Urban Forest Climate Adaptation Framework for Metro Vancouver

Tree Species Selection, Planting and Management

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Metro Vancouver

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Project context

Metro Vancouver's management plans identify adapting to climate change as an important piece of building and maintaining a livable region. Many member municipalities and Metro Vancouver land managers have been actively engaged in evaluating the condition and rate of change in their urban forests, but have had limited practical guidance about how to plan and manage these complex systems in a changing climate.

As a regional government, Metro Vancouver has an interest in increasing the resilience of the urban forest to climate change and maximizing the benefits from urban forests in the region. This project was initiated in response to concern that the region's existing urban forest may not be well suited to the changing climate and, if so, the need for practical guidance on how to adapt the urban forest. Healthy urban forests mitigate climate change and can help people and organisms adapt to the changing climate, playing a large role the region's ongoing livability.

The purpose of this project was to identify the risks facing urban forests, assess regional vulnerability of the existing urban forest and develop a framework and guidelines for building resilience moving forward. Regionally specific guidance on species selection and management techniques can help reduce the risk of significant urban forest mortality and maximize the benefits (ecosystem services) urban forests provide. A second piece of work was developed concurrently to address the design and siting of trees to maximize climate adaptation benefits (Design Guidebook: Maximizing Climate Adaptation Benefits with Trees).

Metro Vancouver staff, municipal partners and external experts were engaged at the outset of the project to provide input on the project scope, content and final product. The first point of engagement consisted of a survey of current perceptions of climate change impacts and adaptation objectives sent out in October 2015. Two workshops followed in October and November and focused on:

- Objectives for managing climate change vulnerability in the tree population;
- Objectives for using trees to adapt communities to climate change;
- Rating risk and vulnerability in the tree population; and
- Key content to communicate when designing priority places for climate adaptation.

Summaries of the outcomes of the Advisory Panel workshops are included in Appendix 1.

1 Introduction

Metro Vancouver's urban forest consists of all of the publicly and privately owned trees and supporting vegetation in the urban areas of the region [1]. Urban forests are integral to our region's urban ecology and livability [2, 3, 4]. Our urban forests are planted or retained by human design and include individual trees and groups of trees located in natural areas, parks, backyards, on streets, and in commercial and industrial zones.

Healthy urban forests are community assets that appreciate in value over time as they grow and produce direct (e.g., shade) and indirect (e.g., encouraging outdoor activity) benefits for human health and well-being. These benefits are effectively services produced by the ecosystem functions of the urban forest. The magnitude of the benefits produced is largely determined by canopy cover extent and forest structure [5].

Urban forests are included in BC's "climate action toolkit"[1] because they provide ecosystem services that help communities to mitigate and adapt to a changing climate. Beyond climate adaptation planning, regional and local government planning initiatives often point to the urban forest as a means to achieve benefits for biodiversity, ecosystem restoration, stormwater, watershed health, energy conservation, microclimate moderation, recreation, urban food foraging and landscape beautification. The capacity of the urban forest to produce beneficial services depends on its health and resilience, as well as the quality of urban forest planning and management. When urban forests or individual elements within them are performing poorly, disservices are the result. Disservices include harmful outcomes such as infrastructure damage, allergic reactions or high management costs.

The changing climate will inevitably impact the urban forest and its capacity to deliver beneficial ecosystem services to our communities. **Trees are a keystone structure of urban ecosystems** [6]**. Maintaining and enhancing the health and resilience of trees is essential for urban forests to continue producing beneficial services**. The Urban Forest Climate Adaptation Framework for Metro Vancouver includes a comprehensive description of potential regional climate impacts and associated risks to the urban forest resource.

The framework and associated guidelines will support land managers in making informed decisions about future urban forest planning and management. Achieving success in adapting Metro Vancouver's urban forest to climate change means to:

1. Maintain a healthy, resilient and safe tree population;
2. Increase the health and resilience of the native tree population to climate change impacts;
3. Enhance soil and water resources available for the urban forest;
4. Maximize the beneficial services provided by the urban forest;
5. Maximize cost efficiencies when managing the urban forest.

Towards meeting these objectives, this project provides regionally specific guidance for species selection and management to grow an urban forest that is resilient to climate change.

[1] http://www.toolkit.bc.ca/Plan-Do/Urban-Forests, coordinated by the Green Communities Committee, Province of BC, Smart Planning for Communities, with the Fraser Basin Council and the Union of BC Municipalities.

2 Metro Vancouver's Urban Forest

Climate broadly drives native tree species distribution and determines which introduced tree species can successfully grow in Metro Vancouver. Climatic conditions across the Metro Vancouver region vary dramatically in terms of temperature and precipitation (Figure 1). The region straddles the Coastal Douglas Fir (CDF) Biogeoclimatic Zone[2] and the drier subzones of the Coastal Western Hemlock (CWH) Biogeoclimatic Zone. Annual precipitation nearly triples moving from the driest parts of the CDF in the southwest to the wettest parts of CWH in the north of the region [7] (Figure 1). Metro Vancouver's current climate is suitable for a broad range of native and non-native tree species and, combined with favourable soils and site conditions, supports the growth of large trees and forests.

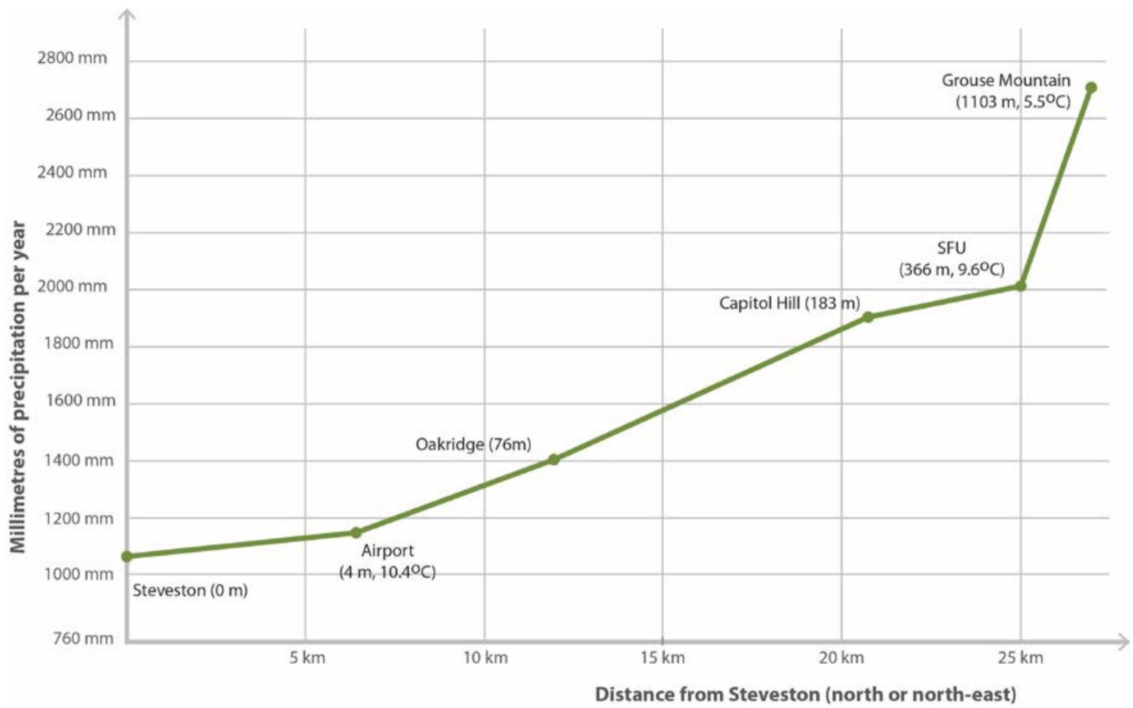


Figure 1. Annual precipitation and average temperature across Metro Vancouver with increasing elevation from sea-level, and increasing distance from southwest to north/north-east (graph adapted from the Lower Mainland Regional Planning Board of B.C., 1952 [8] using data from the Environment Canada climate normals: 1981 to 2010 [9]).

Metro Vancouver's urban forest includes planted trees as well as naturally established native trees and forested areas within the urbanized 'regional core' (Figure 2). Most of the region was cleared of old growth forests at the turn of the last century. Mature native forests that established after this disturbance typically consist of large conifer species including Douglas-fir, western redcedar and western hemlock. Deciduous trees are more often a minor component of mature native forest stands but tend to dominate in riparian areas and on more recently disturbed sites in the region. Common deciduous species include red alder, bigleaf maple, black cottonwood, bitter cherry and

[2] At the regional level, vegetation, soils, and topography are used to infer the regional climate and to identify geographic areas that have relatively uniform climate. A zone is a large geographic area with a broadly homogeneous macroclimate. For more information on Biogeoclimatic Ecosystem Classification visit https://www.for.gov.bc.ca/hre/becweb/index.html.

paper birch. Species dominance and distribution varies because of both local climate and site conditions.

Metro Vancouver's Sensitive Ecosystem Inventory (SEI) maps the 'Sensitive or Modified Ecosystems' across the regional landbase. In addition to forests, the SEI includes wetlands, riparian and alpine ecosystems. Native forests are the most common ecosystems within the SEI. The vast majority of sensitive ecosystem area is concentrated in the northern half of the region and outside the urbanized regional core. As a result, most of the region's native forest areas are not the focus of urban forest management. There are, however, patches of native forest ecosystems in parks and agricultural areas within the regional core that do form part of the urban forest.

Within the region's urban core, trees planted along streets, in parks and on public or private properties form a substantial component of the urban forest. Typically, these trees are managed by municipal governments and private landowners. Planted urban forests often grow in environments that are highly modified from a natural forest state and need to cater to a broad range of competing uses. Not all trees can perform well in urban environments, therefore, planted urban forests usually consist of a combination of native and non-native trees selected for their tolerance to urban conditions. By contrast, native stands of trees in the urban forest tend to occur in locations that have been protected from, or are yet to experience, substantial site modification.

Forest cover across the region is mapped in Figure 2 [10] to illustrate the extent of the urban forest in the regional core. The map shows approximate canopy cover for the region from the year 2000 as well as changes that have occurred between 2000 and 2014. Canopy loss within the regional core tends to be a result of disturbance related to urban development, agriculture, forestry, or wildfire. Canopy gain is associated with reforestation or afforestation.

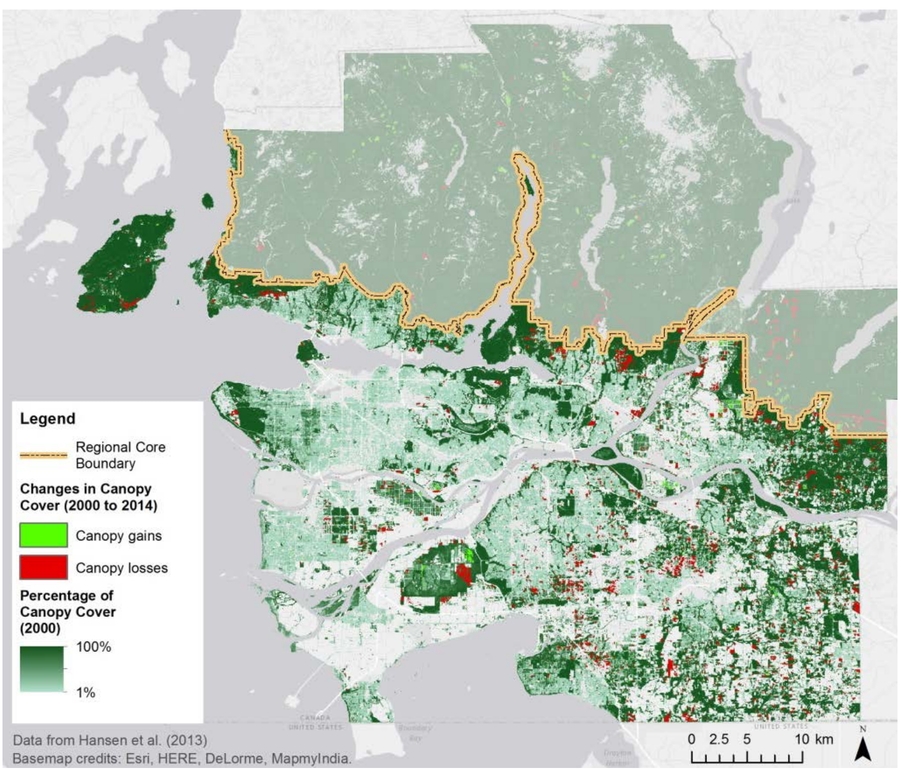


Figure 2. Map of Metro Vancouver showing satellite derived forest cover for 2014.

Member municipalities and the regional government have been adopting ambitious plans and regulations to protect and enhance Metro Vancouver's urban forest. Most member municipalities have adopted bylaws to protect trees on private land and regulate tree removal. Of Metro Vancouver's 21 member municipalities, one Electoral Area and one Treaty First Nation, nine have a city-wide urban forest management plan published online or noted as being in progress:

- City of Maple Ridge (Urban Tree management Plan in progress)
- City of New Westminster
- City of North Vancouver
- City of Port Moody (in progress)
- City of Richmond
- City of Surrey (Shade Tree Management Plan in progress; Natural Area Management Plan)
- City of Vancouver (in progress)
- City of White Rock (in progress)
- Corporation of Delta

The Urban Forest Adaptation Framework provides a synthesis of climate adaptation knowledge and tools to support to the development and implementation of municipal urban forest plans across the region.

3 How is the Urban Forest Vulnerable to Climate Change?

Key Message: Reducing or eliminating existing stressors is the most certain and immediately effective approach for adapting the urban forest to climate change.

3.1 How are urban forest systems already under stress?

Continuous urban forest stressors

Continuous urban forest stressors are common long-term conditions in urban environments that present challenges for tree performance (Figure 3). Growth and intensification of urban areas are the drivers of the stressors described below.

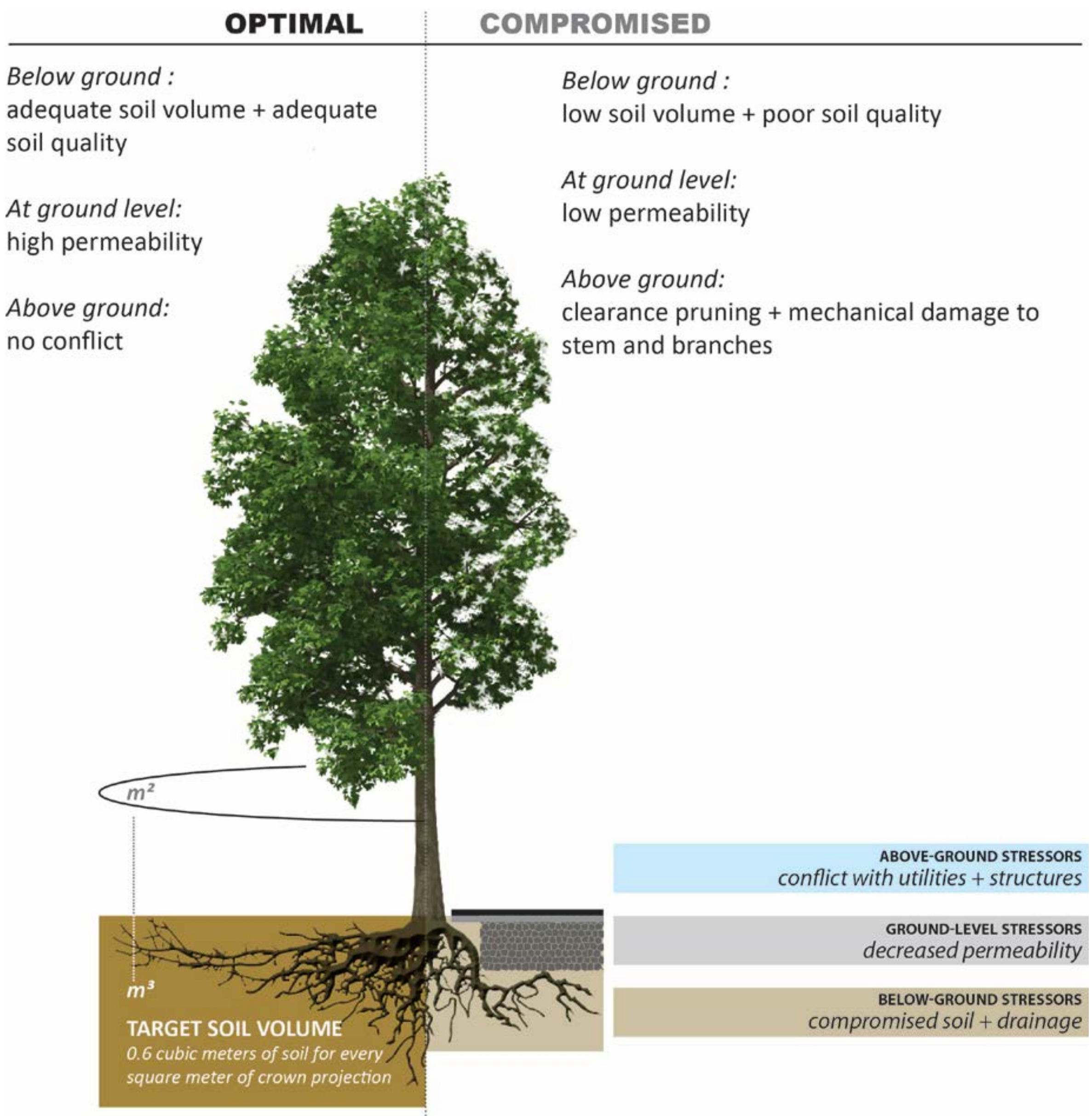


Figure 3. Trees in urban environments often face continuous stress as a result of compromised growing environments.

Below ground stressors*:* In urban areas, native soils have often been displaced and replaced with fill or imported soil. Soil structure of these non-native soils is often compromised by compaction. Underground utility trenches exist at various depths within footpaths or roadways, with connections joining from every property. Basements or underground structures are present in many areas, altering the natural flow of ground water. The various services and structures competing for below ground space effectively limit the volume of soil available to urban trees for root growth.

Ground level stressors*:* In urban areas, permeable natural surfaces are often replaced with impermeable surfaces such as asphalt, concrete or built structures. As cities grow and densify, the area of impermeable surface increases, limiting the area of 'vacant' permeable land. Growth and densification often results in the removal of existing trees and effectively limits the locations where new trees can be planted. Impermeable surfaces also reduce the amount of water and air that infiltrates below ground to recharge soil moisture to support healthy root growth and function.

Above ground stressors: In urban areas, structures and utilities limit the space available for tree canopy and can limit the amount of sunlight each tree receives. Tree canopies must also be suited to, or modified for, the urban site uses above ground so that they do not inhibit the passage of people or transportation, or the delivery of utility services.

The urban forests will always exist in locations that are prone to growth and intensification. Metro Vancouver is projected to add 1 million people (46%) to its population and more than 500,000 dwelling units to house them over the next 25 years [11]. Policy initiatives such as Metro 2040, the regional growth strategy [11], member municipalities' Official Community Plans and urban forest strategies serve to promote the protection and enhancement of the urban forest. In addition, most member municipalities have tree protection bylaws. However, continued growth and intensification present challenges for maintaining forested areas and providing adequate space for replacement tree planting. These challenges can be effectively managed through complementary policies that regulate surface permeability, canopy cover, available soil volume and that protect trees through design and during construction.

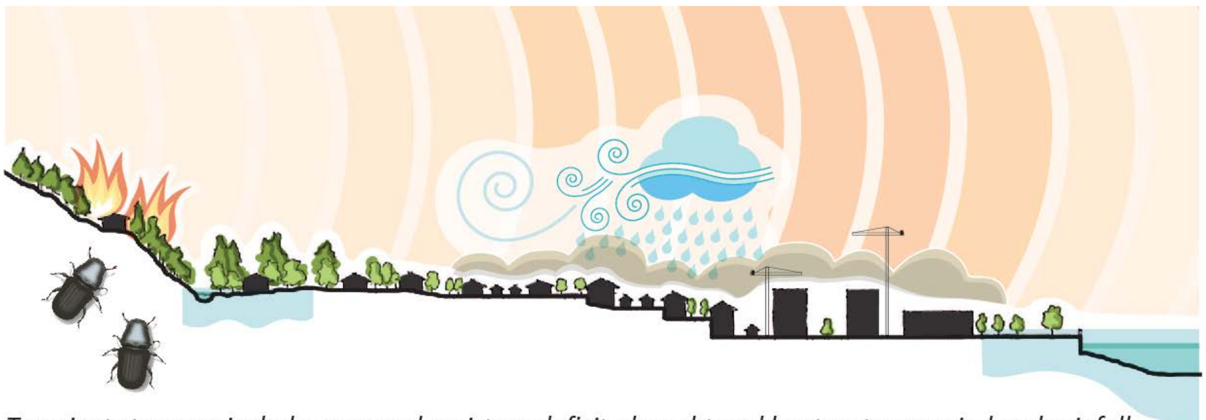
Continuous stressors reduce urban forest function by inhibiting tree growth and survival, thus decreasing the production of benefits for the community. In many cases it is possible to minimize or remove continuous stressors by implementing planning and design interventions that:

- Increase the quality, structure and volume of soil available below ground;
- Maximize the permeability of ground surfaces, and;
- Reduce the potential for conflicts with urban site uses above ground.

Complementary policies that regulate surface permeability, canopy cover, available soil volume and that protect trees through design and during construction can drive uptake of these interventions.

Transient urban forest stressors

Transient urban forest stressors are seasonal, biotic or abiotic stressors that occur for only a period of time. While they exist, transient stressors inhibit urban forest function and reduce the production of benefits for the community.



Transient stressors include: seasonal moisture deficit, drought and heat; extreme wind and rainfall; urban activity and air pollution; pests and disease; and wildfire and flood events

Seasonal moisture deficit, drought and heat:
Seasonal moisture deficits, extended droughts and heat can negatively impact growth, survival and regeneration rates of trees. Metro Vancouver's climate is characterized by a winter-wet summer-dry pattern [12]. The region straddles the CDF Zone and the drier subzones of the CWH Zone. Precipitation amounts at sea level in the CDF zone make it the driest region on the BC coast [13]. Climate oscillations such as the El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) also influence variability in temperature and precipitation regimes from year to year [14].

Seasonal moisture deficits
Annual climatic moisture deficits[3] typically occur in the region's lowlands over the summer season [7, 13, 15] (Figure 4). This means that the precipitation falling is not sufficient to meet vegetation evaporative demand for water. When there is a climatic moisture deficit, moisture is needed from sources other than rain (e.g., soil moisture or irrigation) to avoid drought impacts on plant growth [15]. Seasonal climatic moisture deficits are less common in the northern and higher elevation parts of the region because of lower summer temperatures and higher rainfall. Site-specific factors such as aspect, soil water holding capacity, elevation and depth of water table influence the presence of site soil moisture that may compensate for climatic moisture deficits.

[3] Climatic moisture deficit refers to the difference between atmospheric evaporative demand, estimated using a temperature-based approach, and precipitation [17]. In Wang et al. [17], annual climatic moisture deficit is calculated from the monthly difference between the parameters.

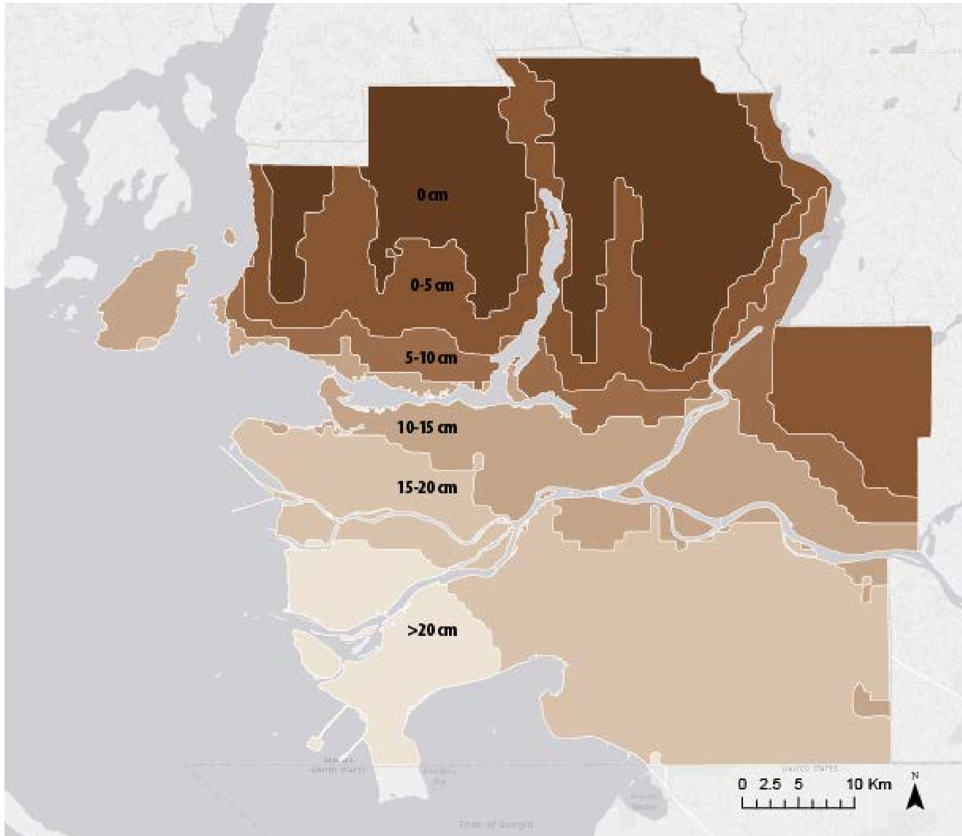


Figure 4. Approximate zones of average annual climatic moisture deficit for plant growth in the Lower Mainland (adapted from Wang, 2012 in [15]).

Drought events

Seasonal climatic moisture deficits are relatively predictable on an annual basis, whereas declared drought is a more unpredictable, though still recurrent, feature of Metro Vancouver's climate. Declared drought occurs when there is a deficiency of precipitation over an extended period of time resulting in water shortages to meet Metro Vancouver's needs [16]. Declared droughts are considered extreme events. Extended drought conditions in our region are sometimes linked to abnormally dry winters caused by persistent high pressure ridges that form over the coast and block the winter storm track and associated rainfall [17].

Heat

Heat impacts tree growth and survival both indirectly, by influencing evaporation rates affecting soil moisture availability, and directly if exceeding the species specific optimal temperature range for physiological processes driving tree growth [18, 19].

Tree responses to seasonal moisture deficits, drought and heat

In native urban forests, species typically succeed because they are well adapted to the climate and site niche they occupy. However, climatic moisture deficits, extreme drought and temperature that exceed species tolerance limits have been found to reduce growth, survival and reproduction in BC's native forests. Various studies have found a trend of increasing tree mortality, decreasing growth and decreasing seedling recruitment in Pacific Northwest forests due to increasing moisture stress, warmer temperatures and in-stand competition [19, 20, 21, 22].

In planted urban forests, many trees grow surrounded by hard surfaces where they are subject to higher temperatures and more evaporative water loss than trees in parkland areas [23]. These harsh urban conditions can exacerbate moisture stress during climatic water deficits and extreme drought. In Metro Vancouver, it is common to compensate for the deficit of summer precipitation by providing supplemental irrigation to young street trees in the first 2-5 years after planting. As trees grow and develop an established root system they become better equipped to tolerate drought, though tolerance varies by species.

Whether moisture stress is induced by seasonal moisture deficits or by an extreme drought event, trees respond with strategies to avoid or tolerate the drought stress [24]. Avoidance involves strategies such as dropping leaves or rapidly closing stomata to reduce water loss from cell tissue. Tolerance involves strategies that slow the flow of water out of cells to reduce evaporative water loss and enable more efficient use of plant available soil water [24]. With respect to the benefits we seek from the urban forest in the heat of summer, species with drought tolerance strategies are preferred because tolerant trees retain their canopy and continue to transpire water thus providing continuous shade and cooling benefits. During the 2015 declared drought in Vancouver, premature leaf-drop was observed in some deciduous street tree species. This was likely due to the tree species' drought avoidance strategies and, over that period of hot weather and for the remainder of the growing season, the trees were not producing the benefits for which they were planted.

Managing irrigation to compensate for moisture deficits
In our climate, most tree growth occurs in spring prior to the depletion of soil moisture. Dendrochronological studies relating tree growth to climate have found strong relationships between precipitation, temperature and tree growth for a number of species [19, 25, 26]. These studies have indicated that annual radial growth (as measured by ring width) is strongly influenced by precipitation and temperature in the current spring [25, 26] and in the previous year's summer and autumn [25, 27]. The effect of the previous year's precipitation and temperature on the current year's radial growth is most likely explained by its impact on the trees' ability to produce and store the carbohydrates needed for spring growth [28, 29, 25, 26].The previous year's summer and autumn also influence leaf size and density in the current year's tree canopy (Roloff 1989 in [25]). These studies suggest that adequate summer and fall precipitation in the previous year followed by adequate spring precipitation in the current year are important factors for maximizing annual growth of trees. As a generalization, the available research supports that supplemental irrigation should benefit tree growth if applied: 1) in spring during years with below average winter/spring precipitation and a resulting soil moisture deficit; and, 2) in summer and fall during periods of soil moisture deficit. However, sensitivity to the range of precipitation variation in Metro Vancouver is likely to vary by species. Improving our understanding of the climatic factors influencing the growth and survival of Metro Vancouver's urban tree species would enable irrigation regimes to be refined to improve annual growth and minimize water stress.

Annual summer moisture deficits and occasional declared drought are recurrent features of Metro Vancouver's climate that exert stress on the urban forest. The region's southern lowlands are more drought-prone than northern and higher elevation areas. Young planted trees usually require supplemental watering for the first 2-5 years of establishment in our climate. Older, established trees are typically able to survive periods of drought, either by avoiding or tolerating drought stress, although their growth and longevity may be negatively impacted. With respect to the benefits we seek from the urban forest in the heat of summer, species with drought tolerance strategies are preferred because tolerant trees retain their canopy and continue to transpire water thus providing continuous shade and cooling benefits. Studies suggest that adequate summer and fall precipitation in the previous year followed by adequate spring precipitation in the current year are important factors for maximizing annual growth of trees. As a generalization, the available research supports that supplemental irrigation should benefit tree growth if applied: 1) in spring during years with below average winter/spring precipitation and a resulting soil moisture deficit; and, 2) in summer and fall during periods of soil moisture deficit. However, sensitivity to the range of precipitation variation in Metro Vancouver is likely to vary by species. Improving our understanding of the climatic factors influencing the growth and survival of Metro Vancouver's urban tree species would enable irrigation regimes to be refined to improve annual growth and minimize water stress.

Extreme wind events:

Extratropical cyclones are a recurring feature of Metro Vancouver's climate and can match Category 3 hurricanes in terms of sustained wind speeds [30, 27, 31]. Wind is a common natural disturbance agent in the region's forests [32]. Westerly and southeasterly windstorms are the two dominant types of cyclonic windstorms that affect Metro Vancouver [30]. Windstorms can cause extensive damage, some of which is related to the impact of tree failures on infrastructure [30]. Average losses related to windstorms in the US Pacific Northwest are estimated at $112 million US per event [27].

Southeasterly windstorms in this region typically have peak winds from the south or southeast, while westerly windstorms have peak winds from a variety of directions. Generally, southeasterly windstorms cause more damage than westerly windstorms [30]. Windstorms most often occur between November and January and storms are rare outside that period [30]. Variability in windstorm frequency and intensity from year to year is controlled by natural variability associated with features such as ENSO, the PDO and the Aleutian Low among others [30, 27, 33]. A trend of increasing frequency in windstorms since the late 19th century has been detected in a study of tree rings from the Pacific Northwest [27].

The strongest windstorm on record for BC is the 1962 Columbus Day storm ("Typhoon Freda") with maximum gusts of up to 145 km/hr which resulted in the widespread loss of trees in Stanley Park [30]. Across the Pacific Northwest, the storm felled 25 million cubic metres of merchantable timber, caused the failure of roofs and transmission towers, and was blamed for the deaths of 46 people [30]. This type of catastrophic event with extreme winds (>90 km/hr) is rare in a century [30]. However, endemic windstorms with peak winds up to 70 km/hr occur more than once per year, with strong (70-80 km/hr winds) and severe (80-90 km/hr winds) windstorms occurring with average return intervals of between 3 and 8 years respectively [30]. Variables that are good predictors of powerline faults, often caused by trees, include storm duration, total precipitation, whether it is a southeaster or westerly, peak winds and the interactions between them [30]. The recent August 29 2015 windstorm was an endemic windstorm but highly unusual in terms of the time of year in which it occurred and the number of tree failures it caused. While the reasons why this storm was so damaging are not entirely clear, the extended drought and the fact that deciduous trees were still in leaf were likely contributing factors.

Tree vulnerability to failure due to wind is influenced by a wide range of variables. In terms of failure of the whole tree (i.e., from the root plate) factors such as soil texture, soil saturation, soil depth, soil volume, soil mass, root biomass, root decay, construction damage to structural roots, newly exposed stand edges, height of the tree above ground, and canopy drag influence the success with which a tree can stay anchored in the soil while resisting the force of the wind. In terms of breakage of the stem or branches above ground, variables such as structural defects, wood strength, dead branches, decay, and canopy drag play into the ability of the wood to resist the force of the wind. Improving our understanding of how different tree species perform in relation to wind resistance, and of the importance of different variables influencing vulnerability to wind, would enable tree selection and management practices to be refined to minimize damage to and from trees due to wind.

Windstorms are the most common form of natural disturbance in the region, with winds up to 70 km/hr recurring more than once per year. Strong and severe windstorms (winds from 70 to 90km/hr) occur less frequently but still up to three times per decade. Catastrophic windstorms (winds >90 km/hr) are much less common, occurring roughly once or twice each century. Healthy trees with good branch structure can resist most windstorms without large limb failures or root plate failures. However, trees in the urban forests are often under stress and are made more vulnerable to failures under wind loading by cultural practices such as poor pruning, poor tree selection, construction damage, inadequate soil volume and surface irrigation. Cutting of trees in mature stands often exposes trees that are not windfirm or leaves narrow bands of forests that are prone to windthrow. Improving our cultural practices will minimize damage to and from trees due to wind.

Extreme rainfall and flooding events:

In the Metro Vancouver region, several hydrologic types are important for stream flow: 1) rainfall-driven streams; 2) snow-melt driven streams; and 3) hybrid streams [34]. The hydrologic type influences the season of peak flow and flooding risk. For rainfall-driven streams, peak flows tend to occur in the fall, while snow-melt driven streams tend to peak in the spring. Every year since 2001, BC has had a significant flood event causes by extreme weather and precipitation [35]. Trees are directly vulnerable to flooding due to saturation of soil, which can suffocate roots or reduce the soil's capacity to hold the tree. Indirectly, flooding can impact trees by transporting a flow of debris that causes physical wounds to tree trunks and roots.

Metro Vancouver tends to experience most of its precipitation between October and January [9]. Year to year variability in rainfall is typically explained by natural variability of features such as ENSO and the PDO [36]. Heavy precipitation events often accompany extratropical storms that bring windstorms to the coast [30]. 'Atmospheric Rivers', which are narrow regions of high volume water vapor transport extending from the tropics to the mid-latitudes beyond the tropics, are another important phenomenon delivering heavy rainfall to the region [37, 38]. Approximately 12-24 heavy precipitation events occur in North America each year where atmospheric rivers encounter mountainous terrain [35].

Trees are generally tolerant of heavy rainfall events except when soil anchoring is affected, or when rainfall results in extended flooding. Flooding is usually an isolated impact because it tends to affect low-lying areas and locations adjacent to watercourses. Flooding during the growing season is typically more damaging than flooding when trees are dormant. Tree species vary in their tolerance of waterlogged soils and adaptation to flooding stress. Most tree species can survive infrequent (less than once per year) and short duration (less than one week) flooding. However, few species can survive extended periods of inundation during the growing season. In locations where periodic waterlogging occurs, the impact can be managed through species selection for waterlogging tolerance or site modifications to elevate the trees above the flood level.

Extreme rainfall events tend to cause flooding between October and January. Trees are generally tolerant of heavy rainfall events except when soil anchoring is affected, or when rainfall results in extended flooding. Flooding is generally an isolated impact because it tends to affect low-lying areas and locations adjacent to watercourses where the trees are typically adapted to these events. Most tree species can survive infrequent (less than once per year) and short duration (less than one week) flooding. However, few species can survive extended periods of inundation during the growing season. In locations where periodic waterlogging occurs, the impact can be managed through species selection for waterlogging tolerance or site modifications to elevate the trees above the flood level.

Pests, disease and invasive species:
Many pest and diseases are native to Metro Vancouver (endemic) and can cause tree mortality. In native forests, endemic pests and diseases are considered healthy agents of disturbance. Small-scale mortality improves the structural diversity of even aged stands and creates features that enhance biodiversity such as dead standing trees and forest openings. However, pest and disease outbreaks causing large-scale tree mortality have a range of negative impacts, particularly in urban environments. Invasive species (whether of plants, insects or disease) tend to harm the function of forests by causing large-scale tree mortality or by outcompeting native species.

Widespread tree mortality due to pests and disease is historically rare in Metro Vancouver. However, large outbreaks of Douglas-fir bark beetle and striped alder sawfly have been recorded in the past. A recent study from the US found that insect damage on trees in downtown urban areas was more severe than damage on the same species growing in parkland environments nearby, suggesting that urban trees may be more vulnerable to pest and disease attack because of existing stressors [39]. Several pests and diseases that occur in the region, or are an emerging threat, and are capable of causing widespread tree damage include:

Table 1. Pests/disease capable of causing widespread tree damage

Pest/disease common name	**Common hosts**
Bark beetles	
Asian longhorned beetle[+]	Many (particularly *Acer* spp., *Aesculus* spp., *Salix* spp., *Ulmus* spp., *Betula* spp., *Platanus* spp.)
Douglas-fir bark beetle	Douglas-fir
Elm bark beetles[+]	Elms (beetles do not cause mortality but are vectors for Dutch Elm Disease)
Emerald ash borer[+]	Ash (*Fraxinus* spp.)
Spruce beetle	Spruce
Defoliating insects	
Birch leaf miners*	Paper birch
Bruce spanworm*	Paper birch, balsam poplar, bigleaf maple
Cottonwood sawfly	Black cottonwood
Douglas-fir tussock moth	Douglas-fir
Fall webworm	Paper birch, cottonwood, red alder, bigleaf maple
Gypsy moth*	Birch, oak, apple, sumac, pear, chestnut, flowering cherry
Striped alder sawfly	Red alder, paper birch, willow
Western blackheaded budworm	Western hemlock, true firs, spruce, Douglas-fir
Western hemlock looper	Western hemlock
Western spruce budworm	Douglas-fir
Western winter moth	Bigleaf maple, paper birch, red alder, black cottonwood
Fungal diseases	
Armillaria root disease	Many
Dutch elm disease[+]	Elms (excluding *Ulmus pumila*, *Ulmus parvifolia* and resistant cultivars)
Laminated root rot	Douglas-fir, western hemlock, spruce
Oak wilt[+]	Oak (particularly oaks in the red oak group)
Sudden oak death	Many

[+] Not yet detected in Metro Vancouver
*Introduced pests

The Asian longhorned beetle, Dutch elm disease, oak wilt and the emerald ash borer, not yet detected in Metro Vancouver, are species of potential concern because they have caused widespread tree mortality in other North American urban cities.

Few invasive plant species impact trees directly. However, English ivy can cause isolated tree mortality by ringbarking, covering their foliage or pulling down trees under the vine's weight. Urban trees can also become invasive by self-seeding into natural areas and displacing native trees. Examples of trees that are currently invasive within some Metro Vancouver ecosystems include green ash, European mountain ash and hawthorn [40].

Ongoing monitoring and management of forest pests and invasive trees will provide information enabling early detection and response to outbreaks or new invaders. Many of the genera planted in Metro Vancouver are broadly susceptible to existing or emerging forest pests and diseases, which highlights the need to enhance diversity across the urban forest population. Exotic, monotypic genera (i.e., only one species in the genus), such as Ginkgo, or genera with few species are often more broadly pest and disease resistant because they have no close relatives that pests or diseases are adapted to as hosts. However, there are not enough examples of broadly resistant urban trees to replace the use of proven genera in the urban forests of our region. Providing quality growing environments and selecting for diversity and non-invasive tree species will improve urban forest resilience.

Many pest and diseases are native to Metro Vancouver but very few are capable of causing tree mortality. Widespread tree mortality due to pests and disease is historically rare in Metro Vancouver. However, future pest and disease outbreaks are a concern, particularly for urban trees that are already under stress. Invasive pests such as the Asian longhorned beetle, Dutch elm disease, oak wilt and the emerald ash borer, not yet detected in Metro Vancouver, are species of great concern because they have caused widespread tree mortality in other North American cities. Ongoing monitoring and management of forest pests and invasive trees will provide information enabling early detection and response to outbreaks or new invaders. Providing quality growing environments and selecting for diversity and non-invasive tree species will improve urban forest resilience.

Wildfire:
Wildfire is an important but infrequent agent of disturbance in Metro Vancouver's CDF and CWH forests [32]. Our wet, coastal temperature rainforests infrequently supported wildfire historically because ignition opportunities were rare, fine fuel build-up was usually low and surface fuels tended to have low flammability [41]. The historic wildfire regime in coastal BC is thought to have been driven by stand gap-dynamics and local biophysical conditions that usually supported low- and mixed-severity fire regimes with very occasional high-severity, stand initiating events in periods of dry climate [41, 32]. However, human activity has likely altered the natural fire regime in Metro Vancouver both by increasing the frequency of ignitions and improving wildfire suppression [42].

In the lowlands of western BC, variability in the area burned between years is closely related to summer drought [14]. Both the CDF and CWH naturally have a high percentage of land covered by flammable forest vegetation [14]. The CDF is more arid than the CWH and 14% of its flammable area has burned since 1920 compared to only 6% in the CWH [14]. Ground fires, which burn in underground organic matter, can also occur in bog ecosystems such as Burn's Bog when the sphagnum moss is dry enough to ignite. Years of high fire activity tend to be associated with the occasional formation of persistent high pressure ridges over the coast that block the winter storm track and associated rainfall, creating extended drought conditions [41].

Within the context of an urban environment, wildfire is usually an undesirable agent of natural disturbance. In areas where urban development meets the wildland, wildfire poses a significant risk to structures and human life. The urban forest can be managed to reduce this risk by selecting species with comparatively low flammability, planting and maintaining landscapes to provide defensible space between vegetation and structures, and by maintaining soil moisture in landscaped areas.

Wildfire is an important agent of natural disturbance in our region, though is secondary to wind. Increased human activity has likely increased the frequency of wildfires in Metro Vancouver by increasing the frequency of human cased ignitions. However, wildfire detection and suppression have been improved by the proximity of urban areas. Due to the risk posed to structures and human life, wildfire is usually an undesirable agent of natural disturbance in our urban forest. The urban forest can be managed to reduce this risk by selecting species with comparatively low flammability, planting and maintaining landscapes to provide defensible space between vegetation and structures, and by maintaining soil moisture in landscaped areas.

Air pollution:

Air pollution negatively impacts the urban forest by reducing growth and causing foliar injury in a range of tree species. Trees also interact with air pollution by aiding the removal of airborne pollutants or, for some species, by contributing to air pollution through the emission of volatile organic compounds (VOCs).

Air pollutants in the Lower Mainland commonly consist of particulate matter and sulfates, and gaseous pollutants such as sulfur oxides, nitrogen oxides, carbon monoxide and volatile organic compounds [43, 44]. Over the last 10 years, air quality has generally improved [43]. However, degraded air quality can occur at the local and regional scale due to busy roads, wood burning stoves, heavy construction and industrial activities [43]. Weather events can also affect air quality across the region. During heat waves, ground-level ozone increases. Smoke from wildfires can blow into the region increasing fine particulate matter. Stagnant air can also allow fine particulates from local sources to become trapped.

The main air pollutants that cause damage to trees during the growing season are oxidising gases (e.g., ozone and nitrogen oxides), acidic gases (e.g., sulfur dioxide), alkaline gases (e.g., ammonia) and heavy metals [45]. Symptoms of air pollution damage include slow growth, foliar injury and defoliation [45]. Species vary in their tolerance to air pollution. Within species, air pollution tolerance is influenced by the presence of other stressors. It is also possible that groups of trees and larger areas of forest are less impacted by air pollution damage because of their buffering properties [46]. It is not known how much injury occurs to trees due to air pollution in Metro Vancouver.

Trees can increase air mixing, which can help disperse air pollution at head height [47] reducing human health impacts, though in the absence of wind the tree canopy may trap pollution beneath it temporarily. Some air pollution is also absorbed by tree leaves, or deposited on the leaves [48], though in small proportions. Trees can also contribute to air pollution by emitting VOCs that combine with nitrogen oxides in the presence of sunlight to form ground-level ozone [45].

Air pollution levels in the region have, overall, been decreasing [43]. Policy actions, technological advances and fossil-fuel alternatives have, and are expected to continue to, reduce air pollution across our region [43, 49]. However, background levels of ground-level ozone have been rising and are expected to continue increasing throughout the world [45]. Aside from reducing pollutant sources, the impacts of pollution damage to trees can be minimized through species selection in areas prone to degraded air quality. In addition, selection of low VOC emission trees can reduce the vegetation contribution to the production of ground-level ozone.

Air pollution levels fluctuate in the Metro Vancouver and, on average, are decreasing due to policy actions, technological advances and increasing use of fossil-fuel alternatives. However, background levels of ground-level ozone have been rising and are expected to continue increasing throughout the world. Air pollution causes damage to trees by slowing growth, damaging foliage and causing premature defoliation. It is not known how much injury occurs to trees due to air pollution in Metro Vancouver. Aside from removing the source of pollutants, the impacts of pollution damage to trees can be minimized through species selection in areas prone to degraded air quality. In addition, selection of low VOC emission trees can reduce the vegetation contribution to the production of ground-level ozone.

Urban activity:

The urban forest exists within areas that are prone to development or redevelopment to support urban growth. Between 2001 and 2011, Metro Vancouver's population increased by 16% with the majority of new residents locating within the existing urban area through intensification rather than expansion of the urban area [50]. The population is projected to grow by another 46% over the next 25 years. As a result, urban trees will continue to compete for space and face potential damage from construction and maintenance activities. The transient stressors related to urban activity occur during the demolition, excavation, site grading and construction phases of projects, and are best managed by implementing tree protection requirements through design and during construction. Complementary policies that regulate surface permeability, canopy cover and available soil volume can drive tree protection in the design phase of development projects.

The urban forest exists within areas that are prone to development or redevelopment to support urban growth. Metro Vancouver is projected to grow by an additional 1 million people and more than 500,000 dwelling units over the next 25 years. As a result, trees will continue to compete for space and face potential damage from construction and maintenance activities. The transient stressors related to urban activity occur during the demolition, excavation, site grading and construction phases of projects, and are best managed by implementing tree protection requirements through design and during construction. Complementary policies that regulate surface permeability, canopy cover and available soil volume can drive tree protection in the design phase of development projects.

Summary:

Urban forest stressors either temporarily or, in severe cases, permanently reduce urban forest function. Urban forest managers usually have little control over the source of the stress but can improve urban forest resilience through planning and management that:

- Selects a diversity of species that are tolerant of or resistant to stressors;
- Provides planting infrastructure that supports adequate soil volume and soil moisture;
- Maintains trees to maximize wind resistance; and,
- Requires appropriate tree protection on sites where construction or maintenance activities occur.

Is climate change already impacting the urban forest?

There is a growing body of research evidence linking observed climate change with impacts on forests in British Columbia and the Pacific Northwest. While most available research focuses on forest stand dynamics in natural ecosystems rather than the urban forest specifically, the effects provide valuable insight into regional challenges.

Tree mortality has been linked directly to changing climate. Studies on forests in western North America have found that warmer conditions combined with changes in the soil water balance, competition and more frequent extreme weather events (e.g., late-winter thaws and freezes) caused:

- Doubling of mortality rates across dominant genera in unmanaged old forests of the Pacific Northwest in recent decades [51];
- Tree populations in western North America to lag behind their optimal climate niche by approximately 130 km in latitude or 60 m in elevation [52];
- Declining annual growth in Pacific Northwest forests [19, 22];
- Altered regeneration patterns and regeneration niches of extant and adjacent tree species being out of equilibrium with current climate [21, 22, 53]; and,
- Widespread decline in yellow-cedar forests on the West Coast of British Columbia [54].

Warmer conditions combined with changes in the soil water balance have also been linked indirectly to tree mortality by causing:

- Enhanced growth and reproduction of insects and pathogens [51, 55, 41]; and,
- Significant shift from infrequent large wildfires of short duration (average of 1 week) to more frequent, longer burning (5 weeks) fires since the 1980s in the western U.S. [56].

Climatic changes affecting the soil water balance, extreme weather, insect and pathogen activity, and wildfire activity are already impacting forests in the Pacific Northwest.

3.2 How is Metro Vancouver's climate expected to change?

The annual average temperature in Metro Vancouver is projected to warm by about 3°C over the next 40 years. Metro Vancouver sourced regionally adjusted climate change projections from the Pacific Climate Impacts Consortium (PCIC) in 2015 [57]. Significant work has been completed to understand the details of how our regional climate may change by the 2050s and 2080s. The projections are based on a subset of climate models selected from the Coupled Model Intercomparison Project 5 following the "business as usual" estimate of greenhouse gas emissions, Representative Concentration Pathway 8.5 (RCP8.5). Adaptation planning typically makes use of this business as usual RCP8.5 projections. Projections do not indicate the frequency and intensity of extreme events such as drought, heat waves, extreme rainfall or wildfire.

In order to define the potential impacts of climate change on the urban forest, the project team relied on the projected changes provided by Metro Vancouver [57] and sourced regionally relevant scientific literature. Table 2 outlines the projected changes in climate between the historical baseline period of 1971-2000 and the 2080s (2071-2100) [57]. It is important to note that the projections in Table 2 are averaged across the entire region and therefore do not represent local variation in precipitation and temperature. To obtain projection results for specific locations within Metro Vancouver, refer to 'Climate Projections for Metro Vancouver' [57].

Table 2. Summary of projected climatic changes, averaged for the region, between the historical baseline period of 1971-2000 and the 2080s (2071-2100).

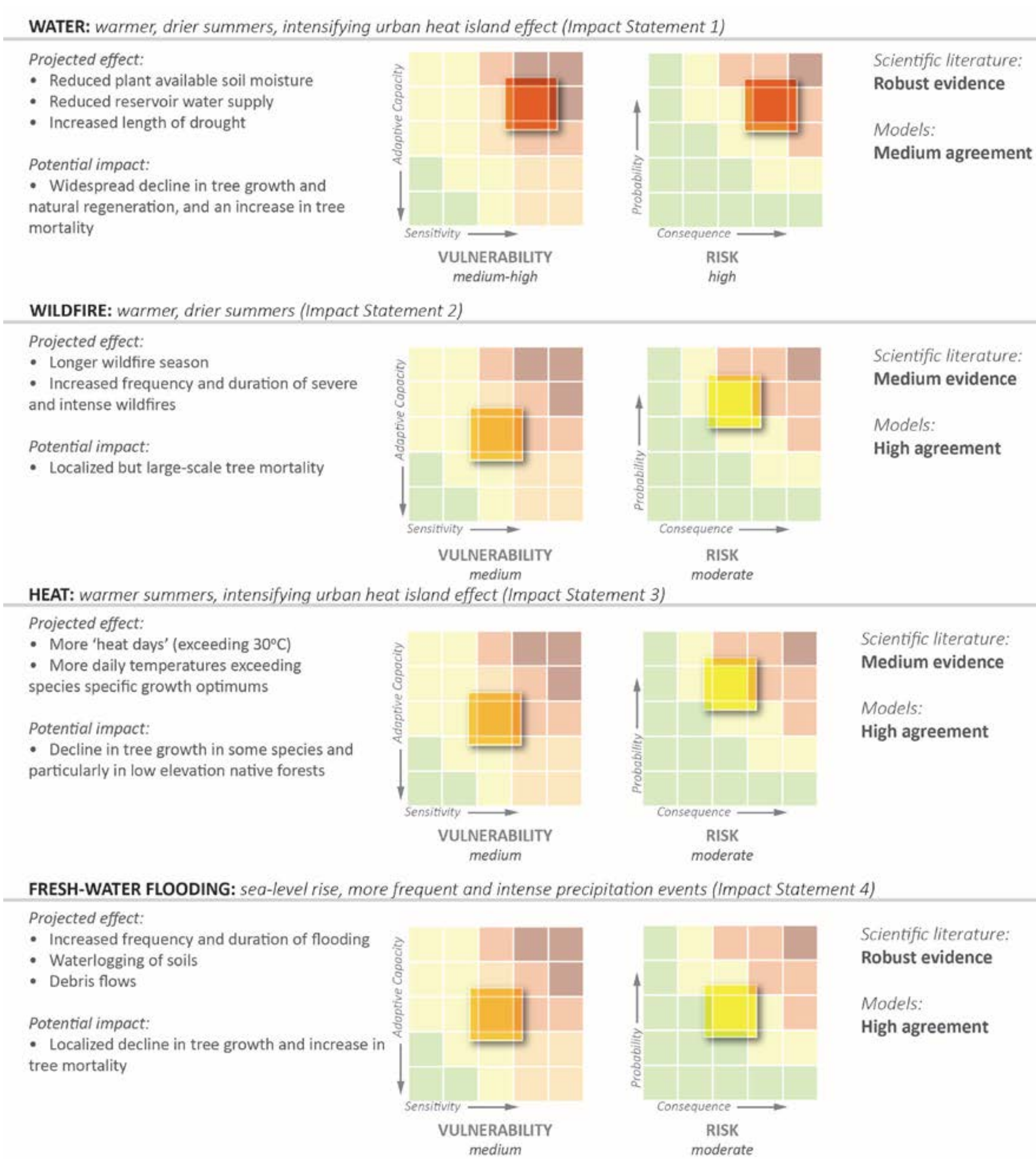
Variable	Season				Range of Magnitude/ Direction of Change
	Winter	Spring	Summer	Fall	
Warmer temperatures			●		↑ from 30°C to 37°C maximum temperature
	●				↑ from -13°C to -5°C minimum temperature
Heat days (above 30°C)			●		↑ from 2 to 29 days above 30°C (on average)
Precipitation		●			↑ 12% (from 400 mm to 447 mm)
			●		↓ 29% (from 206 mm to 147 mm)
				●	↑ 20% (from 580 mm to 693 mm)
Maximum length of dry spell	Annual				↑ 37% increase in the length of dry spells (from 21 to 29 days)
Frost days	Annual				↓ 79% (from 79 to 17 days)
Growing season length	Annual				↑ 31% (from 252 to 331 days)

3.3 How is climate change expected to impact the urban forest?

Relevant scientific studies and regional climate change projections underpin the urban forest impact statements outlined below. The impact statements describe key changes expected to impact Metro Vancouver's urban forest. This project used ICLEI's workbook for municipal climate adaptation [58] to rank vulnerability and risk for each negative impact based on the professional judgement of the project team and Advisory Panel.

The vulnerability rankings reflect how susceptible we perceive the urban forest is to the impacts of climate change based on sensitivity and adaptive capacity. Risk describes our understanding of the probability and consequence of the impact occurring.

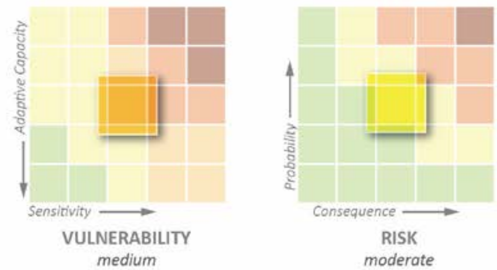
Summary of Impacts



INSECTS, DISEASE AND INVASIVE PLANTS: *milder winters, longer and warmer summers (Impact Statement 5)*

Projected effect:
- Increase in the frequency and severity of insect and disease outbreaks
- Conditions more favourable for establishment of invasive pests, diseases and plants

Potential impact:
- Species-specific, large-scale tree mortality and decline in native biodiversity



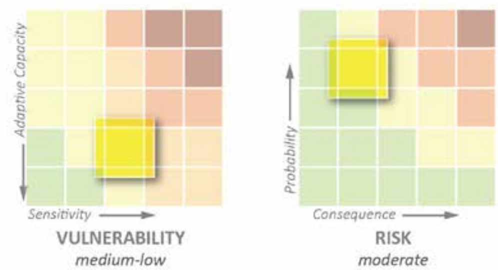
Scientific literature:
Medium evidence

Models:
Medium agreement

AIR POLLUTION: *warmer summers, intensifying urban heat island effect (Impact Statement 6)*

Projected effect:
- More ground-level ozone

Potential impact:
- Decline in tree growth in some species



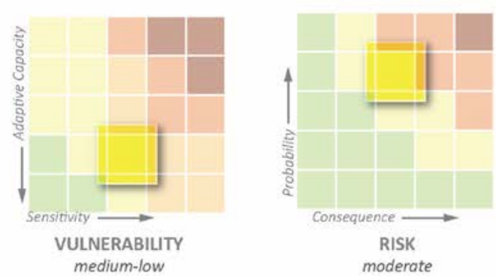
Scientific literature:
Medium evidence

Models:
High agreement

MALADAPTATION: *milder winters, longer and warmer summers (Impact Statement 7)*

Projected effect:
- Flowering occurring earlier
- Bud break occurring earlier
- Lengthened bud dormancy
- Seed germination occurring earlier
- Shorter winter chilling duration

Potential impact:
- Native species lagging behind geographic changes to their realized climate niche
- Trees activity-dormancy cycle and phenology being out of synch for successfully completing developmental processes
- Trees out of synch with pollinators or other dependant wildlife species



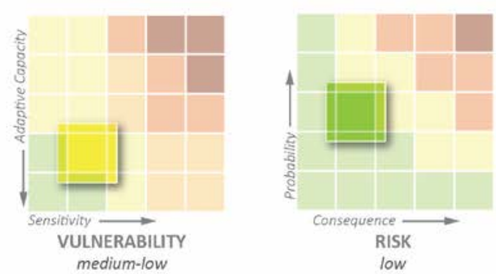
Scientific literature:
Medium evidence

Models:
Medium agreement

SALTWATER INNUNDATION: *sea-level rise (Impact Statement 8)*

Projected effect:
- Increased frequency and duration of salt-water inundation during storm surges
- Salination of soils
- Debris flows

Potential impact:
- Localized decline in tree growth and increase in tree mortality



Scientific literature:
Medium evidence

Models:
High agreement

Almost no quantitative data is available to estimate the probability of the impacts occurring, or to inform our assessment of each impact in terms of the regional magnitude of change in tree growth and survival, ecosystem service delivery, and costs of adaptation. Uncertainty is also inherent in the climate change projections. This uncertainty and lack of quantitative data mean that the risk and vulnerability ratings are highly subjective. However, these descriptions record our current perception of risk and vulnerability to future impact, and form the basis for recommendations for climate adaptation. The risk and vulnerability ratings also provide a baseline, allowing us to adjust to new data and measure improvements in the future.

Several additional impacts were identified at the outset of this project but were not assessed for risk and vulnerability (either because they were positive or poorly understood) and these are summarized below.

GROWING SEASON: *milder winters, more frost free days (Impact Statement 9)*

Projected effect:
- Increase in average annual minimum winter temperatures that plants need to withstand
- Fewer damaging frosts

Potential impact:
- Increase in the range of species broadly suitable for Metro Vancouver's climate

Scientific literature: **Medium evidence**

Models: **High agreement**

WINDSTORMS: *increasing storminess (Impact Statement 10)*

Projected effect:
- Projected effect is unclear due to low agreement in climate models and limited evidence in the scientific literature

Potential impact:
- May be no departure from current conditions

Scientific literature: **Limited evidence**

Models: **Low agreement**

ATMOSPHERIC CO_2: *increased atmospheric CO_2 (Impact Statement 11)*

Projected effect:
- While there is agreement in the models that atmospheric CO2 will increase, the projected effect is unclear because of limited evidence the scientific literature

Potential impact:
- Positive or negative change expected but not well understood

Scientific literature: **Limited evidence**

Models: **High agreement**

The greatest risk to our urban forest from climate change is the potential long-term change in soil moisture availability that threatens tree regeneration rates, establishment success, summer canopy cover and annual growth. The urban forest is vulnerable to this risk because supplying supplemental water to individual trees is logistically difficult and expensive. The urban forest is also moderately vulnerable to the increased risk of wildfire, heat, fresh-water flooding and insect, disease and invasive plant activity. It is these impacts that are most important to address when adapting Metro Vancouver's urban forest to climate change. Growing a healthy and diverse range of trees and reducing existing stressors will increase the resilience of our urban forest population to climate change impacts. The longer growing season expected under climate change may expand the diversity of trees that can be planted in Metro Vancouver. Expanding urban forest research activity in the region will improve our understanding of climate change impacts and inform effective management responses.

Evidence for Impacts

As further support for the summary of urban forest impacts provided above, the complete impact statement is written out below with a description of the scientific evidence used to justify the impact statement.

Impact Statement 1: Water

Impact Statement: Warmer, drier summers, intensifying urban heat island effect, more precipitation falling as rain and less as snow leading to **reduced soil moisture** in the summer, **increased length of drought** and **reduced reservoir water supply** available for supplemental watering, resulting in widespread decline in tree growth and natural regeneration, and an increase tree mortality.

Robust evidence, medium agreement

Evidence indicates that widespread declines in tree growth, regeneration and mortality are already occurring in native tree populations and are expected to worsen as a result of warmer, drier conditions [19, 21, 54, 52, 22] in the summer months. Scientific literature is in agreement that less precipitation falling as snow, earlier snowmelt, less summer precipitation, warmer temperatures and intensified urban heat island effect will increase evaporation, reduce plant available soil moisture and reduce reservoir water supplies. Climate models agree that temperatures will increase, summer precipitation will decrease and that there will be longer dry periods [59, 57]. However, some authors suggest an increase in frequency and severity of drought [60], while others suggest that models do not predict a significant departure from current drought frequency and severity for our region [61, 62].

Impact Statement 2: Wildfire

Impact Statement: Warmer, drier summers leading to a **longer wildfire season**, an **increased risk of severe and intense wildfire** events and an **increase in the area burned overall** resulting in localized large-scale tree mortality.

Medium evidence, high agreement

Tree species in our urban forest, other than Douglas-fir, are generally not adapted to survive low to moderate intensity wildfires. All species are susceptible to being killed by high intensity wildfires, therefore fire may result in localized but large-scale tree mortality. The scientific literature does indicate that climate change will lengthen the fire season and increase the probability of fires starting and spreading resulting in more area burned overall in southwestern BC and the Pacific Northwest [59, 63, 60, 64]. One study suggests that climate change is already increasing wildfire activity in the mid-elevation forests of the Pacific Northwest, though this study does not cover our region [56]. Evidence is generally limited when it comes to projecting the expected change in fire frequency and area burned at the finer scale of our region. Climate models agree that temperatures will increase, summer precipitation will decrease and that there will be longer dry periods [59, 57]. Models agree that there will be an increase in the total annual fire occurrence rate, particularly due to lightening activity in southwestern BC; however the extent of the projected change varies greatly [63].

Impact Statement 3: Heat

Impact Statement: Warmer summers and an intensifying urban heat island effect leading to a **higher number of 'heat days'** (exceeding 30°C) and more daily **temperatures exceeding growing optimums** resulting in decline in tree growth in some tree species and particularly in low elevation native forests.

Medium evidence, high agreement
Evidence suggests that heat which exceeds optimum thresholds is limiting for plant growth generally, and specifically for low elevation native forests in the Pacific Northwest, because photosynthesis declines [19, 65]. Damage to plant tissue can occur when temperatures exceed 30°C in cold-adapted plants [65]. However, tree species vary in their tolerance for heat and it is unclear whether or not changes will exceed optimum thresholds for the diversity of species in our urban forest. Climate models agree that average and maximum temperatures will increase and that there will be a higher number of 'heat days' annually in the region [59, 57].

Impact Statement 4: Fresh-water Flooding

Impact Statement: Sea-level rise and more intense precipitation events leading to an increase in **frequency and duration of flooding and waterlogging** of soils within low lying areas resulting in localized declines in tree growth and increased mortality.

Robust evidence, high agreement

Trees vary in their tolerance to flooding, with some species only able to resist very brief periods of flooding (< 1 week) and others being able to tolerate more than a year of inundation [66]. Localized declines in tree growth and mortality will be primarily driven by flooding extent and duration. Some trees may also be damaged as a result of debris flow carried in floodwaters. The evidence supports that an increased frequency and intensity of precipitation events combined with sea-level rise under climate change will result in an increased frequency, duration and extent of flooding in the region [67, 68, 69, 38, 70, 71]. Models generally agree that rainfall will increase in seasons other than summer and that sea level will rise [57, 38, 71].

Impact Statement 5: Insects, Disease and Invasive Plants

Impact Statement: Milder winters and longer, warmer summers leading to an **increase in frequency and severity of insect and disease outbreaks** and improved **establishment success of invasive plants** causing species-specific, large-scale tree mortality and decline in native biodiversity.

Medium evidence, medium agreement

Tree species vary in their susceptibility to insects and disease, with most pests being host-specific. Tree health also affects the susceptibility of individuals to insects and diseases. Invasive plants rarely directly kill individual trees but can displace native species from forest ecosystems. Evidence suggests that some insects, diseases and invasive plants will be able to expand their ranges further north, or become more damaging under climate change [60, 72, 73, 74]. There is some evidence to suggest that tree mortality due to insect pests has already increased in our region as a result of climate change [55, 51]. However, limited evidence is available regarding specific insect, disease or invasive plant species or their range changes in relation to Metro Vancouver's projected future climate. It is also difficult to predict the introduction of new insect, disease or invasive plants into our region. Climate models generally agree that Metro Vancouver will experience milder winters and longer, warmer summers [57, 59]. While these conditions will likely increase the activity of some insects, disease and invasive plants, further species-specific modelling of the changes to their distributions in our region is needed [75, 74].

Impact Statement 6: Air Pollution

Impact Statement: Warmer summers and an intensifying urban heat island effect leading to **higher air pollution levels during the growing season** at thresholds resulting in decline in tree growth and increased mortality in some tree species.

Medium evidence, high agreement

Tree species vary in their susceptibility to damage from air pollution. In general, pollutants are expected to decline in our region due to policy actions, technological advances and fossil-fuel alternatives [43]. However, ground-level ozone production is expected to continue to increase in our region [49] and around the world due to rising temperatures [45]. There is supporting evidence that projected ozone concentrations will reduce growth and increase mortality in northern hemisphere forests [76]. However, there is an absence of research on the projected effect of ozone pollution on forests in Metro Vancouver. There is high agreement among models that our region will experience warmers summers [57] and that ozone pollution will increase generally as a result of warmer temperatures [77].

Impact Statement 7: Maladaptation

Impact Statement: Warmer temperatures and milder winter conditions resulting in some **species being unsynchronized and maladapted** to the prevailing environment.

Medium evidence, medium agreement

There is already evidence that native forests are lagging behind their optimal climate niches for growth and regeneration [19, 52, 21]. Several studies have predicted changes in the distribution of native conifers in BC [74, 78, 79, 52]. One study indicated that the range of native deciduous trees would generally be unaffected by climate change [79]. The interactions between changing climate and phenology impacts are complex, species specific and difficult to generalize across the urban forest. Regional evidence for how phenology will change within the diverse species of Metro Vancouver’s urban forest is lacking. There is a high level of agreement across climate models that the region will experience warmer temperatures and milder winter conditions [57]. However, there is limited agreement among modelled changes in the distribution of species where the work has been done [78] and there is a lack of modelling data for most of the species occurring in the region’s urban forest. A greater understanding of the capacity for plant populations to adapt to climate change is needed [80].

Impact Statement 8: Saltwater Inundation

Impact Statement: Sea-level rise combined with storm surges leading to an increase in **frequency and duration of salt-water inundation and physical tree damage** within low lying areas, resulting in localized declines in tree growth and increased mortality.

Medium evidence, high agreement
Trees vary in their tolerance to flooding [66] and saline soils. Localized declines in tree growth and mortality due to either inundation or saline soils will be primarily driven by flooding frequency and duration. Some trees may also be damaged as a result of debris flow carried in floodwaters. The evidence supports that sea-level rise under climate change will result saltwater inundation in the event that dykes are breached [68, 71]. However, there is a lack of evidence regarding how soil salinity might be affected. Models generally agree that sea level will rise [57, 71].

Impact Statement 9: Growing Season

Impact Statement: More **frost free days, higher average winter temperatures** and a **longer growing season** leading to improved growth and an increase in the range of species well suited in Metro Vancouver, including increased success of invasive species.

Medium evidence, high agreement
Fewer frosts and milder winters will enable some new tree species to successfully overwinter in Metro Vancouver. It is expected that the dominant extreme minimum temperature zones for the region will shift from USDA Hardiness Zone 7 – 8, to Zones 8 – 9 [57]. Longer growing seasons may also increase the growth and productivity of some tree species given adequate soil moisture and nutrient availability [81]. However, responses are likely to be species specific due to differing developmental cues related to temperature and photoperiod [81]. Regional evidence for how tree species will respond to a lengthened growing season is limited. Models generally agree that there will be fewer frost days, milder winters and a longer growing season [57].

Impact Statement 10: Windstorms

Impact Statement: Increased storminess leading to an increase in the **frequency and intensity of windstorms** in the winter and spring.

Limited evidence, low agreement
While an increase in the frequency and intensity of windstorms is reported as a potential impact of climate change in some scientific literature [60, 82], numerous authors suggest that there may actually be little change or a small reduction in windstorm frequency and intensity in our region [83, 33, 84, 85, 86, 38]. There is low agreement among climate models regarding projections of storm frequency and intensity [33, 84].

Impact Statement 11: Atmospheric CO_2

Impact Statement: Increased **levels of atmospheric CO_2** changing plant phenology and plant physiology in a manner that either slows tree growth or increases it.

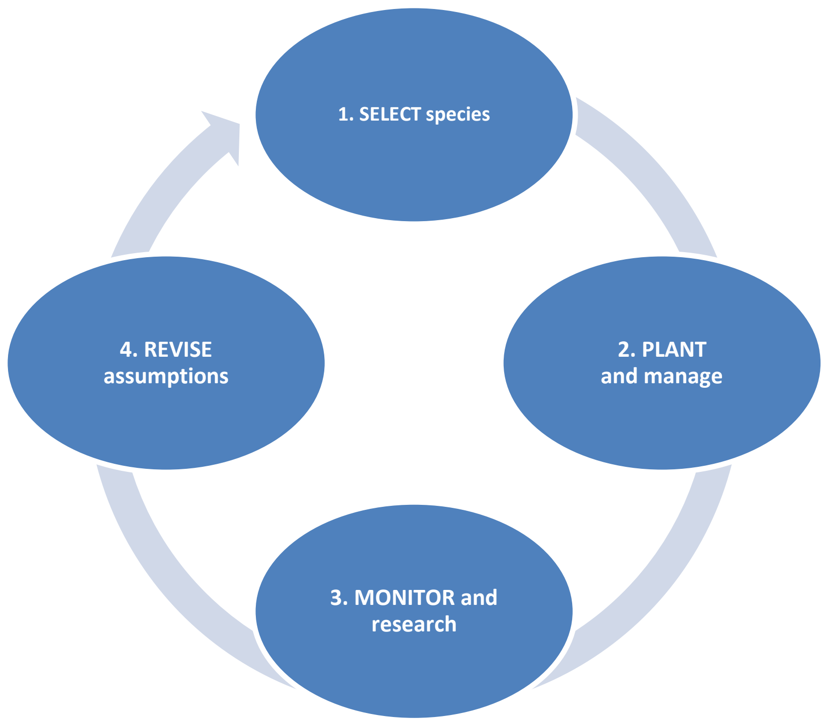
Limited evidence, high agreement

In general, elevated CO_2 increases photosynthesis and decreases stomatal conductance in plants [87], which would potentially increase both growth and water use efficiency. However, the literature provides a wide range of both positive and negative plant responses to increased atmospheric CO_2 and reports very high uncertainty regarding plant responses between species and biomes [73, 18, 87]. Factors such as temperature, soil moisture and ozone concentration also interact with growth responses to elevated CO_2 in complex ways [87]. At this stage there is very limited evidence for positive or negative impacts of increased atmospheric CO_2 on trees within Metro Vancouver's urban forest. Climate models are in agreement that atmospheric CO_2 is increasing.

4 Tools for Growing a Resilient Urban Forest

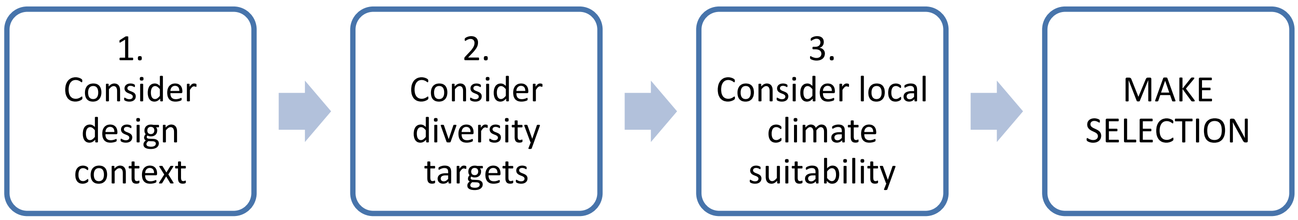
Out of the range of potential climate change impacts, we expect Metro Vancouver's urban forest will be most impacted by reduced soil moisture availability and increased wildfire, heat, fresh-water flooding, insect, disease and invasive plant activity.

Trees already under stress will be to be more susceptible to climate change impacts. We provide the following tools to inform the selection of trees and management approaches that will increase urban forest resilience to existing stressors and climate change impacts. A high degree of uncertainty is inherent in both climate change projections and predicted impacts. To successfully adapt the urban forest, adaptive management and long-term regional urban forest research must be components of the management tool-box.



4.1 Species Selection Framework

The following sections describe a framework for selecting species that will be well-adapted to the existing and future climate of Metro Vancouver. The framework progresses through three key steps prior to reaching a selection:



1. DESIGN CONTEXT: Tree Planting Design Considerations

Before selecting an appropriate species for a tree planting project, review the site design considerations and the benefits that the tree planting is intended to achieve. Metro Vancouver has developed a “Design Guidebook” to assist people in designing tree plantings that maximize the climate adaptation benefits of urban forests. The guidebook provides the context for selecting an appropriate species across a wide range of tree planting opportunities.

As a general principal, the magnitude of urban forest benefits provided is driven by canopy extent and forest structure (e.g., tree number, size, age). Selecting the largest tree suitable for the site will maximize the benefits produced.

2. DIVERSITY TARGETS: Diversity Considerations

In addition to being well-suited to the design context, a resilient tree stock consists of a diversity of tree species carefully selected to optimize desired ecosystem services and minimize disservices [88]. Diversity targets should be considered prior to selecting an appropriate species.

A diverse range of species is expected to reduce vulnerability in the urban forest population because species have variable tolerances for climatic and growing conditions. However, unproven species should be trialed before being integrated into planting programs. Setting tree diversity targets in urban forests is often guided by ‘rules-of-thumb’ such as the 10-20-30 rule [89] for planting no more than 10% of any species, 20% of any genus and 30% of any family [90, 91]. Applying generalized diversity targets to urban forests regardless of where they are in the world is not ideal because local climate and land use will influence the diversity of trees that can be supported [88, 91]. A global analysis of urban forest inventory data found that diversity in temperate climates was comparable at the genus and family level, but not at the species level, to the 10-20-30 rule [91]. In the absence of research specifically focussed on defining diversity targets for Metro Vancouver’s urban forest, we recommend the following considerations for setting diversity targets in the planted urban forest (i.e., excluding areas managed as native forest):

1. Assess the urban forest population against the 10-20-30 rule. Identify vulnerabilities at the species, genus and family level that could be reduced through future tree planting and succession planning.
2. Establish benchmark percentages for the overall population to target. Genus is a practical level at which to manage diversity. A survey of urban forest inventory data from

temperate regions suggests that the 10-20-30 rule is realistic at the genus level; however, a more ambitious target may be preferred to reduce vulnerability to pests with whole of genus host ranges.

3. Refine targets at the neighbourhood spatial scale to accommodate character, cultural and micro-climate considerations that may mean an imbalance in one genus is tolerated in a limited geographical area.
4. Establish age class targets. Research suggests that urban tree population cycles are often driven by young tree mortality occurring in the first 3 to 30 years after planting [92, 93]. Where population cycles are driven by young tree mortality, plant mostly long-lived species over time so that diameter at breast height (DBH) distribution approaches 40 % < 20 cm, 30 per cent = 20-40 cm, 20 per cent = 40 – 60 cm, 10 per cent > 60 cm [94].
5. Encourage nurseries to supply trees grown from seed as well as clonal stock.
6. Consider planting principles that improve spatial diversity at the local scale, such as:
    - Planting a single species on a street but not planting that species in connected streets;
    - Planting multiple species of similar form and appearance on a single street;
    - Planting a high diversity of species in parks where growing conditions are easier;
    - Planting trees with diverse life-expectancies and planting over a long period of time to promote age diversity;
    - Planting trees of diverse genetic stock to promote resistance to pests and disease; and,
    - Planting a diversity of species in layers (understorey to overstory) to promote vertical structure and biodiversity.

The 10-20-30 rule is not generally appropriate to apply to our native forests because it would threaten its inherent biotic nativeness. There is a risk that diverse urban forests with too many non-native species will not function as well as native forests at providing ecosystems services [95]. However, the pace of climate change may exceed the capacity of native trees to adapt and there may be justification to influence the direction and timing of adaptation through assisted migration of better adapted tree species and seed sources [96]. For native trees, seed provenance choice will be an important consideration because trees are already lagging behind their optimal climate niche. Further research is required to understand how assisted migration may be of relevance to managing native forests within an urban forestry context, and within the context of biotic nativeness in our region.

3. CLIMATE: Present and Future Climate Suitability Decision Tree

Ensuring that the next generation of trees is suited to the present and future climate is critical for building urban forest resilience. Species distribution modelling is complex and, at this point in time, limited data and tools are available to define future climate suitability for the wide diversity of tree species planted in urban forests. Further research and development of tools such as climate envelope modeling to assess climate suitability of urban forest tree species would benefit urban forest planners. In the interim, we provide a simplistic and transparent approach for assessing tree climate suitability using data that is widely publicised for a wide variety of tree species.

The approach below uses the US Department of Agriculture (USDA) plant hardiness zones [97], based on extreme minimum temperature, as a first filter. Hardiness zones represent the range of minimum temperatures the plant is expected to survive overwinter. While the system has some limitations, the zones have been used widely and over a long period of time for defining where trees will grow in North America. Metro Vancouver's hardiness zone based on extreme minimum temperature currently ranges from zone 7 – 8 (7 in higher elevation locations such as North Vancouver) [98]. While climate projections indicate that zones will change to 8 – 9 in the 2080s, trees planted today still need to tolerate zone 7. Occasional arctic outflows are assumed to continue to be a feature of the regional climate that will bring sudden temperature drops therefore a conservative approach to hardiness zone changes is prudent. In a particular planting location, micro-climate and urban heat island effects may alter the extreme minimum temperatures likely to be experienced so practitioners need to use local knowledge to adjust the hardiness zone where relevant.

The next level of filtering involves the use of the American Horticultural Society (AHS) heat zones [99], which reflect the number of days above 30°C that a plant can tolerate during the growing season. Metro Vancouver's heat days are projected to change from an average of 2 days per year to approximately 28 days per year in the 2080s. This represents a change from an average of heat zone 2 to an average of zone 4 or zone 5 at the upper range of variability. We expect that most urban trees will be able to survive in the projected future heat zone for Metro Vancouver.

The final filter for climate suitability is drought tolerance. This approach assumes that the area of Metro Vancouver that experiences annual soil moisture deficits will increase, and that the deficits will intensify due to warmer temperatures and lower summer rainfall under climate change. As a result, trees will experience water stress in more locations and more severely than they do today. The filters are applied through a series of steps presented in the decision tree below:

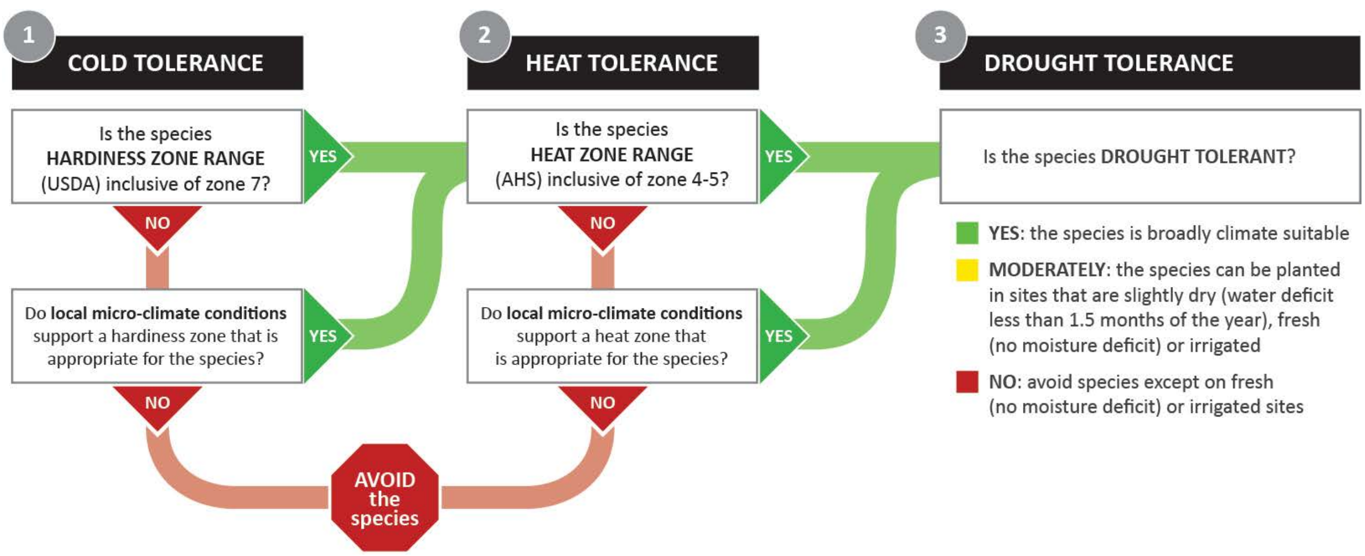


Figure 5. Climate suitability decision tree

SELECTION

Selecting species within the context of site design and climate suitability is important to minimize the likelihood of tree failures. Managing diversity through species selection will also build resilience to climate change impacts in our urban forest population.

The database of 144 tree species includes the attributes needed for input into the climate suitability decision tree, and to inform species selection as guided by the "Design Guidebook" [100]. The species included in the database provide a starting point for a tree selection tool and are not a recommended planting palette for Metro Vancouver. Most of the species in the list are already commonly planted in Metro Vancouver but some are less common potential trial species.

The objectives of the database as a decision support tool are to:

1. Provide a searchable database of climate suitable species (Figure 5);
2. Provide a searchable database of traits to short-list trees suited to a particular location in order to maximize climate adaptation benefits (see "Design Guidebook" [100]); and,
3. Provide practitioners with a rationale for selection of the species or species list.

The database was populated using a broad range of data sources reporting tree species characteristics (a meta-data table is provided Appendix 2). The database format provides flexibility over a list of recommended species because it can be searched by trait, and can be expanded and updated as new information becomes available. The database also integrates recently released species and geographically specific allometric equations, when available, that allow the user to explore predicted leaf area, crown diameter and DBH with known DBH or age [101]. With expansion, this database could provide the basis for a web-based tree species selection support tool to augment local arboricultural knowledge of tree species and their expected performance. The allometric and biomass equations can potentially be applied to predict tree benefits such as carbon storage, air pollution removal, transpiration rates and stormwater interception.

Selecting for Climate Adaptation

The species attributes listed below were chosen for their relevance to the "Design Guidebook" [100] scenarios using trees to maximize benefits for climate adaptation. Within the guidebook, recommended attributes are listed with the intent of cross-referencing to a tree species selection support tool inclusive of these characteristics. We intend to expand the number of species in the future. The attributes recorded:

- Allometric Growth Predictions
    - Enter known DBH or enter known age
    - Predicted leaf area (m2)
    - Predicted crown diameter (m)
    - Predicted DBH
    - Region sampled to derive allometric equation
- Tree characteristics
    - Size class (height m)
    - Evergreen
    - Canopy spread estimated at 40 years
    - Life expectancy
    - Annual growth rate (height cm)
    - Shade density in leaf
- Suitable locations
    - Street with tree pits/boulevard/median < 2 m width
    - Parks and broad boulevards/medians > 2 m width
    - Paved plazas with tree pits

- Containerized sites (low soil volume)
- Parking lot with landscape beds or screens/buffers
- Under overhead utilities

- Recommended minimum and preferred soil volume
- Tolerance
  - Saturated soil
  - Shade
  - Drought
  - Pollution
- Risks
  - Flammability
  - Wind breakage
  - Root damage potential
  - VOC rating
  - Invasive potential
  - Noted sourced of public complaints
- Metro Vancouver practitioner comments
- Habitat value
  - Bird/wildlife attracting
  - Insect and animal pollinated
  - Native
- Recommended locations for maximizing climate adaptation benefits (link to guidebook [100])
  - Major roads (arterials) - curbside
  - Major road (Arterials) - centre medians
  - Minor roads (collector and local)
  - Downtown streets
  - Highways
  - Unique planting areas
  - Surface parking lots
  - Plazas
  - Building edges
  - Infrastructure corridors
  - Playgrounds
  - Parks in proximity to natural areas
  - Parks in urban areas that are well separated from natural areas
  - Steep slopes, riparian, coastal
  - Wildland urban interface
  - Landscape buffers

A meta-data table defining the values and sources used to populate the database is provided in Appendix 2 and a copy of the database can be sourced from Metro Vancouver.

Selecting for Climate Suitability

The climate suitability decision tree (Figure 5) requires the USDA hardiness zone, AHS heat zone and drought tolerance for each species. These were reported in the database using three main sources:

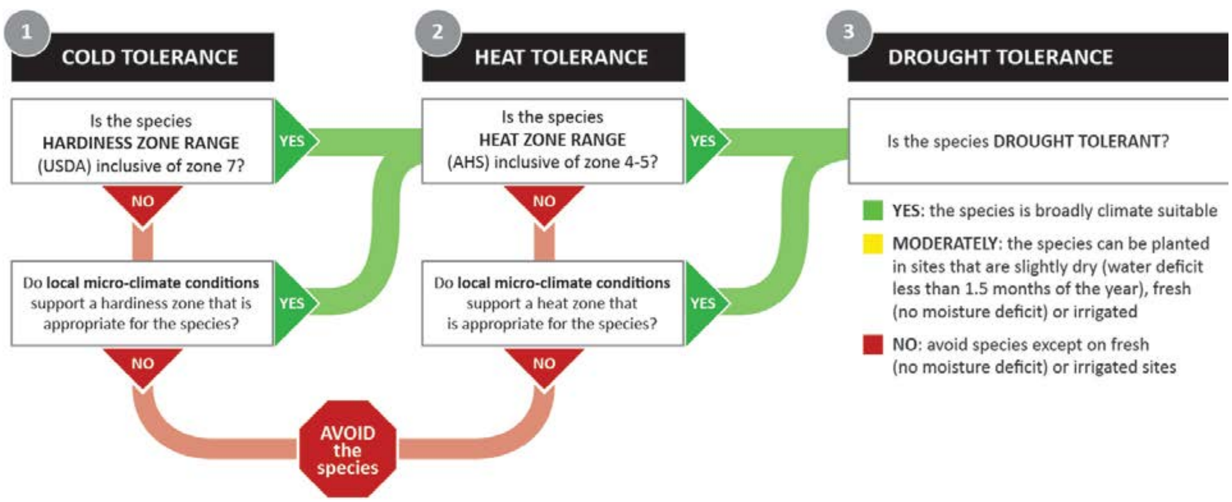
1. **Hardiness zone:**
   University of British Columbia Botanical Gardens. “Vancouver Trees (1.1),” 2015. [Mobile Application Software].[4]
2. **Heat zone:**
   Preferred Commerce “Learn2grow plant search”[5]
3. **Drought tolerance:**
   U. Niinemets and F. Vallardes, "Tolerance to shade, drought and waterlogging in the

[4] Available: www.botanicalgarden.ubc.ca/vancouvertrees/
[5] Available: http://www.learn2grow.com/Plants/

temperate dendroflora of the Northern hemisphere: tradeoffs, phylogenetic signal and implications for niche differentiation"[6]

So far, 144 species commonly planted or naturally occurring in the region have been assessed using the decision tree process outlined in Figure 5. This initial assessment provides a useful starting point to inform local species selection for future climate suitability in Metro Vancouver. Present and future climate suitability is driven by drought tolerance once it is established that a species is hardy to zone 7 and tolerant of heat zone 4-5[7]:

- 'avoid species' – not hardy to zone 7 or tolerant of heat zone 4-5 (no species assessed to date have been in this category).
- 'broadly suitable' – the species tolerates more than 2 months of drought and is expected to do well in even the driest sites in the region.
- 'slightly dry sites' – the species will be restricted to sites that usually have an annual moisture deficit of approximately 1 month of the year (slightly dry sites are expected to become more common in Metro Vancouver); and,
- 'fresh sites' – the species will be restricted to sites that usually have no more than a few weeks annual moisture deficit (fresh sites expected to become less common in Metro Vancouver).



[6] Availabile: https://www.researchgate.net/publication/236160782_Tolerance_to_shade_drought_and_waterlogging_in_the_temperate_dendroflora_of_the_Northern_hemisphere_tradeoffs_phylogenetic_signal_and_implications_for_niche_differentiation

[7] The expected 2050s and 2080s climate projections informing the hardiness and heat zones are based on the business as usual case, which is a high emissions future worst-case scenario [57].

Results indicate that, of the 144 species assessed:

Broadly suitable
Suit even the driest sites

Thirty-three species are broadly suitable for both the current and future climate

amur cork tree | Arizona walnut |Austrian pine | black locust | burr oak | California incense cedar | callery pear| Chinese flame tree | Chinese pistachio | common hackberry | Deodar cedar | eastern redbud | garry oak| ginkgo | golden rain tree | green ash| hardy rubber tree | holly oak | honey locust |Kentucky coffee tree |Lavallei hybrid hawthorn | limber pine | manna ash | Pacific madrone/arbutus | ponderosa pine | sawtooth oak | scarlet oak | scotch pine | shore pine | silk tree | tanoak | toba hawthorn | western catalpa;

Slightly dry sites
Suit most sites except the driest sites

Seventy species are suitable for sites that are no drier than slightly dry, and are still expected to do well in most sites except the driest sites in the region

American elm |American hop hornbeam | American hornbeam | amur maple | atlas cedar | autumn brilliance serviceberry | bald cypress | bitter cherry | black hawthorn | Caucasian lime | Caucasian maple | cherry plum | Chinese redbud | Colorado blue spruce | common catalpa | common horsechestnut | Douglas-fir| English hawthorn | English oak | English walnut | European hop hornbeam | European hornbeam| field maple | Freeman maple | giant redwood | handkerchief tree | Hinoki false cypress | Hungarian oak | Japanese cherry | Japanese flowering crabapple | Japanese hornbeam | Japanese pagoda tree | Japanese snowbell | Japanese stewartia | Japanese zelkova | Judas tree | Kobus magnolia | large-leaf linden | little-leaf linden | London planetree | monkey puzzle | Norway maple | Persian ironwood | red lotus | red oak | ruby red horsechestnut | Sargents cherry | sawara false cypress | Serbian spruce | Shantung maple | Siberian crabapple | Siberian elm | silver linden | snow gum | southern beech | southern magnolia | Spanish chestnut | sweet gum | sycamore maple | tulip tree | Turkish hazel | western yew | white spruce | white swamp oak | whitebeam | willow oak | yellowwood | Yoshino cherry;

Fresh sites
Only suit sites with no more than a few weeks of moisture deficit

Fourty-one species are suitable for fresh sites and are expected to become more restricted as the region becomes drier in summer

American ash | big leaf maple | black walnut | California redwood | black cottonwood | dawn redwood | European ash | European beech | European larch | European mountain ash | false arborvitae | fragrant snowbell | giant dogwood | grand fir | Japanese elm | Japanese maple | katsura | Korean mountain ash | kousa dogwood | Nootka cypress | Norway spruce | Pacific dogwood| paper birch | paperbark maple | pin oak | red alder | red maple | saucer magnolia | Scotch elm | silver birch | Sitka spruce | star magnolia | sugar maple | sweetbay magnolia | tree lilac | trembling aspen | tupelo | vine maple | western hemlock | western redcedar | yellow buckeye;

4.2 Soil and Planting Infrastructure Guidelines

CLIMATE ADAPTATION STRATEGIES FOR IMPROVING SOIL MANAGEMENT AND PLANTING INFRASTRUCTURE: The following guidelines focus on the most important soil management strategies for supporting the growth of a healthy urban forest:

- ***Maximize soil volume***: Provide sufficient soil volume in the rooting zone (upper 1 metre of soil) for healthy tree growth. While more soil is generally better, we recommend a minimum volume of 0.3 m^3 soil per unit area of projected crown area (m^2) [101]. The minimum soil volume guideline is based on a tree's estimated daily water use in our driest month (July) and soil water storage for a sandy loam soil. However, the recommended preferred soil volume is 0.6 m^3 per unit area of projected crown area (m^2) because the larger volume will provide greater soil water storage for trees under a warmer, drier climate. Solutions for load bearing sidewalks or parking areas, such as trenches to connect soil volume, suspended pavements supporting soil volume below, and structural soils [102], should be used to increase soil volume in hardscapes. In an established landscape it is difficult and costly to retrofit soil. Wherever possible, optimal soil conditions should be designed into the construction of new landscapes.

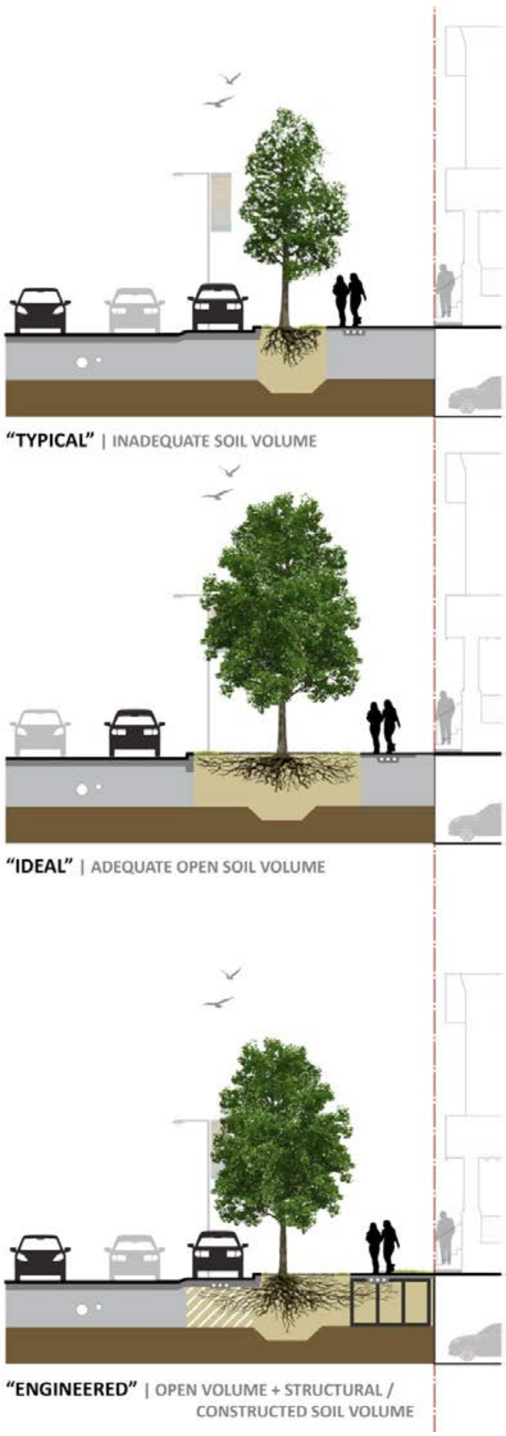
- ***Prevent compaction***: Prevent soil compaction during construction in areas for future tree planting by fencing off planting areas or laying down materials like mulch or matting where machine access is needed. In areas that are already compacted, aerate, rip or deep till soils prior to planting.

- ***Increase water storage capacity and reduce water loss*****:** Protect native soils and soil structure in place or as stockpiles during development. Where importing soil, follow Canadian Landscape Standards (current edition) to select soils or amend soil properties to optimize water-holding capacity while still allowing adequate drainage. Amendments can increase soil porosity and water storage, in addition to providing nutrients and other soil improvements. However, avoid amendments to soil that will be backfilled into a planting hole if they will cause the soil texture will vary from the surrounding soil. Apply mulch to the root zone of trees to reduce water loss in the soil through evaporation.

- ***Minimize competition at planting sites***: Minimize competition for water in root zones. Roots of turf grass and other vegetation compete with tree roots for nutrients, light, oxygen, and water. Use mulch rather than turf grass below the drip-line of trees to the extent possible.

- ***Minimize soil interfaces***: Changes in soil texture create interfaces that can disrupt water flow and create waterlogged soils and perched water tables. Ensure that the entire root ball is within one soil type. Match the soil type of balled and burlap trees with the planting site or plant bare root trees into site soils.

- ***Preserve or improve soil quality:*** Maintain or create suitable soil conditions for trees to grow in. Retain and protect native soils (and soil structure) where possible as they typically have higher organic content, nutrients, water storage capacity, porosity and microbial activity than modified urban soils. Where stockpiling top soil on development sites, it should be drawn from the O and A horizons. Limit potential sources of soil contamination (e.g. salts) and alkalinity (e.g., liquid concrete) that cause nutrient deficiencies in trees [103]. The best quality soil for growing trees is an aggregated, firm but not compacted loam, slightly sandy loam, or slightly sandy clay loam. The addition of organic matter (e.g., mulch) can benefit the activity of fungi, bacteria and soil animals and the process of forming soil aggregates, which improves soil structure and benefits trees.



CLIMATE ADAPTATION STRATEGIES FOR IMPROVING SOIL MANAGEMENT AND PLANTING INFRASTRUCTURE

Guidelines focusing on soil management strategies for supporting the growth of a healthy urban forest are illustrated as related to a range of physical conditions represented within three scenarios (at left).

In an established landscape it is difficult and costly to retrofit soil and drainage. Wherever possible, optimal soil and drainage conditions should be designed into the construction of new landscapes.

MAXIMIZE SOIL VOLUME
Provide sufficient soil volume in the rooting zone (upper 1 metre of soil) for healthy tree growth.

INCREASE WATER STORAGE CAPACITY AND REDUCE WATER LOSS
Select soils or amend soil properties to optimize water-holding capacity (20%) [97] while still allowing adequate drainage. Amendments can increase soil porosity and water storage, in addition to providing nutrients and other soil improvements. Apply mulch to the root zone of trees to reduce water loss in the soil through evaporation.

PREVENT COMPACTION
Prevent soil compaction during construction in areas for future tree planting by fencing off planting areas or laying down materials like mulch or matting where machine access is needed. In areas that are already compacted, aerate, rip or deep till soils prior to planting. Solutions for load bearing sidewalks or parking areas, such as trenches to connect soil volume, suspended pavements supporting soil volume below, and structural soils, should be used to increase soil volume and prevent compaction in hardscapes.

MINIMIZE COMPETITION
Minimize competition for water in root zones. Roots of turf grass and other vegetation compete with tree roots for nutrients, light, oxygen, and water. Use mulch rather than turf grass below the drip-line of trees to the extent possible.

MINIMIZE SOIL INTERFACES
Changes in soil texture create interfaces that can disrupt water flow and create waterlogged soils and perched water tables. Ensure that the entire root ball is within one soil type. Match the soil type of balled and burlap trees with the planting site or plant bare root trees into site soils.

PRESERVE / IMPROVE SOIL QUALITY
Retain and protect native soils (and soil structure) where possible. Where stockpiling top soil on development sites, it should be drawn from the O and A horizons. Limit potential sources of soil contamination that cause nutrient deficiencies in trees. The best quality soil for growing trees is an aggregated, firm but not compacted loam, slightly sandy loam, or slightly sandy clay loam. The addition of organic matter (e.g., mulch) can improve soil structure and benefit trees.

4.3 Water Management Guidelines

CLIMATE ADAPTATION STRATEGIES FOR WATER MANAGEMENT: The following guidelines focus on the most important strategies for maintaining sufficient soil moisture for the growth of a healthy urban forest:

- ***Irrigate efficiently***: Young trees typically require regular watering for the first 2-5 years of life and, beyond that time, supplemental watering in dry periods. Spring, summer and fall supplemental watering in dry years will support a good annual growth increment. Water bags, water pods, water wells, or drip irrigation systems are efficient methods to ensure water is applied slowly and can infiltrate the soil. Use mulches (preferably organic) to reduce evaporation.

- ***Encourage passive water harvesting strategies*****:** Where possible, plant trees in areas that naturally receive runoff but are not frequently waterlogged. Use passive water harvesting in areas prone to seasonal moisture deficits to slow, distribute and store runoff, and allow it to infiltrate into the soil. Examples include bioswales, berms, raingardens, French drains, bioretention tree pits, permeable hardscapes, and infiltration trenches in street designs to help redirect stormwater runoff into planted boulevards. If using passive water harvesting to manage stormwater volumes, additional consideration must be given to the soil media for bioretention and the volume of storage provided by the soil. Refer to Metro Vancouver's "Stormwater Source Control Design Guidelines 2012" [104] for design guidance.

- ***Encourage active water harvesting strategies:*** In locations with a high volume irrigation requirement, use active harvesting systems to collect, store, and reuse water for spring and summer use. Systems can combine storage (e.g. cisterns, rainbarrels, tanks) with pumps to distribute water where and when it is required most.

- ***Reduce vegetation water demand***: Select drought-tolerant trees on sites that are drought-prone unless irrigation is planned. Trees with a high leaf-area density and a high rate of transpiration are more effective at providing shade and cooling [24]. In areas where cooling is a priority, maintaining adequate soil moisture, maximizing permeable surfaces and planting trees with good shade and cooling properties may be preferred over selection primarily for high drought tolerance.

- ***Maximize proportion of permeable surfaces:*** Maximize the area of permeable surface surrounding trees by creating large tree pits or using permeable paving solutions.

- ***Explore emerging opportunities:*** As the regulatory environment evolves, strategies such as greywater irrigation may provide options to reuse water for tree management.

CLIMATE ADAPTATION STRATEGIES FOR WATER MANAGEMENT

Guidelines focusing on maintaining soil moisture for supporting the growth of a healthy urban forest are illustrated as related to a range of physical conditions represented within three scenarios (at left).

In an established landscape it is difficult and costly to retrofit soil and drainage. Wherever possible, optimal soil and drainage conditions should be designed into the construction of new landscapes.

IRRIGATE EFFICIENTLY

Young trees typically require regular watering for the first 2-5 years of life and, beyond that time, supplemental watering in dry periods. Spring, summer and fall supplemental watering in dry years will support a good annual growth increment. Water bags, water pods, water wells, or drip irrigation systems are efficient methods to ensure water is applied slowly and can infiltrate the soil. Use mulches (preferably organic) to reduce evaporation.

ENCOURAGE PASSIVE WATER HARVESTING STRATEGIES

Where possible, plant trees in areas that naturally receive runoff but are not frequently waterlogged. Use passive water harvesting in areas prone to seasonal moisture deficits to slow, distribute and store runoff, and allow it to infiltrate into the soil. Examples include bioswales, berms, raingardens, French drains, bioretention tree pits, permeable hardscapes, and infiltration trenches in street designs to help redirect stormwater runoff into planted boulevards. If using passive water harvesting to manage stormwater volumes, additional consideration must be given to the soil media for bioretention and the volume of storage provided by the soil.

ENCOURAGE ACTIVE WATER HARVESTING STRATEGIES

In locations with a high volume irrigation requirement, use active harvesting systems to collect, store, and reuse water for spring and summer use. Systems can combine storage (e.g. cisterns, rainbarrels, tanks) with pumps to distribute water where and when it is required most.

REDUCE VEGETATION WATER DEMAND

Select drought-tolerant trees on sites that are drought-prone unless irrigation is planned. In areas where cooling is a priority, maintaining adequate soil moisture, maximizing permeable surfaces and planting trees with good shade and cooling properties may be preferred over selection primarily for high drought tolerance.

MAXIMIZE PROPORTION OF PERMEABLE SURFACES

Maximize the area of permeable surface surrounding trees by creating large tree pits or using permeable paving solutions.

EXPLORE EMERGING OPPORTUNITIES

As the regulatory environment evolves, strategies such as greywater irrigation may provide additional options to reuse water for tree management.

4.4 Tree Management Guidelines

TREE MANAGEMENT STRATEGIES FOR CLIMATE ADAPTATION: The following guidelines focus on tree management strategies that can contribute to maintaining a healthy urban forest:

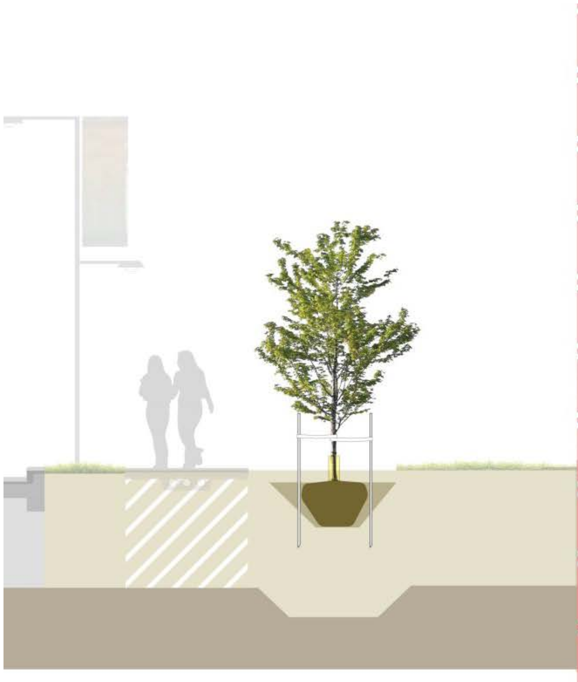
- ***Care for newly planted trees:*** Trees are most vulnerable when young and are expensive to replace both because of cost and lost canopy growth opportunity. Ensure that trees meet Canadian Standards for Nursery Stock and are planted to best practices as published by the International Society of Arboriculture (ISA). Newly planted trees require at least 12 months to establish their root system and need regular watering over that period. Tree staking may be required in high pedestrian traffic or windy locations; however ties should be loose so that the tree is encouraged to become self-supporting. Any accessory structures (e.g., whipper snipper guards, grates, tree guards, ties etc.) must be regularly maintained and removed before they are enveloped by the tree.

- ***Implement scheduled pruning programs***: Ensure that nursery stock meets specifications for good structure or correctively prune newly planted trees. It is recommended that young trees be structurally pruned on a 3-year cycle for the first 15 years of life. Limit pruning cuts to < 7 cm on decay prone species and < 15 cm on decay resistant species. Structural pruning is a cost-effective method to ensure healthy growtzh, form and structure of mature trees for the long-term. In mature trees, pruning may be required for a variety of reasons but live branches should only be pruned when necessary. A mature tree pruning cycle should ideally involve inspection of trees every 7-15 years depending on targets in the area and tree age or condition. Follow industry standards (ANSI A300)and best practices as published by the ISA for pruning to ensure optimum tree care.

- ***Install tree protection barriers during construction:*** Erect barriers (e.g. fences, curbs, planting containers) to protect trees from mechanical injury above ground or to their critical root zones (often estimated at 6 x DBH or to the dripline, whichever is greater). Set minimum tree protection zones at 2 m from tree centre. Encourage modification of tree protection zones to reflect the actual site conditions and protect maximum permeable area around trees. For example, where load bearing hardscape already surrounds one half of the tree's critical roots zone, erect the barrier at the boundary of the hardscape and protect a compensatory area of permeable surface given that this is where the majority of roots will be growing.

- ***Protect suitable trees and supervise works around trees during construction:*** Prioritize retention and protection of healthy and structurally sound trees on the site, not just the largest trees. Measures such as Safe Useful Life Expectancy can assist in identifying candidates for retention that will be best able to adapt to the future site conditions. Where works must be in close proximity to the trees, require an ISA certified arborist to supervise and undertake pruning if needed.

- ***Maintain windfirmness***: For new plantings, select trees that have good wind resistance and provide planting sites with adequate soil volume for trees to be suitably anchored. When creating new stand edges or tree strips by removing trees from existing groups, retain anchoring windfirm trees that protect the group by considering important factors such as buffer width, species, rooting structure, and height-diameter ratio. Trees planted in groups of five or more and less than 3 m apart (but not in rows) have been found to be more windfirm under hurricane force winds [105].



WATERING
Newly planted trees require at least 12 months to establish a new root system and require regular watering over that period.

YOUNG TREE PROTECTION
Tree staking may be required in high pedestrian traffic or windy locations; however ties should be loose so that the tree is encouraged to become self-supporting. Any accessory structures (e.g., whipper snipper guards, grates, tree guards, ties etc.) must be regularly maintained and removed before they are enveloped by the tree.

SCHEDULED PRUNING
Ensure that nursery stock meets specifications for good structure or correctively prune newly planted trees. It is recommended that young trees be structurally pruned on a 3-year cycle for the first 15 years of life. A mature tree pruning cycle should ideally involve inspection of trees every 7-15 years (depending on targets in the area and tree age or condition).

CONSTRUCTION OVERSIGHT
Protect suitable trees and supervise works around trees during construction. Erect fencing to protect trees from mechanical injury above ground or within their critical root zones (often estimated at 6 x DBH or to the dripline, whichever is greater). Set minimum tree protection zones at 2 m from tree centre.

4.5 Measuring Success

Given that achieving success in adapting Metro Vancouver's urban forest to climate change means to:

1. Maintain a healthy, resilient and safe tree population.
2. Increase the health and resilience of the native tree population to climate change impacts.
3. Enhance soil and water resources available for the urban forest.
4. Maximize benefits provided by the urban forest.
5. Maximize cost efficiencies in urban forest management.

The following indicators (with associated targets) would provide a means of measuring success towards meeting these objectives and enabling adaptive management:

- ☐ Canopy cover
- ☐ Tree health
- ☐ Tree species, age and genetic diversity
- ☐ Proportion of climate suitable trees in the population
- ☐ Area of climate suitable native forest cover
- ☐ Soil health
- ☐ Native soil retention
- ☐ Soil erosion
- ☐ Soil quality
- ☐ Soil volume
- ☐ Benefits provided
- ☐ Potable water use
- ☐ Tree failure rates
- ☐ Maintenance costs
- ☐ Data collection costs
- ☐ Legal costs
- ☐ Interagency cooperation and coordination

4.6 Research Needs and Opportunities

The inherent uncertainty underlying climate change planning raises multiple research questions. Several of the key questions identified through this project that would benefit urban forest planners in Metro Vancouver are:

Questions informing policy

1. What are appropriate canopy cover and permeability targets associated with land use and/or zoning for Metro Vancouver?
2. What is an 'ideal' hardscape soil volume for our current and future climate?
3. What are appropriate diversity targets for planted urban forests in Metro Vancouver?

Questions informing management

4. Based on dendrochronological evidence, what are the important climatic factors (e.g., seasonal precipitation, temperatures, soil moisture) driving urban tree growth in Metro Vancouver and what are the implications for management?
5. What are the most significant causes of windthrow and tree failures in Metro Vancouver's urban forest?
6. Which urban forest pests, diseases and invasive species are active where in Metro Vancouver and is it changing over time (regional monitoring and information sharing)?
7. Where and when are soil moisture deficits most acute across Metro Vancouver and which passive irrigation and permeable hardscape interventions are most effective at mitigating them?
8. Of the trees retained and protected under bylaws across Metro Vancouver on different density developments, what proportion of canopy cover is retained on average and how are retained trees performing several years after the development process is completed?

Questions informing species selection

9. Based on the outcomes of urban species trials and species distribution modelling, which new species are becoming, or are most likely to become, suitable for planting in Metro Vancouver?
10. What are the range of growing conditions anticipated under climate change and how are existing and potential tree species in Metro Vancouver tolerant to those conditions (site/species trials to mimic future conditions)?
11. How are different species performing at delivering ecosystem services in Metro Vancouver?
12. How could assisted migration be of relevance to managing native forests within an urban forestry context, and within the context of biotic nativeness in Metro Vancouver?

Questions informing regional climate change

13. Is wildfire frequency and area burned projected to change in Metro Vancouver?
14. What are the projected effects of ozone pollution on forests in Metro Vancouver and are other pollutants emerging as a growing concern?

15. How often will optimum temperature thresholds be exceeded for the dominant species in Metro Vancouver's urban forest?
16. How is the range of specific species of insects, disease and invasive plants projected to change in Metro Vancouver?
17. What is the adaptive capacity of the dominant species in Metro Vancouver's urban forest to projected climate changes?
18. How are trees in Metro Vancouver responding to increased atmospheric CO_2?

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Appendix 1 – Advisory Panel Workshop Summaries

Urban Forest Climate Adaptation Guidelines for Metro Vancouver

Advisory Panel Meeting #1 – workshop summary

November 19, 2015

Submitted to:

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1 Introduction

Meeting #1 with the Advisory Panel for Metro Vancouver's Urban Forest Adaptation Guidelines was held on October 28 in meeting rooms at Metro Vancouver's Kathleen Building. A total of 20 people from organizations across Metro Vancouver attended the 2.5 hour session (Table 1). Apologies were received from representatives of the Corporation of Delta and Simon Fraser University. The meeting agenda is provided in Appendix 1.

Table 1 – Advisory Panel Meeting Attendees

Name	Organization
Lanny Englund	City of Coquitlam
Erika Mashig	City of New Westminster
Jonathan Budgell	City of North Vancouver
Gordon Jaggs	City of Richmond
Kimberly Armour	City of Richmond
Neal Aven	City of Surrey
Bill Stephen	City of Vancouver
Tamsin Mills	City of Vancouver
Rod Stott	District of Maple Ridge
Sinead Murphy	District of North Vancouver
Alison Evely	Metro Vancouver
Conor Reynolds	Metro Vancouver
Erin Embley	Metro Vancouver
Jason Emmert	Metro Vancouver
Josephine Clark	Metro Vancouver
Kristie Goodman-Rendall	Metro Vancouver
Lillian Zaremba	Metro Vancouver
Tom Lancaster	Metro Vancouver
Sara Barron	University of British Columbia
Stephen Sheppard	University of British Columbia

The purpose of the meeting was to establish the objectives and content alternatives for the two key project deliverables:

1. Urban forest climate adaption framework for tree species selection, planting and management
2. Design guidelines for urban trees to maximize climate adaptation benefits

Attendees worked in small, facilitated groups within a 'world café'[1] format to refine the objectives and alternatives for each deliverable. The raw outputs are provided in Appendix 2. The objectives and alternatives proposed as a result of the Advisory Panel's input are summarised below. These will direct the next phase of this project and inform the content of the key deliverables.

[1] A structured conversational process intended to facilitate open and intimate discussion, and link ideas within a larger group. Participants move between a series of tables to discuss each topic or question.

2 Deliverable 1: CLIMATE ADAPTION FRAMEWORK for Tree Species Selection, Planting and Management

Based on input from the Advisory Panel, achieving success in adapting Metro Vancouver's urban forest to climate change means to:

Objective	Means of Achieving Objective
1. Maintain a healthy, resilient and safe tree population by:	• Maximizing tree health • Maximizing proportional tree diversity within the urban tree population • Maximizing the proportion of well-suited trees in the population
2. Increase the health and resilience of the native tree population to climate change impacts by:	• Maximizing the area of well-adapted native forest cover • Maximizing connectivity between native forest patches • Maximizing protection of the "whole system" • Maximizing ecosystem health
3. Enhance soil and water resources available for the urban forest by:	• Maximizing soil quality and health • Maximizing retention of native soils • Minimizing soil erosion in foreshore areas • Maximizing soil water infiltration • Maximizing soil microbial activity • Maximizing soil nutrient availability • Maximizing availability of quality of soil to trees • Minimizing reliance on potable water for irrigation • Maximizing the availability of summer water to trees
4. Maximize benefits provided by the urban forest by:	• Maximizing tree benefit provision to people • Maximizing canopy cover • Minimizing tree conflicts
5. Maximize cost efficiencies in urban forest management by:	• Minimizing maintenance costs • Maximizing interagency coordination and cooperation • Minimizing data collection costs • Minimizing legal expenses

Based on the work completed with the Advisory Panel in defining how to achieve these objectives, the following sections outline content that may be incorporated into the scope of the tools developed for tree species selection, planting and management.

2.1 Species Selection Framework

Framework may consider the following:

- **Define well-adapted native trees**
- **Explore "new native" to expand native tree species list**
- **Develop guidelines for suitable species selection that encourage selection of:**
  - Diverse species/genera
  - Well-adapted native and non-native trees (i.e., tolerance of anticipated impacts)
  - Largest canopy trees (appropriate for sites)
  - The right tree for the benefit needed including:
    - Ecosystem services (i.e., shade, wind/noise/land use buffer, air quality, water quality, stormwater interception, recreation, food production etc.)
    - Visual/aesthetic criteria for species selection (incl. cultural preference)
    - Maintenance of views and solar access
    - Habitat for insects, birds and mammals
- **Encourage tree managers to consider:**
  - Pro-active adaptation/ecosystem migration
  - Age diversity through succession planning
  - Species diversity through species selection
  - Spatial connectivity of species to reduce pest or disease vulnerability
  - Spatial connectivity of native forest patches to maximize ecological function
- **Encourage nurseries to:**
  - Increase availability of well-adapted native trees in stock
  - Select tree seed sources adaptable to climate change
  - Grow a diverse list of suitable species
  - Maximize genetic diversity by growing a diverse range of cultivars

2.2 Soil and Planting Infrastructure Guidelines

Guidelines may consider the following:

- **Define Best Management Practices (BMPs) for managing soil resources that address:**
  - Adequate soil volumes
  - Increased biomass retention (leaves, coarse woody debris)
  - Native soil preservation
  - Increased pervious surface areas
  - Appropriate ground cover for erosion prone soils
  - Soil quality testing and certification
  - Mulching of rooting zones
  - Mechanical technology to improve aeration (e.g. air spade)
  - Soil amendments and fertilization
  - Increasing system-based management for mycelium and soils

2.3 Water Management Guidelines

Guidelines may consider the following:

- Define BMPs for managing water resources that address:
  - Management of storm or grey water for watering/irrigation
    - Passive irrigation systems
  - Management of water availability for vegetation during periods of drought

2.4 Tree Management Guidelines

Guidelines may consider the following:

- Define BMPs for managing trees that address:
  - Scheduled pruning and maintenance programs
  - Prioritized/zoned risk assessment programs
  - Planting and installation specifications (bare roots versus containers, caliper/ size, soil cells/structural soils, stormwater, root barriers)

2.5 Broader Topics for Urban Forest Climate Adaptation

Discussions on achieving each objective spanned a broad range of urban forest management topics and alternatives in addition to those already summarized for the species selection framework and guidelines. The following table, categorized by topic, lists the additional alternatives raised by the Advisory Panel.

Topic	Specific Alternatives
Data	• Increase inventory data collection • Collect and compile regional data for monitoring regional trends
Regional targets/standards	• Recommend tree risk thresholds • Establish regional benchmarks for canopy cover • Set a Pacific Northwest benchmark for canopy cover: 40%? Increase goal?
Regulation and incentives	• Improve legal protection: enforcement (ordinances, bylaw) • Regulate canopy cover • Require cash-in-lieu of replacing canopy cover on lots under development where space for replanting is inadequate • Tree bonding for development: for establishment and survival, appropriate time • Regulate soil preservation, soil imports and soil recycling • Change the building code to allow for on-site water harvesting • Regulate surface permeability through bylaws • Provide incentives to retain/install permeable surface
Education and stewardship	• Encourage citizen tree stewardship • Educate residents to water street trees in front of their homes • Increase public education about tree and ecosystem values • Develop citizen forester programs for data collection • Encourage the use of volunteers to remove invasive species
Interagency cooperation	• Develop regional cost sharing programs (e.g. trucks, orthophotos, LiDAR, species trials, inventories, forest health monitoring etc.)

	• Coordinate replanting opportunities with infrastructure upgrades • Consult with nurseries to develop regional guidance on preferred tree stock, species, propagation, growing cost (grafting vs. seed), purchase agreements (long term) and warranties • Work with internal and external agencies that impact the tree resource to coordinate tree management objectives and BMPs • Coordinate scheduling for interagency planting and pruning projects e.g. hydro pruning and city maintenance
Planning	• Develop preparedness plans for droughts, storms, wildfire, flood • Develop street tree planting plans/master plans that incorporate benefit provision and site considerations
Value-adding	• Develop regional wood markets for pruned trees and removals • Develop bioenergy markets

2.6 Local Research Needs

The following research needs were highlighted by the Advisory Panel:

- Increase our local knowledge about urban tree growth and performance
- Increase knowledge of windthrow and tree failures
- Increase the use of species planting trials in the region
- Development of regional standards for risk management and tree inventory
- Monitoring of regional trends

3 Deliverable 2: DESIGN GUIDELINES for Urban Trees to Maximize Climate Adaptation Benefits

Based on input from the Advisory Panel, achieving success in using trees to adapt Metro Vancouver communities to climate change means to:

Objective	Means of Achieving Objective
1. Maximize benefits to human health and well-being by:	• Maximizing mental health benefits • Maximizing cultural, social and spiritual benefits • Maximizing physical health benefits • Maximizing benefits to vulnerable people • Minimizing disservices and risks (i.e., hazard, trip/slip, Volatile Organic Compounds)
2. Maximize benefits to buildings and infrastructure by:	• Maximizing capture, storage and infiltration of rainfall • Maximizing shading of buildings for energy efficiency • Maximizing shading of hardscape • Minimizing wildfire hazard • Minimizing storm surge hazard • Maximizing winter solar access • Minimizing reliance on potable water for irrigation • Minimizing infrastructure conflicts
3. Maximize benefits to the broader environment by:	• Minimizing erosion in coastal and riparian areas • Maximizing slope stability • Maximizing habitat value for pollinators, species at risk, sensitive plant communities • Maximizing biodiversity
4. Maximize cost efficiencies by:	• Minimizing cost of installation • Minimizing cost of maintenance • Maximizing public stewardship • Maximizing collaboration on "resource" management • Maximizing collective knowledge
5. Minimize conflicts with legal, institutional and economic frameworks by:	• Minimizing policy conflict • Maximizing political support • Maximizing regulatory enforcement

Based on the work completed with the Advisory Panel in defining how to achieve these objectives, the following sections outline content that may be incorporated into the scope of the design guidelines developed for urban trees.

3.1 Design Guidelines for using Trees to Adapt to Climate Change

Design guidelines for the following locations are proposed to best meet objectives:

Street

1. Trees in major roads (including scenarios with transit, parking and services)
2. Trees in minor roads (including scenarios with services, parking)
3. Trees in downtown roads (including scenarios with transit, cycling and services)

Feature

4. Trees in unique planting opportunities (i.e., roundabouts/curb outstands/triangular block corners etc.)

Natural

5. Native trees in urban roads (i.e., wide median, park edge opportunities)
6. Biodiversity corridor in bikeway/greenway
7. Naturescaping around buildings
8. Native plantings for stabilizing steep slopes

Formal

9. Trees in surface parking lots
10. Trees in plazas/squares
11. Tree avenues in streets/parks

Informal

12. Trees around buildings (low – highest feasible density for planting)
13. Trees around playgrounds

Buffer

14. Trees buffering watercourses from built-up areas
15. Trees buffering built-up areas from storm surges
16. Trees buffering built-up areas from high wildfire hazard
17. Trees buffering built-up areas from disruptive land uses (i.e., arterial roads, industrial uses, farming)

Suggested benefit drivers for tree planting were:

- Air quality
- Beautification, character, icons
- Biodiversity
- Buffering wind, noise, privacy, storm surge, riparian areas
- Building energy savings
- Connection to nature and culture
- Ecosystem restoration
- Education
- Food production
- Recreation
- Ecosystem restoration
- Sense of place
- Shading and cooling
- Stabilization
- Stormwater management
- Water quality
- Spirituality and well-being

Suggested drivers for locating tree planting were:

- People
- Vulnerable people
- Equitable distribution of trees among the population
- Building types
- Crime Prevention Through Environmental Design (CPTED)
- Infrastructure constraints
- Metro Vancouver Regional Growth Strategy

3.2 Broader Topics for Using Trees to Adapt to Climate Change

Discussions on how to achieve each objective spanned a broad range of management topics in addition to the focus on developing design guidelines outlined in the previous section. The following table, categorized by topic, lists the additional alternatives raised by the Advisory Panel:

Topic	Specific Alternatives

Regional targets/standards	• Regional or national urban forest planning
	  ○ To decrease political barriers
	  ○ For: Green Infrastructure Network (GIN), canopy cover, opportunities, water sharing, inventories (LiDAR)
	  ○ For BMPs
	• Standardize modeling

Regulation and incentives	• Government grants for green infrastructure
	• Guidelines for tree protection bylaws
	• Address limitations within existing policies
	• Increase private land incentives: tax breaks
	• Increase contribution from development and private land owners
	• Use of reclaimed water for watering (requires regulatory changes)
	• Create incentives for permeability and trees:
	  ○ Reduced stormwater fees
	  ○ Market for green infrastructure (credits, cap and trade)
	• Incentives for competing uses: environmental farm plans, incentives to retain trees on farms
	• Existing constraint: provincial community charter 50.2, current zoning/density yield and reasonable land use, or appropriate compensation for loss of developable area / property value

Education and stewardship	• Increase education and awareness: interpretation and demonstration
	• Public stewardship:
	  ○ Street tree watering
	  ○ Invasive plant removal
	  ○ Planting standards
	  ○ Tree maintenance
	  ○ Education regarding dumping

Interagency cooperation	• Address cross-jurisdiction limitations • Interdepartmental coordination

Topic	Specific Alternatives
	○ BMPs (engineering, parks, planning) ○ Development Permits (DPs) • Increase coordination between crown and municipalities • Create partnerships: school districts • Increase our knowledge through ○ Knowledge sharing ○ Working groups ○ Modeling
Planning	• Guidelines for larger green network, which includes connectivity considerations • Create building guidelines for height and setbacks relative to trees • Increase naturalised parks (program shift) • Smaller scale planning: Precinct or neighbourhood ○ Spatial scenarios at the block or neighbourhood scale ○ Targets or indicators (birds? water?) • Change scale from the micro-ecosystem approach (tree): beyond "right tree right place" ○ Native plant community and ecosystem-based planning ○ Naturalization scenarios that expand the current available land resource • Provide design specs / guidelines ○ Planting clusters symbiosis ○ Land use planning that considers trees ○ Zoning bylaws and density bonus: flexibility for tree protection • Increase flexibility to consider new knowledge/ information ○ Heat island effect ○ Large site rezoning policy • Neighbourhood plans
Funding/Value-adding	• Economic valuation: trees included in asset management, cost of replacement (with grey infrastructure) • Carbon offsetting • Finance urban forestry with savings in health care • Increase urban forest funding with savings in other areas • Nursery program & green waste synergies • Waste management & biofuel synergies

3.3 Local Research Needs

- Increase our local knowledge about tree benefit provision
- Show/deny the benefits of tree canopy, soil and hydrology versus pipes
- Development of standards for green infrastructure
- Leverage existing resource: "bottom-up" approach to study local conditions (plants + trees, soil, topography, etc.) to decide what is appropriate to plant/enhance
- Increase our understanding of groundwater resources (incl. saltwater intrusion risks)

4 Concluding Discussion

Based on input from the Advisory Panel, the following key messages and target audiences should be considered in the development of the Urban Forest Adaptation Guidelines:

Key Messages

- What we know now / what we can do now (collating Municipal/Metro Vancouver data and Best Management Practices)
- What we need to further investigate (Municipal-scale metrics?)
- What are the "good" trees and where do they go?
- How to / where to plant and manage?
- Regional narrative / argument to reinforce the value of a network

Target Audiences

- Urban forest practitioners – development / management ("Code of Practice")
- Developers
- Planning departments
- Consultants (planners, landscape architects, etc.)
- Councils / decision-makers (executive summaries)
- Nurseries
- Professional associations (BCSLA, PIBC, BCNTA, BCLNA)
- General public (accessible information)

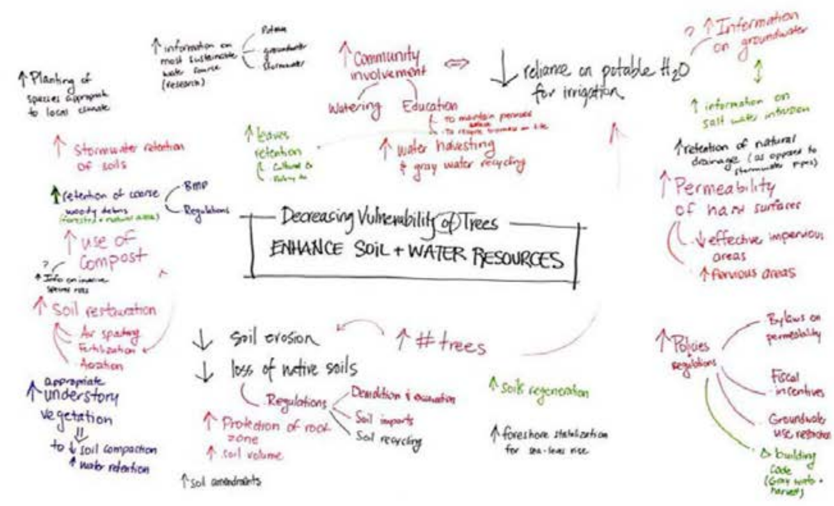
Appendix 1 – Agenda

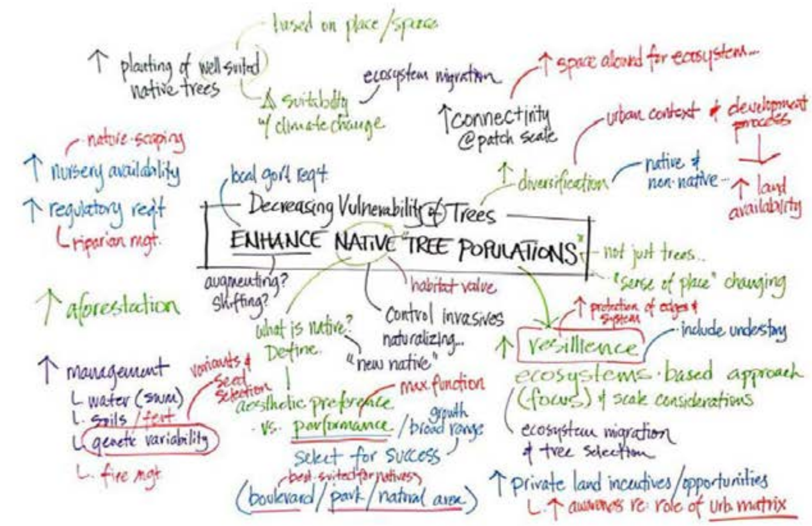
(The agenda below was modified to allow for great time during the "Refining Objectives" brainstorming sessions. The "Reviewing Impacts and Brainstorming Alternatives" and Alternatives Discussion" sessions were deferred to the subsequent Advisory Panel workshop. The concluding session acknowledged local challenges and implementation among Metro Vancouver communities and explored key messages and target audiences.)

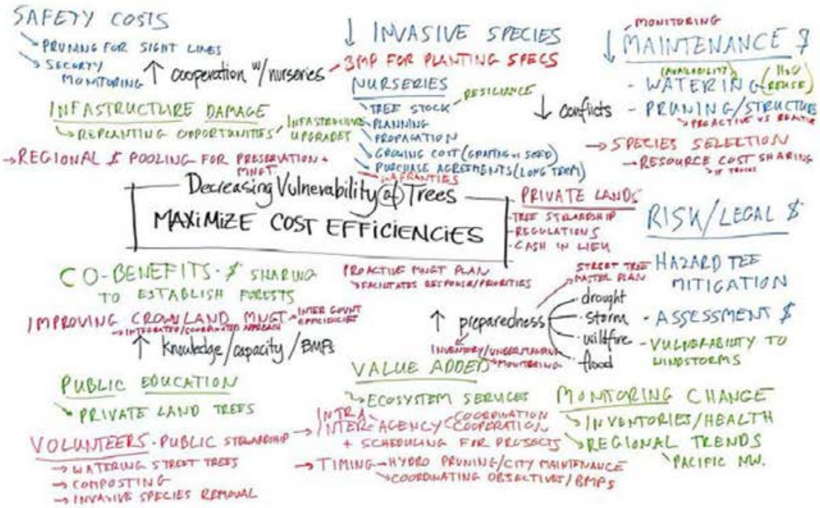
URBAN FOREST CLIMATE ADAPTATION
Guidelines for the Metro Vancouver Region
LOCATION:
DATE: 28 October, 2015
TIME: 1 p.m – 3.30 pm

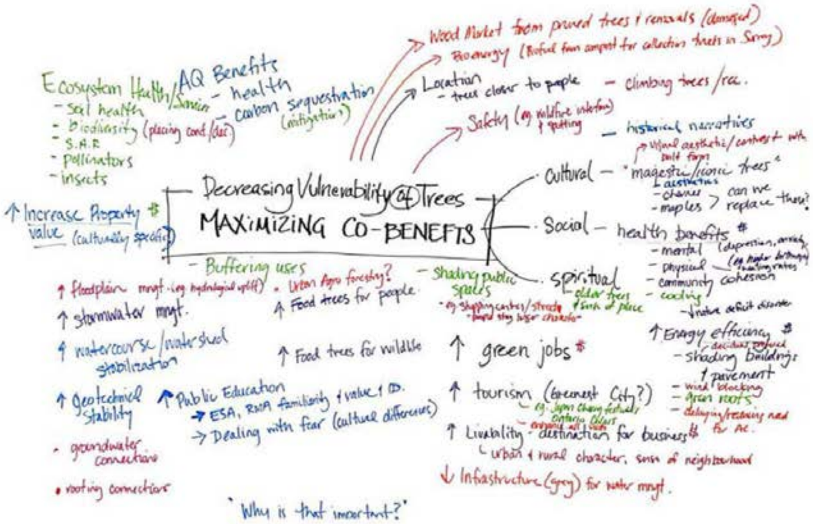
1 p.m. – 1.15 p.m	**WELCOME** Introductions Project overview
1.15 p.m. – 2.20 p.m	**REFINING OBJECTIVES** *(group facilitation: "world café" exercise* **Round 1**: Refining objectives for addressing vulnerability to climate change in the tree population (30 min) *- break 5 min -* **Round 2**: Refining objectives for using trees to provide climate adaptation benefits to our communities (30 min)
2.20 p.m. – 2.50 p.m.	**REVIEWING IMPACTS AND BRAINSTORMING ALTERNATIVES** *(individual list-making/small group discussion exercise)* **Group 1**: Tree Experts - vulnerability in the Metro Vancouver tree population: ***tree traits and management techniques*** **Group 2**: Community Climate Adaptation Experts - maximizing climate adaptation benefits to Metro Vancouver: ***placing trees by design***
2.50 p.m. – 3.00 p.m.	**ALTERNATIVES DISCUSSION** *(facilitated group discussion)* Discuss and expand on identified range of alternatives
3.00 p.m – 3.25 p.m.	**LOOKING AHEAD: LOCAL CHALLENGES AND IMPLEMENTATION** *(facilitated group discussion)* Discuss the audience(s) you envision for this work Discuss the gaps that this work needs to address locally
3.25 p.m. – 3.30 p.m.	**NEXT STEPS AND THANK YOU**

Appendix 2 – Raw Advisory Panel Comment






SAFETY COSTS
↓ INVASIVE SPECIES
↓ MAINTENANCE $
INFASTRUCTURE DAMAGE
Decreasing Vulnerability of Trees
MAXIMIZE COST EFFICIENCIES
RISK/LEGAL $
CO-BENEFITS
HAZARD TREE MITIGATION
PUBLIC EDUCATION
VALUE ADDED
MONITORING CHANGE
VOLUNTEERS


Decreasing Vulnerability of Trees
MAXIMIZING CO-BENEFITS
↑ green jobs
Why is that important?


Decreasing Vulnerability of Trees
MAINTAIN A HEALTHY, SAFE AND PRODUCTIVE TREE POPULATION
↑ quality of tree pruning & risk assessment
↑ proportion of well-suited trees
Plan tree planting – make space for larger trees
↑ diversity
age
species
variability
scale
↑ Soil quality
moisture
nutrient
volume
Decreasing Vulnerability (with) Trees
MAXIMIZE BENEFITS TO THE BROADER ENVIRONMENT
"buffers"
↑ slope stability
↓ erosion
↓ runoff
↑ naturalized parks
↑ system-based mgt.
↑ connectivity
↑ scale
↑ awareness
↑ habitat
↑ biodiversity
↑ collaboration
↑ awareness of risks
flood mgt. (SWM)
↑ interpretation & demonstration

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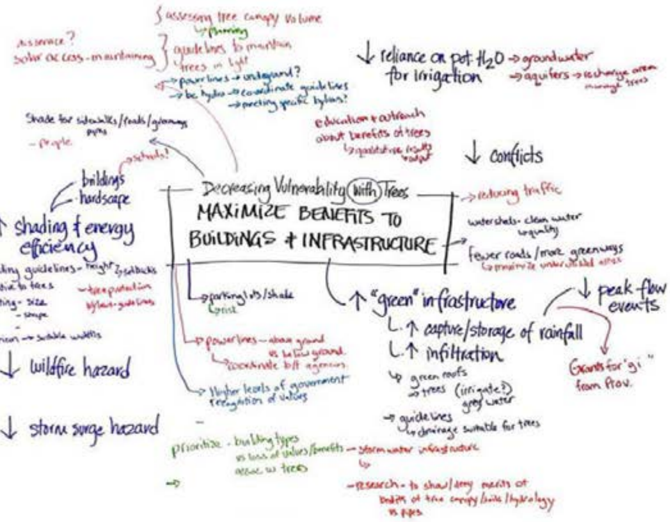
Decreasing Vulnerability with Trees
MAXIMIZE COST EFFICIENCIES
DESIGN SPECS/GUIDELINES
BONDING - DEVELOPMENT
PUBLIC STEWARSHIP
INSTALLATION
NURSERY PRODUCTION
RESILIANCE
SOIL HEALTH
HABITAT BANKING
REGIONAL U.F. PLANNING
LONG TERM PLANNING


Decreasing Vulnerability with Trees
KEEP WITHIN LEGAL, INSTITUTIONAL AND ECONOMIC FRAMEWORKS
Interdepartmental Coordination
Connect to Metro 2040 (RGS)
Design Guidelines (local)
Economic Valuation
policy conflict
CPTED

Panel Meeting #1 – Summary of Advisory Panel Workshop Outcomes



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Urban Forest Climate Adaptation Guidelines for Metro Vancouver

Advisory Panel Meeting #2 – workshop summary

December 15, 2015

Submitted to:

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1 Introduction

Meeting #2 with the Advisory Panel for Metro Vancouver's Urban Forest Adaptation Guidelines was held on November 3 in meeting rooms at Metro Vancouver's Kathleen Building. A total of 14 people from organizations across Metro Vancouver attended the 2 hour session (Table 1). Apologies were received from representatives of the City of Richmond, City of New Westminster, District of Maple Ridge and UBC. The meeting agenda is provided in Appendix 1.

Table 1 – Advisory Panel Meeting Attendees

Name	Organization
Lanny Englund	City of Coquitlam
Jonathan Budgell	City of North Vancouver
Neal Aven	City of Surrey
Bill Stephen	City of Vancouver
Angela Danyluk	Corporation of Delta
Julie Pavey	District of North Vancouver
Alison Evely	Metro Vancouver
Erin Embley	Metro Vancouver
Josephine Clark	Metro Vancouver
Kristie Goodman-Rendall	Metro Vancouver
Lillian Zaremba	Metro Vancouver
Debora Harford	ACT, SFU
Sara Barron	UBC

The purpose of the meeting was to:

1. Review the urban forest climate impact statements and assign rankings for vulnerability and risk; and,
2. Review the proposed document design and end-use utility of the design guidebook (document name changed from 'guidelines' to 'guidebook' following Advisory Panel feedback).

The Advisory Panel (the panel) were provided with a presentation (Appendix 1) and then worked as a group to rank the impact statements. The panel then broke out into two groups to review the design materials. The outcomes are summarised below. The panel's input will inform the risk

3

and vulnerability ratings for the urban forest climate adaptation framework and will inform the draft design guidebook.

2 Assigning Risk and Vulnerability to Climate Impacts

The project team reviewed relevant scientific studies and used regional climate change projections to draft urban forest impact statements. The impact statements describe key changes expected to impact urban forests, and they are the basis for rating risk and vulnerability for this project. Uncertainty, lack of quantitative data and tight timelines make the ratings highly subjective. However, these descriptions record our current perception of risk and vulnerability to future impact, and form the basis for our recommendations. The risk and vulnerability ratings also provide a baseline, allowing us to adjust to new data and measure improvements in the future.

The panel's ratings are helping us refine the impact statements, expand the number of ratings, and incorporate local expertise. The ratings include:

- **Sensitivity:** *If the impact occurs, will it affect the functionality of our urban forest? Will trees be able to grow and deliver beneficial ecosystem services over the next 65 years?*
- **Adaptive Capacity:** *if the impact occurs, can the urban forest absorb the impact with minimal cost and disruption?*
- **Consequence:** *if the impact occurs, will it cause tree decline or mortality?*

The panel's worksheets are provided in Appendix 2. A number of challenges were noted in completing the worksheets, including:

- Differing areas of expertise and relevant scientific knowledge;
- Challenges scaling impacts up to the regional level from the local level;
- Difficulty rating urban forest impacts that combine natural forests, urban parks and street trees in a single score; and,
- High levels of uncertainty.

2.1 Comments on Impact Statements

- Urban forest wildfire return interval and ignition probability should be higher than the historic fire return interval in natural forest due to the human caused ignitions.
- Positive/uncertain impacts: periodic cold fronts from the North/mountains causing frosts will differentiate us from the future warmer climate sometimes compared to Northern California.
- Heat island effect would also be increased significantly by climate change and should be considered.
- Invasiveness and the potential for species to become more invasive as a result of climate change should be considered (e.g., emerging issue in parks include European mountain ash in bog ecosystems, hawthorn, green ash in riparian ecosystems).

2.2 Risk and Vulnerability Ratings Comments

- Are we considering current stressors?
- Considering natural versus urban forests can yield difference answers... should that be amalgamated or addressed individually?
- Regarding maladaptation, did you find anything about pollinators and the way their role might affect the impact on tree?
- How do we factor population growth in, or do we stick to climate change impacts?
- Regarding reduced water supply, it is difficult to rate sensitivity to the impact without municipal experience. A group discussion of the impact followed:
  - Surrey spent $800,000 watering trees last summer and could expect costs to increase in the range of tens of thousands – as an example of additional costs anticipated by one municipality;
  - If water restrictions were in effect, water would either be unavailable or at very high cost;
  - Metro Vancouver is assessing the potential to use reclaimed water but transportation of water would still be very expensive;
  - Vancouver used an aquifer to supplement their water supply during the drought/watering restrictions and other cities did the same;
  - The use of water tanks to transport water from other locations was explored in Surrey and determined to be very expensive;
  - Knowing the distribution of species and ages across the region would help us to know how much money would be involved for increases in watering;
  - BUT site conditions (e.g., soil volume, soil type, aspect etc.) also play an important role and are hard to track regionally; and,
  - City of Vancouver has data on tree mortality that could be made available to this group, if helpful (data since approximately 1990).
- An extreme wildfire would have catastrophic consequences. The probability of human ignition is high in urban areas but early detection and response are also improved by the number of people nearby. It is difficult to rate this impact.

2.3 Risk and Vulnerability Ratings Results

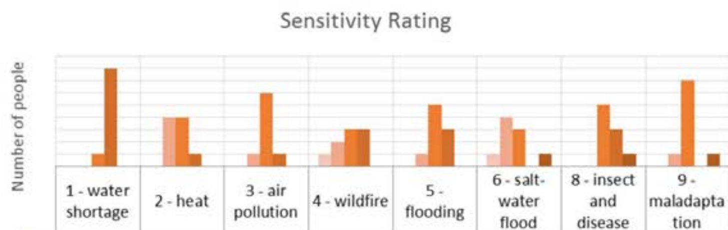
Complete impact statements and ratings worksheets are provided in Appendix 2. Increasing frequency and intensity of windstorms was initially included as an impact statement but, due to high levels of uncertainty in the literature regarding that impact, we did not rate it for risk and vulnerability (i.e., windstorms are a climate reality that will continue to be persist but may or may not become more frequent or more intense due to climate change).

2.3.1 Sensitivity

Timeline: to 2080
Sensitivity: If the impact occurs, will it affect the functionality of Metro Vancouver's urban forest in terms of its trees being able to grow and deliver beneficial ecosystem services over the next 65 years?

No – functionality will stay the same (S1)	Unlikely – functionality will likely stay the same (S2)	Yes – functionality is likely to get worse (S3)	Yes – functionality will get worse (S4)	Yes – Functionality will become unmanageable (S5)

The panel's responses are summarized below. The impact statements have been simplified to one word as a summary but complete impact statements are included in Appendix 2.



	1 - water shortage	2 - heat	3 - air pollution	4 - wildfire	5 - flooding	6 - salt-water flood	8 - insect and disease	9 - maladaptation
S1				1		1		
S2		4	1	2	1	4		1
S3	1	4	6	3	5	3	5	7
S4	8	1	1	3	3		3	
S5						1	1	1

Impact statements

As a rule, the project team selected the majority rating or, where the majority was tied, the rating closest to the mean for use in the vulnerability and risk assessment. The panel generally expects that urban forest:

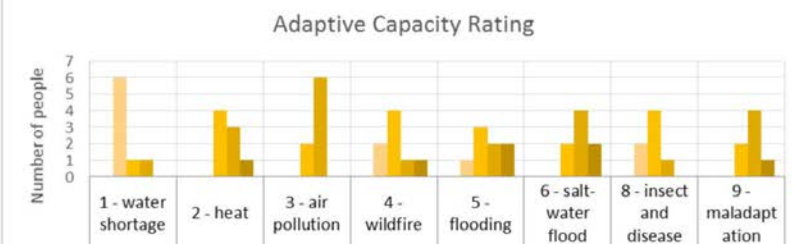
- Functionality **will get worse** as a result of water shortage impacts (S4);
- Functionality is **likely to get worse** as a result of heat, air pollution, wildfire, insects and disease and maladaptation (S3); and,
- Functionality will **likely stay the same** as a result of saltwater inundation impacts (S2).

2.3.2 Adaptive Capacity

Adaptive capacity – if the impact occurs, can the urban forest service area absorb the impact with minimal cost and disruption? Consider $$$$$ to be in the billions, $$$$ to be in the millions, $$$ to be in the hundreds of thousands, $$ to be in the tens of thousands and $ to be in the thousands.

No – will require substantial costs ($$$$$) and professional intervention (AC1)	No – will require significant costs ($$$$) and professional intervention (AC2)	Maybe – will require some costs ($$$) and professional intervention (AC3)	Yes – but will require some slight costs ($$) and professional intervention (AC4)	Yes – No to little costs ($) or professional intervention necessary (AC5)

The panel's responses are summarized below. The impact statements have been simplified to one word as a summary but complete impact statements are included in Appendix 2.



	1 - water shortage	2 - heat	3 - air pollution	4 - wildfire	5 - flooding	6 - salt-water flood	8 - insect and disease	9 - maladaptation
AC1								
AC2	6			2	1		2	
AC3	1	4	2	4	3	2	4	2
AC4	1	3	6	1	2	4	1	4
AC5		1		1	2	2		1

Impact statements

As a rule, the project team selected the majority rating or, where the majority was tied, the rating closest to the mean for use in the vulnerability and risk assessment. The panel generally expects that:

- **Significant costs** and professional intervention will be required to adapt to water shortage impacts (AC2);
- **Some costs** and professional intervention will be required to adapt to heat, wildfire, flood, insect and disease impacts (AC3); and,
- **Some slight costs** and professional intervention will be required to adapt to air pollution, saltwater flood and maladaptation impacts (AC4).

2.3.3 Consequence

Timeline: to 2080
Consequence: Look at each identified impact and assess, to the extent possible, the consequence to the urban forest tree resource.

Consequence Rating	Negligible 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Criteria	No tree decline or mortality	Minor instances of tree decline or mortality that could be reversed	Isolated but significant instances of tree decline or mortality that might be reversed with intensive efforts	Severe loss of urban forest amenity and a danger of continuing tree decline or mortality	Major widespread loss of urban forest amenity and progressive, irrecoverable tree decline or mortality

The panel's responses are summarized below. The impact statements have been simplified to one word as a summary but complete impact statements are included in Appendix 2.

	1 - water shortage	2 - heat	3 - air pollution	4 - wildfire	5 - flooding	6 - salt-water flood	8 - insect and disease	9 - maladaptation
C1	1			1				1
C2	1	4	6	1	4	9	2	4
C3	2	4	5	4	7	2	5	4
C4	5	3		4			3	1
C5	2			1			1	

Impact statements

As a rule, the project team selected the majority rating or, where the majority was tied, the rating closest to the mean for use in the vulnerability and risk assessment:

- **Severe loss** of urban forest amenity and a danger of continuing tree decline or mortality will result from water shortage impacts (C4);
- **Isolated but significant** instances of tree decline or mortality that might be reversed with intensive efforts will result from heat, wildfire, flood, insect and disease, and maladaptation impacts (C3); and,
- **Minor instances** of tree decline or mortality that could be reversed will result from air pollution and saltwater flood impacts (C2).

3 Feedback on Design Guidebook

The panel was split into two groups to discuss the design materials. Each group was provided with two examples of the proposed design modules and asked to provide critical feedback regarding the "end- usefulness" of the draft content. Individuals were asked to consider:

- Audience & Barriers to implementation
- Content & Format
- Legibility & Resolution

Generally, the panel found the graphic content helpful and understood the opportunity to offer design guidance for using trees in the urban landscape to maximize community benefits. Several individuals voiced concern regarding the use of the term "design guidelines" as potentially confusing/conflicting with existing Municipal regulatory policy (often included within Official Community Plans and/or Development Permit Area guidelines).

A discussion about the intent of the resource led to a suggestion for a set of "considerations" and/or a "guidebook" to support best practices at various scales/locations/stages throughout Metro Vancouver.

The following summarized the group discussions:

3.1 Audience & Barriers to Implementation

Discussion regarding audience emphasized the distinction between primary and secondary targets, specifically that: the "guidebook" would be most helpful to facilitate discussion among/between regulators/designers (planners, landscape architects, etc.) and implementing agents (developers and the general public). Specific target audiences discussed included:

- Planners
- Urban foresters
- Landscape designers
- Plan checkers
- Road engineers
- Developers
- The public

The panel acknowledged that the Guidebook should directly address obvious concerns of planners and engineers while maintaining language that is less technical and accessible to a wide range of stakeholders.

Discussions regarding "barriers to implementation" highlighted the opportunity to have earlier influence within the development of plans/principles and Municipal design guidelines. Early involvement would minimize challenges associated with "silos" between departments (e.g., plan checkers – landscape designers – urban foresters - engineers).

3.2 Content & Format

The panel supported the sample document content and form, although many expressed interest in seeing thematic content highlighted and filtered (i.e. stormwater benefits, biodiversity benefits). They acknowledged that the guidebook deliberately considers "tree places" and the multiple-benefit of trees.

The panel also recommended that the guidebook be an information resource with lists of "key questions for consideration" and/or checklists to foster discussion and inform project negotiations.

Participants also expressed interest in making an interactive version of the resource to better address/navigate the complexity of scale, spatial relationships and benefits as they relate to tree placement in the urban realm.

Specific ideas regarding additional content to consider included:

- Acknowledge the variability of resources as distributed over the Region (sensitivity, adaptability and consequence);
- Include guidelines for retention and preservation of soil/tree resources;
- Consider blue-green infrastructure for stormwater (e.g., parks that become lakes, permeable areas);
- Separate nature-scaping from habitat;
- Address passive cooling benefits;
- Incorporate 'typical' existing to ensure constraints are captured and provided as context for the guidebook;
- Represent whole ecosystem – connectivity between adjacent ecosystem boundaries (while also addressing management considerations for unintended consequences such as wildlife conflicts);
- Address maintenance considerations (e.g., if medians are desirable for tree growth, also ensure there is an understanding of the need for road closures to enable maintenance);
- Communicate benefits;
- Provide information for recommended species types in single family dwellings, including maintenance guidance (linkage to urban forest adaptation deliverable);
- Provide information on wildlife pollinator value (linkage to deliverable urban forest adaptation deliverable); and,
- Include case study examples highlighting cost/benefit of interventions.

3.3 Legibility & Resolution

Participants were supportive of a mix of illustrative graphics and photographic content and found the draft graphic presentation legible and helpful.

Further to the overall discussion regarding the creation of the document as a "guidebook", participants suggested providing less prescriptive detail and using specific examples to:

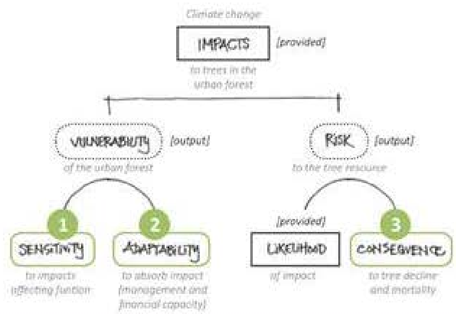
- Better apply across a diverse Region
- Inform development of more detailed standard specs
- Inform sustainability checklists
- Inform developer requirements
- Provide basic dimensions as a starting point

4 Next Steps

The project team is now moving into the development of final draft documents. The Advisory Panel's feedback from the two workshop sessions has guided the preparation of the draft documents and specific feedback is being incorporated into the content of both the design guidebook and the urban forest climate adaptation framework. Complete drafts will be provided to the panel for review early in 2016.

Appendix 1 – Presentation

Rating Vulnerability and Risk



Impact Statements

1. Warmer, drier summers, more precipitation falling as rain and less as snow leading to **reduced soil moisture** in the summer, **increased length of drought** and **reduced reservoir water supply** available for supplemental watering, resulting in widespread decline in tree growth and increased tree mortality.

- **Assumptions:** Less and less consistent soil moisture during the summer. This will reduce overall net primary production and cause mortality in some species.
- **Uncertainties:** Drought frequency and severity changes.

Dai, A., 2012: Increasing drought under global warming in observations and models. *Nature Climate Change*, 3, 52–58.

Impact Statements

2. Higher **number of 'heat days'** (exceeding 30°C) and **intensifying urban heat island effect** in summer resulting in decline in tree growth and increased mortality in some tree species.

- **Assumptions:** Some species will be sensitive to a change in the number of heat days but most will not.
- **Uncertainties:** Physiological limits of native tree species. The impact of 'the blob'.

Karin A. Bumbaco, Kathie D. Dello, and Nicholas A. Bond, 2013: History of Pacific Northwest Heat Waves: Synoptic Pattern and Trends*. *J. Appl. Meteor. Climatol.*, 52, 1618–1631.

Impact Statements

3. Warmer, drier summers leading to **higher air pollution levels during the growing season** at thresholds resulting in tree growth decline and increased mortality in some tree species.

- **Assumptions:** warmer temperatures will lead to an increase in air pollution, air pollution will have a negative impact on tree growth
- **Uncertainty:** Magnitude of increase regionally.

Christian Reuten, Bruce Ainslie, Douw G. Steyn, Peter L. Jackson & Ian McKendry, 2012. Impact of Climate Change on Ozone Pollution in the Lower Fraser Valley, Canada, *Atmosphere-Ocean*, 50:1, 42-53.

Wittig, V. E., Ainsworth, E. A., Naidu, S. L., Karnosky, D. F., & Long, S. P., 2009. Quantifying the impact of current and future tropospheric ozone on tree biomass, growth, physiology and biochemistry: A quantitative meta-analysis. *Global Change Biology, 15*(2), 396-424.

Impact Statements

4. Warmer, drier summers leading to a **longer wildfire season** and an increased risk of severe and intense wildfire events resulting in large-scale tree mortality.

- **Assumptions:** Fire return interval will remain long
- **Uncertainty:** climate factors most influential to wildfire (temperature, precipitations)

Haugian, S. R., Burton, P. J., Taylor, S. W., & Curry, C. L., 2012. Expected effects of climate change on forest disturbance regimes in British Columbia. *Journal of Ecosystems and Management.*

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Impact Statements

5. Sea-level rise and more intense precipitation events leading to an increase in **frequency and duration of flooding and waterlogging** of soils within low lying areas resulting in localized declines in tree growth and increased mortality.

- **Assumptions:** fewer snow, and earlier snowmelt. Potential for stronger atmospheric river events and flooding near major rivers.
- **Uncertainty:** fairly low (many studies of the Fraser River Basin found an increase in flooding)

Khan, K., & Peters, N. (2014). *Simulating the Effects of Sea Level Rise and Climate Change on Fraser River Flood Scenarios.* Victoria: BC Ministry of Forests, Lands and Natural Resource Operations.

Pinna Sustainability, 2014. The Future of Atmospheric Rivers and Actions to Reduce Impacts on British Columbians. Victoria: BC Ministry of Environment, Pacific Institute for Climate Solutions and the Pacific Climate Impacts Consortium.

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Impact Statements

6. Sea-level rise and storm surges leading to an increase in **frequency and duration of salt-water inundation** within low lying areas, resulting in localized declines in tree growth and increased mortality.

- **Assumptions**: sea-level rise will lead to coastal flooding
- **Uncertainty**: the extent and timing of sea-level rise makes the magnitude of the impacts uncertain

Bornhold, Brian D., 2008. Projected sea level changes for British Columbia in the 21st century. Victoria: BC.

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Impact Statements

7. Increase in **frequency and intensity of windstorms** in the winter and spring leading to widespread damage, particularly among trees prone to wind failure.

- **Assumptions:** our assumption were in conflict with literature findings
- **Uncertainty:** conflicting literature, regional modeling puts this impact into question but windstorms can be expected to continue to be part of the natural disturbance regime

Read, W. A., 2015. The climatology and meteorology of windstorms that affect southwest British Columbia, Canada, and associated tree-related damage to the power distribution grid. University of British Columbia.

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8. Milder winters and longer, warmer summers leading to an **increase in frequency and severity of insect and disease outbreaks** causing large-scale tree mortality in susceptible species.

- **Assumptions**: warmer + drier climate (increases growth rate, survival and fecundity of insects)
- **Uncertainty**: potential negative impacts of new climate (predation, etc.) might limit the increase

Bentz, B. J., Regniere, J., Fettig, C. J., Hansen, M., Hayes, J. L., Hicke, J. A., et al. (2010). Climate Change and Bark Beetles of the Western United States and Canada: direct and indirect effects. *BioScience*, 602-613.

Haugian, S. R., Burton, P. J., Taylor, S. W., & Curry, C. L., 2012. Expected effects of climate change on forest disturbance regimes in British Columbia. *Journal of Ecosystems and Management*.

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Impact Statements

9. **Warmer temperatures** and **milder winter conditions** resulting in some species being unsynchronized and maladapted to the prevailing environment

- **Assumptions**: plants plasticity allows for adaptation
- **Uncertainty**: whether the pace will be sufficient to adapt to climate change

Franks, S. J., Weber, J. J., & Aitken, S. N., 2014. Evolutionary and plastic responses to climate change in terrestrial plant populations. *Evolutionary Applications*, 7(1), 123-139.

McCreary, D., Lavender, D., & Hermann, R. (1990). Predicted global warming and douglas-fir chilling requirements. *Annales Des Sciences Forestières*, 47(4), 325-330.

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Positive or Uncertain Impacts

More **frost free days, higher average winter temperatures** and a **longer growing season** leading to an increase in the range of species well suited in Metro Vancouver.

Increased **levels of atmospheric CO_2** changing plant phenology and plant physiology in a manner that either slows tree growth or increases it.

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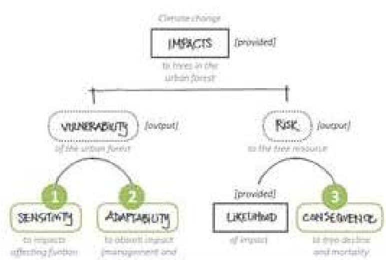
Rating Vulnerability and Risk

- Exercises 1, 2 & 3



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Rating Sensitivity

- ***Timeline***: to 2080
- ***Sensitivity***: If the impact occurs, will it affect the functionality of Metro Vancouver's urban forest in terms of its trees being able to grow and do what we need them to do over the next 65 years?

No – functionality will stay the same (S1)	Unlikey – functionality will likely stay the same (S2)	Yes – functionality is likely to get worse (S3)	Yes – functionality will get worse (S4)	Yes – Functionality will become unmanageable (S5)

Rating Adaptive Capacity

- ***Timeline***: to 2080
- ***Adaptive capacity*** – if the impact occurs, can the urban forest service area absorb the impact with minimal cost and disruption? Consider $$$$$ to be in the billions, $$$$ to be in the millions, $$$ to be in the hundreds of thousands, $$ to be in the tens of thousands and $ to be in the thousands.

No – will require substantial costs ($$$$$) and professional intervention (AC1)	No – will require significant costs ($$$$) and professional intervention (AC2)	Maybe – will require some costs ($$$) and professional intervention (AC3)	Yes – but will require some slight costs ($$) and professional intervention (AC4)	Yes – No to little costs ($) or professional intervention necessary (AC5)

Rating Consequence

- ***Timeline*:** to 2080
- ***Consequence*:** Look at each identified impact and assess, to the extent possible, the consequence to the urban forest tree resource.

Negligible 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
No tree decline or mortality	Minor instances of tree decline or mortality that could be reversed	Isolated but significant instances of tree decline or mortality that might be reversed with intensive efforts	Severe loss of urban forest amenity and a danger of continuing tree decline or mortality	Major widespread loss of urban forest amenity and progressive, irrecoverable tree decline or mortality

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Species Suitability Analysis

- A total of 42 species are being analysed for:
  - Suitability under current climate
  - Suitability under future climate
  - Species characteristics for adaptation

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Species Suitability Analysis

- Sources for trait validation
  - USDA Plant Databases
  - Missouri Botanical gardens
  - Royal Horticultural Society
  - Horticultural extension programs at University of Florida
  - Oregon Wood Innovation Center, College of Forestry, Oregon State University
  - Sacramento Tree Foundation
  - Electronic Atlas of the Plants of British Columbia
  - Fire Performance Plant Selector
  - Plant Facts search engine for Ohio State University
  - Washington State University
  - Nowak D.K., Stevens J.C., Sisinni S.M., Luley C.J. 2002. Effects of urban tree management and species selection on atmospheric carbon dioxide. Journal of Arboriculture 28(3), 113-122

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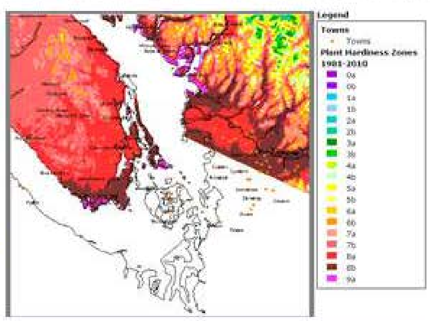
Current Climate Suitability - Cold

Metro Vancouver Plant hardiness zones: 6 – 8 (harshest to mildest)
  - Extreme minimum temperatures range from -23.3 to -6.7°C equivalent for USDA Zones 6 - 8

www.planthardiness.gc.ca



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Future Climate Suitability - Cold

Vancouver

- Past winter monthly minimum is -9°C
- 2080s winter monthly minimum projected is -1.3°C

(Zone 9b – coastal and inland northern California)

North Vancouver

- Past winter monthly minimum is -13°C 2080s winter monthly minimum projected is -4.8°C (Zone 9a – coastal southern Oregon and northern California)

www.planthardiness.gc.ca

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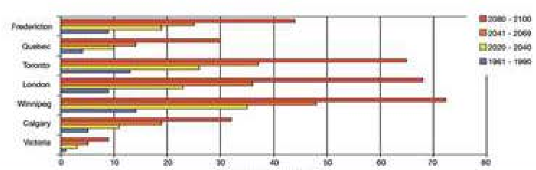
Current Climate Suitability - Heat

- Heat Zones (average number of days per year above 30°C)
- Vancouver currently heat zone 1 (<1 day per year)
- Change to heat zone 3 (7-14 days per year)?



Source: NRCAN, 2015. Overview of Climate Change in Canada.
FIGURE 18: Number of days with temperatures exceeding 30ºC during observed (1961-1990) and future (2020-2040; 2041-2069; and 2080-2100) time periods (Hengeveld et al., 2005).

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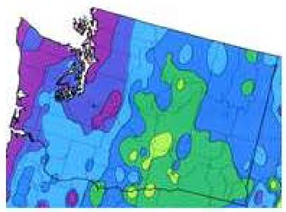
Future Climate Suitability - Heat

- Species assessed were generally tolerant of heat zones 1-3
- Still assessing heat zone tolerance of local native trees or species
- American Horticultural Society heat zone map for Washington



Future Climate Suitability - Drought

- Expected decrease of 3-5% soil moisture in the upper 10 cm
- Increase in length of summer dry spells (from 21 to 29 days per year) and decrease in summer precipitation (29% decrease)
- Annual precipitation similar to past
- Precipitation ranges not available for most species so instead drought tolerance will be reported.

Future Climate Suitability

- Preview of findings:
  - Expect that most of the species assessed will be able to persist under projected temperature and precipitation changes
  - Outcomes will guide selection of species for best performance in relation to high risk, high vulnerability impacts and existing stressors

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DESIGN GUIDELINES

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Design Guidelines

- Design guidelines for urban forest adaptation (companion to the Tree Species Selection, Planting and Management resource guide)
- ***Using trees to maximize benefits*** to local communities throughout Metro Vancouver

Design Guidelines

- Visual Index of the Region
- Menu of strategies ("pattern book")
- Priority Places → Categories → Modules
- Clarifying "end-usefulness":
  - Audience + Barriers
  - Content + Format
  - Legibility + Resolution

Design Guidelines

Coordinating Priorities in a Diverse Region

- **STREET**
  Boulevards + Medians
- **FEATURE**
  Specimens + Landmarks
- **NATURAL**
  Habitat + Biodiversity
- **FORMAL**
  Structured Spaces + Hardscapes
- **INFORMAL**
  Open Spaces + Softscapes
- **BUFFER**
  Filters and Transitions

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Design Guidelines

- Break Out Groups + Group Discussion
- Critical Review of Document Design
- Clarifying "end-usefulness":
  - Audience + Barriers
  - Content + Format
  - Legibility + Resolution

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Results

DIAMOND HEAD CONSULTING LTD.

- Impact statement index:
  1. Reduced soil moisture + drought + water supply
  2. Number of heat days
  3. Air pollution
  4. Wildfire season
  5. Flooding
  6. Salt-water inundation
  7. Windstorms
  8. Disease + insects outbreak
  9. Species unsynchronized or maladapted

Results – Exercise 1

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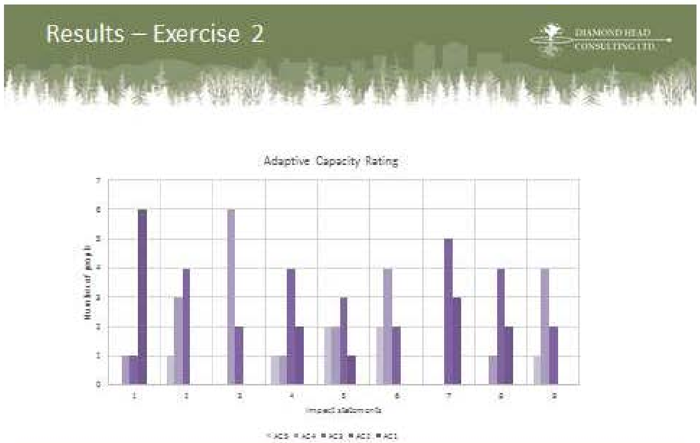
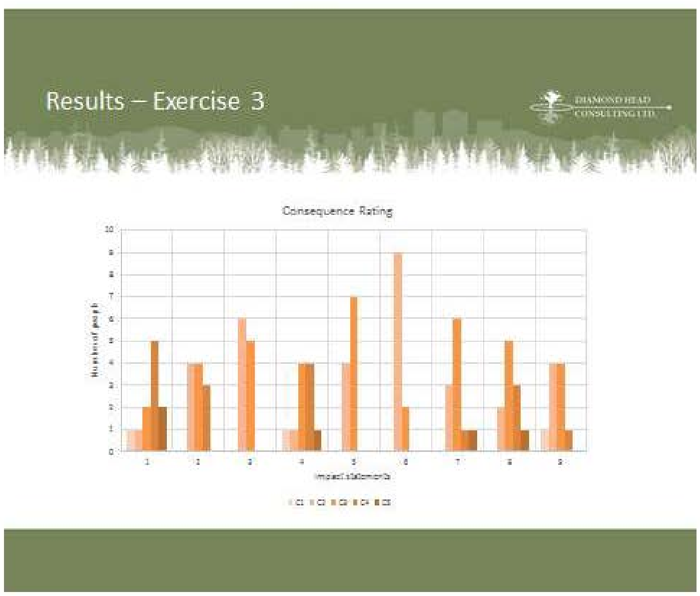

Results – Exercise 2
DIAMOND HEAD CONSULTING LTD.
Adaptive Capacity Rating
Number of people
Impact statements


Results – Exercise 3
DIAMOND HEAD CONSULTING LTD.
Consequence Rating
Number of people
Impact statements

Appendix 2 - Vulnerability and Risk Worksheets

Exercise #1 - Rating Sensitivity

Timeline: to 2080

Sensitivity: If the impact occurs, will it affect the functionality of Metro Vancouver's urban forest in terms of its trees being able to grow and deliver beneficial ecosystem services over the next 65 years?

No – functionality will stay the same (S1)	Unlikely – functionality will likely stay the same (S2)	Yes – functionality is likely to get worse (S3)	Yes – functionality will get worse (S4)	Yes – Functionality will become unmanageable (S5)

Impact Statement		Sensitivity Rating (S1 – S5)
(1)	Warmer, drier summers, more precipitation falling as rain and less as snow leading to **reduced soil moisture** in the summer, **increased length of drought** and **reduced reservoir water supply** available for supplemental watering, resulting in widespread decline in tree growth and increased tree mortality.	
(2)	Higher **number of 'heat days'** (exceeding 30°C) in summer resulting in decline in tree growth and increased mortality in some tree species.	
(3)	Warmer, drier summers leading to **higher air pollution levels during the growing season** at thresholds resulting in tree growth decline and increased mortality in some tree species.	
(4)	Warmer, drier summers leading to a **longer wildfire season** and an increased risk of severe and intense wildfire events resulting in large-scale tree mortality.	
(5)	Sea-level rise and more intense precipitation events leading to an increase in **frequency and duration of flooding and waterlogging** of soils within low lying areas resulting in localized declines in tree growth and increased mortality.	
(6)	Sea-level rise and storm surges leading to an increase in **frequency and duration of salt-water inundation** within low lying areas, resulting in localized declines in tree growth and increased mortality.	
(7)	Increase in **frequency and intensity of windstorms** in the winter and spring leading to widespread damage, particularly among trees prone to wind failure (e.g., newly exposed forest stand edges and retention strips, trees with shallow root plates or restricted soil volume, trees in poor health or with structural defects, trees with root damage, tree species that are less wind resistant etc.).	
(8)	Milder winters and longer, warmer summers leading to an **increase in frequency and severity of insect and disease outbreaks** causing large-scale tree mortality in susceptible species.	
(9)	**Warmer temperatures** and **milder winter conditions** resulting in some species being unsynchronized and maladapted to the prevailing environment (e.g., pre-germination chilling requirements for seeds of native conifer trees not being met, or inadequate chilling hours to produce showy blooming in ornamental trees with high chilling requirements).	

Exercise #2 - Rating Adaptive Capacity

Timeline: to 2080

Adaptive capacity – if the impact occurs, can the urban forest service area absorb the impact with minimal cost and disruption? Consider $$$$$ to be in the billions, $$$$ to be in the millions, $$$ to be in the hundreds of thousands, $$ to be in the tens of thousands and $ to be in the thousands.

No – will require substantial costs ($$$$$) and professional intervention (AC1)	No – will require significant costs ($$$$) and professional intervention (AC2)	Maybe – will require some costs ($$$) and professional intervention (AC3)	Yes – but will require some slight costs ($$) and professional intervention (AC4)	Yes – No to little costs ($) or professional intervention necessary (AC5)

Impact Statement	Adaptive Capacity Rating (AC1 – AC5)
(1) Warmer, drier summers, more precipitation falling as rain and less as snow leading to **reduced soil moisture** in the summer, **increased length of drought** and **reduced reservoir water supply** available for supplemental watering, resulting in widespread decline in tree growth and increased tree mortality.	
(2) Higher **number of 'heat days'** (exceeding 30°C) in summer resulting in decline in tree growth and increased mortality in some tree species.	
(3) Warmer, drier summers leading to **higher air pollution levels during the growing season** at thresholds resulting in tree growth decline and increased mortality in some tree species.	
(4) Warmer, drier summers leading to a **longer wildfire season** and an increased risk of severe and intense wildfire events resulting in large-scale tree mortality.	
(5) Sea-level rise and more intense precipitation events leading to an increase in **frequency and duration of flooding and waterlogging** of soils within low lying areas resulting in localized declines in tree growth and increased mortality.	
(6) Sea-level rise and storm surges leading to an increase in **frequency and duration of salt-water inundation** within low lying areas, resulting in localized declines in tree growth and increased mortality.	
(7) Increase in **frequency and intensity of windstorms** in the winter and spring leading to widespread damage, particularly among trees prone to wind failure (e.g., newly exposed forest stand edges and retention strips, trees with shallow root plates or restricted soil volume, trees in poor health or with structural defects, trees with root damage, tree species that are less wind resistant etc.).	
(8) Milder winters and longer, warmer summers leading to an **increase in frequency and severity of insect and disease outbreaks** causing large-scale tree mortality in susceptible species.	
(9) **Warmer temperatures** and **milder winter conditions** resulting in some species being unsynchronized and maladapted to the prevailing environment (e.g., pre-germination chilling requirements for seeds of native conifer trees not being met, or inadequate chilling hours to produce showy blooming in ornamental trees with high chilling requirements).	

Exercise #3 - Rating Consequence

***Timeline*:** to 2080
***Consequence*:** Look at each identified impact and assess, to the extent possible, the consequence to the urban forest tree resource.

Consequence Rating	Negligible 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Criteria	No tree decline or mortality	Minor instances of tree decline or mortality that could be reversed	Isolated but significant instances of tree decline or mortality that might be reversed with intensive efforts	Severe loss of urban forest amenity and a danger of continuing tree decline or mortality	Major widespread loss of urban forest amenity and progressive, irrecoverable tree decline or mortality

Impact Statement		Consequence Rating (1 - 5)
(1)	Warmer, drier summers, more precipitation falling as rain and less as snow leading to **reduced soil moisture** in the summer, **increased length of drought** and **reduced reservoir water supply** available for supplemental watering, resulting in widespread decline in tree growth and increased tree mortality.	
(2)	Higher **number of 'heat days'** (exceeding 30°C) in summer resulting in decline in tree growth and increased mortality in some tree species.	
(3)	Warmer, drier summers leading to **higher air pollution levels during the growing season** at thresholds resulting in tree growth decline and increased mortality in some tree species.	
(4)	Warmer, drier summers leading to a **longer wildfire season** and an increased risk of severe and intense wildfire events resulting in large-scale tree mortality.	
(5)	Sea-level rise and more intense precipitation events leading to an increase in **frequency and duration of flooding and waterlogging** of soils within low lying areas resulting in localized declines in tree growth and increased mortality.	
(6)	Sea-level rise and storm surges leading to an increase in **frequency and duration of salt-water inundation** within low lying areas, resulting in localized declines in tree growth and increased mortality.	
(7)	Increase in **frequency and intensity of windstorms** in the winter and spring leading to widespread damage, particularly among trees prone to wind failure (e.g., newly exposed forest stand edges and retention strips, trees with shallow root plates or restricted soil volume, trees in poor health or with structural defects, trees with root damage, tree species that are less wind resistant etc.).	
(8)	Milder winters and longer, warmer summers leading to an **increase in frequency and severity of insect and disease outbreaks** causing large-scale tree mortality in susceptible species.	
(9)	**Warmer temperatures** and **milder winter conditions** resulting in some species being unsynchronized and maladapted to the prevailing environment (e.g., pre-germination chilling requirements for seeds of native conifer trees not being met, or inadequate chilling hours to produce showy blooming in ornamental trees with high chilling requirements).	

Appendix 2 – Species Database Metadata

Field Name	Description	Database coding	Source
ID	Unique number identifying each species	Number field	
Common name	Common name for the species	Text string field	
Scientific name	Scientific name for the species	Text string field	
Synonym	Alternative scientific name for the species	Text string field	
Allometric growth predictions	Predictions for leaf area and crown diameter based on dbh, and predictions for dbh based on age using regionally specific allometric growth equations. The limitations of the equations including accuracy to age/dbh value limits and climate region are discussed in detail in the source literature.	N/A – formulas will need to be coded in	• McPherson, G.; N. van Doorn; P. Peper. 2016. Urban tree database. Fort Collins, Co, Forest Service Research Centre: http://dx.doi.org/10.2737/RDS-2016-0005
Size class (height)	Height classes: Small < 10 m Medium 10-15 m Large >15 m	Number field 1 = small 2 = medium 3 = large	• Justice, D. "Vancouver trees App " http://botanicalgarden.ubc.ca/learn/vancouver-trees-app/ • SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University
Evergreen	Trees that retain leaves year round	Number field 0 = no 1 = yes	
Canopy spread (est. m)	The diameter, in metres of the tree crown spread	Number field	• Justice, D. "Vancouver trees App " http://botanicalgarden.ubc.ca/learn/vancouver-trees-app/ • SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University

Life expectancy	The life expectancy of the species: Short <50 years Medium 50 – 150 years Long >150 years	Number field 1 = short 2 = medium 3 = long	• SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University
Growth rate (est. cm height annually)	The expected annual growth rate of the species in centimetres	Number field	• SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University
Shade density in leaf	The expected qualitative density of shade cast: L = low M = moderate H = high	Number field 1 = low 2 = moderate 3 = high	• SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University
Street with tree pits/boulevard < 2 m width	Whether a tree is suitable for planting in a street with tree pits or a planting strip < 2 m width (assuming soil volume requirements are met)	Number field 0 = no 1 = yes 2 = Yes, but capable of self-seeding or known to be invasive so avoid planting in locations where seeds can disperse and germinate	• Diamond Head Consulting Recommendation

Parks and broad boulevards/medians > 2 m width	Whether a tree is suitable for planting in a park or a street with a planting strip ≥ 3 m width (assuming soil volume requirements are met)	Number field 1 = yes (all trees) 2 = Yes, but capable of self-seeding or known to be invasive so avoid planting in locations where seeds can disperse and germinate	• Diamond Head Consulting Recommendation
Paved plazas with tree pits/on slab	Whether a tree is suitable for planting in a hardscape plaza or over slab where trees cannot access native soil (assuming soil volume requirements are met).	Number field 0 = no 1 = yes 2 = Yes, but capable of self-seeding or known to be invasive so avoid planting in locations where seeds can disperse and germinate	• Diamond Head Consulting Recommendation
Containerized sites (low soil volume)	Whether a tree is suitable for planting in a container (assuming soil volume requirements are met).	Number field 0 = no 1 = yes 2 = Yes, but capable of self-seeding or known to be invasive so avoid planting in locations where seeds can disperse and germinate	• Diamond Head Consulting Recommendation

Parking lot with landscape beds/screens/buffers	Whether a tree is suitable for planting in landscape beds or strips as a screen/buffer.	Number field 0 = no 1 = yes 2 = Yes, but capable of self-seeding or known to be invasive so avoid planting in locations where seeds can disperse and germinate	• Diamond Head Consulting Recommendation
Under overhead utilities	Whether a tree is suitable for planting under a powerline	Number field Number field 0 = no 1 = yes 2 = yes with v-shaped pruning 3 = Yes, but capable of self-seeding or known to be invasive so avoid planting in locations where seeds can disperse and germinate 4 = yes, with v-shaped pruning, but capable of self-seeding or known to be invasive so avoid planting in locations where seeds can disperse and germinate	• Diamond Head Consulting Recommendation

Minimum soil volume per tree (m3)	The minimum volume of soil recommended per tree is 0.3 cubic metres per square metre of crown projection (predicted at 40 years). The minimum value was chosen based on the median soil volume requirement calculated from the water use requirements of trees in the database with a predicted leaf area value (25 species), or when selecting a standard Leaf Area Index (LAI) of 4 - 5, growing in a sandy loam soil and using an average 10 day rainfree period. This calculation also assumes that the sites are mulched.	Number field	• Lindsey, P.; Bassuk, N. 1992. Redesigning the urban forest from the ground below: A new approach to specifying adequate soil volumes for street trees. Arboricultural Journal Vol 16, pp 25-39. Accessed online http://www.hort.cornell.edu/uhi/research/articles/ArborJournal16.pdf. • Historical average evapotranspiration from Farmwest website (July 120 mm) http://farmwest.com/climate/et • Predicted leaf area from McPherson, G.; N. van Doorn; P. Peper. 2016. Urban tree database. Fort Collins, Co, Forest Service Research Centre: http://dx.doi.org/10.2737/RDS-2016-0005 • LAI value of 4 to 5 informed by averages for North American deciduous and coniferous trees in Iio, A., and A. Ito. 2014. A Global Database of Field-observed Leaf Area Index in Woody Plant Species, 1932-2011. Data set. Available on-line [http://daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, USA. http://dx.doi.org/10.3334/ORNLDAAC/1231

Preferred soil volume per tree (m3)	The preferred volume of soil recommended per tree is 0.6 cubic metres per square metre of crown projection (predicted at 40 years). This value was chosen because both the average evapotranspiration and the average rainfree period in summer are anticipated to increase under climate change, and therefore a larger soil water storage reservoir will reduce the likelihood of water shortages.	Number field	• Diamond Head Consulting Recommendation
Saturated soil tolerance	Whether a species can survive 30 or more consecutive days of waterlogging or saturated soils during the growing season.	Number field 0 = no 1 = yes	• U. Niinemets and F. Vallardes, "Tolerance to shade, drought and waterlogging in the temperate dendroflora of the Northern hemisphere: tradeoffs, phylogenetic signal and implications for niche differentiation," Ecological Monographs, vol. 76, no. 4, pp. 521-547, 2006.
Shade tolerance	Shade tolerance based on minimum light availability tolerated by the species and modified to include professional forester opinions on species biology: L = low, needs >25% full sunlight M = moderate, needs 10-25% full sunlight H = tolerant, needs < 10% full sunlight	Number field 1 = low 2 = moderate 3 = high	• U. Niinemets and F. Vallardes, "Tolerance to shade, drought and waterlogging in the temperate dendroflora of the Northern hemisphere: tradeoffs, phylogenetic signal and implications for niche differentiation," Ecological Monographs, vol. 76, no. 4, pp. 521-547, 2006.

Drought tolerance	The length of drought tolerance expected for the species based on annual precipitation, potential evapotranspiration, duration of dry periods and minimum soil water potential tolerated long term with <50% foliage damage or dieback: L = low, tolerant of no more than a few weeks of drought M = moderate, tolerant of 1 month of drought H = high, tolerant of more than 2 months of drought	Number field 1 = low 2 = moderate 3 = high	• U. Niinemets and F. Vallardes, "Tolerance to shade, drought and waterlogging in the temperate dendroflora of the Northern hemisphere: tradeoffs, phylogenetic signal and implications for niche differentiation," Ecological Monographs, vol. 76, no. 4, pp. 521-547, 2006.
Pollution tolerance	Whether the species is tolerant of air pollution	Number field 0 = unknown 1 = yes	• USDA Forest Service Fire Effects Information System (FEIS) http://www.feis-crs.org/feis/ • Justice, D. “Vancouver trees App “ http://botanicalgarden.ubc.ca/learn/vancouver-trees-app/
Flammability	Expected flammability of the species based on reported Firewise ratings: L = low flammability, firewise M = moderate flammability, moderately firewise H = high flammability, at risk or not firewise	Number field 0 = unknown 1 = low 2 = moderate 3 = high	• FIREWISE Communities Fire Performance Plant Selector http://www.fire.sref.info/selector/plant-list • BC Ministry of Forests Tree Species Compendium https://www.for.gov.bc.ca/hfp/silviculture/compendium/
Wind breakage potential	The estimated likelihood of a species breaking large diameter branches or failing at the root plate under wind loading: L = low likelihood M = moderate likelihood H = high likelihood	Number field 0 = unknown 1 = low 2 = moderate 3 = high	• SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University • BC Ministry of Forests Tree Species Compendium https://www.for.gov.bc.ca/hfp/silviculture/compendium/

Root damage potential	The estimated likelihood of roots causing damage because they are typically close to the surface: L = low likelihood M = moderate likelihood H = high likelihood	Number field 0 = unknown 1 = low 2 = moderate 3 = high	• SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University
VOC rating	The combined isoprene or and monoterpene emission rates of species: L = <5 micrograms per gram of dry leaf mass per hour M = 5-20 micrograms per gram of dry leaf mass per hour H = > 20 micrograms per gram of dry leaf mass per hour	Number field 0 = unknown 1 = low 2 = moderate 3 = high	• Wiedinmyer, C., Guenther, A., Harley, P., Hewitt, C.N., Geron, C., Artaxo, P., Steinbrecher, R., Rasmussen. (2004) Global organic emissions from vegetation. Chapter in Emissions of Atmospheric Trace Compounds, Edited by Claire Granier, Paulo Artaxo, and Claire E. Reeves. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 115 -170. http://bai.acom.ucar.edu/Data/BVOC/
Invasive potential	Whether the non-native species is capable of self-seeding and if it is known to be invasive in Metro Vancouver.	Number field 0 = not known to be locally invasive 1 = self-seeds but not known to be locally invasive 2 = locally invasive in Metro Vancouver	• Invasive and Exotic Species of North America (A joint project between University of Georgia - Bugwood Network and the U.S. Department of Agriculture): http://www.invasive.org/ • Locally available reports, practitioner comments.
Noted sources of public complaints	Public complaints about the species.	Text string field	• Diamond Head Consulting anecdotal observations from working as city arborists.

Metro Vancouver Practitioner comments	Practitioner comments about their experiences with each species.	Text string field	• Contributions from various practitioners (e.g., Surrey, Coquitlam, Vancouver)
Bird/wildlife attracting	Whether the species is noted to attract birds or other wildlife	Number field 0 = unknown 1 = yes	• SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University
Insect and animal pollinated	Whether the species is insect pollinated (some species noted as being insect pollinated may be both insect and wind pollinated)	Number field 0 = wind pollinated 1 = insect pollinated	• USDA Forest Service Fire Effects Information System (FEIS) http://www.feis-crs.org/feis/ • Chan, S. "Nectar and Pollen Plants for Native Wild Pollinators" http://www.beefriend.org/documents/Planting%20Guide.pdf • Oleaceae Information Site http://www.oleaceae.info/ • Ellsworth, D. (2015). "Ohio Trees for Bees" http://u.osu.edu/beelab/files/2016/03/ENT_71_15-13m1u0u.pdf
Native	Whether the species is native to Metro Vancouver	Number field 0 = non-native 1 = BC native 2 = native to Metro Vancouver	• E-Flora BC Electronic Atlas of the Flora of British Columbia http://ibis.geog.ubc.ca/biodiversity/eflora/E-FloraTreesofBritishColumbia.html
USDA lower hardiness zone	Extreme minimum temperature tolerance by species based on the USDA hardiness zone scale	Text string field	• Justice, D. "Vancouver trees App " http://botanicalgarden.ubc.ca/learn/vancouver-trees-app/ • SelecTree: A Tree Selection Guide http://selectree.calpoly.edu/ Calpoly selectree Urban Forest Ecosystems Institute, NRES Department, California Polytechnic State University

AHS upper heat zone	Range of average number of heat days per year tolerated by the species based on the American Horticultural Society (AHS) heat zone scale	Text string field	• Learn2Grow plant search http://www.learn2grow.com/Plants/
Present and future climate suitability	Present and future climate suitability based on USDA hardiness zone, AHS heat zone and drought tolerance. Fresh sites = suitable for heat and cold but intolerant of droughty sites Slightly dry sites = suitable for heat and cold, and tolerant of sites experiencing up to 1 month of drought Broadly suitable = suitable for heat, cold and the driest sites		Diamond Head Consulting Recommendation based on climate suitability framework described in Metro Vancouver (2016) "Urban Forest Climate Adaptation Framework" http://www.metrovancouver.org/services/regional-planning/PlanningPublications/UrbanForestClimateAdaptationFrameworkTreeSpeciesSelection.pdf
Design guidebook location links	**Major roads (arterials) - curbside** **Major road (Arterials) - centre medians** **Minor roads (collector and local)** **Downtown streets** **Highways** **Unique planting areas** **Surface parking lots** **Plazas** **Building edges** **Infrastructure corridors** **Playgrounds** **Parks in proximity to natural areas** **Park in urban areas that are well separated from natural areas** **Steep slopes, riparian, coastal** **Wildland urban interface** **Landscape buffers**	Number field 0 = no 1 = yes 2 = yes, but capable of self-seeding or known to be invasive so avoid planting in locations where seeds can disperse and germinate	Diamond Head Consulting Recommendation based on climate suitability framework described in Metro Vancouver (2016) "Design Guidebook – Maximizing Climate Adaptation Benefits with Trees" http://www.metrovancouver.org/services/regional-planning/PlanningPublications/UrbanForestClimateAdaptationFrameworkTreeSpeciesSelection.pdf

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