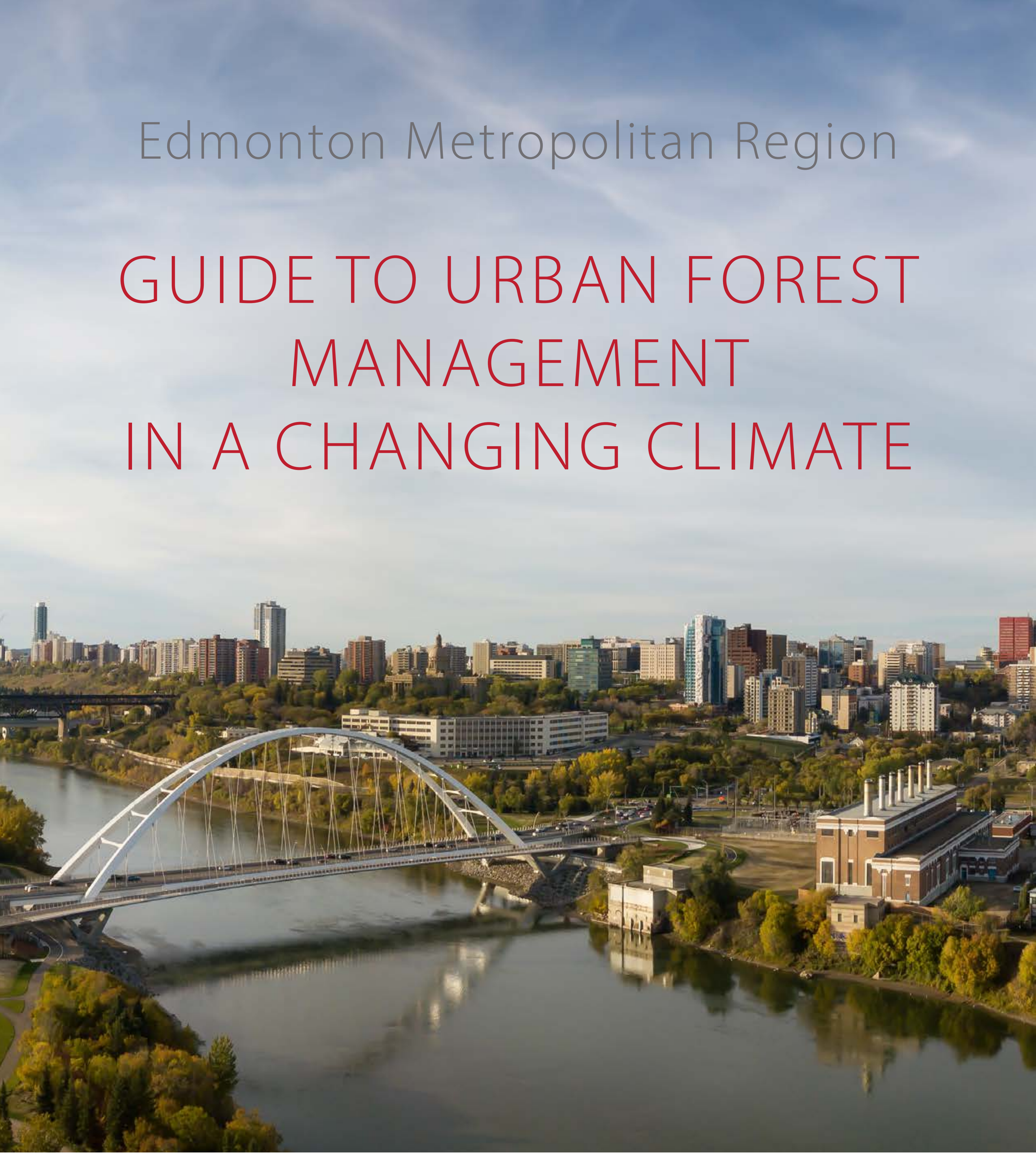
Edmonton Metropolitan Region

GUIDE TO URBAN FOREST MANAGEMENT IN A CHANGING CLIMATE



All One Sky Foundation

FCM Federation of Canadian Municipalities / Fédération canadienne des municipalités

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SUMMARY OF CLIMATE IMPACTS TO URBAN FORESTS

Climate change is predicted to alter the Edmonton Metropolitan Region's (EMR) climate in ways that will impact planted trees and native forests. This guide outlines the anticipated climate changes in the EMR, the anticipated impacts on trees and forests, and the adaptation options for urban forest management.

CHANGES TO...

TEMPERATURES

Average 5 - 7°C warmer by the 2080s. Milder winters. Summer extremes up to 41°C.

GROWING SEASONS

Longer, warmer growing seasons.

PRECIPITATION

More rain particularly in the spring, except in the summer. Less snow.

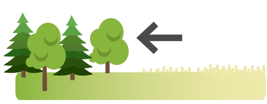
MOISTURE AVAILABILITY

Increased rates of evaporation and transpiration from waterbodies, soil and plants coupled with reduced summer precipitation increase summer climatic moisture deficits.

EXTREME WEATHER

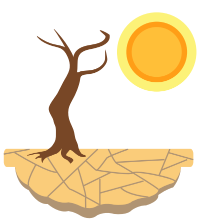
Potential changes in frequency and intensity of extreme weather events.

WILL LIKELY CAUSE...



ECOSYSTEM SHIFTS

Grassland ecosystem types may expand at the expense of aspen parkland and boreal forest.

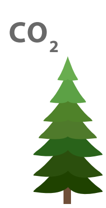


DROUGHT MORTALITY

Less moisture availability may increase drought mortality and urban trees may need more water to establish.

MORE EXTREME WEATHER EVENTS

Heat, extreme precipitation, flooding, icestorms or other events may happen more often leading to more tree damage.



LESS GROWTH AND CARBON CAPTURE

Trees may grow more slowly and not reach as large a size. Disturbance may result in carbon being released from forests.

MORE PESTS AND INVASIVE SPECIES

Pests may reproduce more rapidly and more often. Trees and ecosystems may be more vulnerable to attack and invasion.

LONGER FIRES SEASONS AND LARGER FIRES

Fires may occur more often and burn larger areas, and fire risk is expected to increase everywhere.

SUMMARY OF ACTIONS

Why Take Action?

The EMR's urban forests are anticipated to change significantly as changes in temperatures and moisture availability drive shifts from forest to grassland ecosystems and increase drought stress in urban trees generally. In addition, disturbance due to pests, disease, wildfire and extreme weather are expected to increase. These changes increase the risk of losing existing trees and their significant amenity and ecosystem services value to communities. Given the important role urban forests play in the livability of cities and in supporting climate mitigation and adaptation, it is critical to increase the resilience of urban forests to climate change. Urban forests, as a tool for both climate mitigation and adaptation, deserve broad integration and consideration as essential infrastructure in cities.

Action is Needed Across Urban Forest Management Themes of:

1. **Policy and planning:** Long-range planning, goal setting and policy development related to the planting and management of trees and forests.
2. **Planting:** Planning, design and implementation of tree planting and forest restoration.
3. **Management and plant health care:** Operational plans and programs to maintain tree and forest health.
4. **Risk management:** Plans and programs to manage risks to and from trees and forests.
5. **Engagement:** Plans and programs to engage with and coordinate tree planting and management between stakeholders on public and private land.

Adaptation Options Include:

PLANNING to adapt: Coordinated adaptation policies, programs and actions within and between communities and partners at multiple scales.

RESISTANCE to extirpation: Resist the loss of ecosystems due to climate change by protecting ecosystem resources with important economic, cultural or ecological value.

RESILIENCE to disturbance: Enhance tree health and ecosystem integrity to increase their tolerance for and recovery from climate impacts.

TRANSITION to new normals: Facilitate the transformation of ecosystems to novel conditions.

SUMMARY OF PRIORITY ACTIONS

The table below summarizes the highest priority actions listed under the Adaptation Options section of this Guide. The adaptation options are divided into five broad urban forest management themes to cater to the varied audience involved in this field: policy and planning, planting, management and plant health care, risk management and engagement.

Policy and Planning actions target long-term planning, goal setting and policy development related to the planting and management of trees and forests.

Policy and Planning – Priority Actions
Coordinate and cost share between EMR municipalities when working with, and requesting new powers from, the Province of Alberta to integrate climate adaptation into policy and to advance policy tools.
Integrate urban trees into asset management systems to track lifecycle costs, service levels and vulnerabilities to better inform urban forest management budgeting and decision-making.
Fund an Urban Forest Management Plan or Strategy and an Urban Forester position to guide strategic and operational urban forest management.
Protect climate refugia areas that may continue to support representative forest types (i.e., lands with topographic and edaphic characteristics that will provide more reliable soil moisture).
Regionally compile and share data to report on indicators and track changes in key forest metrics such as tree mortality, tree health (e.g., drought-stress), canopy cover, leaf-out/fall and flowering dates at the regional scale and at regular intervals (3-5 years).
Plan for development and infrastructure to avoid fragmentation and improve connectivity between climate refugia at both the municipal and regional scales.
Develop best practices urban forest design criteria, development guidelines and standards for capital and private development projects.
Incorporate climate adaptation strategies into all levels of provincial, regional and municipal policy planning for land use and that influence tree planting and management.
Establish a regional nursery, or alternative procurement processes and regional buying groups, that enable municipalities to influence the species, genetic material and stock quality so that there is greater access to and consistency of tree stock that is well adapted to future climate.

Planting actions focus on planning, design and implementation of tree planting and forest restoration.

Planting – Priority Actions
Select species suitable for the current site and climate conditions, and that are suitable for anticipated future climate at that location; most sites will become drier without irrigation or natural groundwater and so, in general, favour drought tolerant species
Focus natural area planting efforts in areas with growing season soil moisture inputs other than rainfall and avoid planting in drought-prone areas.
Invest in larger soil volumes and irrigation in streetscapes to support large canopy trees.
Restore hydrology, permeability, soils, understory and nutrient cycling to increase water stored in urban soils.
Establish suitable long-term targets for managing species and age diversity in urban tree populations.
Maintain and enhance age, structural and species diversity in natural area forests.
Identify and trial potentially suitable genotypes of aspen clones from drier climates.
Trial disease and pest resistant cultivars of urban trees, an non-invasive species adapted to warmer, drier climate conditions.
Establish long-term, multi-species trials across the EMR's climate gradients to test different genotypes of urban and native tree species from a range of warmer, drier climates.

SUMMARY OF PRIORITY ACTIONS

MANAGEMENT AND PLANT HEALTH CARE actions focus on operational plans and programs to maintain tree and forest health.

Management and Plant Health Care – Priority Actions
Develop landscape irrigation strategies to build supplemental watering networks for urban trees.
Work together with EMR municipalities, the Province of Alberta and the Canadian Food Inspection Agency to prevent, detect and control priority invasive plant and pest species that will become more competitive in a changed climate.
Extend the average duration and frequency of young tree watering into late summer, and the number of years for which young trees are watered to 4-5 years or as needed based on annual variation.
Slow the flow of surface water across the landscape (e.g., mimic beaver dams, create ditches and mounds etc.) so that more water infiltrates into surrounding soil and promotes vegetation diversity that will also accumulate snow.
Adjust pruning timing, firewood transport and debris management regulations as needed to prevent the spread of insects and disease (e.g. prune elms between October and March).
Train staff in tree pest and disease identification and treatment, and specifically to identify and treat Dutch elm disease and emerald ash borer, to enable rapid response when new detections occur.
Target 5 year preventative pruning cycles (3 years for elms) and young tree pruning at 3 year intervals for the first 15 years after planting.
Integrate passive or active irrigation (non-potable water) into urban landscapes to maintain tree health.
Plan for budget increases to fund increasing demand for tree planting, management and plant health care, and prepare contingency budget plans for managing a major pest outbreak (e.g., emerald ash borer).

RISK MANAGEMENT actions focus on plans and programs to manage risks to and from trees and forests.

Risk Management – Priority Actions
Develop reasonable risk inspection and mitigation standards for municipally managed trees in the vicinity of valued targets and ensure that: 1) standards are implemented operationally; and, 2) that inspection and risk mitigation actions are documented.
Develop community wildfire protection plans and post-fire restoration plans.
Implement FireSmart and support residents to do the same.
Develop extreme weather plans for community tree management to enable rapid and coordinated responses to immediate hazards, post-event clean-up and restoration.
Increase surface and soil water storage, and/or irrigation of landscapes to create wildfire refugia to protect interface areas while also supporting healthier trees.
Reintroduce prescribed fire, thin unhealthy stands and treat hazardous vegetation fuels in the urban interface.
Provide grants to private landowners to encourage private tree maintenance and FireSmart.
Use species selection to minimize risk when planting near structures by selecting deciduous species with low wind breakage potential.

SUMMARY OF PRIORITY ACTIONS

ENGAGEMENT actions focus on plans and programs to engage with and coordinate tree planting and management between stakeholders on public and private land.

Engagement – Priority Actions
Form partnerships between EMR municipalities, First Nations, public sector organizations, institutions, academics, professional associations, the private sector and other relevant stakeholders
Work together with the private sector to align corporate social responsibility efforts with climate adaptation capacity building.
Encourage private and institutional landowners on sites with favourable growing conditions to plant or maintain valued species that are likely to become less suited to future climate.
Encourage private and institutional landowners of climate refugia areas to protect and restore sites native forest.
Encourage and support private and institutional landowners to proactively maintain tree health.
Educate councils, senior staff and external stakeholders about anticipated climate impacts and adaptation options.
Work together with First Nations to identify culturally appropriate stewardship practices for coping with climatic variability and changes in forest structure and function.
Engage residents in urban forest management planning, particularly at the neighbourhood scale, and provide learning opportunities for tree selection, planting and maintenance.
Increase awareness about wildfire risk, and encourage fuel management and prescribed burning, and community FireSmart practices on private land.
Increase awareness about emerging pest and disease threats, and provide guidance for tree health management responses on private land.
Work together with the research community to identify potential sources of seed or vegetative propagules for adapting native tree species, and to monitor climate change and adaptation to inform new and improved climate adaptation options.
Work with production nurseries to increase the genetic and species diversity of trees available to plant in urban environments.
Provide public guidance for climate suitable species selection and managing diversity on private land.

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TABLE OF CONTENTS

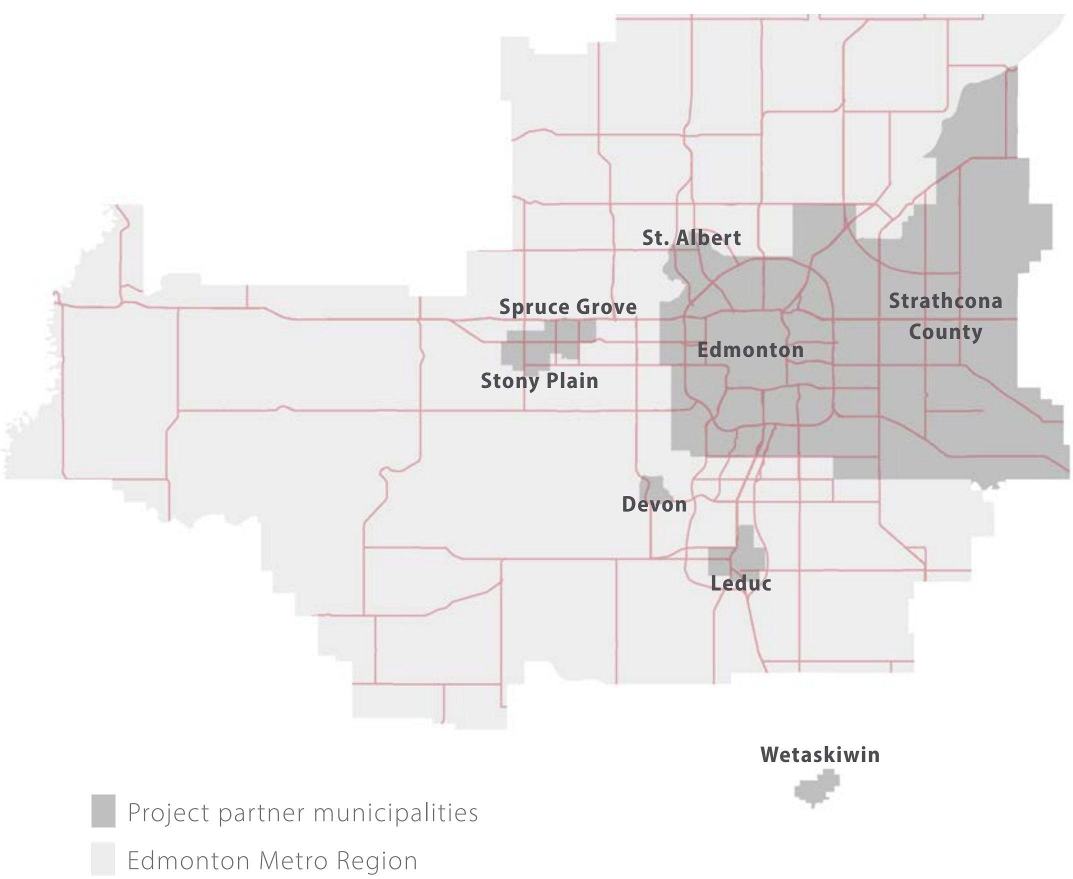
1 Introduction

Guide to urban forest management in a changing climate

Climate change is predicted to alter the Edmonton Metropolitan Region's (EMR) climate in ways that will impact planted trees and native forests. At a global scale, forests at higher latitudes are expected to bear the brunt of negative climate change impacts. This document provides guidance on how local municipalities could adapt their urban forest management practices to sustain trees and native forests through these anticipated changes.

Trees are an important tool for community climate mitigation and adaptation because they provide cooling, stormwater interception, carbon sequestration and storage, and support biodiversity, among many benefits. Adapting urban forest management to climate change now will increase the resilience of our communities to climate change and reduce the risk associated with declining tree and forest health.

This document outlines the anticipated climate changes in the EMR, the anticipated impacts on trees and forests, and the adaptation options for urban forest management. Partner municipalities on this project include the City of Spruce Grove, City of Leduc, Town of Devon, Town of Stony Plain, City of Edmonton, Strathcona County, City of St. Albert and City of Wetaskiwin.



1.1 Benefits of Urban Forests

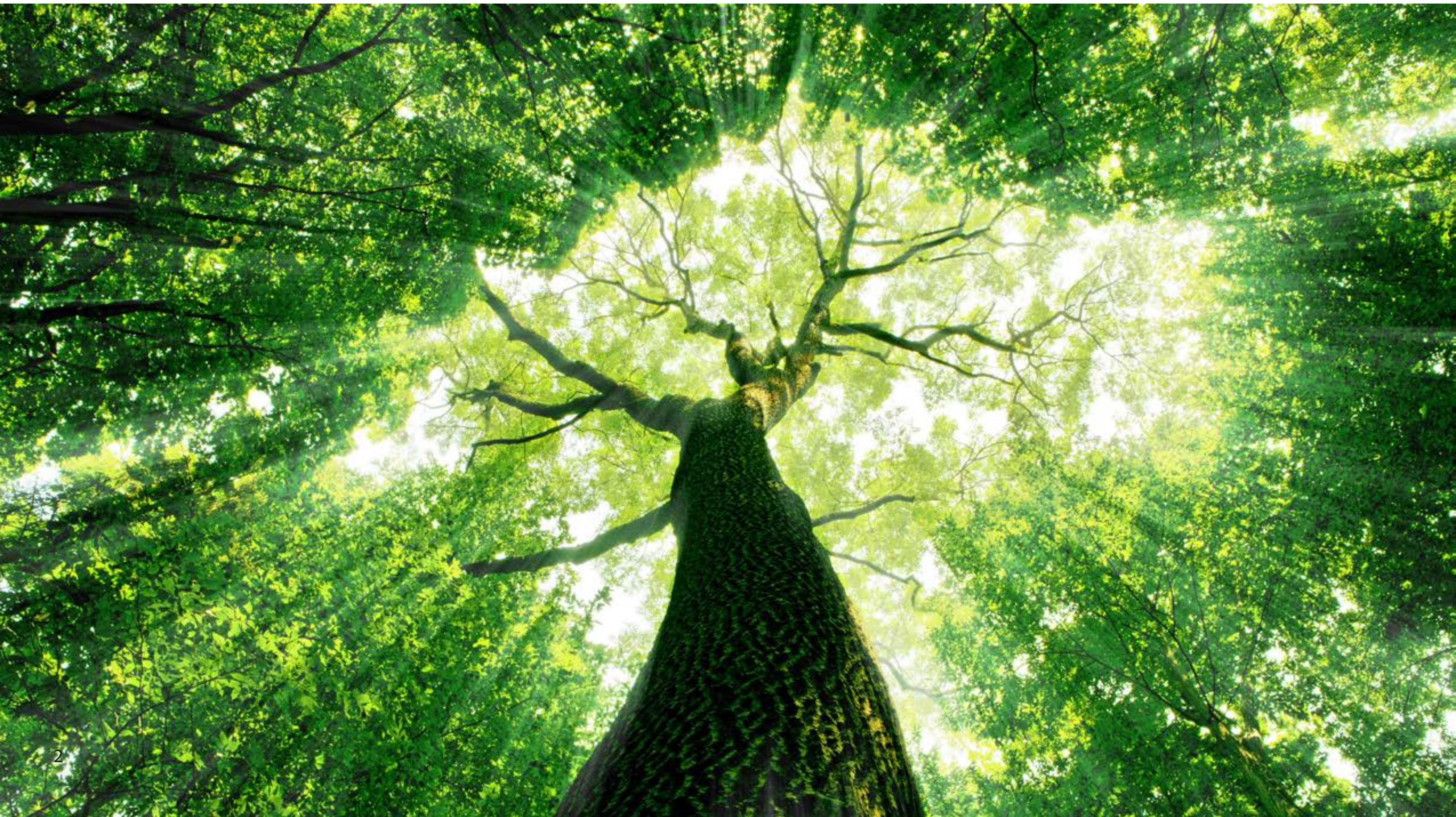
Healthy and well managed urban forests produce 'ecosystem services' often defined in four distinct but inter-connected categories:

- Cultural: benefits that relate to how people value the urban forest in our way of life such as for beautification, sense of place, spirituality, recreation and tourism.
- Provisioning: products extracted directly from the forest like food, traditional medicine, fresh water and firewood.
- Regulating: benefits from the regulation of ecosystem processes like pollination, air and water quality, storm water flow, shade and cooling. With climate change, the role of trees to mitigate extreme heat and flooding becomes particularly acute.
- Supporting: benefits from supporting habitat, biodiversity and enabling natural processes to occur that maintain the conditions to support life – supporting services are essential to the production of all other ecosystem services.

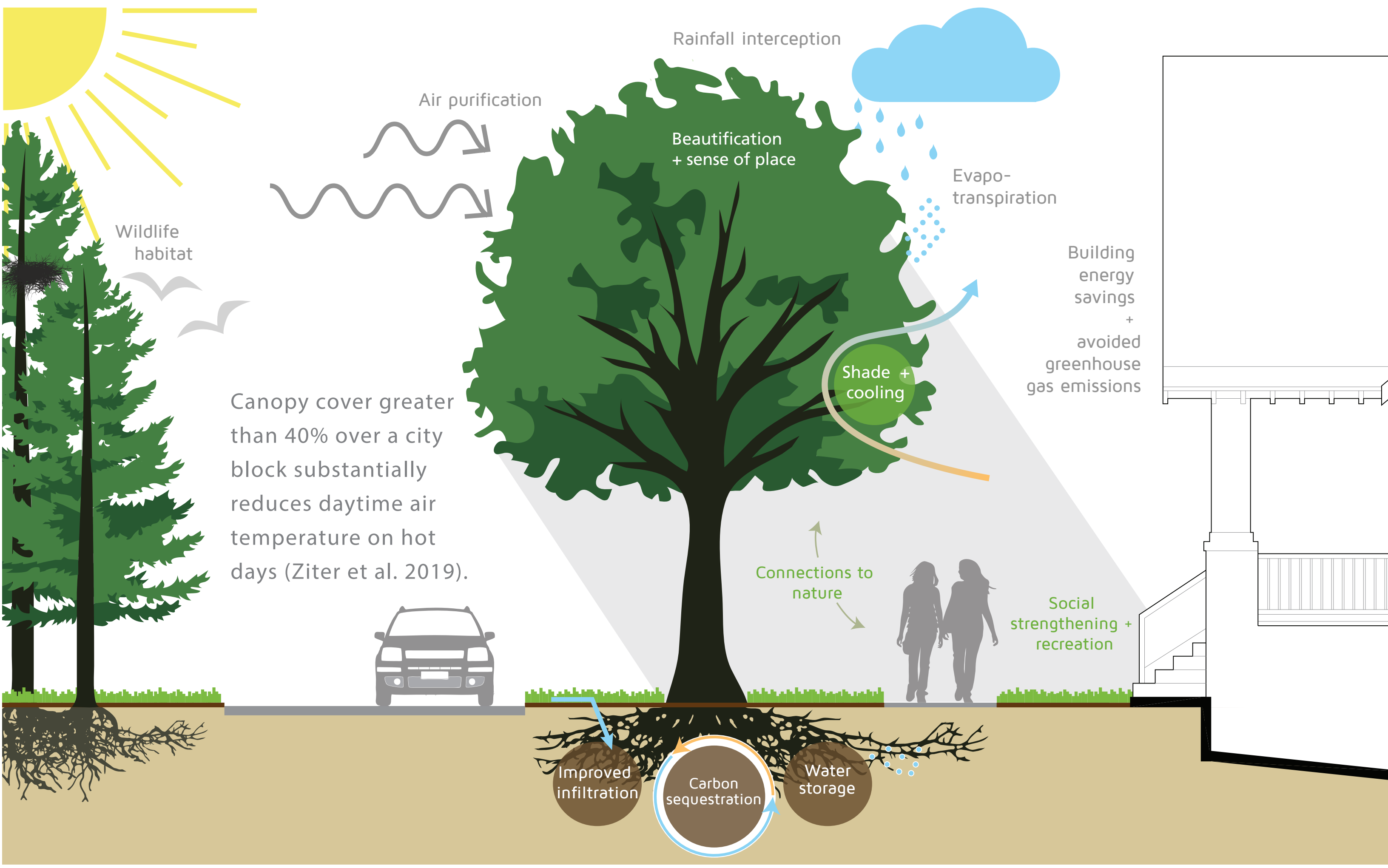
The Green Cities: Good Health website[1] provides a comprehensive compilation and synthesis of current research into the benefits provided by urban forests and nature in cities. Increasingly, the services that urban forests provide to communities are being valued and accounted for as municipal natural assets in financial planning and mainstream asset management systems. Natural assets provide many regulating services equivalent to engineered assets (e.g., stormwater management, flood protection, shade, air quality improvement etc.) so including them as municipal infrastructure helps decisions-makers to prioritize natural asset protection, restoration and maintenance. The Municipal Natural Assets Initiative[2] is a Canada-wide initiative supporting municipalities to develop resilient, long-term infrastructure.

[1] http://depts.washington.edu/hhwb/

[2] https://mnai.ca/

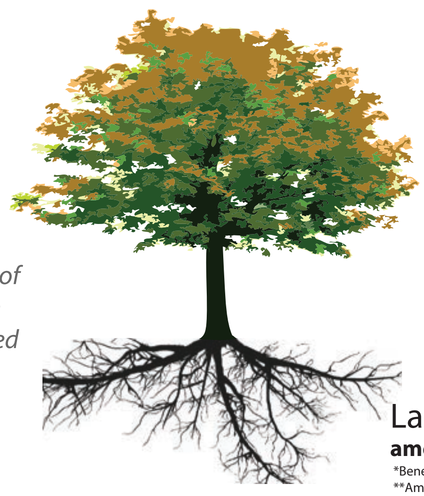


Benefits of Urban Trees



THE LARGE TREE ARGUMENT

Large, long-lived tree species provide many times the value of small tree species over a much longer timeframe when planted in the right place.



Large tree

60 cm bur oak
north side of the Alberta Legislature Building

$69 eco services/year*
>100 years
life expectancy
>$13,000
lifetime eco services*
>$200,000
amenity value potential**

Small tree

25 cm Japanese lilac
north side of the Alberta Legislature Building

$5 eco services/year*
<40 years
life expectancy
<$400
lifetime eco services
<$30,000
amenity value potential**

Large tree species provide **many times the ecosystem services and amenity value** to the community compared to small trees over their lifetime.

*Benefits calculated using i-Tree Design https://design.itreetools.org/ and include stormwater, energy, air quality and carbon dioxide.
**Amenity value potential estimated using CTLA tree appraisal 9th Edition, rating 100% for location and condition, $85 unit tree cost, $750 installed cost.

A 2014 TD Economics report on the value of urban forests in Canadian cities found that, for every dollar spent on trees, the return in benefits was between $1.88 and $12.70 (TD Economics, 2014)

1.2 The Cost of Not Maintaining Urban Trees

Urban trees typically require intensive management compared to natural forests because they need careful site preparation, planting and watering to establish, regular inspections and pruning to keep them safe, and health treatments when stressed. While intensive management comes at a cost, municipalities provide urban trees as a service to the community because the benefits they provide outweigh the costs (see Figure 1). Edmonton's 2010 Corporate Tree Policy Tree Assessment Guidelines valued average boulevard trees at $2,400 to $8,000 based on their amenity value to the community; Edmonton's entire City tree inventory (excluding trees in natural forest areas) was valued at $1.2 billion. Urban trees are unique among municipal infrastructure assets because, unlike roads and pipes which depreciate over time, a tree's value appreciates as it grows, with the greatest benefits provided at maturity.

To maximize the climate mitigation, adaptation and other benefits that urban trees provide, they need to live a long, healthy life. A recent study in Boston, MA found that urban trees grew nearly four times faster but died at twice the rate of rural forest trees, resulting in a net loss of carbon storage in that urban forest over time (Smith et al. 2019). This study highlights the risks associated with implementing a planting program without providing adequate tree care and maintenance to prevent premature loss. Simply planting urban trees is not enough to realize climate mitigation and adaptation benefits from the urban forest — adequate maintenance and plant health care over the tree life-cycle are also essential.

TREE LIFE-CYCLE COSTS AND BENEFITS

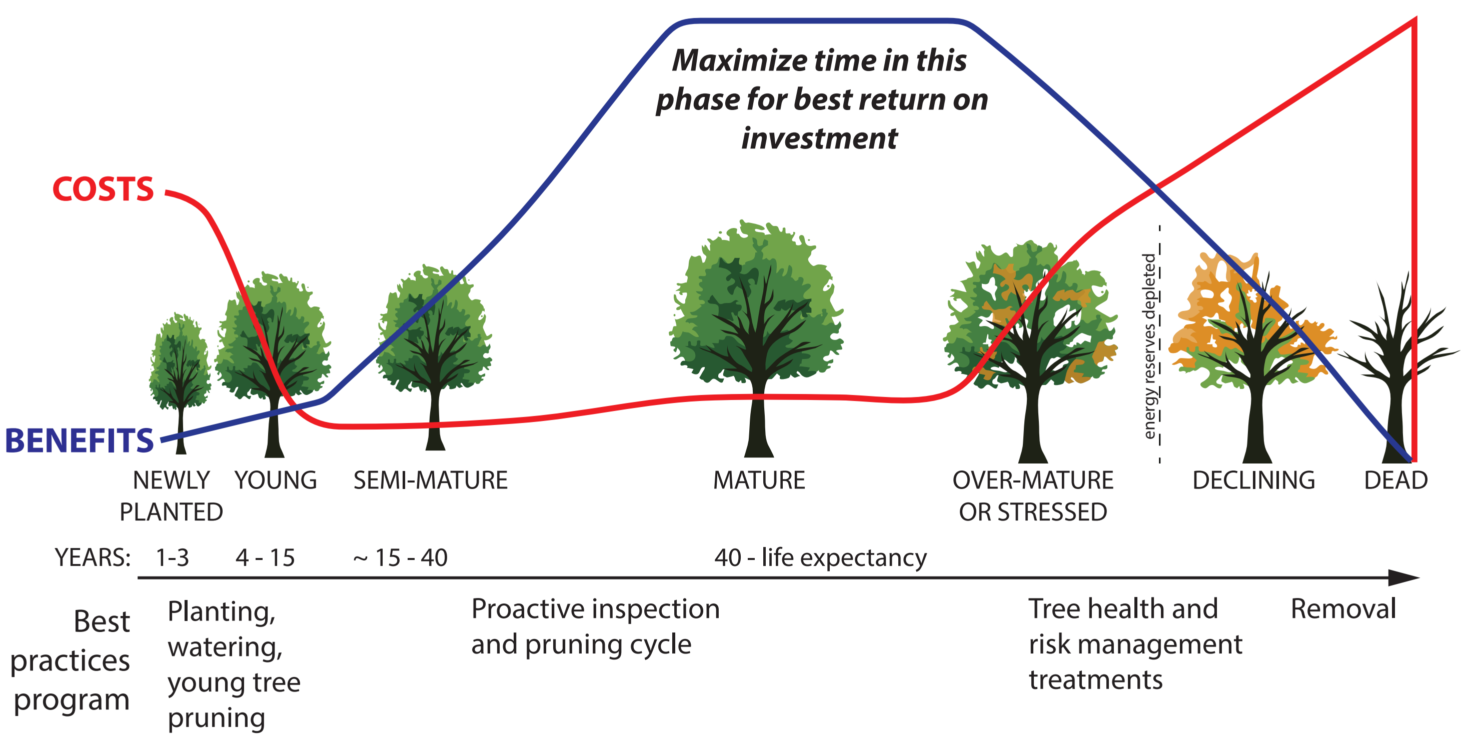


Figure 1. The diagram above represents the magnitude of costs and benefits associated with urban trees throughout their life-cycle. Trees cost the most at the start and end of their lives and produce the greatest benefits in the middle, when they are healthy and mature. Implementing a best practices management program for planting, watering, proactive maintenance and tree care will maximize each tree's healthy lifespan and minimize how often the municipality has to pay removal and replanting costs.

2 Climate Change

Change and what it means for urban forests

2.1 Predicted Climate Changes in the Edmonton Metropolitan Region

The growth and distribution of vegetation, including forests, is strongly controlled by climate and the interactions between water and energy available for plant growth. As such, this report describes the anticipated changes in temperature, growing season, precipitation and moisture deficits to infer potential impacts on trees and forests. The historic normal climate and projected climate variables for the EMR are described below using Edmonton's city centre as the point for reporting climate variables. The historic normal and projected climate data were sourced from ClimateNA software (Wang, Hamann, Spittlehouse, & Carroll, 2012). The normal climate is measured over the 1961-1990 period, 2050s climate is projected over the 2041-2070 period, and the 2080s climate is projected over the 2071 to 2100 time period using an ensemble of 15 climate models. The emissions scenarios used were Representative Concentration Pathway (RCP) 4.5 which assumes the stabilization of GHG by 2100 and PCP 8.5 which assumes a continuous increase of GHG.

Temperature

Edmonton's baseline Mean Annual Temperature (MAT) is 2.3°C. Across the EMR, MAT ranges from 1.6°C to 2.8°C from west to east (Figure 2). In the future, MAT is projected to increase to between 5.9°C – 8.2°C by the 2080s (Figure 3). This change is driven by monthly minimum, maximum and average temperatures being warmer in all seasons. These temperature changes will alter the plant hardiness zones for the EMR.

Relative to other cities, Edmonton's future MAT is projected to be similar to Fargo, ND and Alexandria, MN by the 2050s, and similar to Toronto, ON or Minneapolis, MN by the 2080s.

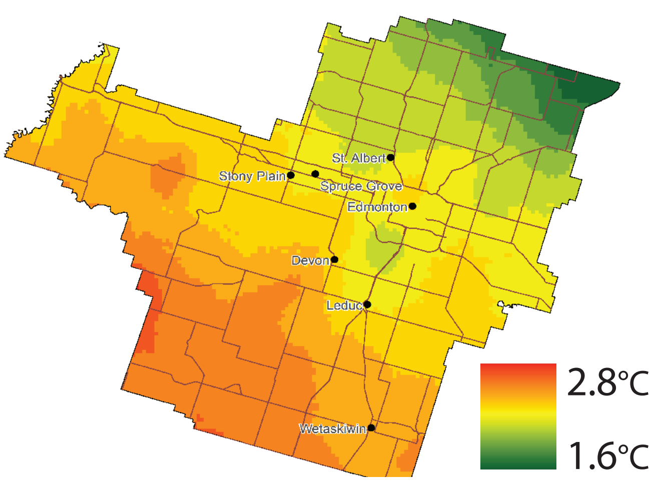


Figure 2. The map above shows the historic normal Mean Annual Temperature range across the Edmonton Metropolitan Region.

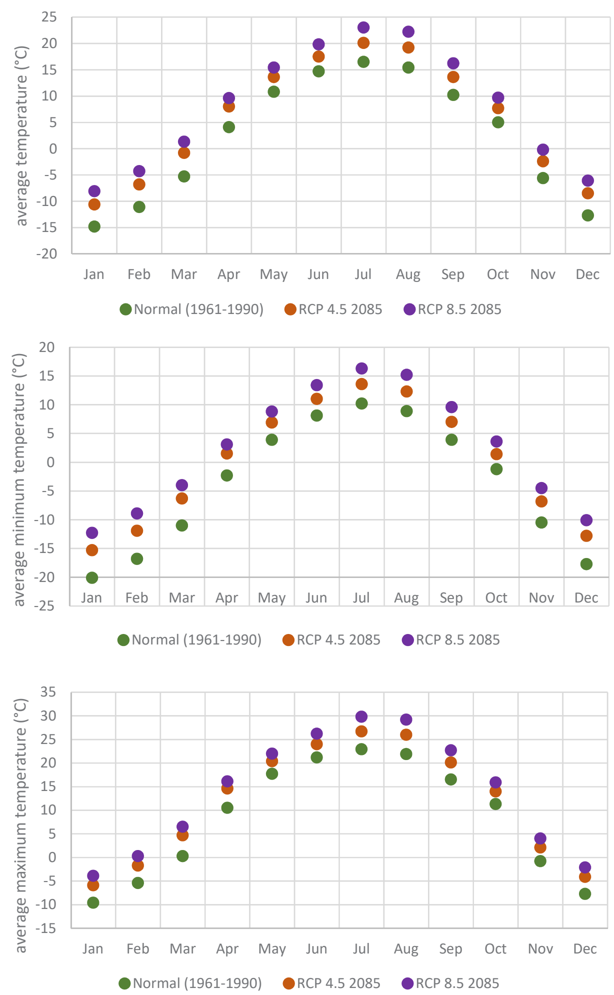


Figure 3. The graphs above show monthly average, minimum and maximum temperatures for Edmonton's normal climate and the projected 2080s climates under the moderate RCP4.5 high emissions RCP 8.5 scenario

Growing Season

Growing degree-days (GDD) provide an index of the amount of heat available to support the growth and maturation of plants and insects. Edmonton's GDD are projected to increase from 1,429 to up to 2,558 by the 2080s (Figure 4). Growing degree days are expected to accumulate most in the summer months but also over longer growing seasons.

The beginning of the frost free period is expected to become earlier, from the present average date of May 31 to April 20 under the high emissions 2080s scenario. Similarly, the end of the frost free period is expected to shift from the present average date of September 12 to October 8 under the high emissions 2080s scenario.

Relative to other cities, Edmonton's future growing season is projected to be similar to Fargo ND and Alexandria, MN by the 2050s, and similar to Minneapolis, MN by the 2080s.

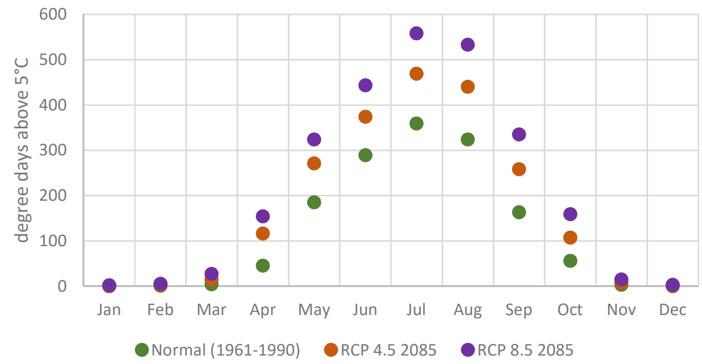


Figure 4. The graph above shows monthly average degree days above 5°C for Edmonton's normal climate and the projected 2080s climates under the moderate RCP4.5 high emissions RCP 8.5 scenario. Growing degree days accumulate whenever the daily mean temperature is above 5°C, or other threshold temperatures may be used; the value is not the accumulation of actual days but rather the number of degrees each day's average temperature is above the threshold temperature.

Precipitation

Edmonton's mean annual precipitation (MAP) is 464 mm. Across the EMR, MAP ranges from 400 mm in the east to 601 mm in the west (Figure 5). In comparison with other Canadian Prairie cities, the EMR's MAP is lower than Winnipeg but higher than Regina, Saskatoon and Calgary.

In the future, Edmonton's MAP is projected to increase to 501 mm by the 2080s, and the wettest parts of the EMR will increase from 601 mm to 645 mm (Figure 6). Less precipitation is expected to fall as snow, which will alter seasonal stream flows. Precipitation will increase in all months except July and August, which will be lower by 10-15 mm, and September which will stay approximately the same. The increases in April, May and June are greater than in other months. These projections imply that springs will be wetter and summers will be drier.

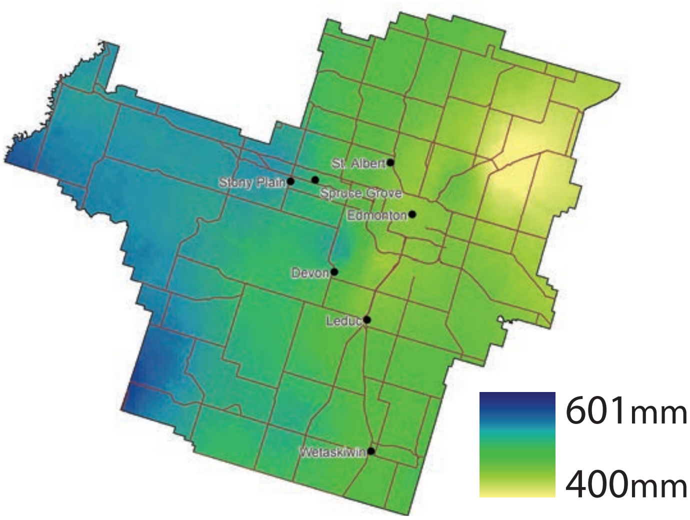


Figure 5. The map above shows the historic normal Mean Annual Precipitation range across the Edmonton Metropolitan Region.

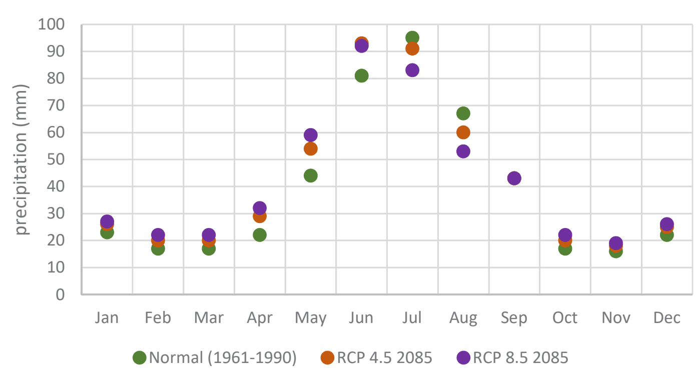


Figure 6. The graph above shows monthly average precipitation for Edmonton's normal climate and the projected 2080s climates under the moderate RCP4.5 high emissions RCP 8.5 scenario.

Moisture Deficits

Combining evaporation rates and precipitation provides information about the moisture available for vegetation growth. Climatic moisture deficit (CMD) is a useful indicator of the amount of moisture needed for vegetation growth that must be met from sources other than rain (Wang, Hamann, Spittlehouse, & Carroll, 2012).

Climatic moisture deficit accumulates for the months when evapotranspiration exceeds precipitation (moisture is in deficit). The EMR's CMD ranges from 64 mm in the west to 242 mm in the east (Figure 7). Edmonton's CMD is projected to increase from 198 mm to up to 305 mm by the 2080s, with the greatest increase occurring in summer and slight increases in spring and fall (Figure 8). The present gradient of moisture deficit increasing from west to east will remain across the EMR.

Based on the historic normal, spring months have typically been drier compared to all other months but projections show that the drying trend will intensify and extend over July, August and September before returning to the historic normal range. These results indicate that the decline in summer precipitation and increase in evapotranspiration will outweigh the effect of increased annual precipitation in terms of overall moisture availability.

A similar metric commonly used to report vegetation shifts is climatic moisture index (CMI), which is also the monthly difference between evaporation and precipitation. However, CMI is summed over the year with months when precipitation exceeds evaporation counting as positive values and months with a moisture deficit counted as negative values. When summed over the year, the final CMI value reflects the annual net moisture surplus or deficit. The EMR's CMI normal indicates a net deficit of moisture down to - 70 mm in the eastern part of the EMR and a surplus of up to 100 mm in the western part of the EMR (Schneider, 2013).

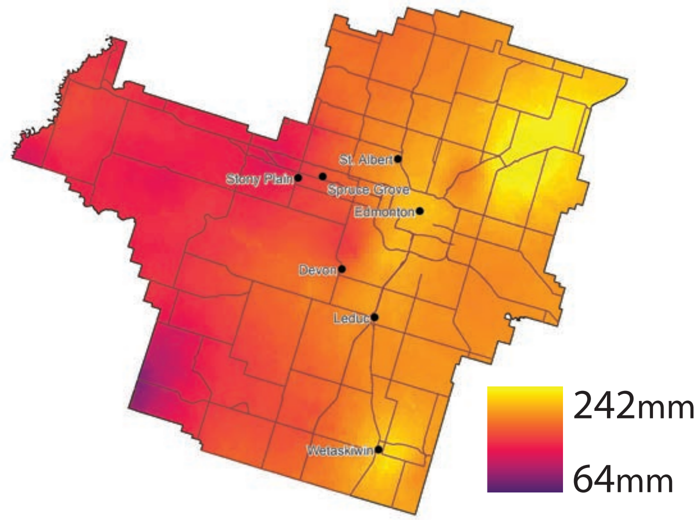


Figure 7. This map shows the historic normal Climatic Moisture Deficit range across the Edmonton Metropolitan Region.

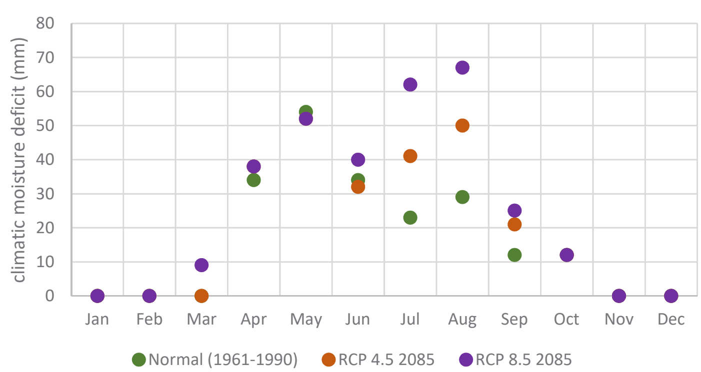


Figure 8. This graph shows monthly average climatic moisture deficit for Edmonton's normal climate and the projected 2080s climates under the moderate RCP4.5 high emissions RCP 8.5 scenario.

In Alberta, the zero CMI isoline corresponds well with the differentiation of closed forest and the transition to open forest and grassland ecosystems (Hogg, 1997). In the province, the lowest CMI values are found in the far southeast of the Province and are associated with dry shortgrass prairie (Schneider, 2013). Moving north and west towards Edmonton, CMI values increase accompanied by a gradual increase in the height of vegetation, the addition of isolated stands of aspen, and then closed aspen forests once CMI values approach zero (Schneider, 2013).

The maps in Figure 9 below illustrate the current and projected extent of Climatic Moisture Index (CMI)[3]. In areas where CMI is negative values below zero, annual evapotranspiration will typically exceed precipitation. Under a hot scenario, the EMR's 2080s CMI values are similar to those of the current dry shortgrass prairie areas in southeastern Alberta. The EMR is projected to shift from CMI values associated with aspen and conifer forests towards values that support grassland.

[3] The CMI projection for the median and hottest change models are based on Special Report on Emissions Scenarios (SRES) from the IPCC 4th Assessment Report (Schneider, 2013).

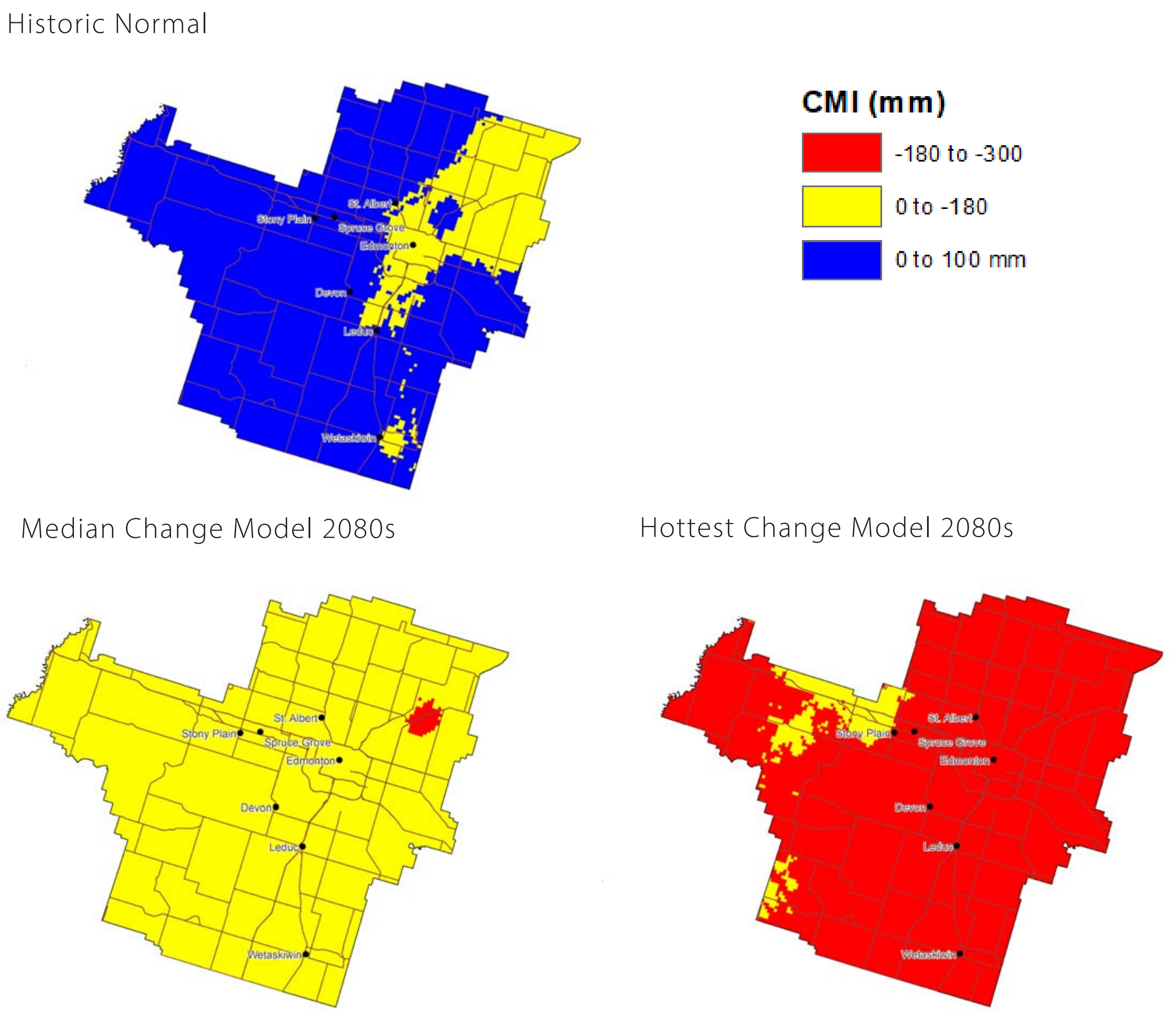


Figure 9. The maps above show the regions historic normal and projected 2050s and 2080s climatic moisture index values under median change and hottest change models.

Extreme Weather

In addition to the long-term climatic trends discussed so far, there will be variability from year to year. Extreme weather can result in sudden and significant financial, health and societal impacts to communities. Scientific community members generally agree that climate change is likely to alter the frequency and characteristics of extreme weather events globally (Seneviratne, et al., 2012). However, modelling difficulties and uncertainties meant that predictions of event frequency often have low confidence, particularly with increasing specificity of location, duration, and intensity predictions (Diffenbaugh, et al., 2017).

There is limited modelling evidence to project specific, targeted impacts for different climate hazards in Alberta (Davidson, 2010). Existing impact assessments largely infer the likelihood of climate hazards from established drivers like temperature and precipitation (Lemmen, Warren, Lacroix, & Bush, 2007; Zukiwsky & Boyd, 2014; Prairie Climate Centre, n.d.). Recent research has started to look back at past events to attribute the role of anthropogenic climate change in increasing the probability or intensity of specific drought, flooding, extreme heat and cold, and wildfire events (Bush and Lemmen, 2019). Past events for which the risk or intensity was increased as a result anthropogenic climate change include the 2015 drought in western Canada (Szeto et al. 2016), the 2013 Alberta floods (Teufel et al., 2017) and the 2016 Fort McMurray wildfire (Kirchmeier-Young et al., 2017).

Municipalities in the EMR are preparing for a range of potential weather conditions, including winter storms, extreme or unseasonable (i.e., rain instead of snow) precipitation and consequent flooding, drought, convective storms with impacts such as hail, lightning, as well as tornadoes, strong winds, heat waves, grass and forest fires, and destructive freeze-thaw cycles (Zukiwsky & Boyd, 2014). In the EMR, the municipalities of Leduc, Edmonton, Spruce Grove and Bruderheim have adopted climate adaptation plans.

Summary of Projected Climate Changes Relevant to Urban Forests

Climate projections (Wang et al., 2012) indicate that, on average:

- **Temperatures** in all seasons will increase (Figure 10), especially in winter, and extreme winter minimums will become less limiting for overwinter survival of trees.
- **Growing seasons** will become warmer and longer, providing more energy for tree growth over a longer period of time.
- **Precipitation** will remain more or less the same in fall and winter, except that less precipitation will fall as snow (Figure 10). Spring will be wetter providing more water for tree growth at the beginning of the growing season but summers will be drier and limit water available for growth later in the season.
- **Growing season moisture deficits** will remain the same in the spring and fall but deficits will increase substantially in the summer months, suggesting that the combination of warmer temperatures and reduced summer precipitation will cause increasingly arid conditions (Figure 10).

The potential for an increase in the frequency of **extreme weather** is also likely to impact the growth and survival of trees and forests in affected locations by directly by causing injury or death.

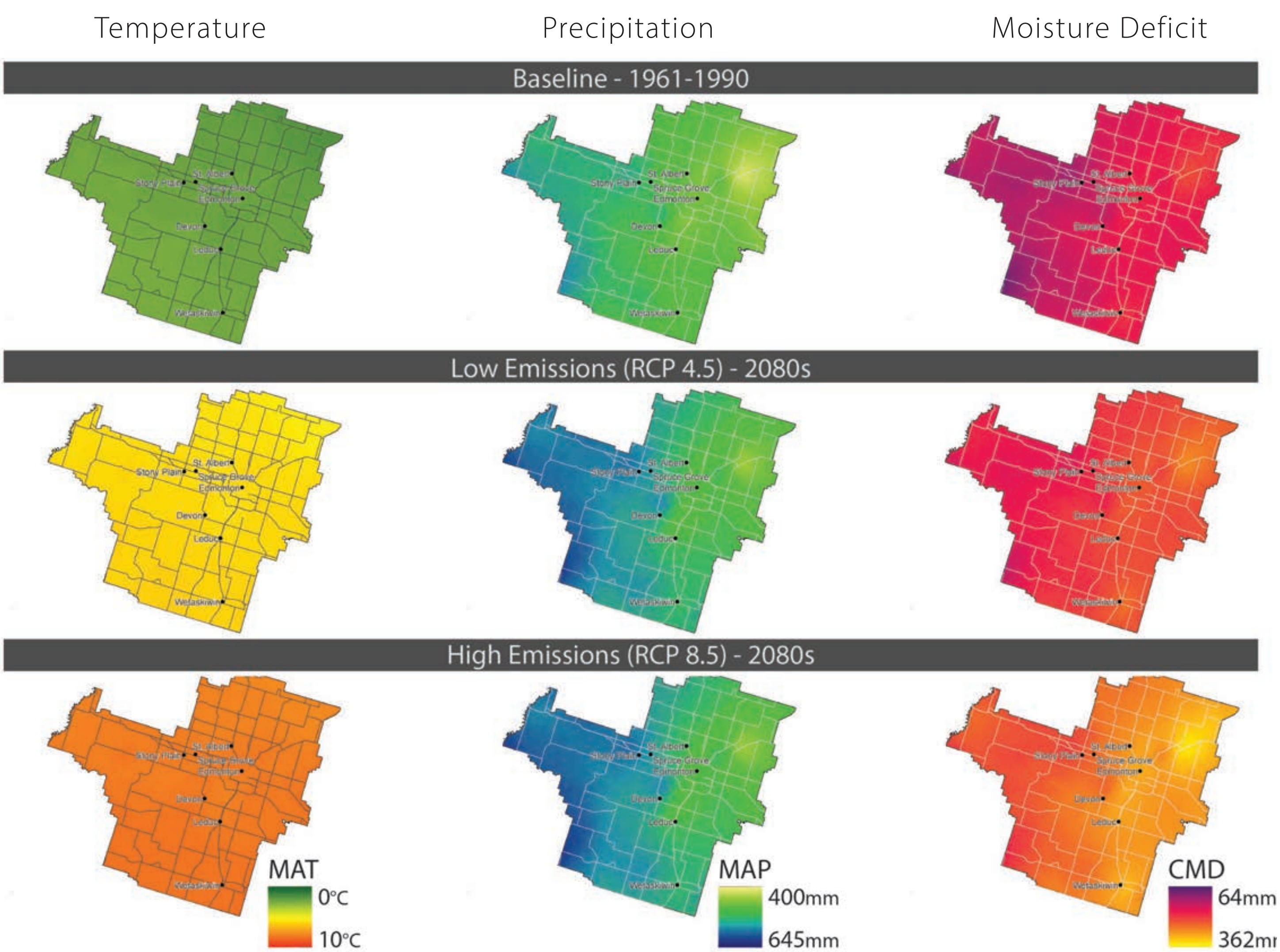


Figure 10. The maps above show the regions historic normal and projected 2050s and 2080s mean annual temperature, mean annual precipitation and annual climatic moisture deficit under baseline normal conditions, low emission and high emissions scenarios.

"For a plant to use energy for growth, water must be available; otherwise the energy acts only to heat and stress the plant. Similarly, for the plant to use water for growth, energy must be available; otherwise water simply percolates through the soil or runs off unused." (Stephenson, 1990)

2.2 Impacts on Urban Forests

The anticipated climate change impacts to the EMR's urban forests can be described as "sudden-onset" or "slow-onset". Slow-onset impacts result from gradual changes to regional climate related to temperature, growing season, precipitation and seasonal moisture availability. Of the gradual changes described in the previous section, growing season moisture deficits drive most of the slow-onset impacts defined below, followed by temperature and growing season. Sudden-onset impacts, also called "climate hazards", are discrete events associated with extreme weather. Risk and vulnerability were qualitatively assessed by the authors based on a review of relevant scientific literature completed in the Phase 1 "Trees and Forest Vulnerability Study" and using rankings adapted from the Local Governments for Sustainability (ICLEI) framework for municipal climate adaptation (ICLEI Canada, 2010).

		RISK		VULNERABILITY	
	IMPACT STATEMENT	Probability	Consequence	Sensitivity	Adaptive Capacity
SLOW-ONSET IMPACT	Grassland ecosystem types may expand at the expense of aspen parkland and boreal forest.	HIGH	HIGH	HIGH	POOR
	Native species genotypes may become maladapted to local climate.	HIGH	HIGH	HIGH	POOR
	Invasive species may become more successful, and pests and diseases may become more harmful.	MODERATE	MODERATE	HIGH	MODERATE
	Tree growth and carbon capture may decline.	MODERATE	MODERATE	MODERATE	POOR
	Urban trees may experience more frequent drought stress and mortality, particularly in young trees.	MODERATE	MODERATE	HIGH	MODERATE
	A wider variety of tree species may be able to be planted in the urban forest.	MODERATE	POSITIVE IMPACT		
SUDDEN-ONSET IMPACT	Wildfire seasons may become longer and fires may become larger.	HIGH	HIGH	HIGH	POOR
	Extreme weather may become more frequent and damaging.	MODERATE	MODERATE	HIGH	POOR

Definitions	Low	Moderate	High/Poor
Probability	Low agreement in scientific literature that the impact will occur.	Moderate agreement in scientific literature that the impact will occur.	High agreement in the literature that the impact will occur.
Consequence	No tree decline or mortality	Minor to isolated but significant instances of tree decline or mortality that could be reversed with effort.	Severe to catastrophic loss of urban forest amenity and a danger of progressive, irrecoverable tree decline or mortality.
Sensitivity	No change in functionality of urban forestry service area.	Functionality of the urban forestry service area to supply and maintain trees and forests is likely to get worse.	Functionality of the urban forestry service area to supply and maintain trees and forests will get worse.
Adaptive Capacity	No to little costs and staff intervention.	Will require some costs and staff intervention to adjust the service area to the impact.	Will require substantial costs and staff intervention to adjust the service area to the impact.

3 Adaptation Options

Options to adapt urban forest management

All municipalities in the EMR have pre-existing vulnerability in their tree and forest populations due to development pressure and baseline levels of environmental stress and disturbance. Planning or operational work that reduces this vulnerability, though it may not be primarily climate adaptation focused, has adaptation benefits because it increases resilience in tree populations. Municipalities in the EMR have also begun adaptation planning but the extent of work targeting the adaptation of tree and forest management to climate change varies among municipalities. This section will focus on the options available to reduce vulnerability to both current challenges and the climate impacts of concern.

Among Edmonton municipalities, the responsibility for urban forest management is typically split between multiple departments and staff with varied strategic and/or operational scope. To better focus adaptation options for this varied audience the following sections are laid out under the broad themes of urban forest management:

1. **Policy and planning:** Long-range planning, goal setting and policy development related to the planting and management of trees and forests.
2. **Planting:** Planning, design and implementation of tree planting and forest restoration.
3. **Management and plant health care:** Operational plans and programs to maintain tree and forest health.
4. **Risk management:** Plans and programs to manage risks to and from trees and forests.
5. **Engagement:** Plans and programs to engage with and coordinate tree planting and management between stakeholders on public and private land.

Within each management theme, the options to adapt tree and forest management to climate change are presented under the broad strategies of planning, resistance, resilience and transition (Millar et al., 2007; Swanston & Janowiak, 2012):

PLANNING to adapt: Coordinate adaptation policies, programs and actions within and between communities and partners at multiple scales.

RESISTANCE to extirpation: Resist the loss of ecosystems due to climate change by protecting ecosystem resources with important economic, cultural or ecological value. These strategies will become less effective as the degree of change increases later in the century.

RESILIENCE to disturbance: Enhance tree health and ecosystem integrity to increase their tolerance for and recovery from climate impacts. Resilience is effective until the degree of change exceeds the species or ecosystem's thresholds for persistence, such as in locations where grassland is expected to replace forests later in the century.

TRANSITION to new normals: Facilitate the transformation of ecosystems to novel conditions (unlike any found today). This strategy may be appropriate where resistance and resilience have a high risk of failure. Transition strategies focus on long-term effectiveness and require strategic planning and gradual implementation to manage uncertainty.

3.1 Policy and Planning

The provincial government's Municipal Government Act (MGA) empowers municipalities to regulate land use in a framework illustrated in Figure 11. Municipalities are required to develop statutory plans for land use and adopt a Land Use Bylaw, which may include provisions to protect the physical environment. The Municipal Development Plan is a long range plan that establishes the vision for land use and how the community will change and develop over time.

Municipalities also typically develop strategic guidance documents that further the community vision adopted in the Municipal Development Plan. These may be on specific topics such as the urban forest, stormwater management or green networks and biodiversity.

In addition, the MGA enables municipalities to develop bylaws for certain other municipal purposes. The protection of trees or other natural features on private land is not specifically enabled by the MGA outside the Land Use Bylaw; however bylaws protecting things in or near a public place, including trees, are enabled. In addition, policies are often adopted by municipalities to guide internal procedures, standards and processes and their administration. Municipalities also develop wide-ranging programs through which staff deliver services to the community.

Two other provincial Acts enable some environmental protections: 1) the Environmental Protection and Enhancement Act, which enables municipalities to accept and enforce conservation easements; and, 2) the Historical Resources Act that enables municipalities to make designations or enter into agreements with landowners to protect historic resources including sites and features of historic, cultural, natural, scientific or aesthetic interest.

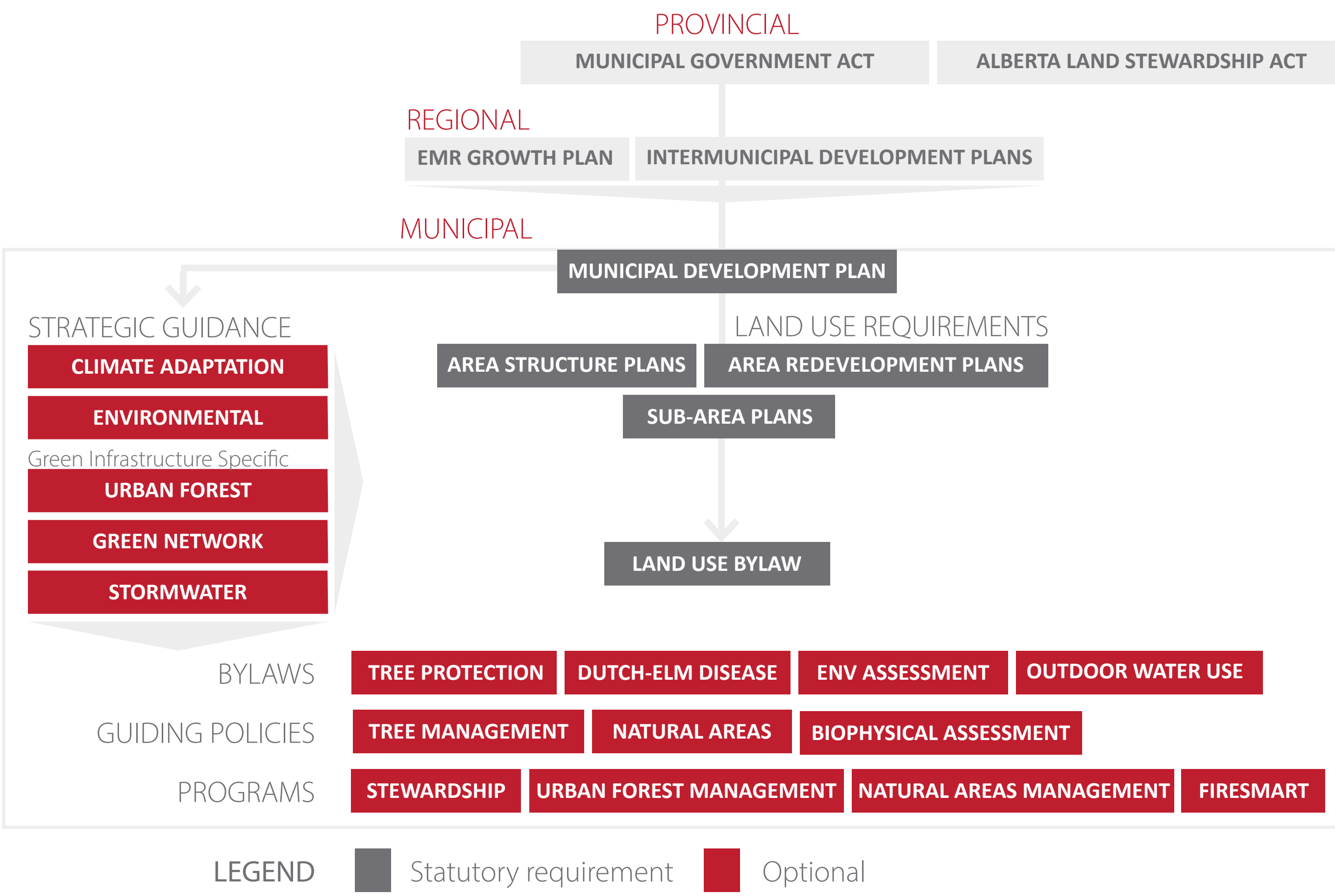


Figure 11. The diagram represents levels of provincial, regional and municipal policy and programs that influence tree and forest management in the EMR. Other than the statutory requirements, municipal policies and programs can be defined by municipalities at their discretion but within the bounds of their authority. The names of optional policies are examples to convey their subject matter rather than specific bylaws, strategies etc. and are not a complete list.

It is critical to integrate climate adaptation strategies and options into various levels of municipal policy and programming because they are the mechanisms by which urban forest management is directed and implemented by municipalities. Across the EMR, partner municipalities vary in the scope and extent of their policy planning and their capacity to implement it.

Pre-existing vulnerabilities include:

- In some municipalities, absence of strategic guidance for tree planting and management in the form of an urban forest strategy and/or green network plan.
- General absence of strategic guidance to manage stormwater as a resource.
- Limited powers to regulate the protection, removal and replacement of trees and forests outside the development process.
- Limited requirements to provide growing sites with adequate soil volume to support healthy trees in developed areas.
- Limited tools or infrastructure to use non-potable water to irrigate trees and landscapes.
- Limited regional planning tools to address climate hazards.

Policy and Planning Adaptation Options

The highest priority actions are in **bold**.

PLAN to adapt

1. **Coordinate and cost share between EMR municipalities when working with, and requesting new powers from, the Province of Alberta to integrate climate adaptation into policy and to advance policy tools** specifically for:
   - Harvest and re-use of grey or black water.
   - Increasing water supply storage capacity for irrigation.
   - Creating landscape-level climate refugia and conserving and adapting region-wide biodiversity.
   - Creating landscape-level wildfire fuel breaks.
   - Requiring FireSmart development in wildfire interface areas.
   - Requiring climate adaptation be considered for trees and landscapes installed with developments.
   - Protecting and growing public and private tree canopy and protecting native soil.

Spruce Grove Water Supply

Spruce Grove's Climate Resilience Express Action Plan identified many local risks associated with climate change, including for the urban forest. Of these risks, they prioritized addressing water supply shortage, freezing rain, urban flooding and thunderstorms, all of which have implications for the urban forest. The Action Plan proposed several measures to manage these climate risks, ranging from reducing water consumption with an on-going residential education program and consideration for implementation of an Outdoor Water Use Bylaw to implementing a stormwater utility fee structure to ensure the system is sustainable into the future.

2. **Integrate urban trees into asset management systems to track lifecycle costs, service levels and vulnerabilities to better inform urban forest management budgeting and decision-making.**
3. **Fund an Urban Forest Management Plan or Strategy and an Urban Forester position to guide strategic and operational urban forest management.**
4. Work together with EMR municipalities, First Nations, institutions, non-government organizations, academics and other relevant stakeholders to:
   - Prioritize the protection, acquisition and restoration of naturally moist ecosystems like springs, riparian and wetland areas that are likely to become climate refugia to house at-risk or displaced species and ecosystems, traditional food and medicinal plants.
   - Prioritize species and forest values at risk for protection.
   - Develop policies, standards, targets, monitoring and reporting frameworks for adaptation strategies.
   - Improve understanding of the equity and social planning dimensions of urban forest climate adaptation — such as prioritizing tree planting in less wealthy neighbourhoods, or where there are vulnerable populations such as seniors who would benefit most from shading and cooling — to better inform tree planting and management decisions.

RESIST extirpation

5. **Protect climate refugia that may continue to support representative forest types (i.e., lands with topographic and edaphic characteristics that will provide more reliable soil moisture).**
6. Determine the feasibility of creating 'artificial' irrigated (non-potable passive or active irrigation) reserves to preserve local native forest values of importance in the long-term.

RESILIENCE to disturbance

7. Embed measurable monitoring indicators and adaptive management into adaptation plans.
8. **Regionally compile and share data to report on indicators and track changes in key forest metrics such as tree mortality, tree health** (e.g., drought-stress), **canopy cover, leaf-out/fall and flowering dates at the regional scale and at regular intervals** (3-5 years).
9. **Plan for development and infrastructure to avoid fragmentation and improve connectivity between climate refugia at both the municipal and regional scale.**

Edmonton Green Network

The City of Edmonton has adopted Breathe: Edmonton's Green Network Strategy which provides the framework for the City's Green Network. One of the key contributions of the Green Network will be to regulate climate for the benefits of communities across the city. Together with the Ribbon of Green, the documents will guide the protection and use of environmentally sensitive areas.

10. **Develop best practices urban forest design criteria, development guidelines and standards for capital and private development projects** regarding:
    - Soil quality and volume, or irrigation to compensate for less soil.
    - Permeability and vegetative cover of the private and public realm.
    - Stormwater harvesting and storage at multiple scales including consideration of novel catchments such as connected and centralized harvesting from roofs.

TRANSITION to new normals

11. Incorporate natural asset valuation into municipal asset management programs and to build the business case for climate adaptation with natural assets.
12. **Incorporate climate adaptation strategies into all levels of provincial, regional and municipal policy planning for land use and that influence tree planting and management.**
13. **Establish a regional nursery, or alternative procurement processes and regional buying groups, that enable municipalities to influence the species, genetic material and stock quality so that there is greater access to and consistency of tree stock that is well adapted to future climate.**

Edmonton Tree Nursery

Edmonton has operated the Old Man Creek tree nursery since 1910. Currently, the Old Man Creek tree nursery grows, receives and distributes all trees, shrubs and naturalization plants used by City of Edmonton operations. On average the nursery handles 3,000 trees, 100,000 pieces of naturalization plants and over 3,500 shrubs annually. The nursery has been involved in trials aimed at expanding plant diversity as part of the Regional Woody Plant Test Project 2008 and the Prairies Trial for Rural and Urban Shade Trees.

3.2 Planting

Tree planting is a fundamental activity for sustaining and expanding a healthy urban forest. Planting trees enables restructuring of urban forest composition over time to operationally implement the adaptation of trees and forests to climate change. Edmonton municipalities are actively planting thousands of new and replacement trees every year into:

- Natural areas as part of ecosystem restoration and enhancement initiatives.
- Landscaped parks either as part of City tree planting initiatives or with development in newly built parks.
- Streets either as part of City tree planting initiatives or with development in newly built parks.

Pre-existing vulnerabilities include:

- Current climate limits diversity in species selection.
- Elm and ash dominate planted tree populations and are susceptible to serious pest and disease threats.
- Many species bring planted are susceptible to serious pest and disease threats.
- Local genotypes of native species planted in natural areas may already be maladapted to local climate.

Planting Adaptation Options

The highest priority actions are in **bold**.

PLAN to adapt

1. Develop neighbourhood-scale planting plans to replace declining species and plant new trees that maximize the climate adaptation benefits of the urban forest while reducing vulnerability through design and species selection.
2. Develop natural area restoration and enhancement plans that account for changes in the distribution of native species and the potential to introduce them to new habitats as existing habitats become unsuitable.
3. **Select species suitable for the current site and climate conditions, and that are suitable for anticipated future climate at that location; most sites will become drier without irrigation or natural groundwater and so, in general, favour drought tolerant species** (a species list with future climate suitability and other attributes is included in Appendix 1).

Devon Species Selection

The Town of Devon's 2015 Urban Forest Management Plan guides parks operations with regard to tree management and health care, risk management, and replacement guidelines. The Plan is based on four principles: to promote a healthy, diverse and sustainable urban forest in Devon, to inform and engage the community in the work of protecting and managing the urban forest, to think globally and regionally while planning and acting locally, and to use best practices, innovation, science research, information and technology. The plan identifies preferred tree species with superior genetics for park spaces and boulevards based on the microclimate in which the tree is being placed, and the proven hardiness of that species for the local climate and conditions.

RESIST extirpation

4. Maintain representation of valued species that are likely to become less suited to future climate by prioritizing their planting in urban sites that have favourable growing conditions (e.g., year round moisture availability).
5. **Focus natural area planting efforts in areas with growing season soil moisture inputs other than rainfall and avoid planting in drought-prone areas.**

RESILIENCE to disturbance

6. **Invest in larger soil volumes and irrigation in streetscapes to support large canopy trees.**
7. **Restore hydrology, permeability, soils, understory and nutrient cycling to increase water stored in urban soils.**
8. Re-align species composition and genotypes to meet expected future conditions and accept novel assemblages of native and nearby native plants.
9. **Establish suitable long-term targets for managing species and age diversity in urban tree populations** (excluding natural areas):
   - Target tree age class distribution of no more than 40% of the tree population being young (proxy less than 20 cm dbh), 30% being semi-mature (proxy 20 cm to 40 cm), 20% being mature (proxy 40 - 60 cm) and 10% being over-mature (proxy >60 cm).
   - Establish a genus-level diversity target of 20% and aspire to more ambitious targets over time as climate shifts.
10. **Maintain and enhance age, structural and species diversity in natural area forests.**
11. **Encourage nurseries to supply trees grown from seed in addition to clonal stock to promote genetic diversity.**

TRANSITION to new normals

12. **Identify and trial potentially suitable genotypes of aspen clones from drier climates.**
13. Assist changes in the distribution of regionally native species by introducing them to suitable new habitats in the region as part of restoration activities.
14. **Trial disease and pest resistant cultivars of urban trees, an non-invasive species adapted to warmer, drier climate conditions.**
15. **Establish long-term, multi-species trials across the EMR's climate gradients to test different genotypes of urban and native tree species from a range of warmer, drier climates.**
16. Use forest revegetation opportunities to realign species composition to meet expected future conditions.

EMR species list for current and future climate

This list consists of species that are commonly, or could be, planted in the EMR today and indicates those that are likely to do more or less well under future climate. It is not an exhaustive list of every species that could be planted in the region. Given that moisture is going to become more limiting and temperature less limiting for urban trees, future climate suitability is driven by drought tolerance. As a general rules, drought tolerant species should be planted more often than less drought tolerant species. Despite warmer winter temperatures, species planted today still need to tolerate present hardiness zones except in warm microclimates. Over the next ten years, the list of species to trial should be expanded to include more species hardy to zone 5 or the plant hardiness zones as updated by Natural Resources Canada. See Appendix 1 for a species list with additional attributes.

PLANT MORE ↑ ↓ PLANT LESS

SUITABLE - species anticipated to tolerate all but the driest sites under future climate (once established)

Celtis occidentalis*	Juniperus scopulorum	Pinus ponderosa
Crataegus crus-galli var inermis	Maackia amurensis	Pinus sylvestris*
Crataegus x mordenensis	Phellodendron amurense*°	Pinus uncinata
Eleagnus angustifolia*	Pinus albicaulis °	Prunus malaheb °
Fraxinus pennsylvanica*	Pinus aristata	Pyrus calleryana*
Ginkgo biloba	Pinus banksiana	Quercus alba
Gleditsia triacanthos	Pinus contorta var. latifolia	Quercus macrocarpa
Gymnocladus dioicus°	Pinus flexilis	Quercus mongolica °
Juniperus occidentalis	Pinus mugo	Quercus x warei
Juniperus sabina	Pinus nigra	Sorbus aria °

SOMETIMES SUITABLE - Species require moderately moist (no more than a few weeks of drought) or irrigated sites

Acer ginnala	Picea omorika	Pyrus ussuriensis
Acer negundo	Picea pungens	Quercus bicolor
Acer platanoides*	Pinus cembra	Quercus ellipsoidalis
Acer saccharinum	Pinus strobiformis	Quercus robur x alba
Acer tataricum*	Platanus x acerifolia	Quercus rubra
Acer x freemanii	Populus alba*	Sorbus decora
Aesculus glabra	Populus tremula	Sorbus x hybrida
Aesculus hippocastanum*	Populus x jackii	Syringa pekinesis
Alnus hirsuta	Prunus cerasifera*	Tilia americana
Amelanchier alnifolia	Prunus cerasus*	Tilia cordata
Betula platyphylla	Prunus salicina x	Tilia x flavescens
Malus baccata*	Prunus virginiana	Ulmus americana*
Picea glauca	Pseudotsuga menziesii	Ulmus pumila*

MARGINAL- species require year round soil moisture or irrigated sites

Abies balsamea	Juglans cinerea	Populus x canescens
Acer rubrum*	Larix laricina	Prunus maackii
Acer saccharum	Larix occidentalis	Prunus padus commutata
Alnus crispa	Larix sibirica	Quercus palustris*
Alnus incana	Picea abies*	Salix alba
Betula nigra	Picea mariana	Salix babylonica
Betula papyrifera*	Pinus monticola	Salix pentandra
Betula pendula*	Pinus strobus*	Sorbus americana
Fraxinus americana	Populus balsamifera	Sorbus aucuparia*
Fraxinus mandshurica	Populus deltoides	Syringa reticulata
Fraxinus nigra	Populus tremuloides	Ulmus thomasii

*Invasive potential - capable of self-seeding so avoid planting in locations where seeds can disperse and germinate

° Trial - species has the potential for introduction in the Edmonton region

General guidelines to maximize tree health and adaptation benefits

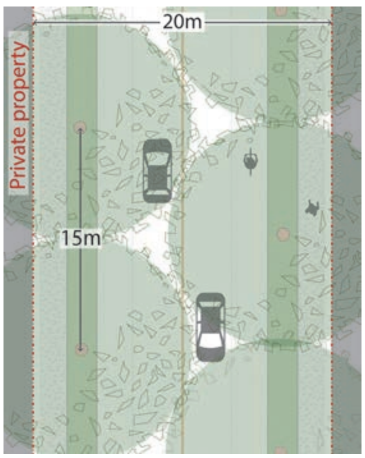
Several guidelines are highlighted below that will maximize both tree health and the climate adaptation benefits that can be provided by urban trees.

Canopy Cover

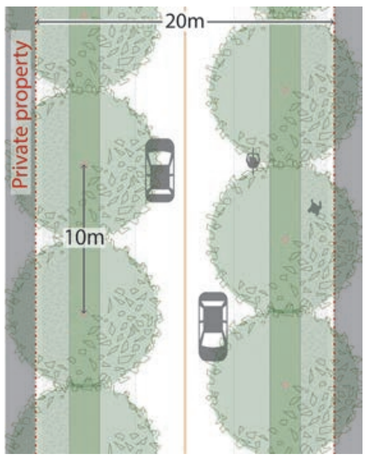
To maximize potential benefits from cooling, target a minimum of 40% canopy cover in streets and over city blocks except on arterial routes where canopy would trap vehicle pollution. Research indicates that, to get maximum cooling benefits from trees, canopy cover needs to exceed 40% (Ziter, 2019). This level of canopy cover will also increase the area for rainfall interception and storage. Achieve canopy cover targets efficiently by using large trees whenever possible because large trees provide a much greater magnitude of benefits than small trees. The efficiency of using large trees to achieve canopy cover targets in streets is illustrated below:

In this streetscape example...

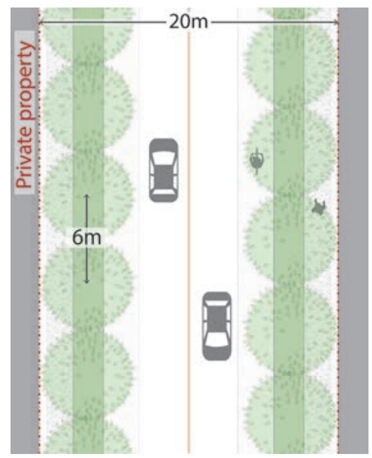
...5 large trees provide more than 80% canopy cover



...7 medium trees provide ~40% canopy cover



...11 small trees provide ~20% canopy cover



Species Selection

As a general rule, select the largest tree suitable for the planting site (based on soil volume and above ground growing space). In urban streets and plazas, select trees that:

- Are suitable as street trees.
- Have moderate to high shade density in leaf.
- Have moderate to high drought tolerance (unless the site is irrigated).
- Have low to moderate branch breakage potential.

In parks and yards, species selection is often less restricted than in streets because growing spaces are larger and less constrained. However, near buildings or other structures select species that are deciduous (less flammable) and have low wind breakage potential. Appendix 1 provides a list of species and attributes to aid species selection.

Given the risk from Dutch elm disease and emerald ash borer, avoid planting elm and ash unless they are species with proven resistance to those threats. Overall, plan to increase diversity in the tree population overall by having no single genus represent more than 20% of the tree population.

General guidelines to maximize tree health and adaptation benefits

Soil Volume and Quality

Ensure that there is adequate soil volume to provide soil moisture and growing space for trees:

- Target 0.6m^3 of soil for every 1 m^2 of crown projection (~1 m depth) (Lindsey and Bassuk, 1992). To reduce volume requirements by approximately half, connect soil volume between trees, or provide irrigation. Planting trees that are too big for the soil volume will reduce the ultimate size and life expectancy of the tree and increase root damage potential.
- Coarsely, depending on canopy width, this corresponds to soil volume of:
  - 20 to 150 m^3 for large trees (>15 m tall).
  - 15 to 70 m^3 for medium trees (10-15 m tall).
  - 5 to 35 m^3 for small trees (<10 m tall).
- Maximize permeable surfaces surrounding trees.
- Soil volume can be achieved with existing soils, bridging to adjacent soil volumes, or by using engineered solutions such as structural soils or soil cells.
- To manage soil quality, preserve healthy native soils where they exist and prevent soil compaction during construction by fencing off areas or laying down mulch or matting. If soil is already graded and compacted, consider rebuilding the soil profile using the methods described by Susan Day's "Soil Profile Rebuilding Specification" (Day, 2016)[1]. If importing or amending soils, then follow the relevant topsoil specification for your municipality.

Management

Maximize tree life expectancy:

- Ensure that trees meet Canadian Standards for Nursery Stock and are planted to best practices as published by the International Society of Arboriculture (ISA).
- Water young trees for the first 3-5 years of life and, beyond that time, supplement watering in dry periods when trees are stressed:
  - Water bags, water pods, water wells, or drip irrigation systems are efficient methods to ensure water is applied slowly and can infiltrate the soil.
  - Encourage passive water harvesting strategies by planting trees in areas that naturally receive runoff but are not frequently waterlogged. Examples include bioswales, berms, raingardens, French drains, bioretention tree pits, permeable hardscapes, and infiltration trenches.
  - In locations with a high volume irrigation requirement, use active harvesting systems to collect, store, and reuse water for spring and summer use.
- Structurally prune young trees on a 3-year cycle for the first 15 years of life.
- A mature tree pruning cycle should ideally involve inspection of trees every 5-15 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.
- Apply (preferably organic) mulch to reduce evaporation and encourage nutrient cycling.
- Protect trees with fencing during construction and have an ISA Certified Arborist consult on and supervise potentially damaging works around trees.

For helpful information to communicate to the public on tree selection and care, the ISA's treesaregood.org provides a Tree Owner's Manual and instructional brochures.

[1] https://www.urbanforestry.frec.vt.edu/SRES/

3.3 Management and Plant Health Care

Management and plant health care refers to activities such as inventory, health and risk assessment, watering, pruning, mulching, ecosystem restoration and treatments for pests and diseases. These activities are focussed on maintaining ecosystems and keeping trees in a healthy and safe condition in urban landscapes.

All EMR municipalities water young trees during establishment. Typically this involves spring and summer watering for 4-6 months for the first two, three or four years depending on the municipality. In periods of drought, watering may be extended to older trees.

Most municipalities manage their trees on a regular pruning cycle. The tree pruning cycles reported were 5 years, 6 years, 7 years or 10 years but some were coupled with 3 year cycles for elms, chokecherry and mountain ash. Most municipalities attempt to formatively prune newly planted trees at least once before age 10. Elms are pruned outside the elm bark beetle flight period.

A broad range of insects, pests and diseases are being managed or monitored. Animal damage from rabbits and beavers is also an issue. There are concerns among municipal staff about drought and the potential arrival of emerald ash borer and Dutch elm disease.

Pre-existing vulnerabilities include:

- Young tree mortality rates in landscaped parks and streets is approximately 5 to 10% in most cases and two municipalities noted mortality of 15% and 25%. In natural areas, mortality can be as high as 30 to 40%. Drought stress is the likely cause of high mortality rates in young trees.
- Numerous pest, disease and animal damage agents are active in the urban forest.
- Edmonton has the largest concentration of Dutch elm disease free American elms in the world, the beetle vectors of the disease are already present, and the disease is present in Saskatchewan.
- Ash is a significant component of the urban forest and emerald ash borer is present in Manitoba — within the City of Edmonton, almost 90,000 ash trees represent 25% of the City's tree population.
- Increases in drought-related mortality have been observed in the natural and planted urban forest.
- Potable water supply for irrigation of vegetation is limited and general demand for water is increasing.

Management and Plant Health Care Adaptation Options

The highest priority actions are in **bold**.

PLAN to adapt

1. **Develop landscape irrigation strategies to build supplemental watering networks for urban trees.**
2. **Work together with EMR municipalities, the Province of Alberta and the Canadian Food Inspection Agency to prevent, detect and control priority invasive plant and pest species that will become more competitive in a changed climate.**
3. Update integrated pest management plans to include species of greatest concern to the region's structurally dominant species (aspen, elm, ash and white spruce).
4. **Track forest health metrics such as tree mortality and cause, tree health and condition, and maintenance activity time and costs annually to identify management issues requiring correction, and to inform budgeting.**

RESIST extirpation

5. **Extend the average duration and frequency of young tree watering into late summer and the number of years for which young trees are watered to 4-5 years or as needed based on annual variation.**
6. **Slow the flow of surface water across the landscape (e.g., mimic beaver dams, create ditches and mounds etc.) so that more water infiltrates into surrounding soil and promotes vegetation diversity that will also accumulate snow.**
7. **Adjust pruning timing, firewood transport and debris management regulations as needed to prevent the spread of insects and disease** (e.g. prune elms between October and March).
8. **Train staff in tree pest and disease identification and treatment, and specifically to identify and treat Dutch elm disease and emerald ash borer, to enable rapid response when new detections occur.**
9. Fence young planted trees until they are resistant to animal browse.
10. Prevent the introduction and spread of invasive species as outlined in "Managing Invasive Species and Pests in a Changing Climate" (Diamond Head Consulting, 2019).

Leduc Weather and Climate Readiness

The City of Leduc identified water scarcity and drought as a risk to their trees and green space in their Weather and Climate Readiness Plan. The Plan identified an action to increase the watering capability, potentially with the use of gaiters or additional water trucks. The City's Water Conservation, Efficiency and Productivity Plan further defines how the City will conserve water to ensure its availability for important uses such as consumption and trees and natural areas watering.

RESILIENCE to disturbance

11. **Target 5 year preventative pruning cycles (3 years for elms) and young tree pruning at 3 year intervals for the first 15 years after planting.**
12. **Integrate passive or active irrigation (non-potable water) into urban landscapes to maintain tree health.**
13. Identify opportunities to utilize urban timber removed due to pests and disease infestation.

TRANSITION to new normals

14. **Plan for budget increases to fund increasing demand for tree planting, management and plant health care, and prepare contingency budget plans for managing a major pest outbreak** (e.g., emerald ash borer).
15. Accept eventual transition from natural forest to grassland in drier areas and focus management and plant health care efforts in locations where moisture will continue to be adequate to support trees (in the west of the region and moist, cool microclimates like those in river valleys, ravines and wetlands).
16. **Establish monitoring plots in natural forest stands across the EMR's climate gradients to detect changes in canopy mortality and regeneration rates to inform management and plant health care decisions.**

3.4 Risk Management

Municipalities and landowners need to manage risk to trees from climate hazards as well as the risk from trees to life and property from limb or whole-tree failure. To manage risk from trees, many municipalities inspect trees on an area-based cycle to assess their health and condition regularly, and to identify appropriate pruning requirements. Where a risk is suspected or identified, additional actions are generally taken to investigate, monitor and/or mitigate risk. Climate change impacts, such as drought, pest and disease attack, wildfire and extreme weather are a risk to trees and, due to direct damage or declining tree health, may also increase the risk from trees to life and property.

Pre-existing vulnerabilities include:

- Disturbance events including wildfire, extreme rainfall and flooding, tornados, severe thunderstorms and windstorms, severe winter storms and long-term droughts already periodically impact the EMR.
- Trees are already experiencing stress due to drought, pests and disease.

Risk Management Adaptation Options

The highest priority actions are in **bold**.

PLAN to adapt

1. **Develop reasonable risk inspection and mitigation standards for municipally managed trees in the vicinity of valued targets and ensure that: 1) standards are implemented operationally; and, 2) that inspection and risk mitigation actions are documented.**
2. **Develop community wildfire protection plans and post-fire restoration plans.**
3. **Implement FireSmart and support residents to do the same.**
4. **Develop extreme weather plans for community tree management to enable rapid and coordinated responses to immediate hazards, post-event clean-up and restoration.**

6. Devise a protocol for restoration with climate resilient, ecologically suited species after disturbance events and when opportunities arise in both natural areas and the urban forest.

Strathcona County FireSmart

Wildfire is a natural part of the landscape in and around Strathcona County and is best fought by preventing it. The County has a number of programs developed with FireSmart® principles to help residents reduce the risk to their property and their neighbours'. The County offers public workshops, property assessments and subdivision assistance to assist in reducing risk to wildfire. These programs identify potential hazards and fuel sources so that residents can take action to reduce these risks. FireSmart also provides residents with information on the best types of vegetation to use in their landscaping to help reduce the overall risk.

Each summer, County staff assess selected public parks in the community to identify their risk for wildfire. Residents can access an interactive map on the website that allows residents and park users to get park information, view assessments and report any fire hazards.

RESIST extirpation

7. **Inspect trees and forest edges adjacent to high value targets on a regular schedule and after major storm events.**
8. **Increase surface and soil water storage, and/or irrigation of landscapes to create wildfire refugia to protect interface areas while also supporting healthier trees.**

RESILIENCE to disturbance

9. **Reintroduce prescribed fire, thin unhealthy stands and treat hazardous vegetation fuels in the urban interface.**
10. Prune trees and alter forest structure to reduce severity or extent of wind and ice damage.
11. Restore damaged trees and disturbed sites promptly.
12. **Provide grants to private landowners to encourage private tree maintenance and FireSmart.**

TRANSITION to new normals

13. Minimize the density of roads, trails and urban interface to manage.
14. **Use species selection to minimize risk when planting near structures by selecting deciduous species with low wind breakage potential.**
15. Use revegetation opportunities to realign species composition to meet expected future conditions.

3.5 Engagement

Municipalities typically take leadership in urban tree planting and management by developing urban forest plans and policy, setting landscaping standards for development, planting trees and restoring natural areas, maintaining tree health and managing risk. However, the urban forest occurs across jurisdictional and ownership boundaries meaning that many stakeholders other than municipalities can and do play an important role in urban tree planting and management. The people who live, work, learn and play in and amongst the EMR's trees and forests can contribute essential resources, information and perspectives on adapting tree and forest management to climate change.

Community engagement through education, outreach and stewardship events offer the opportunity to improve public understanding climate change impacts and adaptation options for tree and forest management. In the case of stewardship programs, when volunteers are involved, they feel a vested interest in the success of the program and advocate for the urban forest.

Municipal staff play a key role in tree planting and management both directly if they manage trees, or indirectly if their work impacts trees. Staff are also a key source of information for members of the public with tree management questions. Interdepartmental cooperation and shared ownership for managing trees as a municipal asset is essential to protect trees and grow a resilient urban forest.

The nursery and arboriculture industry are important partners in progressing climate adaptation. Nurseries in particular play a critical role because they source and provide the tree species and stock planted throughout the region. The arboriculture industry typically provides advice and tree care to private landowners and is therefore in a position to educate and demonstrate best practices for tree planting and management on private land.

Several other organizations provide resources and support for tree planting and management, including professional organizations, non-government organizations, educational institutions and other government agencies. Keeping in touch and seeking their assistance will enable municipalities to stay current on recent technological advancements, research and practices as well as partner on projects and programs to develop region specific resources and knowledge.

Pre-existing vulnerabilities include:

- Resources within municipalities to engage and coordinate stakeholders, or participate in interdepartmental processes are typically limited.
- Public awareness of and support for urban forest climate adaptation is limited.

St. Albert Community Engagement

The City of St. Albert has a larger number of community events and programs that engage the community with trees and natural areas. These include programs such as the "Clean and Green River Fest", Naturalization Planting Events and Arbour Day. Through these events, the City of St. Albert recorded participant numbers totalling 1,300 volunteers planting a total of 3,557 native tree and shrub species over a total area of 1.66 ha (4.11 ac) in 2019.

Engagement Adaptation Options

The highest priority actions are in **bold**.

PLAN to adapt

1. **Form partnerships between EMR municipalities, First Nations, public sector organizations, institutions, academics, professional associations, the private sector and other relevant stakeholders** to:
   - Share knowledge.
   - Identify research and technology priorities.
   - Identify funding requirements, create and/or capitalize on funding opportunities.
   - Provide educational opportunities and materials to municipal staff, other agencies and the public.
   - Partner in implementing adaptation options.
2. Develop communication and engagement plans to guide messaging of and stakeholder involvement in urban forest management and climate adaptation at the municipal level.
3. **Work together with the private sector to align corporate social responsibility efforts with climate adaptation capacity building.**

RESIST extirpation

4. **Encourage private and institutional landowners on sites with favourable growing conditions to plant or maintain valued species that are likely to become less suited to future climate.**
5. **Encourage private and institutional landowners of climate refugia areas to protect and restore sites native forest.**
6. **Encourage and support private and institutional landowners to proactively maintain tree health.**

Devon Community Engagement

The Town of Devon has been engaging its community about watershed health and how they can contribute to it, including workshops where residents learn to harvest live stakes (of willow and poplar species) and re-plant them in creek beds and banks to stabilize the soil and reduce erosion caused by spring thaw, flooding and other forces. The Town's Communities in Bloom Committee is also starting a Heritage Tree program.

RESILIENCE to disturbance

7. **Educate councils, senior staff and external stakeholders about anticipated climate impacts and adaptation options.**
8. Expand professional development opportunities for relevant municipal and private sector professionals related to urban forest climate adaptation and particularly for engineered solutions to construct urban planting sites and integrate stormwater management/low impact development.
9. **Work together with First Nations to identify culturally appropriate stewardship practices for coping with climatic variability and changes in forest structure and function.**
10. **Engage residents in urban forest management planning, particularly at the neighbourhood scale, and provide learning opportunities for tree selection, planting and maintenance.**
11. **Increase awareness about wildfire risk, and encourage fuel management and prescribed burning, and community FireSmart practices on private land.**
12. **Increase awareness about emerging pest and disease threats, and provide guidance for tree health management responses on private land.**

TRANSITION to new normals

13. **Work together with the research community to identify potential sources of seed or vegetative propagules for adapting native tree species, and to monitor climate change and adaptation to inform new and improved climate adaptation options.**
14. **Work with production nurseries to increase the genetic and species diversity of trees available to plant in urban environments.**
15. Work together with NGOs, schools and community organizations to expand monitoring networks to track phenological changes in natural and urban forests.
16. **Provide public guidance for climate suitable species selection and managing diversity on private land.**

Stony Plain Community Engagement

The Town of Stony Plain updated its Environmental Stewardship Strategy in 2011 to continue providing direction for environmental priorities. One identified initiative was Arbour Day; an annual tree planting event to educate and inform residents on the importance urban forests in the community, erosion caused by spring thaw, flooding and other forces. The Town's Communities in Bloom Committee is also starting a Heritage Tree program.

4 Conclusion

Adapting urban forests to climate change

The EMR's urban forests are anticipated to change as a result of climate change. Most significantly, changes in temperatures and moisture availability are expected to drive shifts from forest to grassland ecosystems and increase drought stress in urban trees generally. In addition, disturbance due to pests, disease, wildfire and extreme weather are expected to increase. Given the important role urban forests play in the livability of cities and in supporting climate adaptation, by providing cooling, stormwater interception, carbon and biodiversity benefits, it is critical to increase the resilience of urban forests to climate change. Urban forests, as a tool for both climate mitigation and adaptation, deserve broad integration and consideration as essential infrastructure in cities.

All municipalities have pre-existing vulnerability in their tree and forest populations and can reduce vulnerability to both current challenges and the climate impacts of concern. This guide has outlined a range of adaptation options for urban forest management under the themes of policy planning, planting, management and plant health care, risk management and engagement. Given uncertainty in climate projections and scientific literature to guide climate adaptation strategies, this document and the assumptions within it should be reviewed and updated at regular intervals.

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Appendix 1 – Species List

Climate suitability of common (from EMR inventories) and trial species (from Calgary and Minnesota) based on cold hardiness and drought tolerance is ranked. Species that are 'suitable' have high drought tolerance and are tolerant to at least USDA hardiness zone 4. Species outside those parameters are 'sometimes suitable' or 'marginal' but may be supported with irrigation or favourable microclimates. Limiting future species selection entirely to drought tolerant species would greatly reduce the range of species available for planting. Additional site factors, tolerances, invasive potential and vulnerability to pests and disease are relevant to species selection and are not reflected in climate suitability.

Species		Species Tolerance					Species Characteristics			Placement	Climate Suitability	
Botanical name	Common name	Shade[1]	Drought[1]	Water-logging[1]	Branch breakage potential[2]	Salt[4]	Size Class[3] (height)	Deciduous	Shade density in leaf[2]	Suitable as street tree	USDA lower hardiness zone[2]	Future Climate Suitability
Abies balsamea	Fir, Balsam	H	L	L		L	L	No	H	No	2	Marginal
Acer tataricum*	Maple, Amur	M	M	L	M	L	S	Yes	M	Yes	3	Sometimes suitable
Acer negundo	Maple, Manitoba	M	M	Tolerant	H	M	M	Yes	H	Yes	2	Sometimes suitable
Acer platanoides*	Maple, Norway	H	M	L	M	M	L	Yes	H	Yes	4	Sometimes suitable
Acer rubrum*	Maple, Red	M	L	Tolerant	H	L	L	Yes	M	Yes	3	Marginal
Acer saccharinum	Maple, Silver	H	M	Tolerant	H	L	L	Yes	M	Yes	3	Sometimes suitable
Acer saccharum	Maple, Sugar	H	L	L	L		L	Yes	H	Yes	3	Marginal
Acer x freemanii	Maple, Red "Freeman"	M	M		H		L	Yes	M	Yes	4	Sometimes suitable
Aesculus glabra	Ohio Buckeye	M	M	L			M	Yes	H	Yes	3	Sometimes suitable
Aesculus hippocastanum*	Horsechestnut	M	M	L		M	L	Yes	H	Yes	4	Sometimes suitable
Alnus crispa	Alder, Green	L	L				S	Yes	H	No	4	Marginal
Alnus hirsuta	Alder, Manchurian	L	M	Tolerant			M	Yes	H	No	3	Sometimes suitable
Alnus incana	Alder, speckled	L	L	Tolerant		L	M	Yes	H	No	2	Marginal
Amelanchier alnifolia	Saskatoon, Tree Form	M	M	L			S	Yes	M	No	4	Sometimes suitable
Betula nigra	Birch, River	L	L	Tolerant	M	L	M	Yes	M	No	4	Marginal
Betula papyrifera*	Birch, Paper	L	L	L	H	L	L	Yes	M	No	3	Marginal
Betula pendula*	Birch, Weeping	L	L	L	M	L	L	Yes	L	No	2	Marginal
Betula platyphylla	Birch, Dakota Pinnacle	L	M	L		L	L	Yes	M	No	4	Sometimes suitable
Celtis occidentalis*	Hackberry	M	H	Tolerant	M		M	Yes	H	Yes	3	Suitable

Rows colour-coded by future climate suitability: Green = Suitable, Orange = Sometimes suitable, Red = Marginal.
* Invasive potential – capable of self-seeding therefore avoid planting in locations where seeds can disperse and germinate into natural areas.
[1] Data primarily from Niinements and Valladares (2006) or UFEI Selectree https://selectree.calpoly.edu/ L = low, M = Medium, H = High, Blanks = Unknown.
[2] Data primarily from UFEI Selectree https://selectree.calpoly.edu/ L = low, M = Medium, H = High, Blanks = Unknown.
[3]Tree height and recommended soil volume: S = Small (<8 m; 15–30 m^3 soil per tree), M = Medium (8-12 m; 20–70 m^3 soil per tree), H = High (>12 m; 45–150 m^3 soil per tree)
[4] Data primarily from Wentz (2001), L = low, M = Medium, H = High

Species		Species Tolerance					Species Characteristics			Placement	Climate Suitability	
Botanical name	Common name	Shade[1]	Drought[1]	Water-logging[1]	Branch breakage potential[2]	Salt[4]	Size Class[3] (height)	Deciduous	Shade density in leaf[2]	Suitable as street tree	USDA lower hardiness zone[2]	Future Climate Suitability
Crataegus crus-galli var inermis	Hawthorn, Thornless	L	H			M	M	Yes	M	Yes	4	Suitable
Crataegus x mordenensis	Hawthorn, Morden	M	H		L	M	M	Yes	M	Yes	4	Suitable
Eleagnus angustifolia	Russian Olive		H			H	S	Yes	H	Yes	2	Suitable
Fraxinus americana	Ash, White	L	L	Tolerant	M	L	M	Yes	M	Yes	4	Marginal
Fraxinus mandshurica	Ash, Manchurian	M	L	Tolerant			M	Yes	H	Yes	2	Marginal
Fraxinus nigra	Ash, Black	M	L	Tolerant			L	Yes	M	Yes	2	Marginal
Fraxinus pennsylvanica*	Ash, Green	M	H	Tolerant	H	M	L	Yes	H	Yes	2	Suitable
Ginkgo biloba	Gingko Biloba	L	H	L	L		M	Yes	M	Yes	4	Suitable
Gleditsia triacanthos	Honeylocust	L	H	Tolerant	M		M	Yes	L	Yes	3	Suitable
Gymnocladus dioicus	Coffee Tree, Kentucky	M	H		L		M	Yes	M	Yes	3	Suitable - trial
Juglans cinerea	Butternut	L	L	L	L		M	Yes	M	No	2	Marginal
Juniperus occidentalis	Juniper, Western	L	H	L			M	No	H	No	4	Suitable
Juniperus sabina	Juniper, Arcadia	L	H	L			S	No	H	No	3	Suitable
Juniperus scopulorum	Juniper, Rocky Mountain	L	H	L			M	No	H	No	4	Suitable
Larix laricina	Larch, American	L	L	Tolerant			L	Yes	M	No	2	Marginal
Larix occidentalis	Larch, Western	L	L	L			L	Yes	M	No	2	Marginal
Larix sibirica	Larch, Siberian	L	L	L			L	Yes	M	No	2	Marginal
Maackia amurensis	Maackia, Amur	L	H		M		S	Yes	H	Yes	3	Suitable
Malus baccata*	Crabapple, Siberian	M	M			M	M	Yes	H	Yes	3	Sometimes suitable
Phellodendron amurense*	Cork Tree, Amur	L	H	L	M	M	M	Yes	H	Yes	3	Suitable - trial
Picea abies*	Spruce, Norway	H	L	L	M	L	L	No	H	No	2	Marginal
Picea glauca	Spruce, White	H	M	L	M	M	L	No	H	No	3	Sometimes suitable
Picea mariana	Spruce, Black	H	L	L			M	No	H	No	3	Marginal
Picea omorika	Spruce, Serbian	H	M	L	M		M	No	H	No	4	Sometimes suitable
Picea pungens	Spruce, Blue/Colorado	H	M	L	M	L	L	No	H	No	3	Sometimes suitable
Pinus albicaulis	Pine, Whitebark	H	L	L			M	No	M	No	4	Suitable - trial
Pinus aristata	Pine, Bristlecone	L	H	L			S	No	M	No	4	Suitable

Rows colour-coded by future climate suitability: Green = Suitable, Orange = Sometimes suitable, Red = Marginal.

* Invasive potential – capable of self-seeding therefore avoid planting in locations where seeds can disperse and germinate into natural areas.

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[2] Data primarily from UFEI Selectree https://selectree.calpoly.edu/ L = low, M = Medium, H = High, Blanks = Unknown.

[3] Tree height and recommended soil volume: S = Small (<8 m; 15–30 m^3 soil per tree), M = Medium (8-12 m; 20–70 m^3 soil per tree), H = High (>12 m; 45–150 m^3 soil per tree)

[4] Data primarily from Wentz (2001), L = low, M = Medium, H = High

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Botanical name	Common name	Shade[1]	Drought[1]	Water-logging[1]	Branch breakage potential[2]	Salt[4]	Size Class[3] (height)	Deciduous	Shade density in leaf[2]	Suitable as street tree	USDA lower hardiness zone[2]	Future Climate Suitability
Pinus banksiana	Pine, Jack	L	H	L	M		M	No	H	No	2	Suitable
Pinus cembra	Pine, Swiss Stone	M	M	L			M	No	H	No	4	Sometimes suitable
Pinus contorta latifolia	Pine, Lodgepole	L	H	Tolerant			L	No	M	No	3	Suitable
Pinus flexilis	Pine, Limber	L	H	L	M		L	No	M	No	4	Suitable
Pinus monticola	Pine, Western White	M	L	L	M		L	No	M	No	4	Marginal
Pinus mugo	Pine, Mugo	L	H	L		M	S	No	H	No	2	Suitable
Pinus nigra	Pine, Austrian	L	H	L	M		L	No	H	No	4	Suitable
Pinus ponderosa	Pine, Ponderosa	L	H	L	L	M	L	No	H	No	3	Suitable
Pinus strobiformis	Pine, Southwestern White	L	M	L			L	No	M	No		Sometimes suitable
Pinus strobus*	Pine, Eastern White	M	L	L	H	L	L	No	M	No	3	Marginal
Pinus sylvestris*	Pine, Scots	L	H	Tolerant	M		L	No	H	No	2	Suitable
Pinus uncinata	Pine, Mountain	L	H	L			L	No	M	No	2	Suitable
Platanus x acerifolia	Plane, London	M	M	Tolerant			L	Yes	M	Yes	5	Sometimes suitable
Populus alba*	Poplar, Silver	L	M	L	H		L	Yes	M	No	3	Sometimes suitable
Populus balsamifera	Poplar, Balsam	L	L	Tolerant	H	M	L	Yes	M	No	2	Marginal
Populus deltoides	Poplar, Cottonwood	L	L	Tolerant		L	L	Yes	H	No	3	Marginal
Populus tremula	Aspen, Swedish Columnar	L	M	L		L	M	Yes	M	Yes	2	Sometimes suitable
Populus tremuloides	Aspen, Trembling	L	L	L	H	M	M	Yes	M	No	1	Marginal
Populus x canescens	Poplar, Grey	M	L			M	L	Yes	M	Yes	2	Marginal
Populus x jackii	Poplar, Northwest					M	L	Yes	M	Yes		Sometimes suitable
Prunus cerasifera*	Plum, Cherry	L	M	L	M		S	Yes	H	Yes	4	Sometimes suitable
Prunus cerasus*	Cherry, Sour	M	M	L			M	Yes	M	Yes	4	Sometimes suitable
Prunus maackii	Cherry, Amur	L	L	L			S	Yes	M	Yes	3	Marginal
Prunus mahaleb	Cherry, Mahaleb	L	H	L			S	Yes	L	No	4	Suitable - trial
Prunus padus commutata	Plum, Mayday	M	L			M	S	Yes	M	Yes	3	Marginal
Prunus salicina x	Plum, hybrid	L	M				S	Yes	M	No	3	Sometimes suitable
Prunus virginiana*	Chokecherry	M	M	L	M	L	S	Yes	M	Yes	3	Sometimes suitable
Pseudotsuga menziesii	Douglas-fir	M	M	L	L	L	L	No	M	No	3	Sometimes suitable

Rows colour-coded by future climate suitability: Green = Suitable, Orange = Sometimes suitable, Red = Marginal.

* Invasive potential – capable of self-seeding therefore avoid planting in locations where seeds can disperse and germinate into natural areas.

[1] Data primarily from Niinements and Valladares (2006) or UFEI Selectree https://selectree.calpoly.edu/ L = low, M = Medium, H = High, Blanks = Unknown.

[2] Data primarily from UFEI Selectree https://selectree.calpoly.edu/ L = low, M = Medium, H = High, Blanks = Unknown.

[3] Tree height and recommended soil volume: S = Small (<8 m; 15–30 m^3 soil per tree), M = Medium (8-12 m; 20–70 m^3 soil per tree), H = High (>12 m; 45–150 m^3 soil per tree)

[4] Data primarily from Wentz (2001), L = low, M = Medium, H = High

Species		Species Tolerance					Species Characteristics			Placement	Climate Suitability	
Botanical name	Common name	Shade[1]	Drought[1]	Water-logging[1]	Branch breakage potential[2]	Salt[4]	Size Class[3] (height)	Deciduous	Shade density in leaf[2]	Suitable as street tree	USDA lower hardiness zone[2]	Future Climate Suitability
Pyrus calleryana*	Pear, Glen's Form	L	H	L	M		S	Yes	M	Yes	4	Suitable
Pyrus ussuriensis	Pear, Ussurian	L	M	L			M	Yes	M	Yes	3	Sometimes suitable
Quercus alba	Oak, White	M	H	L	L	M	L	Yes	M	Yes	3	Suitable
Quercus bicolor	Oak, Swamp White	M	M	Tolerant	M		L	Yes	M	Yes	4	Sometimes suitable
Quercus ellipsoidalis	Oak, Northern Pin		M				L	Yes	H	Yes	3	Sometimes suitable
Quercus macrocarpa	Oak, Bur	M	H	L	L	M	L	Yes	H	Yes	3	Suitable
Quercus mongolica	Oak, Mongolian		H				M	Yes	H	Yes	3	Suitable - trial
Quercus palustris*	Oak, Pin	L	L	Tolerant	L		L	Yes	H	Yes	4	Marginal
Quercus robur x alba	Oak, Crimson Spire	L	M			M	M	Yes	H	Yes	5	Sometimes suitable
Quercus rubra	Oak, Red	M	M	L	L	M	L	Yes	H	Yes	3	Sometimes suitable
Quercus x warei	Oak, Kindred Spirit		H				M	Yes	H	Yes	4	Suitable
Salix alba	Willow, Golden	L	L	Tolerant			L	Yes	H	No	2	Marginal
Salix babylonica	Willow, Weeping	L	L	Tolerant	H		L	Yes	H	No		Marginal
Salix pentandra	Willow, Laurel Leaf	L	L	Tolerant		M	L	Yes	H	Yes	3	Marginal
Sorbus americana	Mountain Ash, American	M	L	L		M	M	Yes	H	Yes	3	Marginal
Sorbus aria	Beam, White	M	H	L			M	Yes	H	Yes	4	Suitable - trial
Sorbus aucuparia*	Mountain Ash, European	M	L	L	M		M	Yes	H	No	4	Marginal
Sorbus decora	Mountain Ash, Showy		M				M	Yes	H	Yes	2	Sometimes suitable
Sorbus x hybrida	Mountain Ash, Oakleaf		M				S	Yes	H	Yes		Sometimes suitable
Syringa pekinesis	Lilac, Peking		M			M	S	Yes	M	Yes	4	Sometimes suitable
Syringa reticulata	Lilac, Japanese Tree	L	L	L	M	M	S	Yes	M	Yes	3	Marginal
Tilia americana	Linden, American	H	M	L	M	L	L	Yes	H	Yes	3	Sometimes suitable
Tilia cordata	Linden, Littleleaf	H	M	L	M	L	M	Yes	H	Yes	4	Sometimes suitable
Tilia x flavescens	Linden, Dropmore		M				M	Yes	H	Yes		Sometimes suitable
Ulmus americana*	Elm, American	M	M	L	H	M	L	Yes	H	Yes	2	Sometimes suitable
Ulmus pumila*	Elm, Siberian	M	M	L	H	M	L	Yes	M	Yes	3	Sometimes suitable
Ulmus thomasii	Elm, Rock	M	L	L			L	Yes	M	No	1	Marginal

Rows colour-coded by future climate suitability: Green = Suitable, Orange = Sometimes suitable, Red = Marginal.
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