 2005). To persist in changing climates, trees will have to cope with extreme climate conditions, especially during periods of frequent and severe heat waves and summer droughts (Roloff et al., 2009). Direct human intervention would be needed to conserve species that are vulnerable to climate change (Bocsi et al., 2016). Climate-related stressors involving reduced summer precipitation, increased frequency of heat waves, and pest and disease outbreaks can cause physiological stress to trees (Hirons et al., 2021; Teskey et al., 2015).

1.2 Climate Change and Botanical Gardens

Botanical gardens hold a plethora of living plant collections for research, conservation, education, and aesthetics (Entwisle and Symes, 2017). While botanical gardens are engaged in managing plants and their habitats, the predicted impacts of climate change will require a more strategic approach to safeguard plant species and their landscapes (Entwisle, 2019). Climate change adds urgency to the need to protect and ensure the health of tree collections in botanical gardens (Cavender and Donnelly, 2019). Research at botanical gardens offer advancements in the understanding of climate change impacts on plant phenology, physiology, ecology, and conservation (Primack et al., 2021). With a botanical garden's expertise on growing species beyond their current natural range, researchers and partners with botanical gardens have an ideal environment for testing assisted migration for species outside of their current range (Primack and Miller-Rushing, 2009). Botanical gardens have the capacity to host and address climate change research that could aid the broader community with climate change adaptation planning while engaging the public in the process (Primack and Miller-Rushing, 2009). To address climate change, botanical gardens are looking towards on-the-ground action surrounding conservation and education and bridging climate and biodiversity in policy and decision-making (Lopez-Villalobos et al., 2022).

1.3 Western redcedars in British Columbia

In British Columbia (B.C.), western redcedar (*Thuja plicata*) is a cultural keystone species for the Coastal Indigenous peoples (Garibaldi and Turner, 2004) and an economically important commercial tree species (Fan et al., 2008). Western redcedar has an extensive and continuous coastal-cascade range in North America that extends along northern California, Oregon, Washington, British Columbia to southeastern Alaska (Klinka and Brisco, 2009) between 56° 30' and 40° 30' N latitude, and a Rocky Mountains range from Idaho, Montana, Alberta, and B.C. between 54° 30' and 45° 50' N latitude (Chambers, 2020). Within B.C. specifically, western redcedar is a mesic species with a native coastal and interior range (Roberts and Hamann, 2015). The western redcedar range is expected to continue to shift northward (O'Connell et al., 2008), to higher elevations and into central and southern-interior B.C. (MacKenzie and Mahony, 2021). Gray and Hamann (2013) found that by 2050, the suitable habitat for western redcedar populations in B.C.'s Coastal Western Hemlock zone is anticipated to shift northward.

The University of British Columbia Botanical Garden (UBCBG) has expressed concerns about western redcedar dieback in the Pacific Northwest. One of the concerns is that climate change is occurring at a rate that is faster than the rate that western redcedar can adapt to warmer or hotter climates. There is a collection of 395 western redcedars at the UBCBG that may be at risk in the future due to climate change (UBCBG, 2021c). While the western redcedars at the UBCBG is within a managed site, the UBCBG currently does not have any climate change adaptation strategies to ensure live plant collections are resilient in future climates. The purpose of examining the potential vulnerabilities of the western redcedar trees under different climate change scenarios is to guide climate change adaptation strategies for the UBCBG.

1.4 Research Questions

Specifically, the research questions that this report will address are:

1) What are the projected stressors and management challenges for western redcedar that the UBCBG will have to address under future climate scenarios projected for 2071 to 2100 based on the Intergovernmental Panel on Climate Change (IPCC) adopted greenhouse gas concentration trajectories known as Representative Concentration Pathways (RCP) 4.5 and 8.5 and the Shared Socioeconomic Pathway (SSP) scenarios SSP2-4.5 and SSP5-8.5?

2) What can the UBCBG do to prepare for the RCP 4.5, SSP2-4.5, RCP 8.5 and SSP5-8.5 climate scenarios modelled for 2071 to 2100?

2.0 About the UBCBG: David C. Lam Asian Garden

2.1 Site Location and Uses

This study takes place within the David C. Lam Asian Garden (known as the Asian Garden within this report), located within the UBCBG (Figure 1). The Asian Garden is approximately 14 hectares and is the largest garden at the UBCBG (UBCBG, 2021d). The UBCBG sees over 100,000 visitors annually (Luker et al., 2021). Activities at the UBCBG include educational workshops, tours, research, conservation, public displays, and community outreach (Luker et al., 2021). A network of trails (either paved or covered with wood chips) circumnavigates and winds through the planted areas of the Asian Garden (UBCBG, 2021d). An important educational and tourism feature within the Asian Garden is the 310-metrelong aerial canopy walkway (Greenheart TreeWalk) that hangs from large and mature grand fir (*Abies grandis*), douglas fir (*Pseudotsuga menziesii*), and western redcedar (*Thuja plicata*) (UBCBG, 2021a).

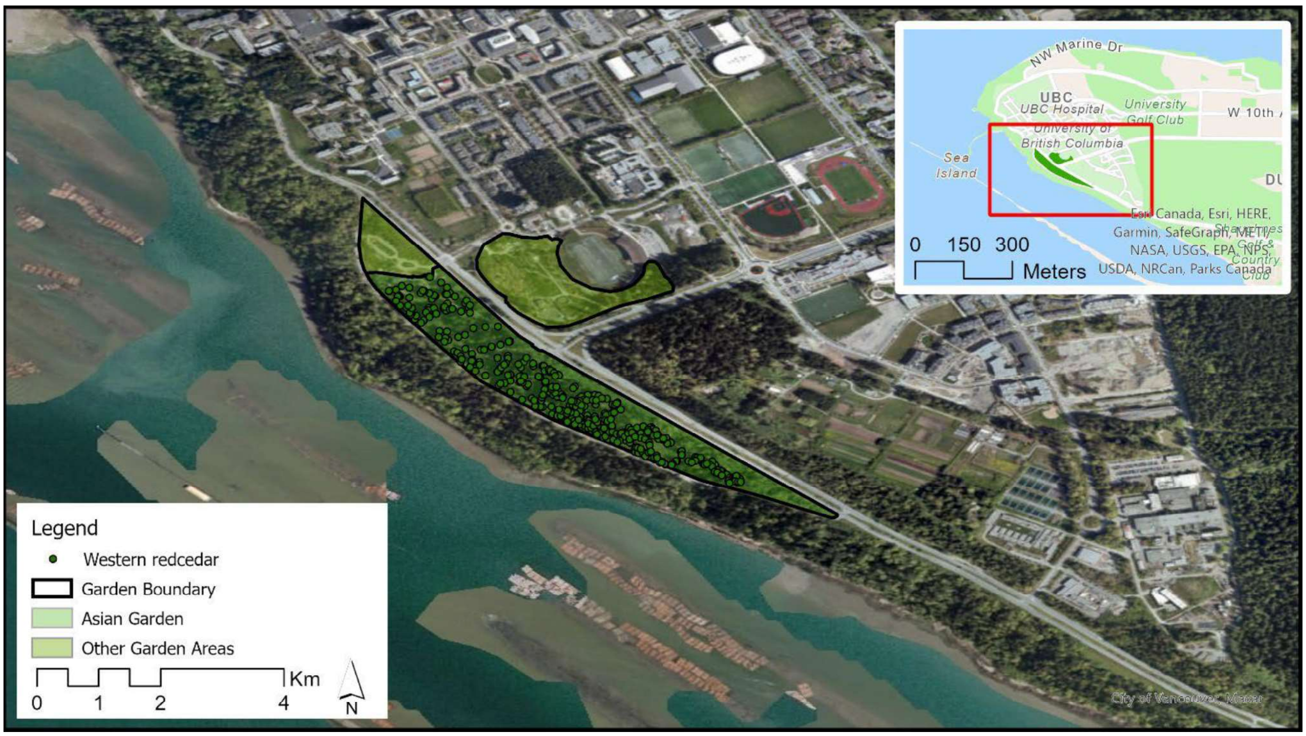


Figure 1. Map of the University of British Columbia Botanical Garden (UBCBG), showing the aerial view of the university campus, including green polygons representing the boundary of the UBCBG and green dots representing the georeferenced individual western redcedars. The inset map represents the University Endowment Lands, an unincorporated area that lies to the west of the city of Vancouver in British Columbia. The map was created by Virginia Hang on December 10, 2021, using ArcGIS Pro and data from UBCBG (2021c). Spatial Reference: GCS WGS 1984.

2.2 Site History

In 1916, the UBC campus was clear-felled and the trees in the Asian Garden were either planted around the mid-1970s or arose naturally after the logging (Iain, 2010; UBCBG, 2021d). The Asian Garden is a coastal native second-growth forest under-planted with trees, shrubs, woody vines, and evergreen and herbaceous perennials of known Asian origin (UBCBG, 2021d). The second-growth forest includes western redcedar (*Thuja plicata*), grand fir (*Abies grandis*), western hemlock (*Tsuga heterophylla*), douglas fir (*Pseudotsuga menziesii*), red alder (*Alnus rubra*), and bigleaf maple (*Acer macrophyllum*). There are also relevant plant collections of considerable conservation value within the Asian Garden such as rhododendrons (*Rhododendron*), maples (*Acer*), mountain ashes and whitebeams (*Sorbus*) and magnolias (*Magnolia*) (UBCBG, 2021d).

2.3 Climate Conditions

The UBCBG is within the Coastal Western Hemlock (CWH) zone that represents a cool mesothermal climate (Centre for Forest Conservation Genetics, 2021). More specifically, the UBCBG is associated with a "xm1" subzone that represents a very dry maritime climate with annual precipitation amounting to 1,427mm (Table 1) (Centre for Forest Conservation Genetics, 2021). While the CWHxm1 subzone has cool summers and mild winters, winter temperatures normally reach below freezing at the UBCBG, with a historic low of -18°C (Iain, 2010). Summer temperatures normally reach around 27°C (Iain, 2010). In June of 2021, temperatures reached a record high of 36.6°C, amounting to an extreme temperature event that is not historically experienced in the region (Nipen and Howard, 2021).

Table 1. Climate Data for the CWHxm1 Subzone. Data was obtained from the Centre for Forest Conservation Genetics, 2021. MAT – mean annual temperature, MWMT – mean warmest month temperature, MCMT – mean coldest month temperature, MAP – mean annual precipitation (mm), MSP – mean summer precipitation (mm), AHM – annual heat moisture index, SHM – summer heat moisture index. Data retrieved from the Centre for Forest Conservation Genetics, 2021.

MAT (°C)	MWMT (°C)	MCMT (°C)	MAP (mm)	MSP (mm)	AHM	SHM
9.3	17.0	2.4	1,427	285	14	62

2.4 Conditions of Western Redcedar at the UBCBG

Western redcedars are important icons in Vancouver's coastal temperate rainforest and it is important to preserve the species rich cultural value. Approximately 395 western redcedar individuals form part of the backdrop of the second-growth forest at the Asian Garden (Figure 1) (UBCBG, 2021c). Currently, two cultivars of western redcedars exist at the UBCBG, 'Excelsa', and 'Filifera'. There are 20 'Excelsa' cultivars and one 'Filifera' cultivar (UBCBG, 2021c). In the Asian garden, the oldest western redcedar individuals are estimated to be 140 years old (D. Justice, personal communication, November 25, 2021). In 2021, curators at the Botanical Garden noted the following: 1) nearly all western redcedar trees showed varying levels of cladoptosis (branch shedding or self-pruning); 2) cladoptosis was more prominent in 2021 due to summer heat waves despite areas of the Asian Garden receiving irrigation; 3) there were no visible signs of disease or pests on any western redcedar individuals; 4) decline in western redcedar is limited to individuals that are under stress from root damage, and/or significant changes in soil hydrology from trenching or road construction (D. Justice, personal communication, November 25, 2021). Currently, cladoptosis is not a major concern as it is a natural phenomenon evident in the Cupressaceae (cypress family) (Millington and Chaney, 1973). The seasonal loss of innermost or old foliage from shading, known as "flagging," is normal and not an indicator of decline (Zobrist, 2011).

2.5 Current Management Practices

The Asian Garden has a less intensive maintenance regime as a regenerative approach has been in place for the last decade (Despard, 2021). Occasional human interventions are non-intensive, allowing the Asian Garden to evolve at its own pace (Despard, 2021). Soil disturbances are kept to a minimum and applications of compost and fertilizers are avoided (Iain, 2010). The UBCBG has fast draining, shallow, sandy soil that quickly depletes moisture during warm summer temperatures (Justice, 2021). Late June to mid-September usually experiences a lack of precipitation leading to challenges in water storage capacity in the thin soils (Iain, 2010). To address summer droughts, a new irrigation system installed in 2021 with efficient sprinkler heads and remote electronic timers are now in place at the Asian Garden (Justice, 2021). Although there are currently no formal tree health monitoring protocols in place, the UBCBG does comply with an Integrated Pest Management approach (UBCBG, 2022).

3.0 Policy Alignment Directions

The UBCBG plays an integral role in stopping the loss of global plant diversity. Although western redcedars are not recognized to be a threatened species globally, the species is considered to have immense cultural value. The existence of international and national policy frameworks that support the protection of global biodiversity helps provide justification and support for the conservation of western redcedars at the UBCBG. A selection of policies or recommendations from five frameworks is outlined: 1) United Nations' Sustainable Development Goals; 2) Global Strategy for Plant Conservation (2011-2020); 3) North American Botanic Garden Strategy (2016); 4) Biodiversity Action Plan for Botanic Gardens in Canada (2010); and 5) BC First Nations Climate Strategy and Action Plan (2022). These policies link to the importance of building partnerships, offering educational programs, and preserving culturally important plants such as western redcedar. For further information about ways to build education, deliver awareness around western redcedar conservation, and promote community engagement through citizen science, see section 9.6.

3.1 United Nations' Sustainable Development Goals

The United Nations' Sustainable Development Goals (SDGs) address high level global objectives to protect biodiversity and ensure a sustainable future for all on a worldwide scale (Cowell et al., 2022). The SDGs are a call-to-action framework that consists of 17 goals, 169 targets and 232 indicators intended to be achieved by 2030 (Lopez-Villalobos et al., 2022). The following section reviews the SDGs that are most relevant to climate change and plant conservation at the UBCBG. Future collaboration and actions that could be endeavored to further align with certain SDGs are also explored in section 9.6.

SDG 4 - Quality Education
Target 4.7 is associated with UBCBG's delivery of educational garden experiences that link plant conservation with cultural diversity. Contributions to target 4.7 also include the integration of Indigenous languages and knowledge through interpretive signage.

SDG 13 – Climate Action
In relation to climate change and western redcedars, SDG 13 – Climate Action is a relevant connection. Target 13.2 involves integrating climate change measures into national policies, strategies, and planning. The UBCBG has identified launching a 5-year climate adaptation planning process to increase capacity of the garden and other botanical gardens to adapt to climate change (Lopez-Villalobos et al., 2022). Target 13.3 includes the improvement of education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

SDG 15 – Life on Land
Target 15.a requires mobilizing and significantly increasing financial resources to conserve and sustainably use biodiversity and ecosystems. The UBCBG strives to maintain an establishment that works towards plant conservation, education, research, and engagement. Quality engagement that directly involves citizen scientists can contribute to achieving these SDG targets.

SDG 17 – Partnership for the Goals
A survey conducted by the UBCBG amongst its staff identified a future action related to SDG 17 (Lopez-Villalobos et al., 2022). The identified action would entail leveraging collaborations with government and other partners to initiate on the ground action towards plant conservation and climate action in policy and plans. The proposed action is associated with SDG targets 17.16 and 17.17. Target 17.16 consists of enhancing the Global Partnership for Sustainable Development through multi-stakeholder partnerships that pool in resources related to knowledge, expertise, technology, and funds to support the SDGs. Target 17.17 is related to effective public, public-private, and civil society partnerships. Botanical gardens often have partnerships with local, regional, national, and international agencies to address plant conservation and climate change (Cowell et al., 2022). A potential UBCBG metric that was identified in Lopez-Villalobos et al. (2022) is the number of botanical gardens and/or garden networks that the UBCBG collaborates with.

3.2 The Global Strategy for Plant Conservation (2011-2020)

The Global Strategy for Plant Conservation (GSPC) 2011-2020 report has 5 overarching objectives and 16 outcome-oriented targets (principles and objectives) aimed at aligning actions by global botanical and plant protection communities by 2020 (Sharrock, 2012). The Global Partnership for Plant Conservation (GPPC) developed a new draft set of GSPC targets for 2021-2030 (CBD, 2021).

The most relevant GSPC objective associated with the study of western redcedars and climate change at the UBCBG is Objective IV, whereby education and awareness about plant diversity, and its role in sustainable livelihoods and importance to all life on earth is promoted. The associated target for objective IV is target 14, which is: The importance of plant diversity and the need for its conservation incorporated into communication, education, and public awareness programmes.

3.3 North American Botanic Garden Strategy (2016)

The GSPC targets have promoted sector-specific responses such as the development of the North American Botanic Garden Strategy for Plant Conservation, which is adding to the collective effort to achieve the targets in the GSPC 2011-2020. The 2016 North American Botanic Garden Strategy presents a set of targets and sub-targets for each of the identified objectives related to the GSPC objectives. An example of an overarching objective in the North American Botanic Garden Strategy is “conserving plant diversity,” and an associated target is “botanic gardens will expand ex situ conservation efforts and partnerships” (BGCI, 2016a).

The following outlines objectives and targets that would be relevant to conserving western redcedars at the UBCBG. Activities surrounding the conservation of western redcedars would contribute to 4 objectives, 6 targets, and 6 subtargets (Table 2) (BGCI, 2016a).

Table 2. Objectives and targets in the North American Botanic Garden Strategy (2016) that align with the conservation of western redcedars. Targets and objectives are retrieved from BGCI, 2016a.

Target	Description
Objective B. Conserving plant diversity	
Target B4	**Botanic gardens will contribute to the conservation and preservation of economically and culturally important plants, including crop wild relatives.**
Subtarget 1	Botanic gardens will increase efforts to identify priorities, set targets and take action for preserving economically and culturally important plants in North America and other regions where they work.
Target B6	**Botanic gardens and their networks will increase support and contributions to conservation biology research.**
Subtarget 3	The number of botanic gardens participating in formal research collaborations with other gardens, universities, government agencies, and non-governmental organizations will increase.
Objective C. Using plant diversity sustainably	
Target C2	**Botanic gardens will contribute to the awareness and protection of ethnobotanical knowledge, and cultural and Indigenous uses of plants.**
Subtarget 1	Targets for protection of cultural and Indigenous Knowledge will be set, current levels of local, national, regional, and international activity determined, and appropriate partners identified.
Objective D. Promoting public awareness of the importance of plant diversity and the wise use of resources	
Target D1	**Botanic gardens will educate their visitors, community members, partners, staff, volunteers, and other stakeholders about the importance of plant diversity such that its irreplaceable value to human and ecosystem well-being is recognized.**
Subtarget 1	Botanic gardens will incorporate conservation and ethnobotanical messages in interpretation, outreach, and formal and informal educational programs directed to all ages and audiences.
Objective E. Building capacity for conservation of plant diversity	
Target E2	**Botanic gardens will work with appropriate stakeholders to develop tools and methodologies to support policy formation and implementation and obtain resources to affect plant conservation activities.**
Subtarget 2	Botanic gardens will contribute to, inform, and provide expertise for public policy at the local, regional, national, and international levels to increase understanding, funding, and other resources available for plant conservation.
Target E4	**Botanic gardens and their networks will better share and promote existing information and resources on how to achieve plant conservation objectives.**
Subtarget 1	All botanic gardens will work to join, support, and participate in conservation networks to effectively share information and expertise.

3.4 Biodiversity Action Plan for Botanic Gardens in Canada (2010)

In a 2010 update to the Biodiversity Action Plan for Botanic Gardens in Canada, a list of recommendations was provided to help the Canadian botanical gardens community lead conservation and education projects.

The following presents recommendations from the Action Plan update that would be relevant to conserving western redcedars at the UBCBG (Galbraith and McIvor, 2006):

Recommendations for Enriching Biodiversity Education

- Number 2.1: Continue to emphasize the importance of plant conservation in formal and formal education programs at botanical gardens by seeking new resources, promoting networking, and supporting meetings of educators.
- Number 2.3: Gardens should continue to promote conservation messages in their interpretation and expand efforts to actively engage Canadians in conservation.

Recommendations for Cultivating Partnerships, Resources and Capacity

- Individual gardens should form new alliances to promote the importance of plant conservation, and better share and promote existing information and resources.

3.5 BC First Nations Climate Strategy and Action Plan (2022)

The BC First Nations Climate Strategy and Action Plan involves a central vision, five guiding principles, and four priority pathways for climate action (First Nations Leadership Council, 2022). Two notable pathways are aligned to the conservation of western redcedars: 1) Land and Water Protection; and 2) Climate Response and Preparedness.

The following table recognizes a selection of themes and associated objectives and strategies under each priority pathway that would help with furthering initiatives surrounding western redcedar conservation and management at the UBCBG (Table 3).

Table 3. Themes and associated objectives and strategies under the Land and Water Protection and Climate Response and Preparedness pathways in the BC First Nations Climate Strategy and Action Plan. Objectives and strategies are retrieved from the First Nations Leadership Council, 2022. See section 10, number 5 for research gaps regarding achieving partnerships to further the identified strategies.

Pathway: Land and Water Protection	
Theme 3.1 Restoration and Conservation	
Objective 3.1.2	**Strengthen long-term conservation efforts and accountability measures to preserve and protect the lands, waters, habitats, and non-human beings while adapting to climate impacts.**
Strategy E	Support the development and implementation of First Nation-led conservation plans and nature-based solutions projects that enhance conservation, restoration, and climate mitigation goals.
Strategy F	Develop and deliver materials, resources, and projects to amplify First Nation voices and to increase public education and awareness on the essential and unique role that First Nations play in restoring and conserving biodiversity.

Theme 3.3 Forest Protection and Sustainable Management	
Objective 3.3.2	**Protect Old-Growth forests and their contributory role in water retention, species protection and survival, human health, and combating climate change.**
Strategy F	Ensure all future climate-related legislation, policies, and programs provide for the protection of intact and old growth forests aligned with local First Nation protocols for forestry management.
Strategy G	Support First Nations in conducting their own forestry mapping and research as well as accessing relevant data.
Theme 3.5 Resource Management	
Objective 3.5.1	**Support First Nations in developing and maintaining laws, policies, and guidelines for land, water, air, and resource management to use within and between their territories.**
Strategy A	Respect and recognize First Nations inherent jurisdiction to access, use, and manage their traditional lands, waters, and resources.
Strategy B	Support the development and compliance of First Nation-led land use plans, management plans, and resource laws.
Strategy F	Increase engagement and collaboration with First Nations in state and/or corporate-led resource management systems and decision-making
Theme 3.6 Collective Stewardship	
Objective 3.6.1	**Strengthen collaboration, partnership, and information sharing within and between First Nations communities, organizations, and others to collectively care for the Earth and build climate leadership and resiliency.**
Strategy B	Support agreements, laws, initiatives, and networks that promote and enhance local and regional collaboration and support between First Nations on climate response and the protection of lands, waters, and resources for future generations.
Strategy C	Support research and raise awareness about the limitations and opportunities that nature-based solutions offer to First Nations and society as a whole in addressing climate change.
Strategy E	Explore stewardship partnerships and project initiatives following the First Nations Principles of Ownership, Control, Access, and Possession and self-determined processes and priorities of partnered communities.
Pathway: Climate Response and Preparedness	
Theme 4.6 Climate Plans, Monitoring, and Risk Assessments	
Objective 4.6.2	**Recognize First Nations authority to conduct climate- related assessments and monitoring work in their own self-determined ways to generate their own data and inform their self-determined climate response and planning**
Strategy A	Support First Nations in developing Nation-specific climate strategies and action plans based on their own needs, priorities, and self-determined processes. This may include strategies and plans relating to adaptation and mitigation, emergency response, clean energy, net-zero emissions, and/or others.

Strategy D	Support the development and implementation of First Nation-led monitoring and data collection frameworks to establish robust baseline data on climate, environmental, social, cultural, and economic factors to inform climate response
Strategy E	Support First Nations in developing appropriate and effective strategies to mitigate or avoid climate-related impacts to cultural rights and heritage sites. This may include mapping of cultural heritage sites and identifying and designating places of significance

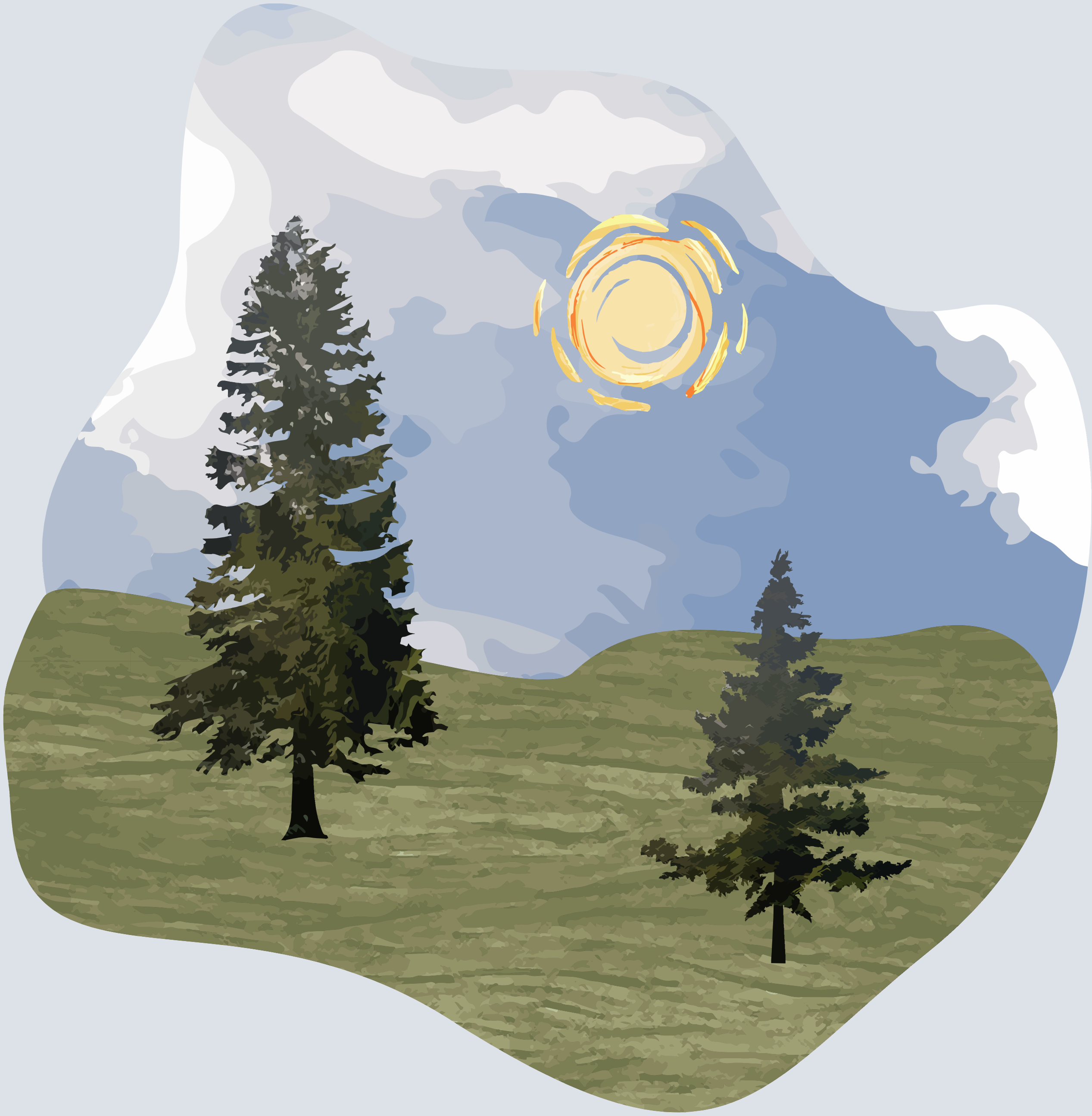
II. Research Methods

4.0 Research Methods

The preliminary research within this report is to determine the stressors and management challenges for western redcedar that the UBCBG will have to address under future climate scenarios projected for 2071 to 2100 based on RCP 4.5, RCP 8.5, SSP2-4.5 and SSP5-8.5. The academic literature was examined to determine if there could be any connections made between species vulnerability and climate change. To answer the first research question, the following was conducted: 1) literature review on the tolerance of western redcedars to abiotic and biotic stressors; 2) comparison between the current distribution and the projected distribution of western redcedars in B.C. using maximum entropy (MaxEnt) species distribution modeling, and the CanESM2 climate model from the Natural Resources Canada Plant Hardiness website; and 3) comparison of the changes in six climate parameters using the ClimateBC computer program. Regarding step 2, the MaxEnt model was chosen to determine species distribution because the model is accessible, widely used, and performs well with presence-only data (Elith et al., 2006). The three steps allow for an informed statement on the vulnerability of western redcedar and the expected management challenges arising from projected impacts related to climate change.

The second part of the research report entails recommending strategies that the UBCBG can adopt to prepare for the RCP 4.5 or SSP2-4.5, and RCP 8.5 or SSP5-8.5 climate scenarios modelled for 2071 to 2100. Strategies include practicing adaptive management, assisted seed migration, consideration of future planting lists with climate adapted species, multi-age inventory monitoring, and phenology monitoring. To achieve success of the proposed monitoring initiatives, community engagement and partnerships with organizations already involved with monitoring trees are emphasized.

III. Results



5.0 Projected Stressors and Management Challenges

There have been many reports of western redcedar declining or dying from cumulative drought stress in the Pacific Northwest region over the past decade (Woods et al., 2010, Wilson, 2018; Rippey, 2018; Portland Parks and Recreation, 2019; Brend, 2019; Vikander, 2019; Buhl, 2021). However, there has been no consistent evidence of biotic agents (insects or diseases) causing western redcedar decline (WSU Extension, 2018). The Forest Health Watch Program (2021) has conducted preliminary analyses from iNaturalist observations uploaded by members of the community since October 2020, which revealed dieback symptoms such as dead branches, brown canopy, and thinning foliage.

In the future, abiotic and biotic factors may contribute to the decline of western redcedar. There are several factors that can influence a location's suitability for western redcedar. Factors such as edaphic suitability, increases in temperature, decreases in precipitation, freeze and thaw fluctuations, and diseases and pests can impact the occurrence of western redcedar at a given location. The projected stressors (non-exhaustive) for western redcedar that the UBCBG will have to address under future climate scenarios projected for 2071 to 2100 under RCP 4.5 and 8.5 can include: 1) changes in edaphic factors; 2) changes in temperature and precipitation; and 3) biotic agents influenced by the changes in climate. Although alterations in temperature and precipitation patterns will directly affect tree distributions (Allen et al., 2010), an increase of natural disturbance agents such as insects and diseases will become more positively affected by climate change (Woods et al., 2010). Insects, pathogenic fungi, and disease outbreaks will ultimately drive climate change-related vegetation shifts. Thus, it is important to address both abiotic and biotic factors.

The sections below investigate the tolerance levels of western redcedar against each of the projected stressors to determine whether the species requirements are within narrow parameters or whether the species will tolerate a range of conditions.

5.1. Edaphic Factors

Soil moisture and nutrient regimes are responsible for large variations in environmental suitability within regions of suitable climate (MacKenzie and Mahony, 2021). Western redcedar has broad edaphic amplitude (Klinka and Brisco, 2009), and is widely distributed under contrasting environmental conditions and habitat types (Fan et al., 2008; Grossnickle and Russell, 2010). While western redcedar is tolerant to a variety of soil types, moisture, and pH, it prefers moisture-receiving sites (Krakowski, 2009). The soil moisture regime for western redcedar is between mesic and hydric (Klinkenberg, 2020). The UBCBG is within the very dry maritime Coastal Western Hemlock zone (CWHxm1) (Chourmouzis et al., 2009). Further changes to underground moisture patterns may negatively impact the health of mature established trees that are currently adapted to the existing conditions (Klinka and Brisco, 2009).

Challenge: Soil Moisture

- The feasibility of western redcedars is expected to be lower on dry sites than on wetter sites (MacKenzie and Mahony, 2021).
- Seedlings are most likely to establish on sites with abundant moisture, disturbed mineral soil, and little or no canopy hindrance (Weber et al., 2003).

Tolerance to Water Deficiency

- Western redcedar tolerates water deficient sites, but populations are susceptible to water deficit conditions in dry and warm mesothermal coastal climates (Klinka and Brisco, 2009).
- Grossnickle and Russell (2010) saw evidence of drought tolerance in populations that experienced short-term induced drought along a precipitation gradient from various biogeoclimatic zones in B.C (Pacific coast to southern interior). Drier interior populations were more drought tolerant than coastal populations from a temperate maritime climate (Grossnickle and Russell, 2010).
- Harmer and Alexander (1986) hypothesized that Ca-rich litter that undergoes nitrification allows western redcedar to have a competitive advantage in N-poor soils. Keenan et al. (1996) found indications that western redcedar is efficient at growing on N-poor soils and contributes to the development of N-poor soils. Prescott and Vesterdal (2005) also indicate that western redcedar does not prefer N-rich conditions and does not facilitate such conditions.
- Optimum soil conditions include slightly acidic to neutral, Ca, Mg, and nitrate N-rich soils (Klinka and Brisco, 2009).
- Although slow-growing on nutrient-poor sites, western redcedar can adapt to poor soil conditions over the long term (Kranabetter, 2003).
- Western redcedar tolerates water surplus and flooded soils (Antos, 2016). Greater flood tolerance may allow western redcedar to access nutrients that are located deeper within saturated soils (Negrave et al., 2007).

5.2. Climate Factors

Overall, it is plausible to expect more precipitation in the already wet seasons, and less precipitation in already dry summers. The change in climate is expected to bring more rainfall in some years, while other years will experience droughts. The warmer annual temperatures, and longer dry spells over the summer months, could increase strains on the existing water supply during the summertime when temperatures are high, and water is in greatest demand (PCIC, 2016). A decrease in precipitation can translate to water management challenges at the UBCBG site. There will need to be efficient methods to store water during days of heavy rainfall and intense storms. The following climate challenges are presented for Metro Vancouver based on an RCP 8.5 high emissions scenario between 2071 and 2100. For projected site-specific changes of climate parameters at the Asian Garden, see section 7.0.

Challenge: Precipitation Change

- Under RCP 8.5, Metro Vancouver is expected to experience wetter falls and winters and drier summers in the 2050s (referring to 2041 to 2070) and the 2080s ((2071 to 2100). In the fall, precipitation is expected to increase 11% by the 2050s and 20% by the 2080s (PCIC, 2016).
- Under RCP 8.5, summer precipitation will experience a decline of 19% by the 2050s, and a decline of 29% by the 2080s (PCIC, 2016).

- The past (1971 to 2000) average longest period of consecutive days without or less than 1 mm of rain in the Metro Vancouver region is 21 days. Dry spells on average are expected to increase to 26 days by the 2050s, and 29 days by the 2080s under RCP 8.5 (PCIC, 2016).

Challenge: Temperature Increase

- Future summers in Metro Vancouver may have 55 days above 25°C by the 2050s, and 79 days by the 2080s under RCP 8.5, compared to an average of 22 days for 1971 to 2000 (PCIC, 2016).
- By the 2050s, maximum daytime temperatures will be warmer (an increase of 3.7°C) in the summer. By the 2080s, summer daytime highs are expected to increase by 6°C (PCIC, 2016).

See section 7.1 for maximum mean temperature changes local to the UBCBG.

Tolerance to Temperature

- In coastal populations, western redcedar is most common in cool and cold mesothermal climates (Klinka and Brisco, 2009). The species is adapted to climates with abundant precipitation and high humidity (Fan et al., 2008; Klinka and Brisco, 2009).
- Mesothermal species in the coast like western redcedar are projected to increase in range at projected temperature increases of 1 to 4°C and decline at temperature increases above 4°C under RCP 8.5 (MacKenzie and Mahony, 2021).
- Western redcedar foliage does not have cutin or wax layers to protect against excessive transpiration (Minore, 1983), and therefore will struggle to maintain moisture during extreme temperatures.

Challenge: Frost

- Frost days is an annual count of days when the daily minimum temperature is less than 0°C. Frost days is an indicator for predicting how pests and invasive species may thrive. In the past, Metro Vancouver had 79 frost days a year. Areas within the City of Vancouver experienced only 39 frost days and projections indicate conditions where the climate will be entirely frost-free (PCIC, 2016).

See section 7.6 for changes in the frost-free period for the Asian Garden based on SSP2-4.5 and SSP5-8.5.

Tolerance to Frost (specific to seeds and seedlings)

- If considering assisted seed migration, freeze and thaw fluctuations could inflict cold damage in the future to tree seedlings when seeds are moved from warmer climates to cooler climates (Gu et al., 2008).
- Trees will need a sustained acclimatization or hardening period to low temperatures before building adequate tolerance to frost and freeze events (Thomashow, 1999).

Tolerance to Frost

- Coastal populations are not frost-resistant and are easily damaged by frosts (Klinka and Brisco, 2009). However, a master thesis study found that western redcedars did not indicate geographic patterns of local adaptation for cold hardiness (van der Merwe, 2020).

5.3. Biotic Factors

With higher temperatures and fewer frost days, invasive species and diseases are more likely to affect the health of western redcedars.

Challenge: Cedar Leaf Blight

- Cedar Leaf Blight (*Didymascella thujina*) is a serious fungal disease of western redcedar (Gray et al., 2013).
- Cedar leaf blight is most prevalent in dense stands with high humidity levels (Allen et al., 2016).

Tolerance to Cedar Leaf Blight

- Natural resistance to cedar leaf blight varies between different populations: coastal, low-elevation populations have greater resistance than populations in higher elevations in interior British Columbia (Russell et al., 2007). However, populations with higher resistance to cedar leaf blight are found in milder and wetter conditions (Gray et al., 2013).
- *Thuja plicata* 'Excelsa' and *T. plicata* var. *atrovirens* are the most susceptible western redcedars to cedar leaf blight (Ministry of Agriculture, 2015; Sinclair, 1987). The UBCGB has 20 'Excelsa' cultivars (UBCBG, 2021c).
- *Thuja standishii* × *plicata* is a hybrid from Denmark that is resistant to cedar leaf blight (Tesky, 1992).

Challenge: Western Cedar Borer

- Western cedar borer (*Trachykele blondeli*) is an insect that causes damage by tunneling in the heartwood of young and mature stressed trees (Natural Resources Canada, 2015).

Challenge: Cedar Bark Beetles

- Cedar bark beetles (*Phloeosinus* spp.) are known to attack trees that are stressed from drought, soil compaction, animal browsing, and mechanical damage (Klinka and Brisco, 2009; Forest Service USDA, 2011).

Tolerance to Insects

- Western redcedars are not severely affected by many insects including borers and bark beetles (Minore, 1990). However, a warming climate will increase the diversity of insects and ultimately increase the rates of feeding and predation on tree hosts (Dale et al., 2001).

- Pest outbreaks will occur in the driest areas with frequent droughts as stressed trees are more susceptible to natural disturbance agents (Woods et al., 2010).

For more information on potential pests and diseases (including fungal) on western redcedars, see Allen et al., 2016, Burleigh et al., 2014, and Sturrock et al., 2017. Although pests and diseases may be indirect or secondary damaging agents to western redcedars, they can lead to the destruction of entire trees.

6.0 Species Distribution Model Results from NRCAN

By 2050, the suitable habitat for western redcedar populations in the Coastal Western Hemlock zone is projected to shift 568km northward (given a constant elevation) and 250m up in elevation (given a constant latitude) (Gray and Hamann, 2013). The following section explores the estimated western redcedar distribution from the MaxEnt species distribution model, and CanESM2 climate model outputs obtained from the Natural Resources Canada (NRCAN) Plant Hardiness website. The MaxEnt models provide occurrence probabilities for species that have adequate data on known occurrence or presence locations (Natural Resources Canada, 2021d). The occurrence data used in the species modelling is from a variety of sources, including provincial natural resource agencies, national forest inventories, the Nature Conservancy in the United States, and contributions from private researchers and naturalists (J. Pedlar, personal communication, August 11, 2022).

MaxEnt relates species occurrence data with environmental conditions such as annual mean temperature, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, precipitation of warmest month, and precipitation of coldest month) (Natural Resources Canada, 2022). The CanESM2 climate model output shows the probability of occurrence values colour coded on a species distribution map. The values from 0 to 1 provide an indication of whether western redcedar will occur at the Asian Garden. A value closer to 1 indicates locations with highly suitable climate conditions for occurrence (J. Pedlar, personal communication, February 25, 2022). Historically between 1971 and 2000, the probability of occurrence value for western redcedars specifically at the Asian Garden is 0.5 to 0.6 (Natural Resources Canada, 2021c). Western redcedar's climate suitability ranges from 0 to 0.7 within its natural range in North America, so values between 0.6 to 0.7 would be highly suitable climates for the species. Values between 0.3 to 0.5 could be considered moderately suitable, and values less than 0.2 would be considered to have low suitability. The current values of 0.5 to 0.6 is near the top of the suitability ratings for the species, making the current UBCBG site a highly suitable location. However, the probability of occurrence for western redcedars at the UBCBG site shows declines under RCP 4.5 and 8.5 scenarios, which indicates decreased climate suitability (Table 4).

Based on an RCP 4.5 scenario:

- For the years 2011-2070, the probability of occurrence for western redcedars at the UBCBG site is low because the probability value is only 0.1 to 0.2.
- By 2071, the probability of occurrence changes to 0.0, indicating that the UBCBG site is projected to no longer have a suitable climate condition for western redcedars.

Based on an RCP 8.5 scenario:

- For the years 2011-2040, the probability of occurrence for western redcedars at the UBCBG site is low since the probability value is only 0.1 to 0.2.
- After 2041, the UBCBG site is expected to no longer have a suitable climate to allow western redcedars to persist as indicated by the 0.0 occurrence probability value.

A zero probability of occurrence can indicate that the UBCBG site no longer has a suitable habitat for western redcedars. Although the MaxEnt models are showing the extirpation of western redcedars at the UBCBG, western redcedar may still be managed in-situ to mitigate losses.

Table 4. Probability of occurrence of western redcedars at the UBCBG site for historic vs. future years. The values from 0 to 1 in the table correspond to the probability of occurrence or abundance levels. The values between 0.1 to 0.2 refers to the locations with lowest suitable climate conditions for occurrence. The values were retrieved from the species climatic distribution maps based on the future climate scenarios of RCP 4.5 and RCP 8.5 using the CanESM2 climate model (Natural Resources Canada, 2021c). In the RCP 8.5 scenario, greenhouse gases will continue to rise until the end of the century, indicating more severe climate change. Under an RCP 8.5 scenario, western redcedars are expected to be extirpated by 2041, 30 years earlier compared to an RCP 4.5 scenario. Although RCP 4.5 assumes that greenhouse gases will peak around 2040 and then decline to 2080 before stabilizing (Thomson et al., 2011), the UBCBG site is still not expected to have a strong suitable climate environment for western redcedars in the future.

Historic Years	**Probability of Occurrence Values (Climate Suitability Value)**	
1971-2000	0.5-0.6	
Future Years	**RCP 4.5 Climate Scenario**	**RCP 8.5 Climate Scenario**
2011-2040	0.1 – 0.2	0.1 – 0.2
2041-2070	0.1 – 0.2	0.0
2071-2100	0.0	0.0

7.0 Changes in Climate Variables at the UBCBG Site

While the projected western redcedar distribution data from Natural Resources Canada (2021c) is associated with the RCP framework, data from ClimateBC is based on a new systematic scenario approach, the Shared Socioeconomic Pathway (SSP) scenarios. It can be considered that SSP2-4.5 is a counterpart to RCP 4.5 and SSP5-8.5 is counterpart to RCP 8.5 (Tebaldi et al., 2021).

In the ClimateBC v7.3 desktop program, climate data was obtained using the 8-model ensemble mean provided for SSP2-4.5 and SSP5-8.5 (Wang et al., 2016). The justification for using the 8-model general-purpose ensemble is because it excludes climate models that have an equilibrium climate sensitivity (ECS) or greenhouse gas forcing above or below the IPCC-assessed 2-5°C range (Mahony, 2022). The 8-model ensemble is generated from 8 GCMs that are within the IPCC's latest assessed ECS range and is consistent with Mahony et al. (2022) and Hausfather et al. (2022). An 8-model ensemble is more appropriate for ensemble analyses of climate change relative to time whereby years are displayed on the x-axis (Mahony, 2022).

Using data from ClimateBC v7.3, the historical baseline of 1961 to 1990 and 1991 to 2021 is compared to four future 20-year periods based on SSP2-4.5 and SSP5-8.5: 1) 2021 to 2040; 2) 2041 to 2060; 3) 2061 to 2080; and 4) 2081-2100.

The following section investigates the data retrieved from ClimateBC v7.3. The climate variables that were examined include: 1) maximum mean temperatures; 2) Hogg's climate moisture index; 3) Hargreave's climatic moisture deficit; 4) monthly precipitation; 5) winter precipitation as snow; and 6) first and last day of frost-free period.

Snapshot from the Projections

For the Asian Garden between 1961 and 2020, the mean temperature has risen by 0.8°C, and during the same period, the mean annual precipitation has increased 17mm. On average, the climate is projected to become warmer throughout the year, with summers (June to August) becoming drier, and fall and winters (October to March) becoming wetter. Despite the increase in rainfall in the fall and winter months, the precipitation as snow is expected to decrease. Historically, the 1961–1990 mean annual temperature is around 10°C at the Asian Garden. However, by 2081, the mean annual temperature could rise to 13.1°C based on a SSP2-4.5 scenario. The realisation of an SSP5-8.5 scenario could result in a mean annual temperature of up to 15°C projected by 2081.

7.1 Maximum Mean Temperatures

Projections for SSP2-4.5 and SSP5-8.5 show that the temperature is expected to warm across all months in future years compared to the baseline (1961-2020).

Overall temperatures have been warming over the last six decades. The maximum mean temperature in August by 2081-2100 based on SSP2-4.5 is projected to increase to 25.8°C, which is an increase of 3.7°C from the mean August temperature of 22.1°C in 1961-2020 (Figure 2). Although minimum mean temperatures are not graphically shown in the report, it has been identified through ClimateBC that the minimum mean temperatures for all months have been increasing for both SSP2-4.5 and SSP5-8.5. Historically, January typically has a minimum mean temperature of 0.4°C in 1961-1990. However, based on an SSP2-4.5 scenario, January will be expected to have a minimum mean temperature of 3°C, while an SSP5-8.5 scenario is showing a minimum of 4.7°C.

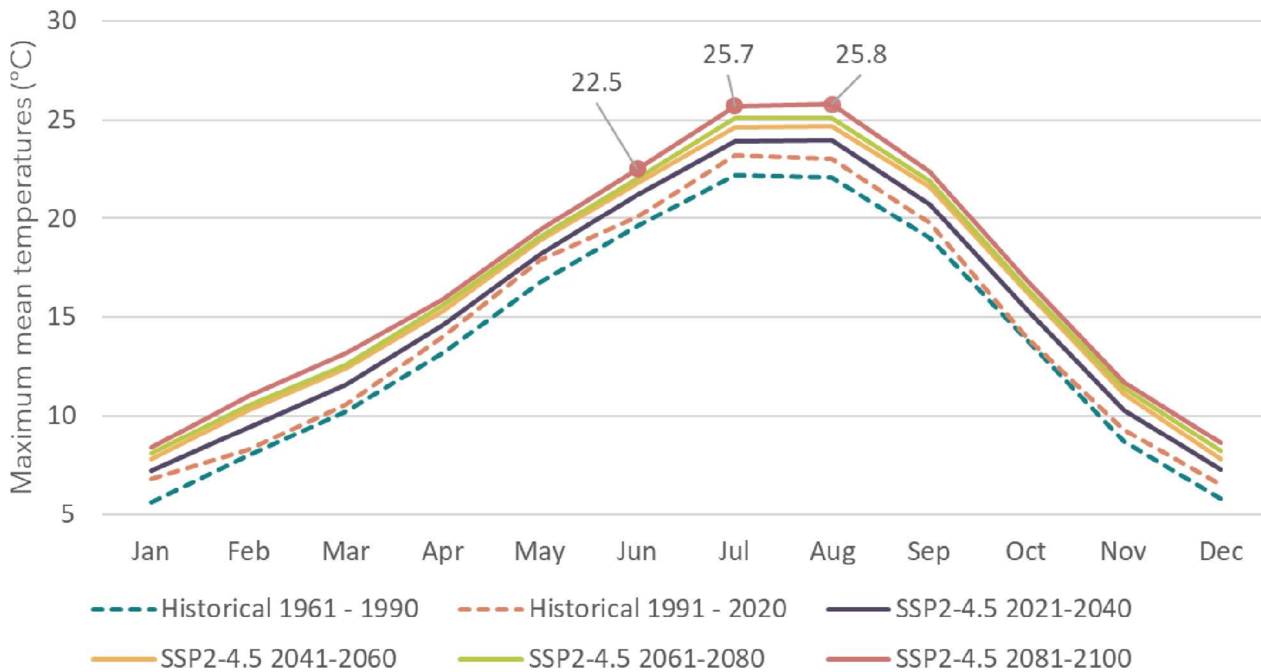


Figure 2. Maximum Mean Temperatures (°C) by month for historical years between 1961-2020 vs. SSP2-4.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

Based on SSP5-8.5, the maximum mean temperature in August in 2081-2100 is expected to increase by 6°C to 28.1°C from 22.1°C in 1961-1990. Maximum mean temperatures are also expected to increase in the winter months (Figure 3).

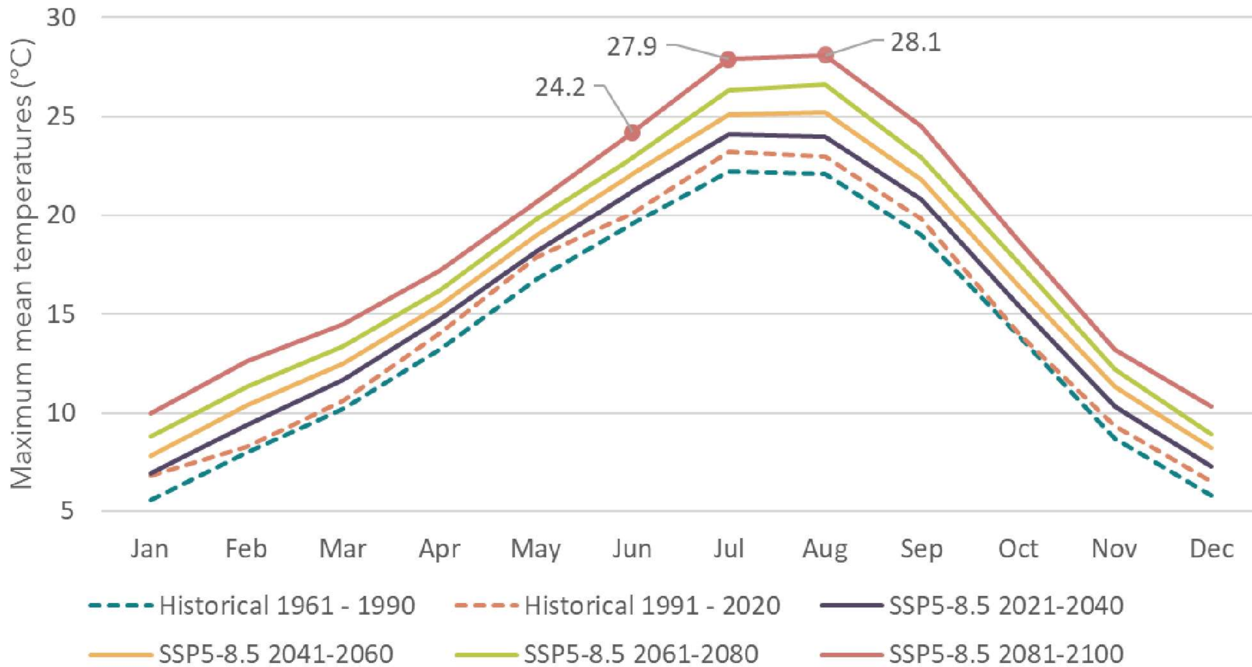


Figure 3. Maximum mean temperatures (°C) by month for historical years between 1961-2020 vs. SSP5-8.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

7.2 Hogg's Climate Moisture Index

The Climate Moisture Index (CMI) is an indicator of drought calculated as the difference between annual precipitation and annual potential evapotranspiration (Wang et al., 2014). In this case, the annual potential evapotranspiration is the estimated loss of water vapour from a landscape with established vegetation when the soil moisture is not limiting (Wang et al., 2014). There is a balanced moisture condition when the CMI is zero as this means that precipitation equals the potential evapotranspiration (Wang et al., 2014). Positive CMI values indicate moist conditions where precipitation is adequate to maintain the existence of a closed-canopy forest, while negative CMI values indicate dry conditions that are suitable for discontinuous parkland-type forests (Wang et al., 2014).

The projections based on SSP2-4.5 and SSP5-8.5 indicate the potential for much drier summer months extending into September. The CMI for the month of July in 1961-1990 was 4.2 while for SSP2-4.5 in 2081-2100, it is projected to be -6.32. The greater negative value indicates that the Asian Garden site at UBCBG may become drier during the summer (Figure 4).

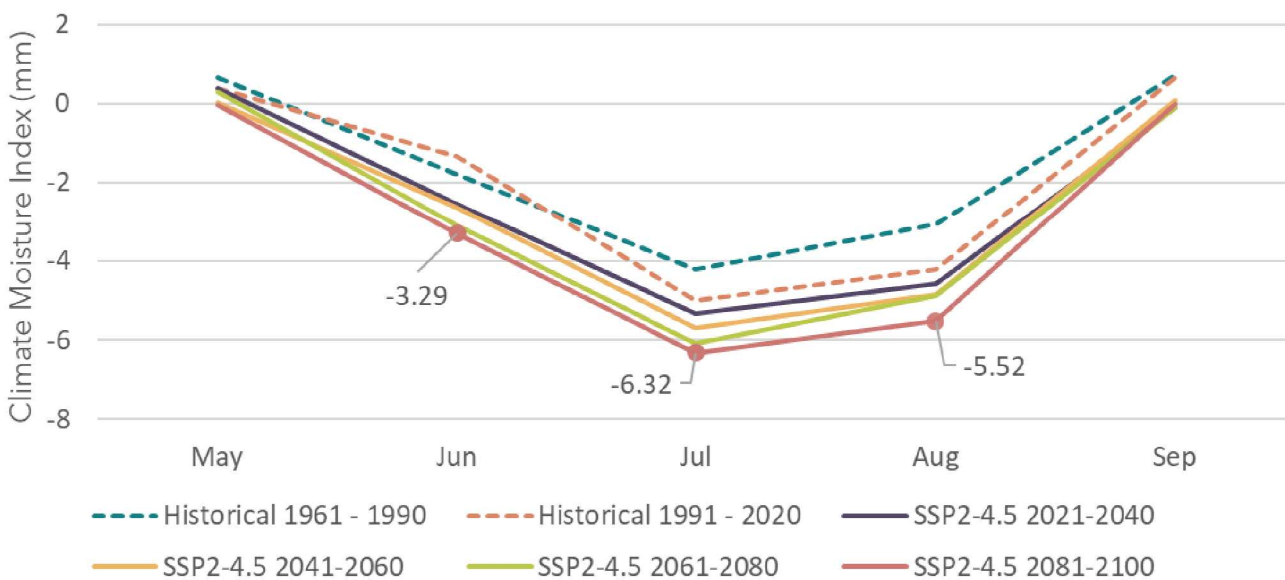


Figure 4. Hogg's Climate Moisture Index (mm) between May to September for historical years between 1961-2020 vs. SSP2-4.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

For SSP5-8.5 in 2081-2100, it is projected to be -7.72. A further decline in the CMI value indicates drier conditions (Figure 5).

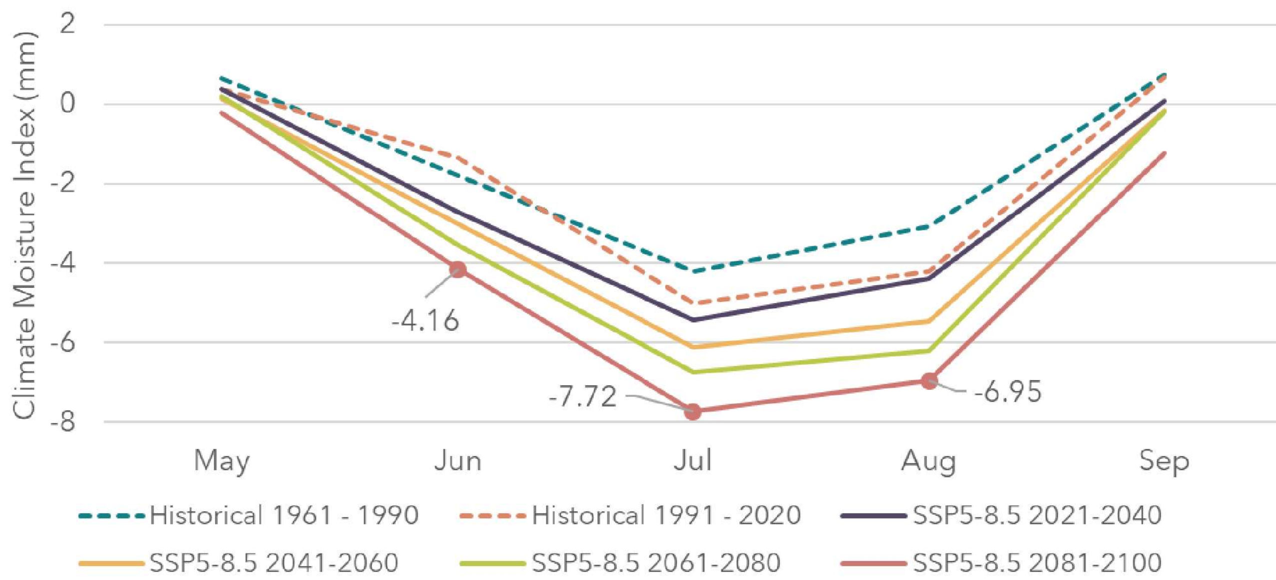


Figure 5 Hogg's Climate Moisture Index (mm) between May to September for historical years between 1961-2020 vs. SSP5-8.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

7.3 Hargreave's Climatic Moisture Deficit (CMD)

Hargreave's climatic moisture deficit (CMD) is a useful index to assess the potential risk of drought on plants because the index represents the sum of the monthly difference between a reference evaporation and precipitation state (Hynes and Hamann, 2020). Deficits occur when the monthly precipitation is less than the monthly evaporative demand. Higher CMD values indicate that there is evaporative demand that is not met by available precipitation (Hynes and Hamann, 2020). Growing season moisture deficits are projected to increase between May to August based on both SSP2-4.5 and SSP5-8.5. The greatest CMD typically occurs in July based on historic data and this is expected to be the case until the end of the century.

The greatest difference between past CMD values and the SSP2-4.5 projections can be seen in August (Figure 6). Between 1961 to 2100, there is an expected 17mm difference for the month of August.

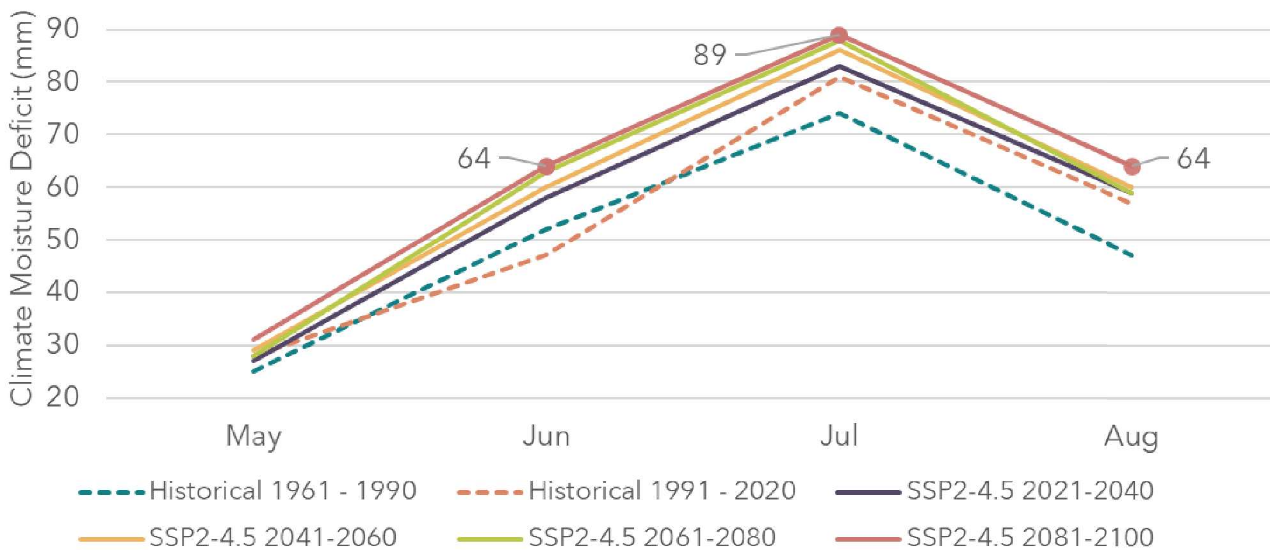


Figure 6. Hargreaves climatic moisture deficit (mm) between May to August for historical years between 1961-2020 vs. SSP2-4.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

Based on SSP5-8.5, a CMD of 72mm is estimated to occur in August between 2081-2100 (Figure 7). Compared to the 1961-1990 period, this represents an increase of 25mm in evaporative demand that is not met by available precipitation in August.

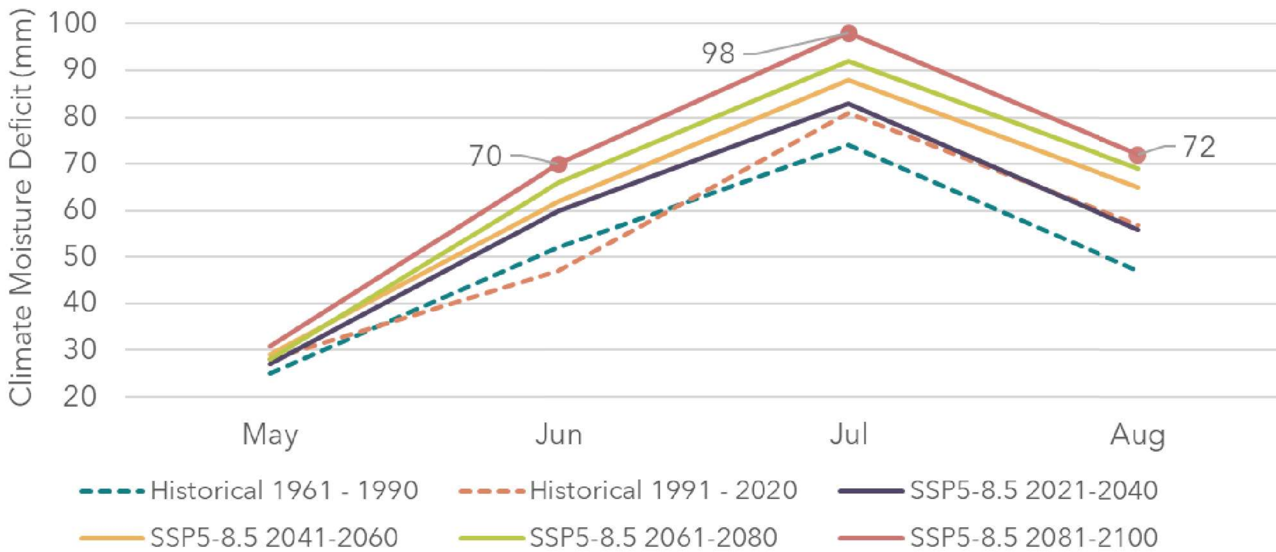


Figure 7. Hargreaves climatic moisture deficit (mm) between May to August for historical years between 1961-2020 vs. SSP5-8.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

7.4 Monthly Precipitation

Despite the expectations of annual rainfall increasing 6% and 9% from 1961 to 2100 based on SSP2-4.5 and SSP5-8.5 respectively, the largest increase in rainfall is predicted to occur during the fall and winter months. Noticeable seasonal changes to precipitation have been trending, as a decline in rainfall can be observed for July and August since 1961. Based on both SSP2-4.5 and SSP5-8.5, there is an expectation of more rainfall in the already wet seasons between October to February, and less rainfall in the already dry growing season between June to August by the 2080s.

Based on a SSP2-4.5 modelled climate, changes in precipitation appear not exceptionally significant as the projected precipitation follows closely to historical precipitation up to the months of September (Figure 8). However, there is a slight noticeable decrease in July and August. By 2081 in August, there is a projected decrease in precipitation of 10mm from 46mm in the 1960s. Like historical trends, precipitation is projected to increase after September. The greatest increase occurs in November reaching 216mm, which is a 28mm increase compared to the 1960s precipitation amount of 188m in the same month. Monthly precipitation amounts begin to drop after November.

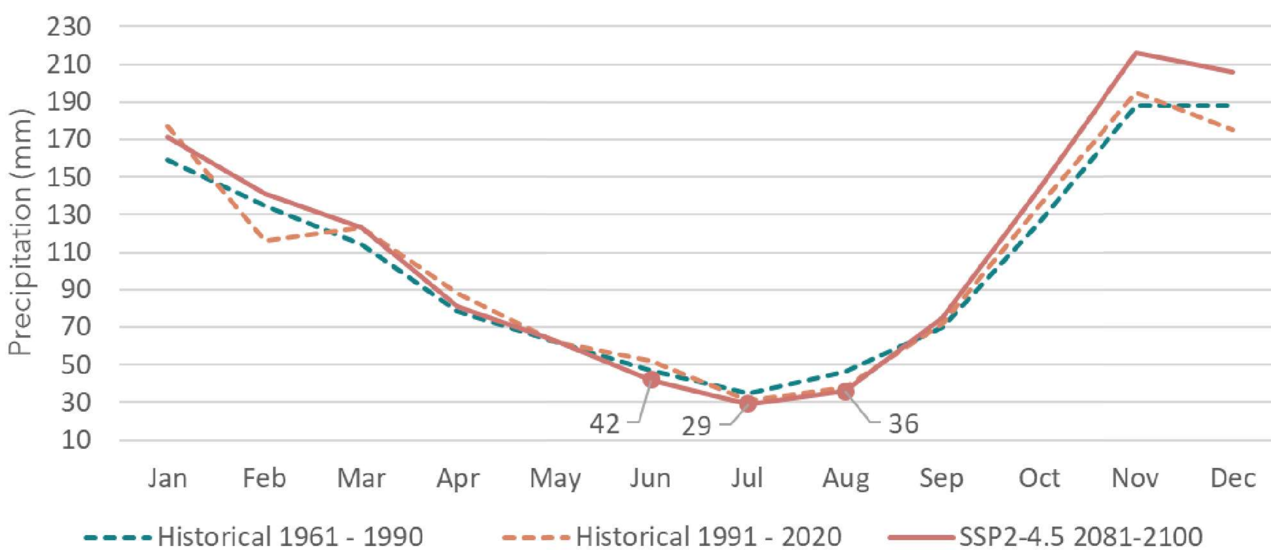


Figure 8. Monthly precipitation (mm) for historical years between 1961-2020 vs. SSP2-4.5 between 2081-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

Summer is already the driest season and will continue to experience less rainfall. When comparing the past 1961-1990 precipitation data to 2081-2100 projected data based on a SSP5-8.5 scenario, there is an expectation that precipitation will see a 17% decline in June, a 37% decline in July, and a 33% decline in August (Figure 9). For the years between 2081-2100, the greatest decrease in monthly precipitation is expected to occur in August, with a decrease of 15mm from 46mm between 1961-1990 to 31mm between 2081-2100. Historically, the most rainfall occurs over the late fall and winter months, and this trend will continue to occur in the future. The largest percentage increase in rainfall will occur in November, increasing 22% by 2081 from 1961. November sees a projected 42mm increase in precipitation from 188mm in 1961-2020 to 230 in 2081-2100.

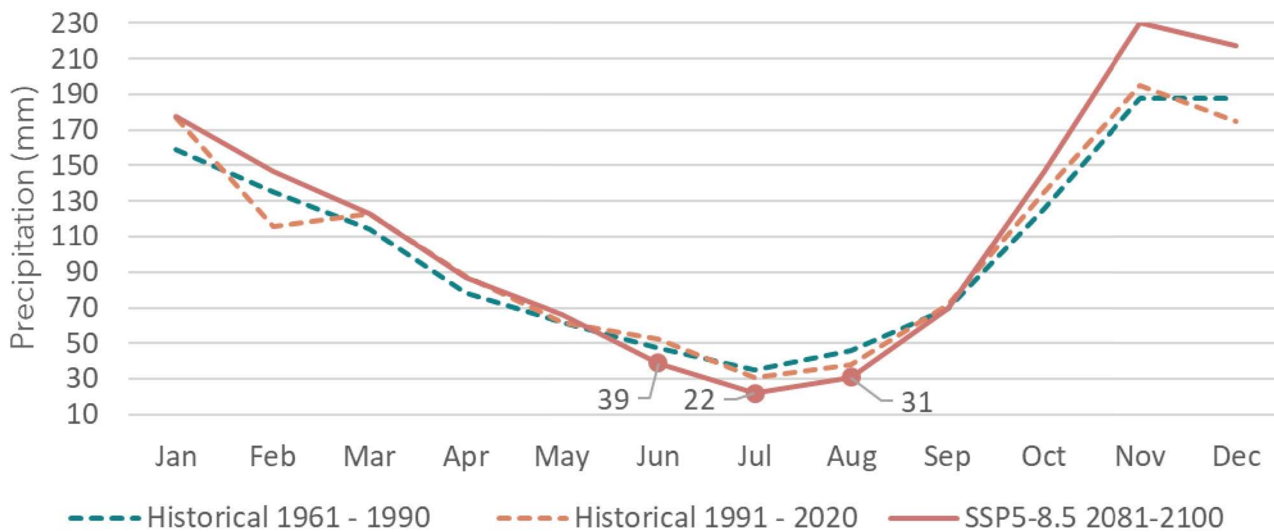


Figure 9. Monthly precipitation (mm) for historical years between 1961-2020 vs. SSP5-8.5 between 2081-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

7.5 Winter Precipitation as Snow

The Asian Garden at UBCBG is expected to see a reduced occurrence of snowfall as the years progress towards the end of the century according to both SSP2-4.5 and SSP2-8.5 (Figure 10). Winter snow is expected to decrease from 31mm in 1961-1990 to 10mm in 2081-2100 based on SSP2-4.5. Based on SSP5-8.5, winter precipitation is expected to decrease to 5mm in 2081-2100.

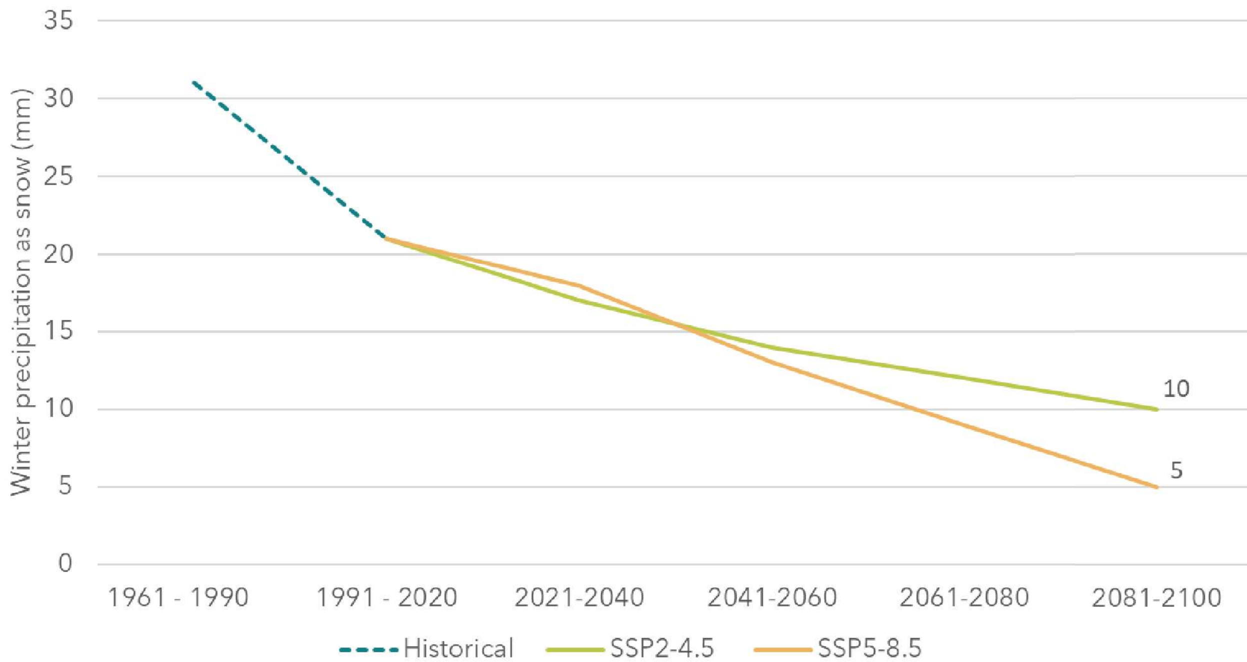


Figure 10. Winter precipitation (mm) as snow for historical years between 1961-2020 vs. SSP5-8.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Winter is considered January, February, and December. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

When assessed monthly, the greatest differences between the historical years and the future years can be seen in the months of November, December, and January (Figures 11 and 12). Projections for both SSP2-4.5 and SSP5-8.5 show no snow in March and April by 2081 to 2100. The historical precipitation as snow typically peaks in January. However, by 2081-2100 in January, SSP2-4.5 projections indicate a 64% decrease in precipitation as snow (Figure 11) and SSP5-8.5 projections indicate a 79% decrease (Figure 12).

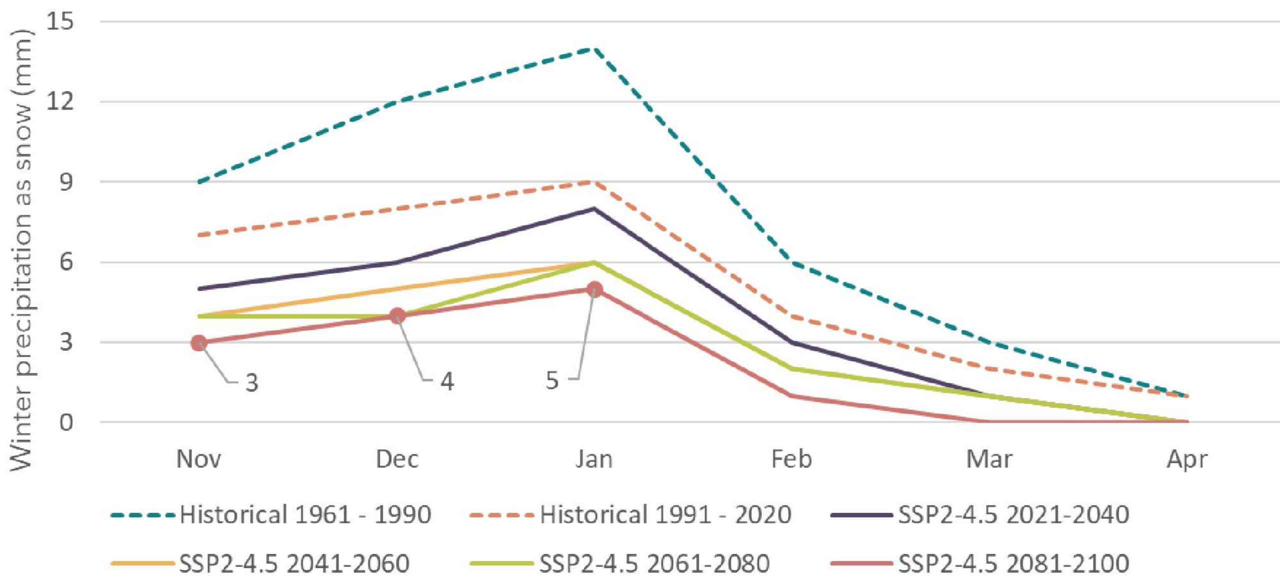


Figure 11. Winter Precipitation (mm) as snow between November to April for historical years between 1961-2020 vs. SSP2-4.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

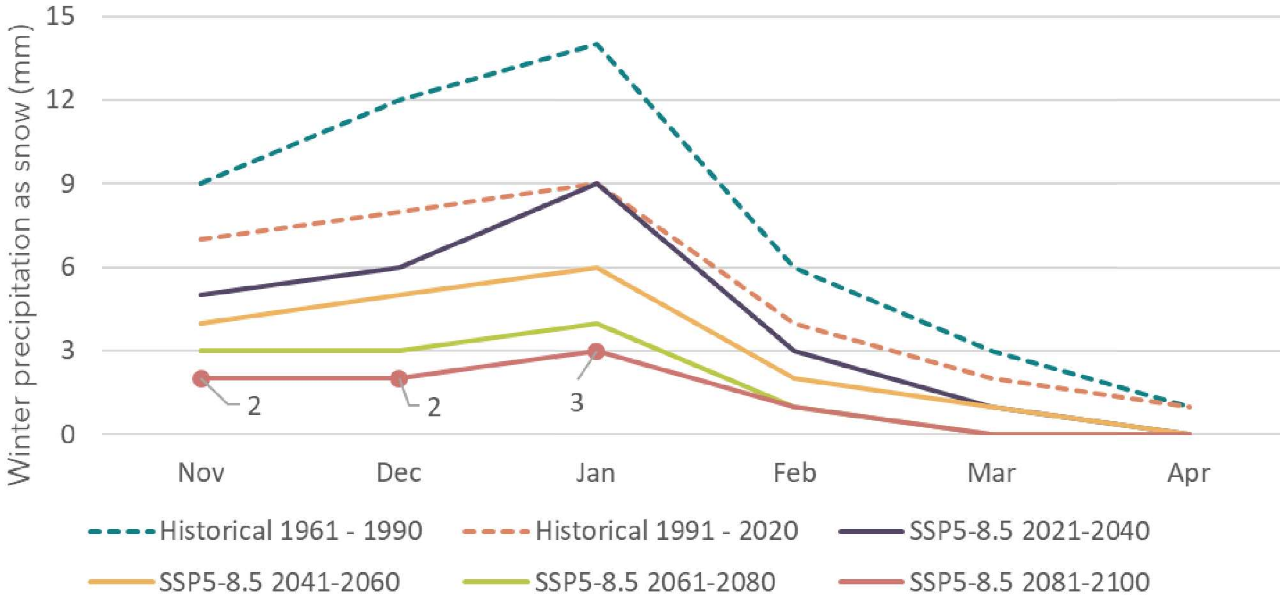


Figure 12. Winter Precipitation (mm) as snow between November to April for historical years between 1961-2020 vs. SSP5-8.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

7.6 First and Last Day of Frost-Free Period

A gradual increase in the frost-free period can be seen between 1961and 2020, indicating a decrease in the number of frost days. This trend is expected to continue in the future until the end of the century.

Historically, the expected number of days between the last frost in spring (early to late March) and the first frost in fall (mid to late November) is typically 232 days between 1961 and 1990, and 256 days between 1991 and 2020. In a SSP2-4.5 scenario, the frost-free period is expected to grow to 302 days between 2081 and 2100 (Figure 13). SSP2-4.5 suggests that by 2061, the first frost day is expected to arrive in early December instead of late November as shown in historical trends. The last frost day is projected to occur in mid February by 2041, and early February by 2081.

Although the monthly frost-free day variable is not graphically represented in the report, the number of frost-free days is expected to increase noticeably between November and March for both SSP2-4.5 and SSP5-8.5. For instance, December months in 2081-2100 under an SSP2-4.5 scenario is projected to have an increase of seven frost free days, from 18 days in 1961-1990 to 25 days in 2081-2100. This means that most of the month of December will eventually be frost-free compared to historic years when only half the month is frost free.

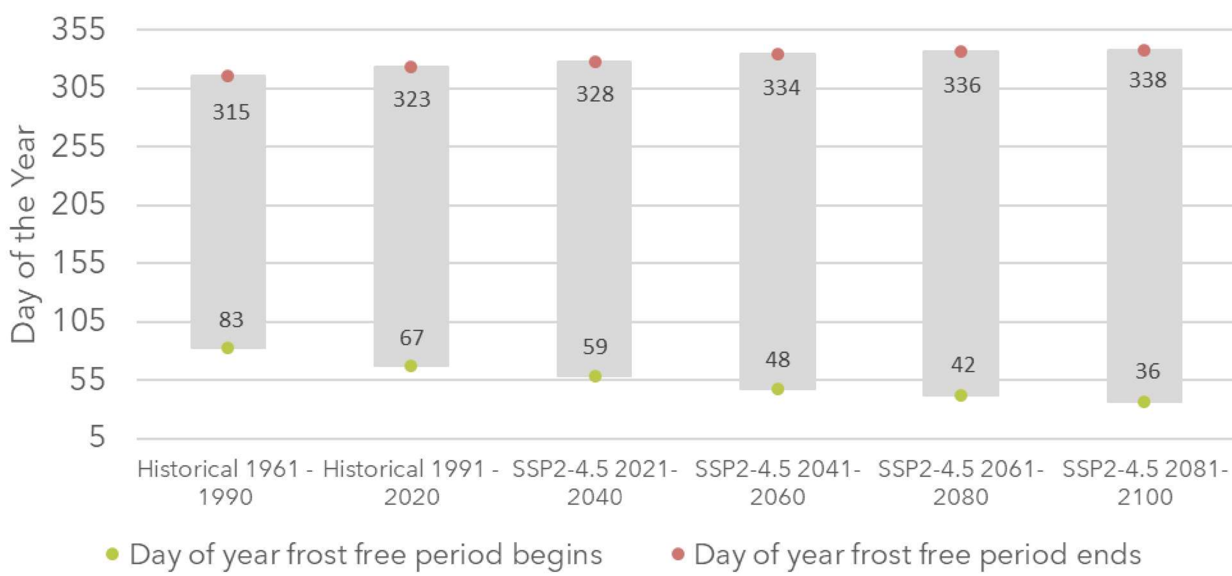


Figure 13. First and last day of frost-free period for historical years between 1961-2020 vs. SSP2-4.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

The frost-free period is expected to get longer every year. According to a SSP5-8.5 scenario, the frost-free period is 333 days by the 2080s, with the last frost date occurring in mid January, and the first frost date happening in mid December.

For the monthly frost-free day variable, December months in 2081-2100 under an SSP5-8.5 scenario, is expected to have 29 frost-free days, up 11 days, compared to only 18 days in 1961-1990.

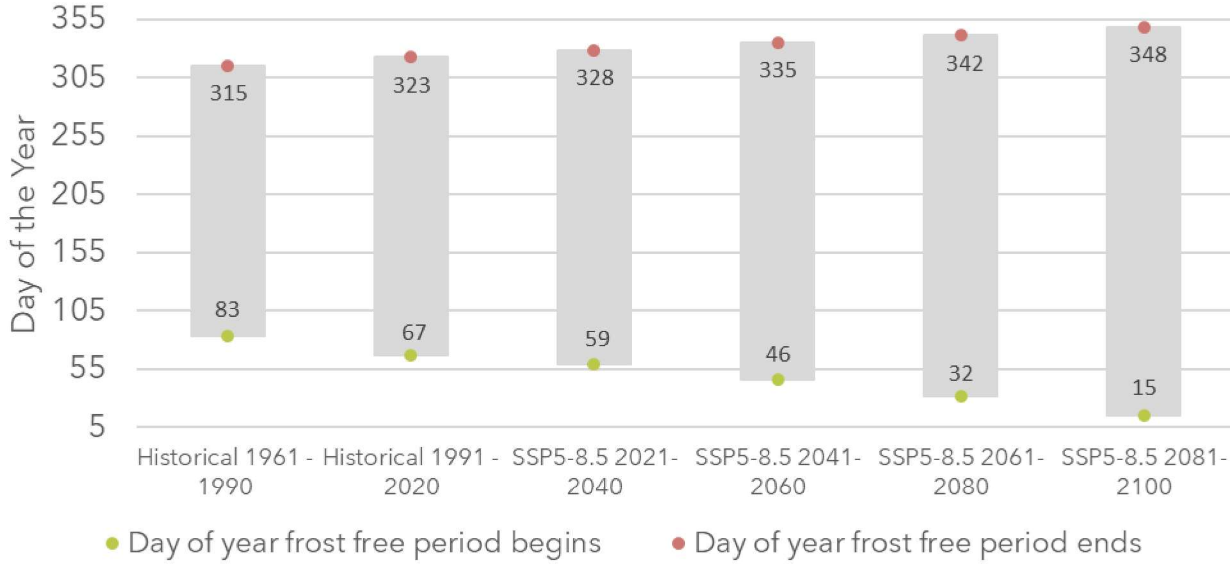


Figure 14. First and last day of frost-free period for historical years between 1961-2020 vs. SSP5-8.5 between 2021-2100 at the Asian Garden, UBC Botanical Garden. Data retrieved from Wang et al., 2016. Graph created by Virginia Hang.

7.7 Effects of Climate Change on Western Redcedars

Historically, the UBCBG receives around 1200mm of precipitation annually, with most of the precipitation falling between October and April (Wang et al., 2016; Lopez-Villalobos et al., 2022). Moisture is quickly depleted from the garden's shallow, fast draining soils as temperatures warm in the growing season (Lopez-Villalobos et al., 2022). The risks surrounding the projected reductions in precipitation during the growing months could be managed through supplementary irrigation (Kendal et al., 2008). The western redcedars in the David C. Lam Asian Garden are situated with an assortment of exotic species from Asia that receive supplementary water through a modern irrigation control system (Lopez-Villalobos et al., 2022). The irrigation system is designed to consist of a network of sensors that record real-time data to monitor changes for climate change research (Lopez-Villalobos et al., 2022).

Data on the past and current distribution of western redcedars, coupled with climate data, offers further understanding of the models that show species range changes under future climate scenarios (Cowell et al., 2022). In a short-term climate simulation study involving several tree species on Vancouver Island, Laroque and Smith (2005) found that non-generalist tree species such as western redcedar are less able to respond to climate change because factors such as drier-warmer or wetter-cooler summertime conditions influenced more dramatic changes to the species' radial growth rate. Western redcedar is more sensitive to specific climate variables such as summertime (June, July, and August) temperatures when compared to mountain hemlock, yellow-cedar, and douglas fir (Laroque and Smith, 2005). The simulations in Laroque and Smith (2005) were based on temperatures set at 1.0°C above or below the historic 100-year average, and with precipitation set at one standard deviation for each month in each climate change scenario. According to the model that Laroque and Smith (2005) used, western redcedars had significantly above normal radial growth in a wetter summer that was 1.0°C cooler, and below normal growth in a summer that was drier and warmer by 1.0°C. For western redcedars in the study, it took 10 years for dramatic changes in radial-growth to stabilize during the wetter-cooler or drier-warmer climate scenarios during the summertime, which is much longer compared to other conifer species (Laroque and Smith, 2005). Regarding tree health and chances for survival, slower tree growth has been associated with drawbacks such as higher susceptibility to disease, insect infestation, and a higher probability of death (Black et al., 2008). These findings support previous studies that investigate how temperature extremes, either colder or hotter summers, have an undesirable effect on western redcedar growth in the coastal region (Klinka and Brisco, 2009; Seebacher, 2007).

Generally, warmer temperatures make trees use more water and photosynthesize less if trees do not adapt to drought (Sperry et al., 2019). Rising temperatures could impact the carbon storage of trees since the rate of carbohydrate consumption required to maintain respiration is significantly connected to temperature (Allen et al., 2019). Greater tree respiration during elevated temperatures leads to drought-induced mortality, especially since western redcedars do not have cutin and wax to prevent water loss (Minore, 1983). Abnormally warm winters maintain physiological activity after the summer growing season, furthering tree respiration at the expense of stored carbohydrates (Allen et al., 2019).

According to both SSP2-4.5 and SSP5-8.5, results for all months between January to December from 2021 to 2100 show at least a 1.3°C increase in the maximum mean temperatures. Based on the projected 2081-2100 results shown in Figures 3 and 4, an increase of up to 3.7°C in the SSP2-4.5 scenario or an increase of 6°C in the SSP5-8.5 scenario during the growing season would drastically affect the radial growth of western redcedars in the Asian Garden. If 1.0°C of warming is considered to have moderate to high risks to western redcedars, risks are expected to be more severe as temperatures continue to increase. Drier-warmer environments during June, July and August would negatively impact the critical growth period of western redcedars (Laroque and Smith, 2005).

The increase in length of the frost-free period, warmer temperatures, less precipitation in the summer, and greater moisture deficits in the future can stress western redcedars. These changes in climate variables may facilitate the establishment of new pests and diseases. However, when it comes to increases in the minimum mean temperatures and increases in the number of frost-free days in the winter months, this may present an advantageous opportunity to collect and plant western redcedar seed from southern climates that would otherwise be more sensitive to frost.

IV. Discussion

8.0 Recommended Management Practices for a Resilient Future

Post-glacial tree migration rates of 50km per century are slower than the estimated rate of climate change (Lemprière et al., 2008). Climate projections for the 21st century show that trees will need to migrate north more than 300-500km per century to track favourable climates for their survival (Davis and Shaw, 2001). Similarly, McKenney et al. (2007) estimate an average northward shift of 700 kilometres in suitable climate by 2100 for 130 North American tree species, including western redcedar. To promote greater resilience for the projected 2100 climate, the planting of seeds should be sourced from locations that have a similar climate to what western redcedars may be exposed to at the Asian Garden under future climates. Furthermore, to ensure the continuation of living plant collections, the UBCBG could select plantings that are better suited to the projected climate and environmental conditions of 2100.

8.1 Adaptive Management

Adaptive management can be used to approach climate adaptation planning at the UBCBG because it is a structured iterative process for decision making that is useful for managing projects under conditions of ongoing uncertainty. The six overarching steps to engage in adaptive management to address climate change impacts on western redcedars at the UBCBG are recommended below. The steps are 1) assessment; 2) design; 3) implementation; 4) monitoring; 5) evaluating; and 6) adjustment. This iterative process focuses on learning and adapting using the current state of knowledge and resources available to better inform future management actions (Williams et al., 2009).

Step 1 - Assess: Western redcedar can tolerate some water deficiency but not sites in warm coastal climates that are too dry and hot (Klinka and Brisco, 2009). Since local microclimate (soils, topography, and water table-depth) conditions impact the global influence of climate (Park and Talbot, 2018), it is essential to assess the different microclimates at the UBCBG, preferably through temperature-moisture sensors (Ng, 2022). It may be possible to utilize future data from the sensors that are part of the smart irrigation system installed within the Asian Garden. Additionally, it is beneficial to understand the potential for ex-situ conservation of non-native species through exploration of species distribution models (Breed et al., 2018) and climate analogue models (Fitzpatrick and Dunn, 2019). Incorporating data from a species' entire distribution may lead to a more comprehensive assessment of future ranges and a close approximation of the species' fundamental niche (Beaumont et al., 2009). The UBCBG will benefit from assessing the suitability or survivability of each species currently within the garden under future climates.

Step 2 - Design: The UBCBG can prioritize two methods of assisted migration through the design of a climate adaptation strategy. Firstly, assisted seed migration plans can involve planting provenances from areas that have better tree growth potential than local provenances (Benito-Garzón et al., 2018). An aspect of seed saving to consider is that the long-term storage of western redcedar seeds will decrease germination success (Terskikh et al., 2008). The UBCBG can study through trials of provenance responses to climate, patterns of seasonality, and physical conditions (Park and Talbot, 2018). However, a climate adaptation strategy can also include the use of local provenances to ensure that there is an alternative plan if species distribution models happen to be inaccurate (Benito-Garzón et al., 2018). The second method of assisted migration involves the assisted migration of species outside of their current range to the UBCBG. This would require a future planting list that prioritizes species that are aligned with the UBCBG's collection policies and collections development goals, including those of practical conservation potential. Section 8.3 and Appendix A, B, and C describes planting lists with recommended species.

Step 3 - Implement: To study climatic adaptability and test hypotheses about the value of planting various species, the UBCBG will need to establish new transplant experiments for multiple tree species identified in the future planting lists (Booth, 2017; Kingsford et al., 2017). The UBCBG can implement experiments that incorporate climate extremes, competition, and pathogens to discover relationships about tree-climate interactions (Park and Talbot, 2018).

Step 4 - Monitor: Planting projects should have detailed records of provenance sources, climate data, site preparation, and establishment outcomes (Breed et al., 2013). The UBCBG can monitor on-site seed migration projects (see section 8.2 for more details) for western redcedar and provide valuable sources of long-term data to describe how the trees are responding to climate change (Primack and Miller-Rushing, 2009). Monitoring can compare the resiliency of assisted seed migration provenances and local provenances to climate change (Park and Talbot, 2018). While trees can grow in conditions different from their natural distributions, climate change can affect the phenology of translocated species (Park and Talbot, 2018). See section 9.5 and 9.6 for more information on how to link the monitoring of phenological data with the power of citizen scientists. The long-term collection of data on flowering and seeding from tree species trials can provide information about successful reproduction (Booth, 2017).

Step 5 - Evaluate: Regarding the planting of new species, the UBCBG can evaluate species' establishment potentials and work with other public gardens to enhance cross-border collaborations (Prasad et al., 2020). Continuous data collection on reproduction success and phenology over the lifetime of trees can help with evaluating the success or failure of assisted migration practices (Park and Talbot, 2018).

Step 6 - Adjust: MaxEnt models that are used to understand a species' probability of occurrence may have limitations due to problems of geographically biased samples of presence data when there is a lack of information of species prevalence (Gould et al., 2014). The reason for the bias is because species occurrence datasets can contain unequal sampling efforts and could potentially result in inaccurate model predictions that would require methods of bias correction (Fourcade et al., 2014). Instead of solely relying on species distribution models and climate models, it may be necessary to explore studies using forest ecosystem modeling methods such as the 3-PG (Physiological Principles in Predicting Growth) process-based modelling, which relies on physiological processes and biophysical parameters (Gupta and Sharma, 2019). Forest ecosystem modeling methods could be combined with automated decision tree analyses that are able to predict the limits to growth and tree distributions due to climatic changes (Coops et al., 2011). Predictions of species vulnerability will likely be improved if climate variables and physiological traits are combined and related with direct measures of tree growth and mortality (Hanley et al., 2021).

The UBCBG can adjust future planting lists by using newer species distribution models that incorporate abiotic variables (i.e., soils, topography, and vulnerability to disturbance) as well as knowledge-based evaluation (Park and Talbot, 2018). If the UBCBG discovers the unlikeliness of a particular new species to persist after the assisted migration experiments, then they can choose to test a different seed sourcing strategy (Notivol et al., 2020), or select another species in the planting list that is better suited. Adaptive management emphasizes learning while doing and building the capacity of decision-makers to be well informed when it is necessary to adjust the path being used to achieve goals in response to changes (Rogers and Macfarlan, 2020). Overall, the information from planting alternative species is to learn about the impacts of such actions and using the data to update and adjust management actions purposefully with new knowledge, instead of ad hoc trial and error.

8.2 Assisted Seed Migration

As addressed in the previous section, seed migration is a climate adaptation strategy (Fontaine and Larson, 2016). Seed migration involves the intentional movement of seeds from known locations to planting sites that are expected to be the most climatically suitable for growth within the species' established native range (Ying and Yanchuk, 2006). Pedlar et al. (2011) state that the existence of provenance trials, seed transfer guidelines, seed procurement systems, and tree breeding programs in B.C. allow seed migration to be more feasible for commercial tree species such as western redcedar. Similarly, McKenney et al. (2009) state that assisted migration will be the most effective if seed transfer guidelines based on climate conditions are already in place. Within the forestry sector, the Province of British Columbia currently has seed source selection guidelines, seed transfer guidelines, and seed planning zones for native commercial species, including western redcedar (Pedlar et al., 2012). In addition, government researchers in B.C. are conducting an ongoing long-term climate change research study called the Assisted Migration Adaptation Trial (AMAT) to help forest managers understand tree species' climate tolerances and thereby select seedlots that are the best adapted to the current and future climates (Williams and Dunroese, 2013). Although the focus of AMAT is for the forestry sector (Pickles et al., 2015), further research on the application of the trial and its results on western redcedar could transfer the potential of implementing seed migration at the UBCBG (Fontaine and Larson, 2016).

Breed et al. (2013) suggest the use of predictive provenancing for species that are likely to undergo predictable significant shifts in climate. Predictive provenancing is a climate modelling strategy that matches seed stock with projected future climatic conditions (Sgrò et al., 2011; Wang et al., 2010). In B.C., the Climate Based Seed Transfer (CBST) system for forestry is an ongoing climate and science-based project that strives to prevent seeds from being planted within sites that are too warm (O'Neill et al., 2008). The CBST would allow for warmer climate adapted seed to be planted into sites that are slightly colder in anticipation of ongoing climate change (O'Neill et al., 2017). CBST is risk-averse because the focus is on catching up to climate change to date, rather than projecting too far into the future (Ukrainetz et al., 2011). There is a growing need for seed migration to be implemented outside of the forestry sector to help important native species persist (Park and Talbot, 2012). The CBST tool can be used to inspire seed migration efforts at the UBCBG. For instance, coastal western redcedar seeds may be transferred across international borders (Leech et al., 2011), from northern coastal United States to the UBCBG.

Despite the existence of a Seedlot Selection Tool, a GIS mapping program designed to help foresters match seedlots with planting sites in the Pacific Northwest based on climatic information, it does not allow the user to specifically select for western redcedars within the tool as a limited number of species are currently available (Climate Change Resource Center, 2022).

Nevertheless, seed migration has the lowest risk for introducing invasive species compared to other assisted migration strategies (McLachan et al., 2007). Nevertheless, further research and trials are required to remove uncertainties concerning the use of climate projection models, species distribution models (Wang et al., 2012), selection of optimal provenance seed sources (Aitken et al., 2008), and outplanting designs (Breed et al., 2013).

8.2.1 Western Redcedar Adaptive Traits for Seed Migration

Johnson et al. (2010) state that assisted migration should be employed for species that have the genetic ability to tolerate a wide range of environmental conditions. While the genetic variability of western redcedar is homogenous, the species is plastic in its morphological development and response to site-conditions (El-Kassaby, 1999). Phenotypic plasticity is a relevant factor that will determine the extent to which populations will adapt to climate change (Aitken et al., 2008). The broad habitat tolerance that enabled western redcedar to previously persist in a tenuous interior glacial refugium may support its capacity to sustain future stability (Fernandez et at., 2021). Grossnickle and Russell (2010) have found that the physiological response patterns of different western redcedar populations can offer information for developing reliable gene resource management strategies such as seed migration, gene conservation, and tree breeding. However, western redcedar is currently viewed as low priority for in situ conservation efforts compared to other conifer species in B.C. (Yanchuk and Lester, 1996). The UBCBG may need to adopt seed migration efforts to ensure western redcedar remains as an important cultural living collection at the botanical garden.

8.3 Planting List for the Future

If western redcedars are not able to adapt to the projected change in climate, then it may be necessary to look at future plantings of species that are capable of surviving in the future climates at the Asian Garden. To determine which species would be suitable for planting under future climate conditions at the Asian Garden, the species list from the "Urban Tree List for the Metro Vancouver in a Changing Climate" document authored by Diamond Head was assessed. The document identifies a list of 289 tree species (including non-natives) that have been assessed for suitability to the future climate, based on USDA hardiness zone, American Horticultural Society heat zone and drought tolerance (Diamond Head, 2019b). There are three planting group lists for the 289 species: 1) the "Very Suitable" planting group lists species that can handle heat and cold and are tolerant of sites experiencing up to approximately 1 month of drought; 2) the "Suitable" planting list contains species anticipated to tolerate all but the driest sites under future climates; and 3) the "Marginal" planting list contains species that are anticipated to be restricted to moist sites under future climate (Diamond Head, 2019b). For reference, western redcedars are placed in the "Marginal" planting list.

Using Natural Resources Canada's MaxEnt range maps, I recorded the probability of occurrence value for each of the species listed under the three planting groups based on the current distribution, as well as the RCP 4.5 and 8.5 scenarios for 2071 to 2100 at the UBCBG. I based the recommended future planting list for each RCP scenario (RCP 4.5 and 8.5) for 2071 to 2100 on the following available considerations: 1) the projected species distribution under future climate conditions as per the MaxEnt range maps for the period of 2071-2100 (Natural Resources Canada, 2021d); and 2) the invasive potential of the species (Diamond Head, 2019a).

The results are organized in three tables based on the original naming for each planting list: 1) "Very Suitable" (Appendix A); 2) "Suitable" (Appendix B); and 3) "Marginal" (Appendix C). I have recommended species that have greater than 0.1 probability of occurring at the UBCBG site based on the MaxEnt model to be a species to consider under the planting list. The planting lists in the Appendices shows a column for "RCP 4.5 Scenario" and "RCP 8.5

Scenario," with an indication for "Yes" or "No" to depict whether a species is recommended to be part of the planting list under each of the RCP scenarios. Some species do not have enough occurrence data to suggest an occurrence probability, and this is indicated by "N/A" under the occurrence probability columns. However, until proven that the species does not have a chance of occurring at the UBCBG, it is still considered as a recommended planting. Further sampling data would be necessary to create species distribution projections for species with a lack of presence data.

Since invasive species are a significant threat to biodiversity, the recommendations minimize planting potentially self-seeding invasive species identified within the "Very Suitable," "Suitable," and "Marginal" lists. The species within the "Very Suitable" and "Suitable" lists can be appropriate for a broad range of conditions, including the driest of sites (Diamond Head, 2019a). The risk of a new invasive species colonization may cause the need for expensive post-establishment control and eradication procedures (Curnutt, 2000). There are exceptions for potentially invasive *Acer* and *Magnolia* if they already exist in the UBCBG's significant conservation collections. For instance, Diamond Head (2019a) identified Japanese maple (*Acer palmatum*) with invasive potential, but the UBCBG has an extensive collection of Japanese maple cultivars, and the species is projected to be suitable between 2071 to 2100 for both RCP 4.5 and 8.5 (Natural Resources Canada, 2021a). Cultivation in a managed setting may overcome some of the limitations to dispersal and allows species to exist in areas outside of their fundamental niche (Kendal et al., 2018). If the species are not potentially invasive but do not have enough occurrence data to be mapped through the MaxEnt model, they are still considered to be suitable for planting, until proven otherwise. However, with milder winters (Figures 2 and 3) and longer duration of frost-free periods (Figures 13 and 14), some invasive species may have a better chance of thriving in warmer conditions and outcompete native species and more desirable species. For instance, the pink silk tree (*Albizia julibrissin*) has been identified as potentially invasive in the "Very Suitable" list (Appendix A) and is an example of a species that should not be further planted in RCP 4.5 and 8.5 scenarios despite the expectation that the UBCBG will have moderate to high climate suitability for the species in 2071-2100. Pink silk trees prefer warm microclimates in lower elevations as they cannot withstand temperatures lower than -4°C (Weber, 2003). Pink silk trees are difficult to control once established as one tree can produce over 8000 seeds per year with high germination rates following scarification (Koepke-Hill et al., 2012). Damage to an actively growing silk tree stimulates vegetative regeneration through root sprouts (Pitman, 2008). Thus, milder winters could facilitate the growth of invasive silk trees and displace more desirable species at the UBCBG.

The recommendations for the planting list attempt to not include species that are projected to have poor adaptive potential to future climates (Breed et al., 2013). For instance, although Diamond Head (2019a) identified that southern live oak (*Quercus virginiana*) occurs in future climate analogues, Natural Resources Canada (2021b) identified that the species has a zero chance of occurrence at the UBCBG in the future. If the species-specific model is accurate and the UBCBG plants southern live oaks, then there is a risk of maladaptation. Thus, southern live oak is not considered in the planting lists for the RCP 4.5 and 8.5 climate emissions scenarios. Nevertheless, this may be an opportunity to involve adaptive management (see section 8.1) if certain species are desired as per UBCBG's collection policies and collections development goals. For instance, incense cedar (*Calocedrus decurrens*) is listed as a potentially invasive species due to its ability to self-seed and is consequently not recommended to be planted. However, incense cedar has a moderate probability of occurring at the UBCBG site between 2071 and 2100 under RCP 4.5, and a low occurrence probability under RCP 8.5 in the "Very Suitable" planting list (Appendix A). It may be worthwhile to consider the risks of planting incense cedar in this case.

Of the 289 species evaluated, there are152 species across all three planting lists that are recommended to be planted at the UBCBG under the RCP 4.5 scenario for 2071 to 2100 (Table 5).

Based on an RCP 4.5 scenario:

- There are 62 species listed in total in the "Very Suitable" group (Appendix A), and 29 species are recommended to be considered for planting at the UBCBG under RCP 4.5.
- In the "Suitable" (Appendix B) group, 83 out of a total of 152 species in the planting list are recommended to be considered for planting.
- In the "Marginal" (Appendix C) group, 40 out of the 75 species are recommended to be considered for planting in the UBCBG in the future.

For the RCP 8.5 scenario,144 species from across all three planting lists may be possibly considered further at the UBCBG for 2071 to 2100 (Table 5). Fortunately, this is not a large decrease in the number of species that can be considered for planting compared to the RCP 4.5 scenario.

Based on an RCP 8.5 scenario:

- With 62 species listed in total in the "Very Suitable" group (Appendix A) and 26 species could be considered for planting at the UBCBG under RCP 8.5.
- In the "Suitable" (Appendix B) group, 80 out of a total of 152 species in the planting list are recommended to be considered for planting.
- In the "Marginal" (Appendix C) group, 38 out of the 75 species are identified for consideration in the UBCBG for planting in the future.

Table 5. The number of species from each planting group list that should be considered for future planting under RCP 4.5 and RCP 8.5. The numbers are summed based on filtering the "Yes" results in the "RCP 4.5 Scenario" and "RCP 8.5 Scenario" in Appendix A, B, and C.

	Very Suitable	Suitable	Marginal	Totals
Total number of species	62	152	75	289
To be considered under RCP 4.5	29	83	40	152
To be considered under RCP 8.5	26	80	38	144

There are 138 different genera across all three planting lists. The number of genera that could be considered for planting is 95 under an RCP 4.5 scenario and 93 under an RCP 8.5 scenario (Table 6).

Table 6. The number of species from each planting group list that should be considered for future planting under RCP 4.5 and RCP 8.5. The numbers are summed based on selecting the number of unique genera resulting from the filtered plant lists used to populate Table 4.

	Very Suitable	Suitable	Marginal	Totals
Total number of genera	34	66	38	138
To be considered under RCP 4.5	21	49	25	95
To be considered under RCP 8.5	21	47	25	93

9.0 Monitoring Plan Recommendations

Monitoring is a key step within adaptive management because it can be designed to inform decision making. Robust data on western redcedar could help address the projected management challenges discussed in section 5.0 of the report. Adequate data can inform future strategic directions and plans for climate change adaptation. An appropriate database, advanced planning on what data to collect and clear goal setting are important in ensuring the quality and consistency of monitoring data (Roman et al., 2013). A single static inventory is only useful for describing the structural and spatial patterns of an urban forest at one point in time, while long-term field monitoring data can describe change over time (van Doorn et al., 2020). For instance, a potential question to be answered in the future with monitoring data could be: "was there a change in the average level of western redcedar crown dieback over a 10-year period?"

9.1 Current Data

The UBCBG has the following inventory data for western redcedar (UBCBG, 2019d):

- Accession date and code
- Provenance code
- International Union for Conservation of Nature (IUCN) Red List
- Provincial Red List
- Name of recorder
- Site location
- Site type
- GPS coordinates
- Altitude
- Taxon information including cultivar
- Stem diameter
- Stem girth (circumference)
- Record date
- Item status (observed, planted, present, or item split)
- Item comments

Notes Regarding the Current Data:

- Most data entries are recorded by 'admin.'
- Item comments are sparse, only 11 out of the 395 trees contain an "item comment".
- Item comments do not provide the necessary depth of information on the condition of the trees (the following comments were available for certain trees: "a large one by Straley trail," "hollow tree," "double trunks," "growing on a stump," "supporting climber," "supporting tree for TreeWalk platform").
- Measurements and comments are collected at the time the trees were accessioned in 2016 (data represents a static inventory).
- The height at which stem diameter and girth was measured is unknown.
- The data from the inventory is only for the living collection and does not reflect removed or dead trees.

9.2 Proposed Data Collection

Longitudinal studies in research on tree demography can reveal information about changes over time in tree mortality, growth, and health (van Doorn et al., 2020). For instance, Canham and Murphy (2017) conducted a study on 50 common tree species in the eastern United States (U.S.) using data from plots censused by the U.S. Forest Service Forest Inventory and Analysis program from the years 2000 to 2011. The research aimed to quantify relationships between aspects of climate (mean annual temperature and growing season water deficit) and rates of sapling and canopy tree survival (Canham and Murphy, 2017). The same tree at the UBCBG can be observed over time due to the existence of recorded geographic coordinates. However, the UBCBG uses a collection management software (IrisBG) that does not appear to support longitudinal data management (IrisBG, 2021). A new database will need to be designed and customized to support long-term monitoring. In addition to the current data collected, Morgenroth and Östberg (2017) recommend collecting information about the training level of the field measurement personnel to allow any spurious data to be validated or discounted in the future if necessary. Monitoring should be conducted by trained field crew (Roman et al., 2013) that could include trained citizen scientists. The following list contains additional useful field variables that could be collected for monitoring western redcedar for the long-term:

Tree Size Measurements:

- Height
- Crown diameter
- Stem diameter at standardized height (i.e., diameter at breast height at 4.5 feet from the ground)

Tree Condition and Maintenance:

- Mortality status
- Crown vigor
- Indications of discoloration of foliage
- Crown branch dieback
- Structural condition
- Abiotic and biotic damage/ cause of damage
- Indication of support for Greenheart TreeWalk
- Health condition

Other

- Ground cover
- Photograph of entire tree

An example monitoring spreadsheet exemplifying the proposed inventory variables is included in the report (Appendix D). While there are currently no indications of pests and diseases on western redcedars at the UBCBG, monitoring can detect emerging threats from pests and diseases (van Doorn et al., 2020). Pests such as insects that would have otherwise been managed by cold winters, may experience outbreaks due to the projected increases in the frost-free periods (Figures 13 and 14).

Results from monitoring could also help decision-makers and tree care personnel during tree risk identification and mitigation (Morgenroth and Östberg, 2017). Although tree risk assessment is not listed above, it should be conducted for trees that are used as support for the popular Greenheart TreeWalk aerial program. Consequences of tree failure could result in personal injury or death. Tree risk assessments, maintenance requirements, wood condition evaluations, and structural stability should be conducted by professional arborists (van Doorn et al., 2020). However, if data collectors observe something potentially dangerous, then the tree should be flagged to provoke a second inspection from a qualified professional. At the UBCBG, curators have the capacity to report on tree condition and maintenance variables such as branch dieback and presence of pests or disease (D. Justice, personal communication, November 25, 2021).

9.3 The Capacity to Monitor

It is important to note the requirements for funding, staff time and organizational capacity to facilitate future monitoring processes (Roman et al., 2013). Currently, the UBCBG has a long-term phenology monitoring project for Magnolias that has been ongoing for over 20 years (UBCBG, 2021b). The monitoring project for Magnolias is a joint effort between a Friends of the Garden group and staff members from the UBCBG (UBCBG, 2021b). A long-term monitoring project consisting of annual updates to the baseline inventory of western redcedar like that of the Magnolia project would be helpful in identifying potential links between species condition, tree demography and climate change. Monitoring could be conducted via trained personnel or citizen scientists in collaboration between UBC's Horticulture Training Program and the UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program (Luker et al., 2021). In 2017, UBC Campus and Community Planning, Faculty of Forestry, and SEEDS funded a campus tree inventory pilot project that relied on LiDAR (Naveau et al., 2017). Unfortunately, the pilot project did not achieve high accuracy using LiDAR data (Bellis, 2017). In 2019 and 2020, the UBCBG and SEEDS coordinated an Urban Forest Inventory and Assessment field course (UFOR 101) that involved 123 students over the course of two years (Devisscher and Nesbitt, 2019; Devisscher and Almas, 2020). The course taught students how to conduct urban forest inventories and ecosystem service assessments (Devisscher and Almas, 2020). Future monitoring initiatives for western redcedar could be incorporated into courses such as UFOR 220, previously UFOR 101. Tools such as DBH tapes, laser rangefinder/hypsometers, open-reel measure tapes, and clinometers could be resourced from the UFOR 220 course.

9.4 Multi-age Inventory Monitoring

The proposed monitoring type is multi-age inventory monitoring whereby the inventory spans multi-aged classes (Van Doorn et al., 2020). The UBCBG has recorded varying stem diameters and stem circumferences of western redcedar within the Asian Garden (Figure 15 and 16) indicating uneven age classes. Due to the goal of measuring change and tree demography, repeated measurements should be conducted around the same time each year and from the same height from the ground for consistency. Tree measurements should be linked to the first record (i.e., the accession record) of each tree in the database (van Doorn, 2020). However, the succession data from 2016 does not provide a complete baseline record that can be used for monitoring. Thus, a new baseline record for the first full inventory is required. It may not be logistically feasible to conduct a complete census of all 395 western redcedar within the Asian Garden. There may be limited access to the trees as the second-growth forest is underplanted with other live collections. Intensive data collection for western redcedar may need to proceed during the wintertime or early spring when understory vegetation undergoes a dormancy period.

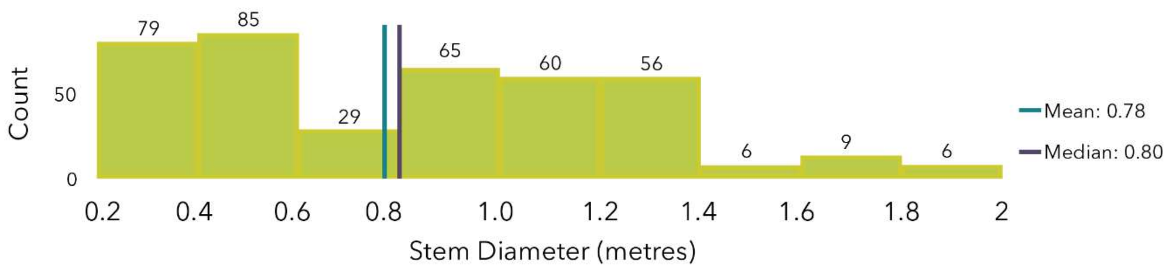


Figure 15. Histogram of stem diameter in metres for 395 western redcedar in the UBCBG. Data retrieved from UBCBG, 2021d. Data recorded in metres in 2016 during time of accession.

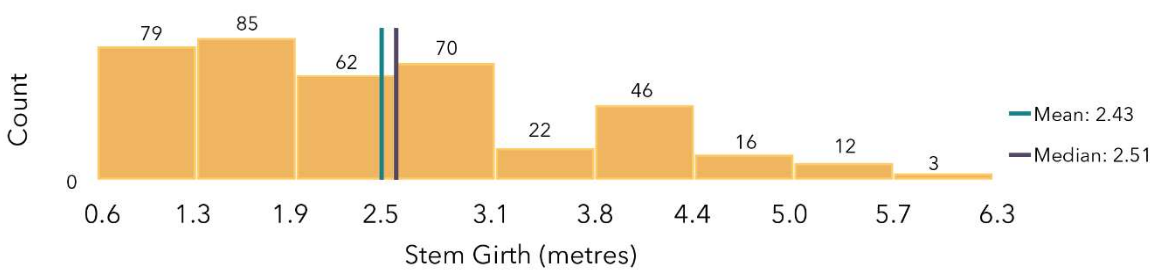


Figure 16. Histogram of stem girth (circumference) in metres for 395 western redcedar. Data retrieved from UBCBG, 2021d. Data recorded in metres in 2016 during time of accession.

Further discussion with the UBCBG is necessary to determine the sampling strategies for monitoring western redcedar if a full census cannot be conducted. Discussions with the UBCBG and SEEDs will be necessary to select data collection software, solidify project goals, validate project variables, confirm sampling and data collection strategies, and identify course programming, supervisors, and field crews. An annual update to the baseline inventory for long-term monitoring requires consistent data. Data quality issues can be lessened if crews receive thorough training and technical assistance (van Doorn et al., 2020). Next steps include the creation of protocols for quality control, training, and safety. Regarding engagement, the monitoring program could entail engaging citizen scientists (see section 9.6) and encouraging training and assistance between UBC and Botanical Garden staff members, hired experts and students from UBC's urban forestry and other programs.

9.5 Phenology Monitoring

Understanding the impacts of climate change through modelling and monitoring requires data on plant systematics, distribution, and physiology (Trivedi and Ali, 2009). One notable trend of climate change is the earlier spring onset in northern temperate areas of the world (Beaubien and Hall-Beyer, 2003). The study of when seasonal physiological processes occur in temperate trees can provide information on tree functions and enable predictions of how changes in the environment will affect tree health and ecosystem productivity (Harrington et al., 2016). International scale datasets are showing the connections between climate change and plant phenology (Primack and Miller-Rushing, 2009). The study of phenology of living collections is useful for predicting how ecosystems may change as phenology can be considered an indicator of climate change (Cowell et al., 2022). If the collection of phenological data is formalized using standardized documentation, it is possible to inform better management of plant collections within botanical gardens (Cowell et al., 2022). Data can also be gathered on the seasonal weather, temperature, rainfall, day length, and light conditions under which living collections are grown to supplement phenology data (Primack and Miller-Rushing, 2009). Involving the public to monitor phenology does not only assist botanical garden staff and professional researchers, but it also promotes support for scientific research and enhances knowledge about scientific processes related to climate change (Primack and Miller-Rushing, 2009). Section 9.6 recommends linking potential monitoring endeavors with citizen scientists.

Recurring biological events such as height growth initiation in trees can be examined through the timing of spring bud growth (Harrington et al., 2016). Since western redcedar does not form vegetative buds, its phenological processes can be analyzed by periodically measuring the shoot length during spring (Harrington et al., 2016). Western redcedar does not have a minimum or obligate winter chilling requirement, as in it can resume height growth without exposure to cool temperatures (Harrington and Gould, 2015). However, increased chilling will help reduce the amount of forcing (exposure to warm temperatures) required to start height growth in the spring (Harrington et al., 2016). Based on section 7.6, periods of frost are likely to be shorter in the future. For western redcedars, seasonal diameter growth occurs earlier and later in the season, representing an indeterminate growth pattern, while years with favourable environmental conditions contribute to a more linear diameter growth progression (Harrington et al., 2016). The reproductive phenology of western redcedar can vary year to year as it is influenced by climate cues and past winter and spring weather conditions (El-Kassaby, 1999). Western redcedar is wind pollinated and monoecious, whereby individual cones on the same tree are either male pollen cones or female seed cones (Ritland et al., 2020) (Figure 17). Pollination typically occurs in early March, with cone maturity occurring in late July to mid-August, and seed shedding occurring in September and October (Owens and Molder, 1980; Owens et al., 1990). The mechanism of wind pollination facilitates a potential for selfing (self-fertilization) as pollen shedding and stigma receptivity are simultaneous and synchronized under the current climate (Owens and Molder, 1980). Selfing may decrease western redcedar productivity by up to 10% (Ritland et al., 2020). Further research is required to understand if pollen release and female flower receptivity may respond differently to a warming climate and lead to phenological mismatches (Harrington et al., 2016). Disruption in male and female cone phenology can reduce genetic diversity or result in fewer sources of pollen being available to receptive ovules in a brief period, thereby reducing the viability of seeds (Harrington et al., 2016). See

Owens and Molder (1984) and Owens et al. (1990) for further information on the reproductive cycles of western redcedar.

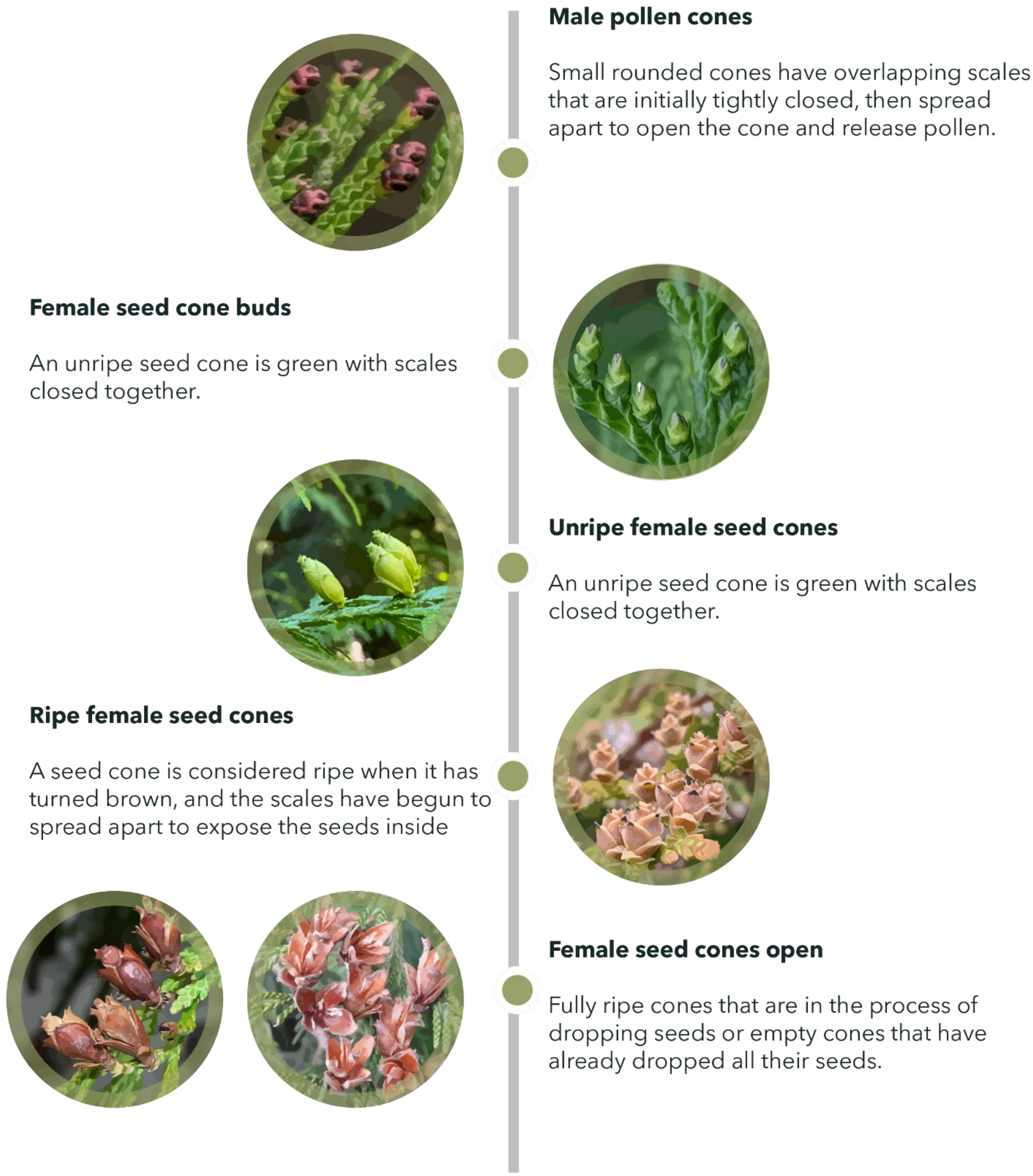


Figure 17. A brief example of western redcedar phenophases displaying male pollen cones and unripe and mature female pollen cones. Images are adapted from the following photo sources as shown in order from top to bottom: 1st) Grant, 2022a; 2nd) Grant, 2022c; 3rd) Barron, 2022; 4th) Grant, 2022b 5th) Siegmund, 2008; and 6th) Barkworth, 2006.

9.6 Linking Community Engagement, Partnerships and Monitoring

9.6.1 Partnership: Museum of Anthropology

As discussed in section 3.1, future alignment with SDG target 4.7 could be to work with the UBC Museum of Anthropology to lead Indigenous teachings on western red cedar within the Asian Garden. The UBC Museum of Anthropology's in-person field trip and educational program, Cedar: The Tree of Life, is geared towards students in grades three to five (MOA, 2022). The program shares Indigenous ways of life surrounding the historical and ongoing importance of cedar trees to the Northwest Coast First Nation cultures (MOA, 2022). During the program, the museum's Education Volunteer Associates lead the students through the galleries to learn about a variety of cultural belongings such as canoes, bentwood boxes, and baskets, which are created from the cedar tree (MOA, 2021). Hands-on experience allows students to interact with Indigenous traditions, stories, knowledge, and belongings (MOA, 2021). The program provides resources to teachers for in-class activities to lead before or after participating in the Cedar: The Tree of Life Program at the museum (MOA, 2021). To further nurture multicultural awareness, the UBCBG can offer educational tours specifically focusing on the western redcedars within the Asian Garden. To facilitate this tour experience, the UBCBG can:

- Hire an Indigenous garden interpreter through the UBC Work Learn program or involve volunteers to lead cultural walks through the Asian Garden. The cultural walk can consist of sharing relationships to the land, aspects of life and community, oral history, ancestral connections, traditional stories, and belongings related to western redcedar throughout the tour.
- Set up learning areas at specific waypoints with permanent signage within the Asian Garden showcasing cultural belongings from the museum's teaching collection to allow students to observe and understand which part of the tree (trunk, bark, and roots) were used to create certain belongings.
- Sharing traditional knowledge by interacting with the trees: an example could be to demonstrate the ways people chose specific trees for felling to be used for canoes, houses, and other belongings. Jeoff White of Old Masset, grandfather of Haida master carver James (Jim) Hart who worked on the UBC reconciliation pole, said that he looks at the crown of the tree to see if there is any dead wood indicating rot in the heartwood (Stewart, 1984). David Frank of Ahousat, a veteran canoe maker from Ahousat on western Vancouver Island, shared his method for checking the soundness of a cedar: "I walk around that tree, hit it with a piece of wood, and I listen to the sound it makes. If it's got some rot in it, then its gonna be hollow inside, and it's gonna make a different sound. I listen to the tree – it tells me."

Collaboration with the Museum of Anthropology could be measured to support the potential UBCBG metrics associated with target 4.7. For instance, calculating the percentage of participants that have attended the cultural walk, and finding the percentage of permanent display signs that include Indigenous knowledge and languages in the garden.

Citizen scientists have the power to improve plant conservation efforts, build scientific knowledge, contribute to informing policy and facilitate public action (McKinley et al., 2017). There are several programs that partner up with citizen scientists on various scales for plant conservation research. Citizen-science focused organizations that the UBCBG could find inspiration from to advance plant conservation include phenology-based programs such as PlantWatch, Budburst, and Nature's Notebook. Other citizen-science programs such as TreeSnap and the Forest Health Watch monitor tree health. A snapshot of these organizations is provided below.

9.6.2 PlantWatch

PlantWatch is a Canadian citizen science platform that tracks spring development of common plants (Beaubien and Hamann, 2011). While PlantWatch is organized regionally by province and territory in Canada, it could potentially be set up to involve finer divisions (Beaubien and Hamann, 2011). The UBCBG can become a local champion of the PlantWatch program to ensure a strong personal connection with its volunteers. Currently western redcedar is not an identified species that is part of PlantWatch, although it is considered a suitable species based on the suggested requirements for including a species in the program. The benefit of working with PlantWatch is that having national coordination lowers the costs of promotional materials and allows for the sharing of resources within regional networks (Beaubien and Hamann, 2011). Beaubien and Hamann (2011) recommends focusing on efforts that will retain volunteers in citizen science programs for the long term as many years of experience in plant observation contributes to higher quality and more precise data. To encourage volunteers to stay in the citizen science program, coordinators will need to provide adequate training, frequent feedback, rewards, and engage with the needs and interests of the volunteers (Beaubien and Hamann, 2011).

9.6.3 Nature's Notebook

Nature's Notebook is a multi-taxa citizen science phenology monitoring program that is run by the USA National Phenology Network and involves professional scientists, managers, and volunteers. Participants in Nature's Notebook must collect data according to standardized published protocols and submit data sheets into a professionally managed database (McKinley et al., 2017). The USA National Phenology Network is strictly collecting observations from within the United States, so direct collaboration is not possible as the UBCBG cannot contribute phenological observations to this program. Nevertheless, the USA National Phenology Network offers resources such as guidelines to help leaders start local phenology programs. The program provides Phenophase Photo Guides to help citizen scientists identify phenophases (life cycle stages) in individual species using a photo reference (USA-NPN, 2022). While western redcedar is identified in the species database, it currently does not have an associated photo guide. There is however a Phenophase Photo Guide template for conifers (without needles) that would be a suitable starting point to develop a phenophase guide for western redcedar. The guide contains definitions for pollen cones, open pollen cones, pollen release, unripe seed cones, ripe seed cones, and recent cone or seed drop, which are not allowed to be re-interpreted or re-worded to maintain rigorous data integrity and mitigate inconsistencies from the data collectors (USA-NPN, 2022) (Appendix E). The USA National Phenology Network website has a thorough frequently asked questions page to help users make quality observations and understand all the phenophase definitions.

9.6.4 Project Budburst

Project Budburst is a citizen science project organized by the Chicago Botanic Garden and has both an app and an online platform for recording continental-scale phenological data (Henderson et al., 2017). The project has ties to other botanic gardens and other community partners in the United States who are striving to understand how plants are responding to climate change (BGCI, 2016b). Scientists are bringing in the data about the timing of phenological changes in a particular species into climate computer models to understand and predict seasonal patterns and long-term changes in climate (Chicago Botanic Garden, 2022). The observation form for conifers that is provided to citizen-scientists to record their data asks participants to select the most appropriate phenophases (none, first, early, middle, and late) for needle emergence, pollen release, and cone maturity (Appendix E) (Chicago Botanic Garden, 2021). Although Project Budburst is a partner in the USA National Phenology Network, the program accepts observations from across the world. While there are observations for western redcedars on Project Budburst, all observations are within the United States.

Typically, 5 to 10 years of data collection is sufficient to obtain reliable average dates to characterize phenological timing in an area and to inform trends (Beaubien and Hall-Beyer, 2003). Working with existing citizen scientist platforms that require their participants to record data in a standardized method and format promotes data integrity and consistency across observers (McKinley et al., 2017). Choosing a suitable observation template will allow the phenology studies to be fit for purpose. Organized phenological data collecting programs can allow the UBCBG to study the citizen gathered data and generate local climate actions while building the capacity of communities to respond to climate change.

Compared to Budburst, Nature's Notebook provides more thorough and detailed definitions of phenophase terminology in its data collection template (Appendix E). The Budburst phenology observation form is briefer as it asks participants to check off the most applicable option for each of the pollen and cone categories, while Nature's Notebook asks the participant to identify further quantitative details surrounding each phenophase.

9.6.5 TreeSnap

TreeSnap is a mobile phone app that allows citizen scientists to monitor trees and forests in the United States through the lens of tree health, invasive diseases, and pest threats (Crocker et al., 2019). Citizen scientists submit tree photos and observations linked to global positioning system locations to help scientists at the University of Kentucky and the University of Tennessee study healthy trees that are resilient to forest pests and pathogens (Crocker et al., 2019). The main research objectives are to study genetic diversity and developing better tree breeding programs (Crocker et al., 2019). Citizen scientists are required to fill out research partners' question forms related to tree characteristics, canopy health, and signs of pests or disease by selecting answers from a drop-down menu with the added ability to type additional comments (Crocker et al., 2019). The app is designed to allow observers to submit a record within one minute by minimizing technical terminology in the questions and offering figures and diagrams to guide users during data collection (Crocker et al., 2019). Currently, western redcedar is not identified as a focus tree species within the TreeSnap program. New focal species can be added to TreeSnap if scientific partners request data for a certain species (Crocker et al., 2019). The TreeSnap app's source code and web app are available free and open source on GitHub (Crocker et al., 2019).

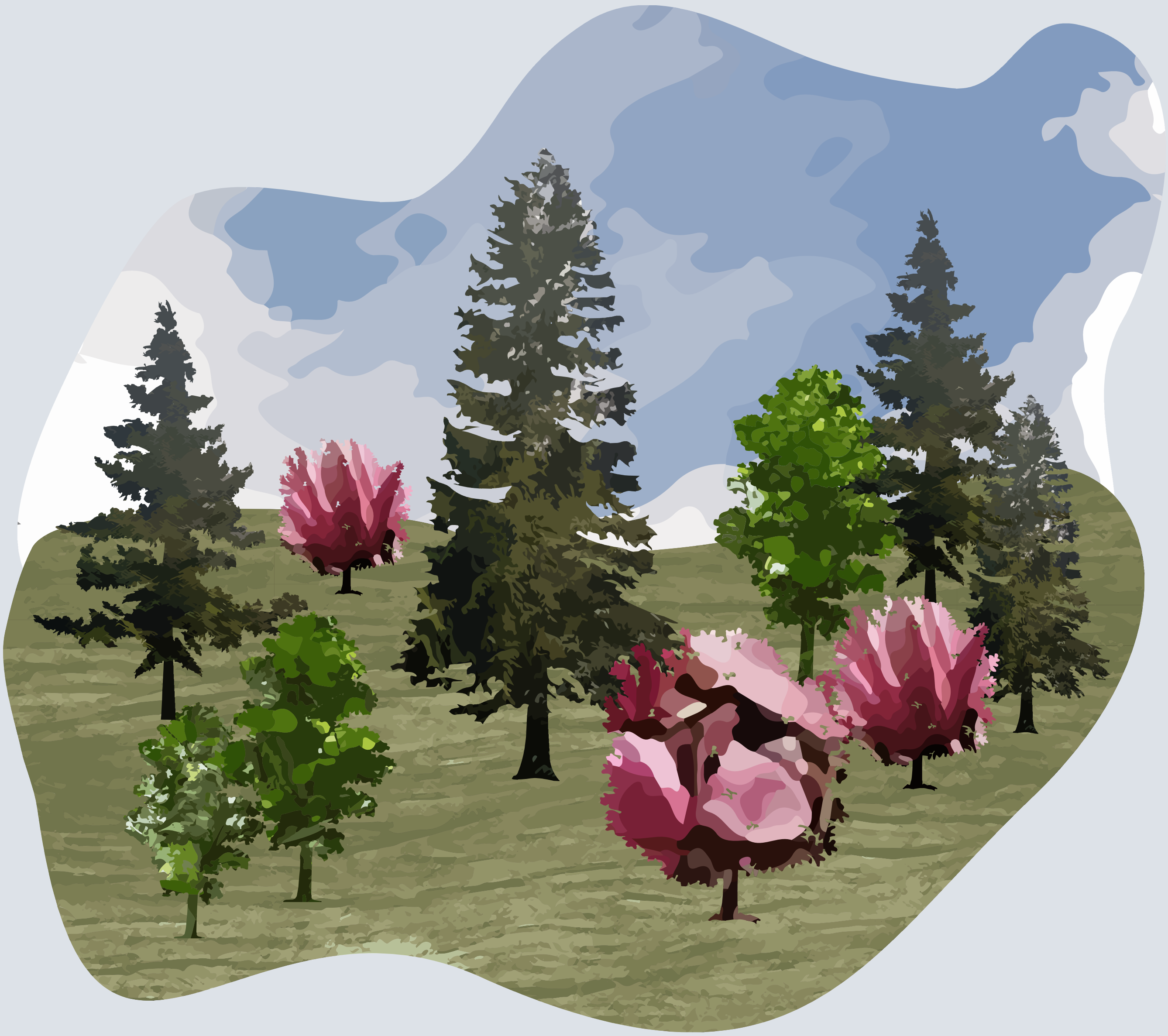
9.6.6 Forest Health Watch

The Western Redcedar Dieback Map pilot project is organized by the Forest Health Watch Program co-designed by researchers in the Pacific Northwest. The program allows citizen scientists to add observations of western redcedar health on iNaturalist via the mobile app or internet browser. The project is transparent in its methods for gathering the data publicly on the iNaturalist app and analyzing and communicating updated observation results daily on the program's website via Tableau, a data visualization software (Forest Health Watch Program, 2020). The monitoring program uses iNaturalist to connect professional research with non-professionals through meaningful collaboration. The project provides a Tree Health Classification – Field Manual that acts as a background information guide for citizen scientists to reference example photos of dieback symptoms and biotic factors affecting western redcedar health (Evans, 2022). The Field Manual presents dieback symptoms such as yellowing canopy, browning canopy, top dieback, branch dieback, thinning canopy, heat damage, and stress cone crop (Evans, 2022). Citizen scientists are also encouraged to look out for other factors that could have a negative impact on the health of western redcedar trees such as Armillaria root disease, cedar bark beetle damage, and invasive plants such as English ivy, Himalayan blackberry, and scotch broom (Evans, 2022). There is a suitable opportunity to collaborate with the Forest Health Watch Program because of their focus on collecting data within the Pacific Northwest and working with Pacific Northwest communities. One avenue for collaboration is to include the western redcedars, or a sample of them from the Asian Garden under a hypothesis test study so that certain questions can be answered surrounding the health of the trees. The Western Redcedar Dieback Map project on iNaturalist prompts users to answer useful data collection questions and offers the ability to take photos associated with the observation. The benefit of using iNaturalist is that all the data is aggregated in an intuitive online interface. There are 20 observation fields that are available to the user for reporting: 1) number of additional unhealthy trees (of same species) in area (within sight); 2) access to water; 3) site hydrology; 4) site type; 5) site/area disturbance level; 6) site/location description; 7) tree size; 8) signs or symptoms of insect, disease, or other damage; 9) percent canopy affected; 10) tree canopy symptoms; 11) heat damage; 12) slope position; 13) timing of symptoms estimate; 14) other unhealthy plant species on the site; 15) dieback percent; 16) estimated time spend to make the observation in minutes; 17) precent of trees (of same species) within sight that are unhealthy; 18) other observed factors; 19) notes; and 20) can researchers follow up with participant (iNaturalist, 2022).

The benefit of using an app like TreeSnap or iNaturalist is that users do not need to be connected to the internet since the data is saved locally on their phone and can be synced to the web server when internet is available again. Both apps can allow for the custom-tailoring to specific research needs.

Overall citizen science can help the UBCBG understand what is happening with the western redcedar population within the Asian Garden. With many eyes in the garden, detection of environmental changes can happen faster. Image analysis through photo collection can fill in data gaps. Any negative impacts or unusual occurrences to the western redcedars may be identified faster and trigger management responses (McKinley et al., 2017). Not all citizen science projects gain a lot of traction since people are driven by their personal curiosities and concern (McKinley et al., 2017), but western redcedars have the cultural charisma to stimulate widespread public interest on the UBC campus. There could be greater enthusiasm generated to conserve the western redcedars in the garden if more people are aware of its cultural significance. Since admission to the garden is free for UBC students, it allows for the potential citizen science students to have a more accessible experience collecting data. A citizen science program surrounding the western redcedars at the Asian Garden can uncover local perspectives, traditional knowledge, and bring out new questions and ideas regarding climate adaptation that might not otherwise be obvious to UBCBG management. Engaging the public early on will be helpful as they can be involved in crafting management activities when the time comes to initiate climate adaptation planning at the UBCBG.

V. Conclusions



10. Research Gaps (Needs and Opportunities)

1. Regarding the planting lists mentioned in section 8.3, it would be useful to determine whether each of the species within the "Very Suitable" (Appendix A), "Suitable" (Appendix B) and "Marginal" (Appendix C) lists are already present in the botanical garden. This could help the UBCBG look up the proportion of plants under the recommended planting lists that are already within the garden and determine their likelihood of persisting on the site based on RCP 4.5 and 8.5. The information could also help the UBCBG determine whether certain species may become more invasive under future drier and warmer climates.

2. Further planning is necessary to determine ways to link phenology monitoring to demographic population monitoring for western redcedars. The UBCBG can determine whether it is more feasible and organized to keep the two monitoring efforts as separate projects or combine them. Demographic monitoring with citizen scientists may require more rigid training, while phenology is more accessible to the broader public.

3. Although there is interest to use the data from the sensors connected to the irrigation system for future climate change research, data has not yet been collected from the sensors for research.

4. While assisted seed migration is recommended, there are currently no straight-forward web-based mapping applications to identify where in western redcedar's current range the UBCBG should consider making targeted seed collecting trips.

5. In relation to section 3.5 regarding the BC First Nations Climate Strategy and Action Plan, there are opportunities for the UBCBG to support First Nations in developing appropriate and effective strategies to address climate-related impacts to western redcedars. Regarding the proposed monitoring recommendations in section 9.0, the results could help support First Nation-led monitoring and data collection frameworks to establish data on climate, and environmental, cultural factors to inform their climate response. Further connections and engagement with interested First Nations would be necessary to develop partnerships around the conservation of western redcedars.

10.1 Research Needs on Western Redcedars

1. Based on the research to date, there are still no concrete answers on the underlying causes of western redcedar dieback in the Pacific Northwest. Since drought tolerance is linked to wood density in other conifers (Martinez- Meier et al., 2009), perhaps this may be an additional important trait that is not well recognized in western redcedar.

2. There is currently not enough information on the effects of snowpack on western redcedar. Based on figure 10, 11, and 12, precipitation in the form of snow is expected to decrease in the following years. Further research is necessary to determine whether lack of snow in the winter and spring months will affect western redcedars. Climate model projections specifically related to snowpack/snow cover may also help.

3. Further studies that quantitatively examine western redcedar's resilience to climate stressors are needed to decide on appropriate management options for western redcedars in a changing climate. Monitoring western redcedars at the Asian Garden can help determine the rate of growth of the trees. As discussed in section 7.7, slower growth could decrease chances of survival. Furthermore, future research would be required to explore the relationship between the species' growth rate and lifespan. Genotypic plasticity and/or

phenotypic plasticity could play a part in how western redcedars react to climate change. It would be important to know whether climate change is reducing the proportion of typically long-lived trees to favour shorter-lived individuals. This information would be helpful when planning future planting lists as well.

4. There are several cultivars of western redcedar grown in the northwestern United States and Canada with variations in shape, size, and foliage color (Cornell University, 2022). Examples of cultivars include 'Zebrina', 'Canadian Gold', 'Irish Gold', 'Stoneham Gold', 'Aurea', 'Rogersii', 'Cuprea', 'Hillieri' and 'Whipcord' (which is also known as 'Filifera') to name a few (Justice, 2013). Several varieties also exist, including *T. plicata* var. *atrovirens*, and *T. plicata* var. *pyramidalis*. Further research is required on the various cultivars and varieties to determine if some are more resistant to higher temperatures, droughts, and pest and diseases. So far, it is known that 'Excelsa' is not resistant to cedar leaf blight while *Thuja plicata* x *standishii* also known as *Thuja* 'Green Giant' is a hybrid that is resistant to cedar leaf blight (Tesky, 1992; Justice, 2013).

11. Conclusions

The results from the MaxEnt species distribution model predicts a future at the UBCBG that is not conducive to western redcedars in 2071-2100. While a warmer climate may help western redcedars extend their range, a lack of moisture and multi-year droughts as estimated through ClimateBC will likely reduce their distributions at the Asian Garden. With western redcedars being a mesic species, they are projected to have increased productivity in cooler, wetter locations. Although irrigation systems are set up within the Asian Garden at the UBCBG, the site is expected to experience drier conditions in the next decades compared to historic conditions. Climate change favours the spread of pests because warmer conditions reduce some species' winter mortality and allows damaging species to extend their range. Higher temperatures have direct effects on insect population dynamics because high temperatures can accelerate insect development and reproduction, especially in aggressive bark beetle species (Allen et al., 2010). Furthermore, cedar bark beetles are more likely to attack trees that are stressed from drought (Forest Service USDA, 2011).

While novel methods to correct for observer and sampling bias in presence-only models exist, species distribution modelling cannot provide a complete substitute for detailed, continuous collection of field observations, including data on species' distribution, population demography, and phenology (Guisan and Thuiller 2005). Since the western redcedars at the Asian Garden are currently healthy, the continuous and longitudinal monitoring of western redcedar will be able to pick up any decline that may occur in the population. Long-term data from monitoring will aid in the decision-making and development of management actions to address climate-related stressors such as 1) changes in edaphic factors; 2) changes in temperature and precipitation; and 3) biotic agents. Regardless of whether the future falls under an RCP 4.5 or SSP4-8.5 scenario, or RCP 8.5 or SSP5-8.5 scenario, over time, the UBCBG can engage in the following to address the impacts of climate change on western redcedar:

1) Engage in adaptive management that focuses on using evidence from the evaluation of planting seed sources from climate-appropriate provenances versus local provenances to inform decisions and action. Similarly, use adaptive management to test the plantings of new species in case western redcedars are maladapted to the Asian Garden in the future.
2) Set up the logistics, capacity, and software to allow for longitudinal data management on western redcedars at the Asian Garden. Ensure that all monitoring templates (multi-age and phenology) are standardized so that baseline data and subsequent data can be of high quality. Longitudinal data is important for research including tracking trends and changes over time.
3) Collaborate with citizen science monitoring programs for western redcedars and share knowledge and information about population demography, phenology and behaviours that would aid the conservation of western redcedars not just within the Asian Garden at the UBCBG, but in other areas outside the garden where western redcedars exist.

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Appendix A – Very Suitable Species Planting List

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Arbutus menziesii	1038	0.4 - 0.5	0.4 - 0.5	0	Yes	No
Albizia julibrissin *	57	0.5 - 0.6	0.4 - 0.5	0.6 - 0.7	No	No
Arbutus unedo	4	N/A	N/A	N/A	Yes	Yes
Calocedrus decurrens *	2240	0	0.3 - 0.4	0.2 - 0.3	No	No
Catalpa speciosa *	205	0	0	0	No	No
Cedrus deodara *	2	N/A	N/A	N/A	No	No
Celtis occidentalis *	7759	0	0	0	No	No
Celtis sinensis •	N/A	N/A	N/A	N/A	Yes	Yes
Cercis canadensis	3502	0	0	0	No	No
Cotinus coggygria	16	N/A	N/A	N/A	Yes	Yes
Crataegus crus-galli	128	0	0	0	No	No
Crataegus x lavalleei	1	N/A	N/A	N/A	Yes	Yes
Crataegus x mordenensis	3	N/A	N/A	N/A	Yes	Yes
Cupressus arizonica *•	25	N/A	N/A	N/A	No	No
Cupressus macrocarpa *	2	N/A	N/A	N/A	No	No
Cupressus sempervirens	1	N/A	N/A	N/A	Yes	Yes
Cupressus x leylandii	1	N/A	N/A	N/A	Yes	Yes
Eucommia ulmoides	2	N/A	N/A	N/A	Yes	Yes
Ficus carica *	3	N/A	N/A	N/A	No	No
Fraxinus ornus	3	N/A	N/A	N/A	Yes	Yes
Ginkgo biloba	19	N/A	N/A	N/A	Yes	Yes
Gleditsia triacanthos	4465	0	0	0	No	No
Gymnocladus dioicus	721	0	0	0	No	No
Juglans major •	1	N/A	N/A	N/A	Yes	Yes
Juniperus chinensis	17	N/A	N/A	N/A	Yes	Yes
Juniperus virginiana *	7850	0	0	0	No	No
Koelreuteria bipinnata *•	0	N/A	N/A	N/A	No	No
Koelreuteria paniculata *	8	N/A	N/A	N/A	No	No
Lagerstroemia x 'tuscarora'•	0	N/A	N/A	N/A	Yes	Yes
...continued	3	N/A	N/A	N/A	Yes	Yes

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Maackia amurensis •	3	N/A	N/A	N/A	Yes	Yes
Maclura pomifera *•	2895	0	0	0	No	No
Notholithocarpus densiflorus	904	0	0.1 - 0.2	0.3 - 0.4	Yes	Yes
Nyssa sinensis	0	N/A	N/A	N/A	Yes	Yes
Olea europaea *•	0	N/A	N/A	N/A	No	No
Phellodendron amurense *	3	N/A	N/A	N/A	No	No
Pinus banksiana	23,454	0	0	0	No	No
Pinus contorta	23,992	0.2 - 0.3	0	0	No	No
Pinus flexilis	1,135	0	0	0	No	No
Pinus mugo	9	N/A	N/A	N/A	Yes	Yes
Pinus nigra	86	0	0	0	No	No
Pinus pinea *•	0	N/A	N/A	N/A	No	No
Pinus ponderosa	16,266	0.3 - 0.4	0.2 - 0.3	0	Yes	No
Pinus sylvestris *	1,824	0	0	0	No	No
Pinus thunbergii *	3	N/A	N/A	N/A	No	No
Pistacia chinensis	0	N/A	N/A	N/A	Yes	Yes
Prunus dulcis •	0	N/A	N/A	N/A	Yes	Yes
Pyrus calleryana *	8	N/A	N/A	N/A	No	No
Pyrus pyrifolia •	2	N/A	N/A	N/A	Yes	Yes
Quercus acutissima *	4	N/A	N/A	N/A	No	No
Quercus agrifolia •	1,405	0	0.1 - 0.2	0.1 - 0.2	Yes	Yes
Quercus alba	41,186	0	0.1 - 0.2	0	Yes	No
Quercus coccinea	11,465	0	0	0	No	No
Quercus garryana	996	0.2 - 0.3	0.4 - 0.5	0.1 - 0.2	Yes	Yes
Quercus ilex •	0	N/A	N/A	N/A	Yes	Yes
Quercus imbricaria •	2,079	0	0	0	No	No
Quercus macrocarpa	7,328	0	0	0	No	No
Quercus shumardii	1,408	0	0	0	No	No
Quercus suber •	0	N/A	N/A	N/A	Yes	Yes
...continued						

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Quercus virginiana •	2,504	0	0	0	No	No
Rhus typhina	1,304	0	0	0	No	No
Sorbus aria	3	N/A	N/A	N/A	Yes	Yes
Ulmus propinqua •	0	N/A	N/A	N/A	Yes	Yes

Note: The "Very Suitable" planting list contains species that can handle heat and cold and are tolerant of sites experiencing up to approximately 1 month of drought (Diamond Head, 2019b). * Invasive potential - capable of self-seeding. • Trial – the species is present in future comparable climates. Probability of occurrence values are retrieved from Natural Resources Canada (2021d). Yes = considered in planting list for respective scenario; No = not considered in planting list for respective scenario.

Appendix B – Suitable Species Planting List

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Abies concolor	4,396	0.2 - 0.3	0.1 - 0.2	0	Yes	No
Abies procera	1451	0	0	0	No	No
Acer buergerianum •	0	N/A	N/A	N/A	Yes	Yes
Acer campestre *	8	N/A	N/A	N/A	Yes	Yes
Acer cappadocicum	2	N/A	N/A	N/A	Yes	Yes
Acer grandidentatum •	256	0	0	0	No	No
Acer griseum	15	N/A	N/A	N/A	Yes	Yes
Acer japonicum	5	N/A	N/A	N/A	Yes	Yes
Acer miyabei	2	N/A	N/A	N/A	Yes	Yes
Acer negundo *	8,290	0	0	0	No	No
Acer nigrum	649	0	0	0	No	No
Acer platanoides *	3,225	0	0	0	No	No
Acer pseudoplatanus *	10	N/A	N/A	N/A	No	No
Acer rubrum *	79,383	0	0	0	No	No
Acer saccharinum	3,498	0	0	0	No	No
Acer saccharum	48,008	0	0	0	No	No
Acer tataricum *	3	N/A	N/A	N/A	No	No
Acer triflorum	6	N/A	N/A	N/A	Yes	Yes
Acer x freemanii	95	0	0	0	No	No
Aesculus hippocastanum *	40	0.5 - 0.6	0.1 - 0.2	0	No	No
Aesculus x carnea	2	N/A	N/A	N/A	Yes	Yes
Alnus cordata *	0	N/A	N/A	N/A	No	No
Alnus rubra	3,107	0.5 - 0.6	0	0	No	No
Amelanchier canadensis	206	0	0	0	No	No
Amelanchier laevis	899	0	0	0	No	No
Amelanchier x grandiflora	1	N/A	N/A	N/A	Yes	Yes
Araucaria araucana	3	N/A	N/A	N/A	Yes	Yes
Arbutus 'marina' •	0	N/A	N/A	N/A	Yes	Yes
Betula alleghaniensis	29,839	0	0	0	No	No
...continued						

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Carpinus betulus	4	N/A	N/A	N/A	Yes	Yes
Carpinus japonica	1	N/A	N/A	N/A	Yes	Yes
Castanea mollissima	5	N/A	N/A	N/A	Yes	Yes
Castanea sativa	1	N/A	N/A	N/A	Yes	Yes
Catalpa bignonioides *	102	0	0	0	No	No
Cedrus atlantica	4	N/A	N/A	N/A	Yes	Yes
Cercis chinensis	2	N/A	N/A	N/A	Yes	Yes
Cercis occidentalis •	596	0	0	0	No	No
Cercis siliquastrum	1	N/A	N/A	N/A	Yes	Yes
Chamaecyparis obtusa	5	N/A	N/A	N/A	Yes	Yes
Chamaecyparis pisifera	4	N/A	N/A	N/A	Yes	Yes
Chionanthus retusus •	4	N/A	N/A	N/A	Yes	Yes
Cladrastis kentukea	63	0	0.1 - 0.2	0.1 - 0.2	Yes	Yes
Clerodendrum trichotomum	1	N/A	N/A	N/A	Yes	Yes
Cornus controversa	2	N/A	N/A	N/A	Yes	Yes
Cornus florida	27,083	0	0.1 - 0.2	0	Yes	No
Cornus mas	4	N/A	N/A	N/A	Yes	Yes
Corylus avellana *	8	N/A	N/A	N/A	No	No
Corylus colurna	3	N/A	N/A	N/A	Yes	Yes
Crataegus douglasii	263	0.1 - 0.2	0	0	No	No
Crataegus grignonensis •	0	N/A	N/A	N/A	Yes	Yes
Crataegus phaenopyrum *	11	N/A	N/A	N/A	No	No
Cryptomeria japonica *	3	N/A	N/A	N/A	No	No
Davidia involucrata	0	N/A	N/A	N/A	Yes	Yes
Eriobotrya japonica •	0	N/A	N/A	N/A	Yes	Yes
Eucalyptus pauciora •	0	N/A	N/A	N/A	Yes	Yes
Fraxinus angustifolia	2	N/A	N/A	N/A	Yes	Yes
Fraxinus excelsior	8	N/A	N/A	N/A	Yes	Yes
Fraxinus velutina	303	0	0	0	No	No
...continued						

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Heptacodium miconioides •	2	N/A	N/A	N/A	Yes	Yes
Hibiscus syriacus *	20	N/A	N/A	N/A	No	No
Juglans regia	7	N/A	N/A	N/A	Yes	Yes
Laburnum anagyroides *	1	N/A	N/A	N/A	No	No
Laburnum x watereri *	2	N/A	N/A	N/A	No	No
Lagerstroemia indica *•	2	N/A	N/A	N/A	No	No
Ligustrum japonicum * •	0	N/A	N/A	N/A	No	No
Ligustrum lucidum *•	0	N/A	N/A	N/A	No	No
Liquidambar styraciflua	38,584	0	0.1 - 0.2	0.2 - 0.3	Yes	Yes
Liriodendron tulipifera	23,402	0	0	0	No	No
Magnolia grandiflora	1,415	0	0	0	No	No
Malus baccata *	6	N/A	N/A	N/A	No	No
Malus domestica	12	N/A	N/A	N/A	Yes	Yes
Malus floribunda *	2	N/A	N/A	N/A	No	No
Malus pumila *	80	0	0	0	No	No
Malus sylvestris *	7	N/A	N/A	N/A	No	No
Malus transitoria	0	N/A	N/A	N/A	Yes	Yes
Malus tschonoskii •	0	N/A	N/A	N/A	Yes	Yes
Malus x moerlandsii •	0	N/A	N/A	N/A	Yes	Yes
Malus x zumi	2	N/A	N/A	N/A	Yes	Yes
Manglietia insignis	0	N/A	N/A	N/A	Yes	Yes
Morus alba *	847	0	0	0	No	No
Nothofagus antarctica	0	N/A	N/A	N/A	Yes	Yes
Ostrya carpinifolia	0	N/A	N/A	N/A	Yes	Yes
Ostrya virginiana	9763	0	0	0	No	No
Oxydendrum arboreum	10876	0	0	0	No	No
Parrotia persica	3	N/A	N/A	N/A	Yes	Yes
Photinia x fraseri •	1	N/A	N/A	N/A	Yes	Yes
Picea glauca	42021	0.1 - 0.2	0	0	No	No
...continued						

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Picea omorika	7	N/A	N/A	N/A	Yes	Yes
Picea pungens	117	0	0	0	No	No
Pinus parviflora	4	N/A	N/A	N/A	Yes	Yes
Pinus radiata *	89	N/A	N/A	N/A	No	No
Platanus x hispanica	4	N/A	N/A	N/A	Yes	Yes
Platycladus orientalis •	5	N/A	N/A	N/A	Yes	Yes
Populus alba *	387	0	0	0	No	No
Populus fremontii •	0	N/A	N/A	N/A	Yes	Yes
Populus nigra *	12	N/A	N/A	N/A	No	No
Prunus americana	502	0	0	0	No	No
Prunus armeniaca	5	N/A	N/A	N/A	Yes	Yes
Prunus avium *	136	0	0	0	No	No
Prunus caroliniana	0	N/A	N/A	N/A	Yes	Yes
Prunus cerasifera *	3	N/A	N/A	N/A	No	No
Prunus cerasus *	18	N/A	N/A	N/A	No	No
Prunus domestica *	4	N/A	N/A	N/A	No	No
Prunus emarginata	1295	0.6 - 0.7	0	0	No	No
Prunus pendula •	3	N/A	N/A	N/A	Yes	Yes
Prunus salicina	5	N/A	N/A	N/A	Yes	Yes
Prunus sargentii	3	N/A	N/A	N/A	Yes	Yes
Prunus serotina	33511	0	0	0	No	No
Prunus serrula	1	N/A	N/A	N/A	Yes	Yes
Prunus serrulata	1	N/A	N/A	N/A	Yes	Yes
Prunus subhirtella	3	N/A	N/A	N/A	Yes	Yes
Prunus virginiana *	6368	0	0	0	No	No
Prunus x blireiana	0	N/A	N/A	N/A	Yes	Yes
Prunus x yedoensis	2	N/A	N/A	N/A	Yes	Yes
Pseudotsuga menziesii	35121	0.5 - 0.6	0	0	No	No
Pyrus communis *	41	0	0	0	No	No
...continued						

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Pyrus kawakamii •	8	N/A	N/A	N/A	Yes	Yes
Pyrus salicifolia	2	N/A	N/A	N/A	Yes	Yes
Quercus alba x robur	0	N/A	N/A	N/A	Yes	Yes
Quercus bicolor	1282	0	0	0	No	No
Quercus frainetto	0	N/A	N/A	N/A	Yes	Yes
Quercus lobata •	746	0	0	0	No	No
Quercus robur *	18	N/A	N/A	N/A	No	No
Quercus rubra	34661	0	0	0	No	No
Rhamnus purshiana	451	0.5 - 0.6	0.2 - 0.3	0	Yes	No
Salix scouleriana	4476	0	0	0	No	No
Salix x sepulcralis	2	N/A	N/A	N/A	Yes	Yes
Sequoiadendron giganteum	104	0	0	0	No	No
Sophora japonica *	4	N/A	N/A	N/A	No	No
Sorbus x thuringiaca	0	N/A	N/A	N/A	Yes	Yes
Stewartia monadelpha	1	N/A	N/A	N/A	Yes	Yes
Stewartia pseudocamellia	3	N/A	N/A	N/A	Yes	Yes
Styrax japonicus	4	N/A	N/A	N/A	Yes	Yes
Syringa pekinensis •	3	N/A	N/A	N/A	Yes	Yes
Syringa vulgaris *	62	0.4 - 0.5	0	0	No	No
Taxodium distichum	4809	0	0	0	No	No
Taxus baccata	7	N/A	N/A	N/A	Yes	Yes
Taxus brevifolia	2318	0.4 - 0.5	0	0	No	No
Thuja occidentalis *	22464	0	0	0	No	No
Tilia americana	13260	0	0	0	No	No
Tilia cordata	18	N/A	N/A	N/A	Yes	Yes
Tilia platyphyllos	4	N/A	N/A	N/A	Yes	Yes
Tilia tomentosa	4	N/A	N/A	N/A	Yes	Yes
Tilia x euchlora	2	N/A	N/A	N/A	Yes	Yes
Tilia x europaea	8	N/A	N/A	N/A	Yes	Yes
...continued						

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Trachycarpus fortunei	17	N/A	N/A	N/A	Yes	Yes
Ulmus americana *	27112	0	0	0	No	No
Ulmus parvifolia *	3	N/A	N/A	N/A	No	No
Ulmus procera *	7	N/A	N/A	N/A	No	No
Ulmus wilsoniana 'prospector' •	2	N/A	N/A	N/A	Yes	Yes
Ulmus x hollandica xChitalpa tashkentensis	0	N/A	N/A	N/A	Yes	Yes
Zelkova serrata	4	N/A	N/A	N/A	Yes	Yes

Note: The "Suitable" planting list contains species anticipated to tolerate all but the driest sites under future climates (Diamond Head, 2019b). * Invasive potential - capable of self-seeding. • Trial – the species is present in future comparable climates. Probability of occurrence values are retrieved from Natural Resources Canada (2021d). Yes = considered in planting list for respective scenario; No = not considered in planting list for respective scenario.

Appendix C – Marginal Species Planting List

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Abies grandis	6,700	0.4 - 0.5	0.2 - 0.3	0	Yes	No
Acer capillipes	3	N/A	N/A	N/A	Yes	Yes
Acer circinatum	4,251	0.3 - 0.4	0.1 - 0.2	0	Yes	No
Acer macrophyllum	3,114	0.5 - 0.6	0.4 - 0.5	0	Yes	No
Acer palmatum *	38	> 0.9	0.7 - 0.8	0.5 - 0.6	Yes	Yes
Acer pensylvanicum	9,537	0	0	0	No	No
Acer truncatum	4	N/A	N/A	N/A	Yes	Yes
Aesculus flava	638	0	0	0	No	No
Aesculus pavia	28	N/A	N/A	N/A	Yes	Yes
Alnus rhombifolia	1,033	0.2 - 0.3	0.6 - 0.7	0.6 - 0.7	Yes	Yes
Amelanchier arborea	371	0	0	0	No	No
Betula jacquemontii	1	N/A	N/A	N/A	Yes	Yes
Betula nigra	1,667	0	0	0	No	No
Betula papyrifera	90,150	0	0	0	No	No
Betula populifolia	2,587	0	0	0	No	No
Betula utilis	1	N/A	N/A	N/A	Yes	Yes
Carpinus caroliniana	6,189	0	0	0	No	No
Carya illinoinensis •	1,044	0	0	0.2 - 0.3	No	Yes
Cercidiphyllum japonicum	9	N/A	N/A	N/A	Yes	Yes
Chamaecyparis lawsoniana *	235	0.1 - 0.2	0.5 - 0.6	0.7 - 0.8	No	No
Chamaecyparis nootkatensis	1,509	0	0	0	No	No
Cornus kousa	7	N/A	N/A	N/A	Yes	Yes
Cornus nuttallii	1,301	0.3 - 0.4	0.4 - 0.5	0.4 - 0.5	Yes	Yes
Cornus x rutgersiensis *	0	N/A	N/A	N/A	No	No
Fagus grandifolia	24,057	0	0	0	No	No
Fagus sylvatica	9	N/A	N/A	N/A	Yes	Yes
Fraxinus americana	24,800	0	0	0	No	No
Fraxinus latifolia	501	0.5 - 0.6	0.7 - 0.8	0.6 - 0.7	Yes	Yes
Halesia carolina	39	0	0.2 - 0.3	0.3 - 0.4	Yes	Yes
...continued						

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Juglans cinerea	2,458	0	0	0	No	No
Juglans nigra *	9,800	0	0	0	No	No
Larix decidua	67	0	0	0	No	No
Laurus nobilis	0	N/A	N/A	N/A	Yes	Yes
Liriodendron chinense	0	N/A	N/A	N/A	Yes	Yes
Magnolia denudata	1	N/A	N/A	N/A	Yes	Yes
Magnolia 'galaxy'	1	N/A	N/A	N/A	Yes	Yes
Magnolia kobus	4	N/A	N/A	N/A	Yes	Yes
Magnolia sieboldii	7	N/A	N/A	N/A	Yes	Yes
Magnolia stellata	14	N/A	N/A	N/A	Yes	Yes
Magnolia virginiana	6,352	0	0	0	No	No
Magnolia x kewensis	0	N/A	N/A	N/A	Yes	Yes
Magnolia x loebneri	2	N/A	N/A	N/A	Yes	Yes
Magnolia x soulangeana	11	N/A	N/A	N/A	Yes	Yes
Malus fusca	155	0.3 - 0.4	0	0	No	No
Metasequoia glyptostroboides	10	N/A	N/A	N/A	Yes	Yes
Nyssa sylvatica	35,860	0	0.1 - 0.2	0.1 - 0.2	Yes	Yes
Picea abies *	1,054	0	0	0	No	No
Picea sitchensis	1,873	0.4 - 0.5	0	0	No	No
Pinus halepensis •	0	N/A	N/A	N/A	Yes	Yes
Pinus monticola	2,730	0.3 - 0.4	0	0	No	No
Pinus strobus *	24,071	0	0	0	No	No
Platanus occidentalis	5,965	0	0	0	No	No
Populus balsamifera	13,496	0.2 - 0.3	0	0	No	No
Populus tremuloides	48,469	0.1 - 0.2	0.1 - 0.2	0	Yes	No
Prunus ilicifolia •	0	N/A	N/A	N/A	Yes	Yes
Prunus padus *	7	N/A	N/A	N/A	No	No
Prunus persica •	34	0	0	0	No	No
Quercus palustris *	1,837	0	0	0	No	No
...continued						

Species	# of Records Used to Produce MaxEnt Climatic Range Map	Current Distribution Probability (1971-2000) at UBCBG	Occurrence Probability for RCP 4.5 between 2071-2100 at UBCBG	Occurrence Probability for RCP 8.5 between 2071-2100 at UBCBG	Plant in RCP 4.5 Scenario	Plant in RCP 8.5 Scenario
Quercus phellos	6,584	0	0	0	No	No
Salix babylonica	19	N/A	N/A	N/A	Yes	Yes
Salix matsudana *	4	N/A	N/A	N/A	No	No
Sequoia sempervirens	527	0	0	0.2 - 0.3	No	Yes
Sorbus alnifolia	3	N/A	N/A	N/A	Yes	Yes
Sorbus americana	10, 626	0	0	0	No	No
Sorbus intermedia •	3	N/A	N/A	N/A	Yes	Yes
Styrax obassia	3	N/A	N/A	N/A	Yes	Yes
Syringa reticulata	6	N/A	N/A	N/A	Yes	Yes
Thuja plicata	11,641	0.5 - 0.6	0	0	No	No
Thujopsis dolabrata	2	N/A	N/A	N/A	Yes	Yes
Tsuga canadensis	13,792	0	0	0	No	No
Tsuga heterophylla	18,799	0.5 - 0.6	0.1 - 0.2	0	Yes	No
Tsuga mertensiana	4,125	0	0	0	No	No
Ulmus davidiana	2	N/A	N/A	N/A	Yes	Yes
Ulmus glabra	2	N/A	N/A	N/A	Yes	Yes
Umbellularia californica •	1,017	0	0	0.3 - 0.4	No	Yes

Note: The "Marginal" planting list contains species that are anticipated to be restricted to moist sites under future climate (Diamond Head, 2019b). * Invasive potential - capable of self-seeding. • Trial – the species is present in future comparable climates. Probability of occurrence values are retrieved from Natural Resources Canada (2021d). Yes = considered in planting list for respective scenario; No = not considered in planting list for respective scenario.

Appendix D - Proposed Monitoring Form Template

Person Monitoring (Name): Title: Qualifications: Volunteer (Y/N):	Date: Current climatic conditions: Lighting conditions:	Site Location: Site Location Type:														
Tree ID	Support tree for Greenheart TreeWalk	Mortality Status	Ground Cover	Height	Stem diameter	Crown Diameter	Crown Vigor	Discoloration	Crown dieback	Structural Condition	Abiotic Damage	Abiotic Damage Cause	Biotic Damage Cause	Biotic Damage Cause	Health Condition	Notes for supervisory review
#	Y/N	Alive, standing dead, stump, removed	Soil, mulch, understory plantings	From ground to top of crown measured vertically in metres	DBH in metres measured at 1.4 metres above the ground	Live width of the crown in two directions: north-south and east-west in metres	1 - Healthy, 2 - slightly unhealthy, 3 - moderately unhealthy, 4 - severely unhealthy, 5 - dead	Percent and location based on visual evidence	Percent and location based on visual evidence	Tree lean, hollow, splits in trunk, dead limbs, hazardous tops	Y/N	Mechanical injury, windthrow, snow/freeze damage, growing season drought, flooding	Y/N	Pest name, fungal disease name, estimated number and location of damage	Decay symptoms (heart rot decay etc.)	Description of issue that cannot be resolved in the field
Sample	N	Alive	Soil, with understory plantings	5	0.5	N-S: 1.7 E-W: 1.5	3 - Moderately unhealthy	30% discoloration at the top of the crown	20% branch dieback of the crown; individual irregular or uneven locations	Stable	Y	Mechanical injury from construction	Y	*Trachykele blondeli* (western cedar borer), frass and boring holes on the lower trunk	Abnormal branch collar swelling with young branch shoots emanating from swollen area	None

Note. This spreadsheet is adapted from the following sources: iTree, 2021; von Doorn, 2020; Roman et al., 2020

It is useful to note climatic conditions such as cloudy/overcast skies, fog, rain as these conditions may affect visual estimates (i-Tree, 2021). It may be possible to underestimate crown dieback during poor lighting conditions (i-Tree, 2021). Moving around the tree to obtain various views is necessary to produce sound estimates (i-Tree, 2021).

Crown vigor classes are described in Roman et al., 2020, pp. 34. Crown dieback does not capture natural branch dieback from self-pruning due to crown competition or shading in the lower portion of the crown (i-Tree, 2021).

Appendix E - Comparison between the Observation Reporting Format for Phenology between Nature's Notebook and Budburst

Nature's Notebook	Budburst
Pollen cones One or more fresh, male pollen cones (strobili) are visible on the plant. Cones have overlapping scales that are initially tightly closed, then spread apart to open the cone and release pollen. Include cones that are unopened or open, but do not include wilted or dried cones that have already released all their pollen. ***How many fresh pollen cones are present?*** Less than 3 3 to 10 11 to 100 101 to 1,000 1,001 to 10,000 More than 10,000	**Pollen** **None:** No pollen is falling.
Open pollen cones One or more open, fresh, male pollen cones (strobili) are visible on the plant. Cones are considered "open" when the scales have spread apart to release pollen. Do not include wilted or dried cones that have already released all their pollen. ***What percentage of all fresh pollen cones (unopened plus open) on the plant are open?*** Less than 5% 5-24% 25-49% 50-74% 75-94% 95% or more	**Pollen** **First phase:** Plant starts releasing the powdery yellow pollen from cones on three of more branches (from male cones which are usually small and rounded). When open, the male cones will release yellow pollen dust when touched.
Pollen release One or more male cones (strobili) on the plant release visible pollen grains when gently shaken or blown into your palm or onto a dark surface. ***How much pollen is released?*** **Little**: Only a few grains are released. **Some**: Many grains are released. **Lots**: A layer of pollen covers your palm, or a cloud of pollen can be seen in the air when the wind blows	**Pollen** **Early phase**: Some pollen is falling (less than 5%). **Middle phase**: Half or more branches have pollen. When open, the male cones will release yellow pollen dust when touched.

Unripe seed cones One or more unripe, female seed cones are visible on the plant. For *Thuja plicata*, an unripe seed cone is green with scales closed together. ***How many seed cones are unripe?*** Less than 3 3 to 10 11 to 100 101 to 1,000 1,001 to 10,000 More than 10,000	**Cones** **None:** No ripe cones or seeds visible.
Ripe seed cones One or more ripe, female seed cones are visible on the plant. For *Thuja plicata*, a seed cone is considered ripe when it has turned brown, and the scales have begun to spread apart to expose the seeds inside. Do not include empty cones that have already dropped all their seeds. ***How many seed cones are ripe?*** Less than 3 3 to 10 11 to 100 101 to 1,000 1,001 to 10,000 More than 10,000	**Cones** **First phase:** First seed cones becoming fully ripe or seeds dropping naturally from the plant on three or more branches. Record when the seed cones turn brown, and the scales expand (seeds should start dispersing shortly thereafter).
Recent cone or seed drop One or more seed cones or seeds have dropped or been removed from the plant since your last visit. Do not include empty seed cones that had long ago dropped all their seeds but remained on the plant. ***How many seed cones have dropped seeds or have completely dropped or been removed from the plant since your last visit?*** Less than 3 3 to 10 11 to 100 101 to 1,000 1,001 to 10,000 More than 10,000	**Cones** **Early phase:** Only a few branches have fully ripe cones or seeds dropping naturally from the tree (less than 5%). **Middle phase:** Half or more branches have fully ripe cones or most of the seeds are dropping naturally from the tree. **Late phase:** Most cones are open, and seeds have been dispersed from plant (over 95%)
Source: USA-NPN, 2022	Source: Chicago Botanic Garden, 2021