Invasive Species and Pest Vulnerability Study: Edmonton Metropolitan Region

July 29, 2019

All One Sky Foundation

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Acknowledgement:

This report was produced through the Climate Resilience Exchange project led by All One Sky Foundation, and delivered through the Municipalities for Climate Innovation Program, a program of the Federation of Canadian Municipalities with funding provided by the Government of Canada.

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Recommended Citation

Diamond Head Consulting (2019). Invasive Species and Pest Vulnerability Study – Edmonton Metropolitan Region. Consultant Report prepared for All One Sky, Calgary, AB

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1.0 Executive Summary

Municipalities in the Edmonton Metropolitan Region (EMR) want to improve their understanding of the region's vulnerability to invasive species and pests as a result of climate change, and how they might adapt their management practices to improve resiliency. Diamond Head Consulting (DHC) was contracted to research and report on these vulnerabilities (Phase 1) and recommend options for management (Phase 2). This report summarizes how invasive species and pests are likely to respond to climate change in the region and represents the completion of Phase 1 of the project.

Invasive species and pests pose a wide range of negative social, ecological and economic impacts to the region. To assess the region's vulnerability to invasive species and pests under climate change, DHC acquired and prepared climate projections for key variables that influence invasive species and pest growth and survival, including mean and minimum annual and seasonal temperatures, seasonal precipitation, and growing degree-days. Under all modelled scenarios, the climate of the region is projected to become warmer, particularly in the winter, have longer growing seasons, and have potential but uncertain changes in the frequency and duration of extreme weather events.

With these expected climate conditions in mind, DHC conducted a literature review to understand how invasive plants, animals, insect pests and plant diseases are expected to react. Most invasive species and pests have characteristics that facilitate rapid shifts and traits that favour them in a changing environment (e.g. large geographic ranges, broad climatic tolerances, short juvenile periods, long-distance dispersal mechanisms, and growth strategies and genetic variability that enable them to adapt to new conditions faster than native species). Human facilitated dispersal will remain the primary driver of introduction and spread. However, climate change will increase the potential for introduction of new species, increase the abundance and distribution of existing species, and alter the effectiveness of control strategies.

Although changing climatic conditions may harm certain invasive species and pests in specific circumstances, the overwhelming trend is expected that warming will remove climatic barriers previously inhibiting growth or survival, that slow and sudden onset climate impacts will provide new and more frequent opportunities to establish and spread, and that native species are less likely to be able to adapt as quickly as non-native, invasive species.

To understand the region's current invasive species and pests of concern, municipal staff were surveyed, and existing Integrated Pest Management Plans were reviewed in order to compile a list (Tables 3 - 6). To understand which invasive species and pests may be of concern to the region in the future, the current high risk/high priority species of neighbouring jurisdictions were compiled along with those of the regions of Edmonton's future climate analogues cities (Calgary, Fargo, ND, and St Cloud and Alexandria, MN). The list was then narrowed down to only include species for which habitat types exist in Edmonton and for which there would be negative impacts on the region (Tables 3 - 6).

Recommendations for management are detailed in a separate report (Phase 2 report).

2.0 Introduction

This report is focused on defining vulnerability within the Edmonton Metropolitan Region (EMR) to invasive species and pests as a result of climate change.

In 2018, municipalities in the EMR and the All One Sky Foundation, with support from the Federation of Canadian Municipalities (FCM) and Edmonton Community Foundation (ECF), cooperated to establish the *Climate Resilience Exchange*. The exchange is a forum to identify and execute coordinated actions to reduce regional vulnerability to climate change impacts. The framework for this effort is the *Edmonton Metropolitan Region Climate Resilience Exchange: State of Knowledge Summary* (State of Knowledge report) (All One Sky Foundation, 2018). Municipalities included in the EMR are 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.

The State of Knowledge report provided an overview of EMR climate resilience actions currently in place and identified coordinated actions to increase climate resilience. These actions were further workshopped and prioritized with EMR municipalities to develop a list of potential projects for coordinated climate resilience action. One of the projects identified as a priority to reduce regional vulnerability was an analysis of how climate change will affect invasive species and pest populations in the EMR and resulting management implications.

2.1 Project Purpose and Scope

Purpose

The goal of this project is to identify the current and future effects of climate change on the number and types of invasive species and pests in the EMR and to provide actionable recommendations for municipalities. As noted in the State of Knowledge Report, climate related impacts that are both sudden-onset and slow-onset are of interest. Sudden-onset impacts like flooding, freezing rain and wildfire, often already occur in the region but their frequency, intensity, duration, and distribution may change. Slow-onset impacts by contrast are a direct result of climate change and will result in gradual but persistent shifts in climate, such as shifts in mean annual temperature, growing season, and so on.

Ultimately, the project will deliver the Foundation and partner municipalities with reporting and guidance to establish a collective regional understanding and a coordinated response to better manage invasive species and pests in a changing climate. The recommendations will include best practices as they pertain to prevention and control of invasive species and pests. This report summarizing the EMR's vulnerability to invasive species and pests under climate change represents Phase 1 of the project. Phase 2 provides management recommendations.

Scope

The project scope includes invasive species and pests; specifically, terrestrial and aquatic invasive plants and animals, insect pests, and plant diseases that represent current or potential future concerns for the EMR. Species are limited to those already existing in North America.

For the purposes of this project, the following definitions apply:

- Invasive species as those that are introduced out of their natural range and exert substantial negative ecological, economic, and/or public health impacts in the region.
- Pests are native insects or plant diseases for which climate change may trigger range expansions and outbreaks unprecedented in scale and harm.

Native species that are considered urban "nuisance" pests have been excluded (e.g. ants, wasps, mice, voles, deer, beavers, coyotes, magpies, etc.). These species are integral components of the local ecosystem even though their existence may be deemed a nuisance to humans in the urban environment. They are as likely as any organism to be impacted by climate change; however, they are best addressed through a separate study into the impacts of climate change on native species and ecosystems.

This project offers an opportunity to improve understanding of which invasive species and pests are likely to be of concern in the EMR and to define actions that can be taken to reduce potential negative impacts.

2.2 Project Approach

Phase 1 -Vulnerability Study

This document represents the findings of Phase 1. It provides the following:

1. A review of relevant background policy and research documents, and a survey of municipal staff. These were used to develop an overview of the current state of invasive species and pest management in the EMR;
2. A review of climate projections and additional climate modelling to define future climate and climate impacts.
3. A literature review to identify likely climate related impacts, vulnerability, and risk in the EMR for:
    a. Invasive plants;
    b. Invasive animals;
    c. Insect pests; and
    d. Plant diseases.
4. Identification of current and future invasive species and pests of concern in the EMR.
5. A summary of recommendations for management to address in Phase 2, provided in the conclusion of the report.

Phase 2 – Recommendations for Management

Phase 2 of the project provides recommendations for how municipalities in the EMR can better manage invasive species and pests to address the vulnerabilities identified in Phase 1. The Phase 2 report is a separate report.

3.0 Overview of Current Invasive Species and Pest Management in the EMR

3.1 Known Impacts

Invasive species and pests in the EMR have numerous ecological, social, and economic impacts. Based on the species currently present in the EMR, known impacts can be summarized as follows (arguable many of the impacts fall into multiple categories):

SOCIAL IMPACTS	ECOLOGICAL IMPACTS	ECONOMIC IMPACTS
• Pose health and safety risks for humans and domestic animals • Damage or diminish urban tree canopy • Impede recreation access for aquatic activities • Alter and degrade valued landscapes and view corridors	• Reduce biodiversity and alter ecosystem function • Reduce wildlife habitat and forage • Increase vulnerability of species at risk • Increase wildfire risk • Increase risk of soil erosion	• Damage critical infrastructure (e.g. drainage systems, roads, building foundations, etc.) • Degrade and diminish productive agricultural land • Increase maintenance costs • Reduce property values

3.2 Staff Survey

DHC administered an online survey to better understand the current knowledge and practices for invasive species management in the EMR. The survey was constructed using the Survey Monkey web application. The target respondents were identified as staff in environment, public works, parks, and related departments at the member municipalities of the EMR. Invitations to complete the survey were sent via email to staff on March 11, 2019.

In total, 37 responses were collected from all partner municipalities. Respondents come from city departments in several areas including Forestry, Planning and Development, Citizen Services, City Operations, Public Works, Engineering, Environment, and Transportation. Respondents typically hold jobs as technicians, environmental coordinators, supervisors, analysts, and managers. A table summarizing the results for each jurisdiction by question is provided in Appendix 2. A summary of key findings is included below:

Species of Concern

Municipal staff listed over 70 individual invasive plants, animals, insect pests, and plant diseases when polled about the top invasive species and pests of concern in their jurisdiction (Figures 1-4). The figures summarize results as one vote per species per municipality. Some of the species listed haven't yet been detected in the region (e.g. Dutch elm disease, zebra and quagga mussels, etc.) or are new introductions that are still relatively rare (e.g. knotweed species, common reed, etc.). Other species are native species deemed to be nuisance pests whose vulnerability to climate change is outside of the scope of this project (e.g. squirrels, gophers, raccoons, etc.).

The information provided by survey respondents was used as a starting point to pinpoint the top invasive species and pests currently of concern in the EMR.

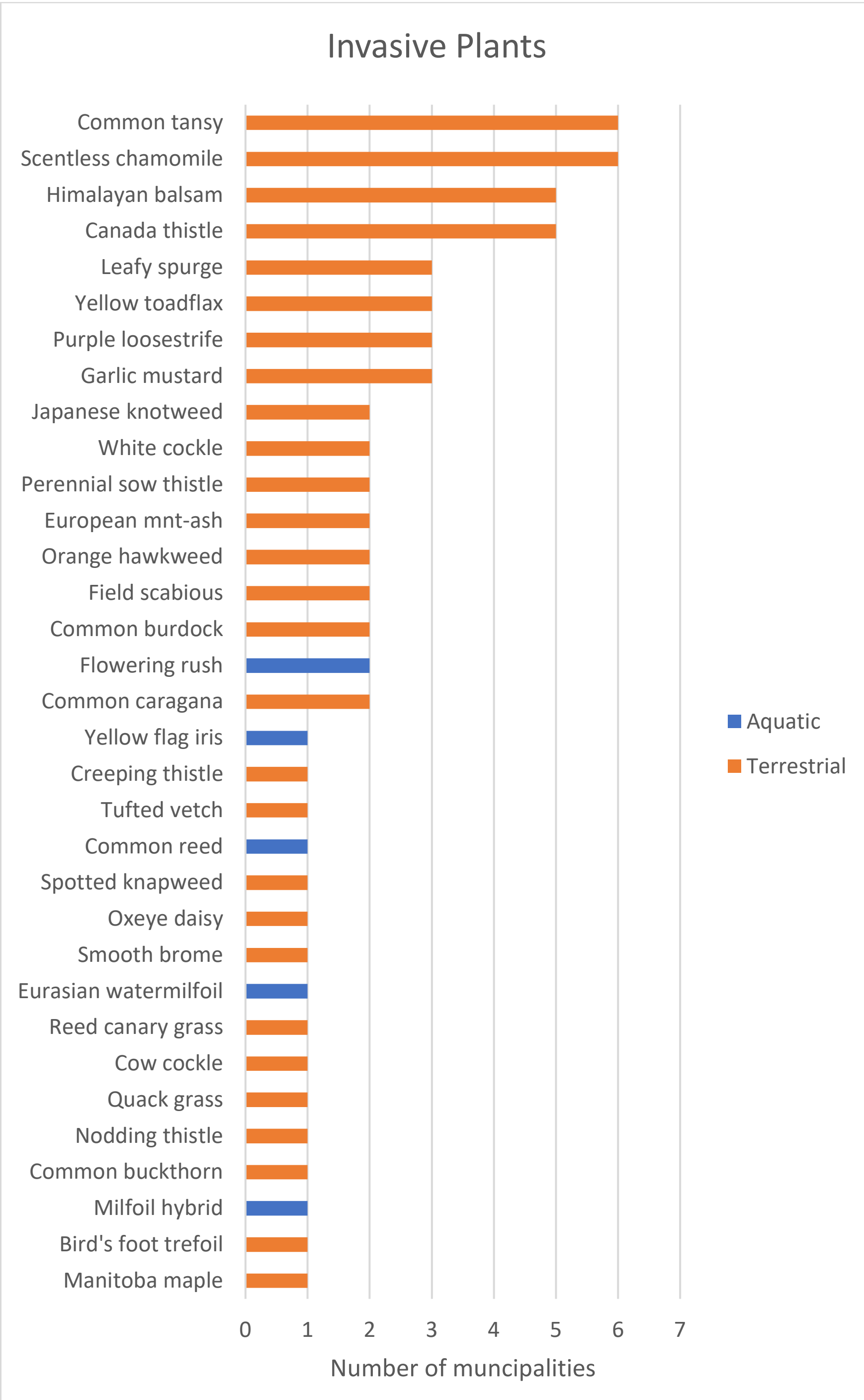

Figure 1. Survey response: Invasive plants of concern in the EMR.

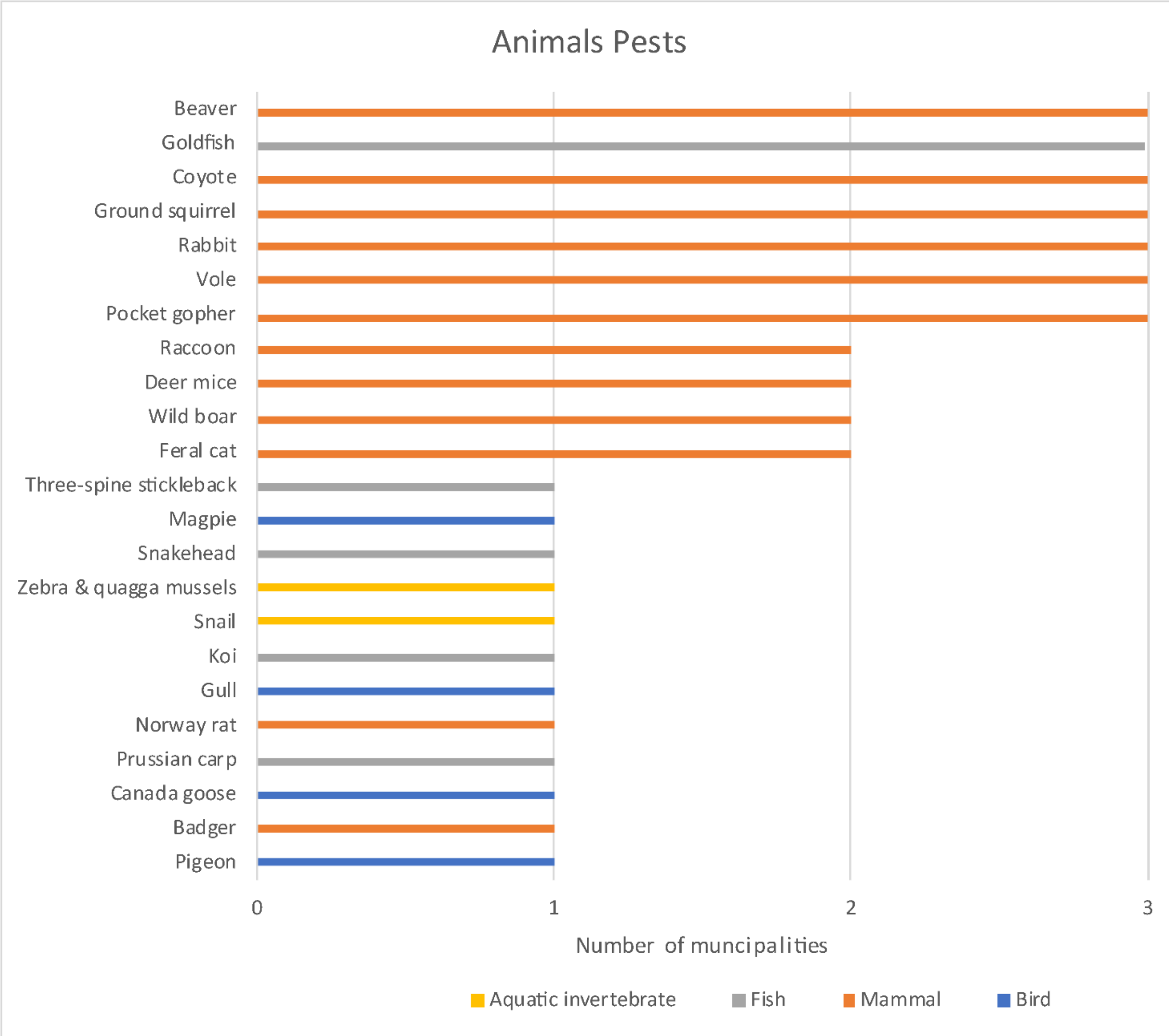

Figure 2. Survey response: Animal pests of concern in the EMR (includes many native species).

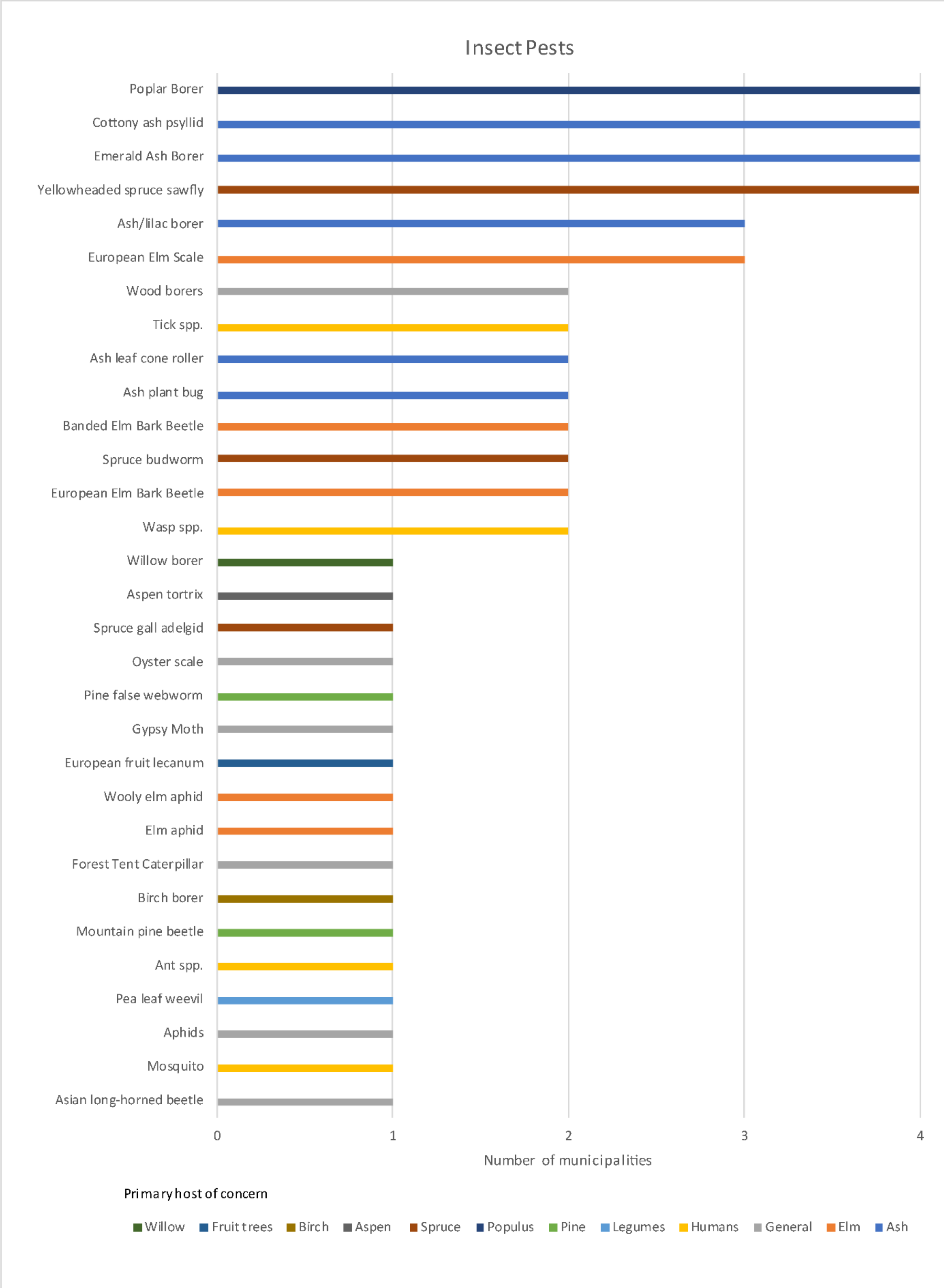

Figure 3. Survey response: Insect pests of concern in the EMR.

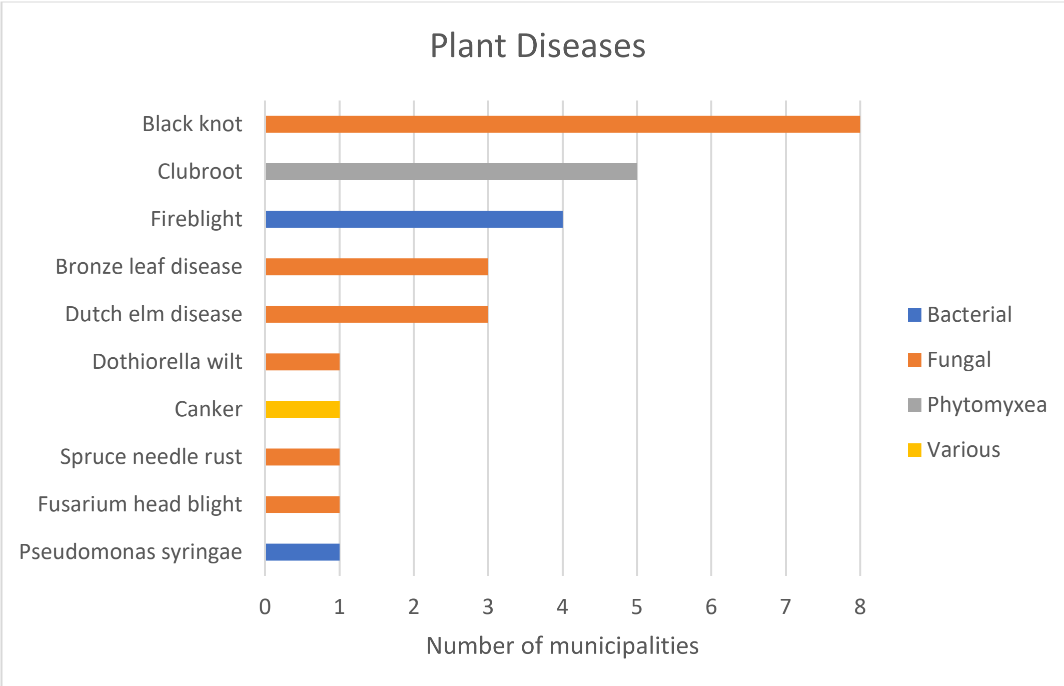

Figure 4. Survey response: Plant diseases of concern in the EMR.

Who manages invasive species and pests?

The responsibility for managing invasive species and pests varies among EMR municipalities. In most municipalities the management is with either the parks, public works, or environment departments, or a combination thereof. In some cases, the city operations, engineering, urban forestry, citizen services, and agricultural services departments are also involved. Several municipalities have dedicated Integrated Pest Management teams.

Municipal staff and contractors, and in a few cases community groups, all play active roles in the control of invasive species and pests. Staff are commonly responsible for monitoring, surveillance, and control of invasive species and pests on public land. Contractors do control work on private lands and are sometimes used for large-scale control involving pesticides and biocontrol, for specialized work and consults on specific issues, and for pest control. The involvement of volunteers and stewardship groups is typically restricted to weed pulls.

Regulations and by-laws

All municipalities regulate invasive species and pest control to some degree through the provincial *Weed Control Act*, the *Agricultural Pest Act* and/or municipal bylaws (e.g. Community Standards by-law, Dutch Elm Disease by-law, Unsightly Property by-law, etc.). Many have designated weed inspectors or bylaw enforcement officers responsible for enforcement of the *Weed Control Act*. Some municipalities have pesticide by-laws that dictate the circumstances under which pesticides can be used to control invasive species and pests.

Invasive species and pest inventory data

Most municipalities have inventory data related to invasive species and pests. This is generally through internal databases or mapping platforms. Many only track a few specific species and/or only track at control or weed notice sites. The City of Edmonton uses EDDMapS Alberta to map regulated weed populations in natural areas. Several cities track elm bark beetle data in cooperation with the City of Edmonton.

Training

Most municipalities either provide annual pest management training for staff and/or send staff to relevant conferences, courses, and training. Training includes weed identification, critical pest training, and IPM orientations and workshops. The Alberta Invasive Species Council, Alberta Environment and Parks, Arboriculture Canada, and Olds College were all mentioned as providers of training or workshops.

Collaboration

The City of Leduc coordinates regional integrated pest management meetings twice annually to share information and promote coordinated efforts between the EMR municipalities.

Most municipalities collaborate with other organizations or government agencies (e.g. Alberta Invasive Species Council, province of Alberta, Canadian Food Inspection Agency, etc.) and/or participate in provincial or federal programs (e.g. StopDED).

Summary

All municipalities in the EMR have resources dedicated to managing invasive species and pests. In most municipalities the responsibility of managing invasive species and pests only falls under the jurisdiction of the parks departments. Management is guided by an Integrated Pest Management Plans in four of the municipalities. There is wide variation in the type and number of species managed by municipalities; however there are a core group of species that were mentioned as top concerns by most (i.e. Dutch elm disease, black knot, elm bark beetles, elm scale, Prussian carp and other goldfish, Canada thistle, common tansy, and Himalayan balsam). There is also wide variation in which species are inventoried or tracked. Invasive species and pest training are provided or received by most municipalities to some degree; most have staff attend IPM workshops or conferences, and some initiate public outreach/education events. The majority collaborate with various invasive species and pest organizations and government agencies; for the majority, that includes the Alberta Invasive Species Council and the StopDED program. Most participate in the biannual regional integrated pest management meetings.

3.3 Summary of Relevant Policy and Planning Documents and Programs

A more detailed review of EMR policy and planning documents will form part of the work for Phase 2. Appendix 2 provides a preliminary list of the policies and planning documents that EMR municipalities currently use to guide their invasive species and pest management activities. Most municipalities have Integrated Pest Management Plans or policy that guides the management of invasive species and pests.

4.0 How Climate is Changing in the EMR

In order to describe the effects of climate change on invasive species and pests in the EMR, DHC reviewed recent literature and conducted an analysis of climate projection data. The literature review focused on publicly available reports on the current climate and projected impacts of climate change to the EMR, the province of Alberta, and the Canadian Prairies as a whole. The climate projection analysis primarily uses data output from the ClimateNA software (Wang, Hamann, Spittlehouse, & Carroll, 2016), which can export past and modeled future climate data for cities throughout North America. The following sections summarize current climate and observed trends, describe how Edmonton's future climate is projected to change, and the broad climate impacts resulting from those changes.

4.1 Current Climate and Observed Trends

Climate is principally driven by long term trends of temperature and moisture. It is well established that the EMR has a relatively dry, continental climate characterized by cold winters and cool summers (Powell, 1978). Table 1 describes the 1961-1990 baseline for several annual climate variables of interest for vegetation growth in the EMR, using Edmonton as the central point in the region. These variables are also compared for several other cities. Edmonton's Mean Annual Temperature (MAT) of 2.3°C is cool relative to selected comparison cities. Edmonton's Mean Annual Precipitation (MAP) of 464 mm is higher than Calgary's MAP of 409 mm, but lower than comparison cities to the south and east.

Table 1. Climate variable values for Edmonton's historical baseline period of 1961-1990 and selected comparison cities in Canada and the U.S.

Scenario	*Mean annual temperature (MAT) °C*	*Mean annual precipitation (MAP) mm*	*Precipitation as Snow (PAS) mm*	*Extreme minimum temperature (EMT) °C*	*Extreme maximum temperature (EXT) °C*	*Hargreaves reference evaporation (Eref) mm*	*Degree-days above 5°C/growing degree-days (DD5)*	*Hargreaves Climatic Moisture Deficit (CMD) mm*
Edmonton Baseline (1961-1990)	**2.3**	**464**	**101**	**-45.3**	**34.5**	**567**	**1429**	**198**
Calgary (1961-1990)	3.6	409	80	-42.4	34.6	597	1360	266
Winnipeg, MB (1961-1990)	2.1	519	117	-44	38.7	628	1704	215
Fargo, ND (1961-1990)	4.9	548	86	-40.9	40.8	721	2124	271
Alexandria, MN (1961-1990)	5.2	639	100	-39.9	39.6	696	2123	185
Ottawa, ON (1961-1990)	5.7	855	232	-37.1	37.1	684	2025	173

Within the EMR, gradients of temperature and precipitation from east to west result in the west being slightly warmer but substantially wetter (Figure 5). As a result of lower rainfall, the eastern half of the EMR has a higher climatic moisture deficit despite being slightly cooler (Figure 5). Combining evaporation rates and precipitation provides more information about the moisture available for vegetation growth and the persistence of certain species. ClimateNA includes a variable for climatic moisture deficit (CMD) (Figure 5), the difference between monthly evaporation calculated based on Hargreaves reference evaporation rate

(Eref) and monthly precipitation calculated over the year, which 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). The CMD accumulates for months with a moisture deficit, when Eref is less than precipitation (moisture is surplus), the month counts as zero. A similar metric commonly used to report vegetation shifts is climatic moisture index (CMI), which is also the monthly difference between evaporation and precipitation but evaporation is calculated using a simplified Penman-Monteith equation (Hogg E. , 1997; Schneider, 2013). Values for CMI are positive when precipitation exceeds evaporation and negative when there is a moisture deficit and so, when summed over the year, reflect the net moisture surplus or deficit.

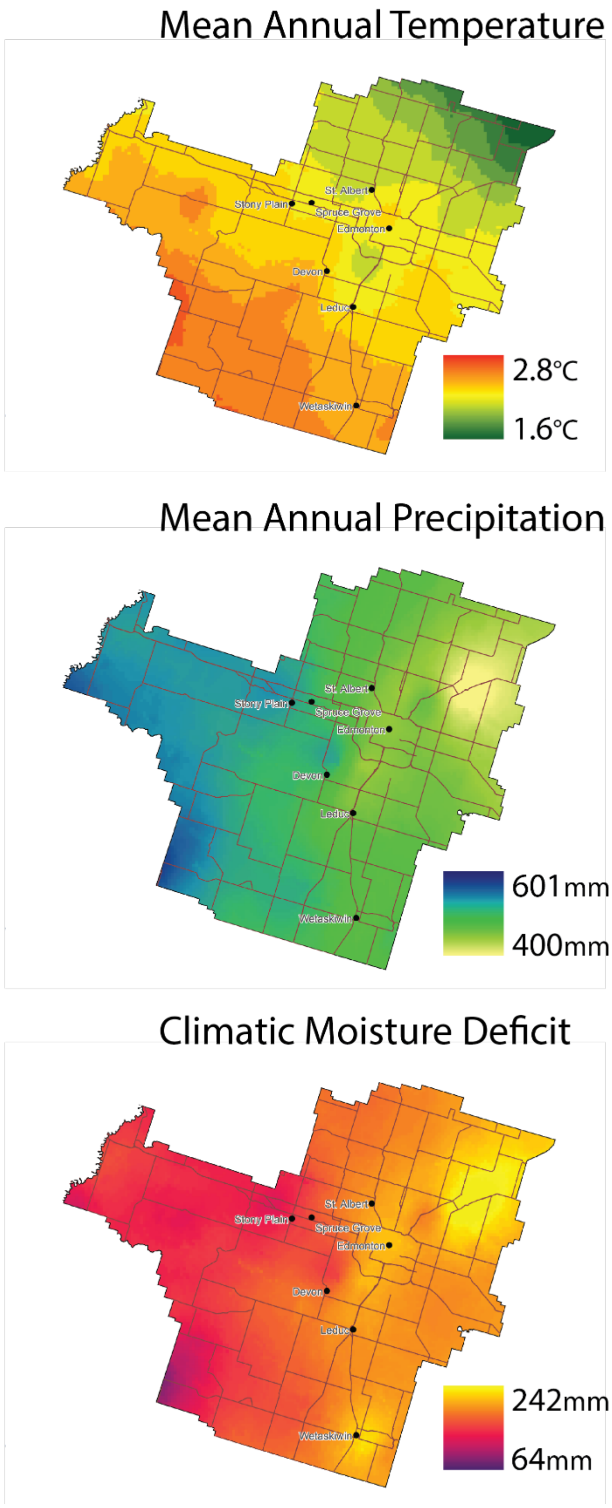

Figure 5. Variability in mean annual temperature (MAT), mean annual precipitation (MAP) and climatic moisture deficit (CMD) across the EMR for historical baseline period of 1961-1990.

The EMR's CMD ranges from 64 mm in the west to 242 mm in the east. Based on historic normals, CMD begins in April, peaks in May and gradually decreases to October. Similarly, the region's CMI reported for the period of 1961 to 1990 indicates a net deficit of moisture down to - 70 mm in the eastern part of the region and a surplus of up to 100 mm in the western part of the EMR (Schneider, 2013). In Alberta, CMI corresponds well with the differentiation of forest and grassland ecosystems (Hogg E. , 1997). The lowest CMI values are found in the far southeast and are associated with dry shortgrass prairie (Schneider, 2013). Moving north 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).

Evapotranspiration (Eref) and growing degree days (DD5) were found to be the most important climatic determinants of tree growth for tree species in the Pacific Northwest (Liu & El-Kassaby, 2018). Though prairie vegetation must deal with a considerably harsher climate than the trees of the Pacific Northwest, available moisture and length of growing season are likely still relevant drivers of plant growth. Table 1 shows that for the region's baseline climate, evaporation levels (Eref) are lower than for the comparison cities shown. Similarly, the region's growing season (DD5) is shorter than the comparison cities except for Calgary. Overall, the EMR has a climate that can better support woody vegetation than drier prairie cities. However, its climate is dry enough that extensive forest cover does not occur naturally.

Changes to the region's climate have already begun and further changes are "locked-in" due to GHG emissions that have been released to date. Mean annual temperature has been shown to be increasing at a rate of 0.17°C per decade since 1917, and a rate of 0.35°C since 1950, indicating an increasing rate of change (All One Sky Foundation, 2018). These changes are close to double the global average rate of warming – an example of how northerly latitudes are changing faster than middle latitudes. Mean Annual Precipitation has decreased in the region since 1950 but there is disagreement over the significance of this trend (All One Sky Foundation, 2018; Jiang, Gan, Xie, Wang, & Kuo, 2017).

Canada's plant hardiness zones (Figure 6), which identify regions where plant species are expected to successfully survive and grow, have been shifting steadily north since they were first mapped in the 1930s (McKenney, Pedlar, Lawrence, Papadopol, & Campbell, 2015). The Canadian zones factor in wind speed, precipitation and minimum temperature of the coldest month. The shifts have been most pronounced in western Canada. The region has shifted from Zone 3B to Zone 4A in the Canadian hardiness zones. These shifts are likely to continue, changing the range of plants that can grow in the EMR.

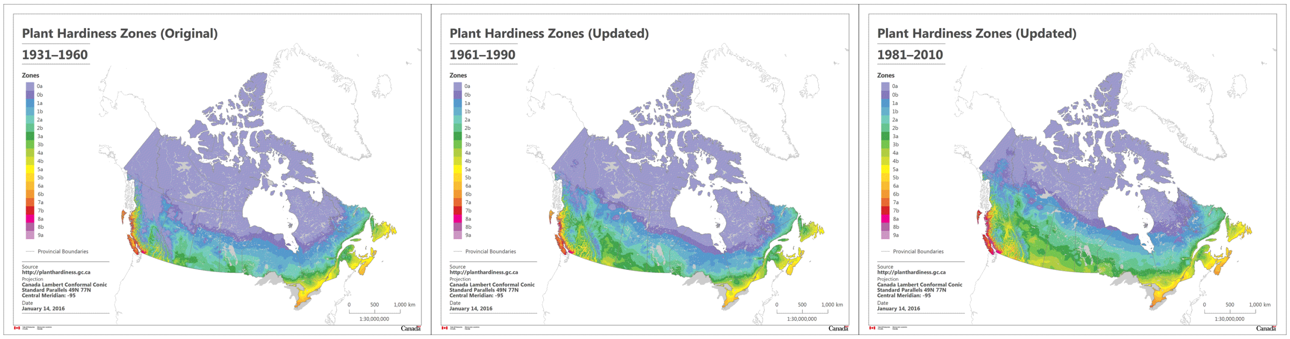

Figure 6. Plant hardiness zone changes over time as mapped by Natural Resources Canada (source: https://www.nrcan.gc.ca/forests/climate-change/forest-change/17778)

4.2 Climate Projections

4.2.1 Projected Changes in Seasonal and Annual Climate

To project future climate under two different emissions scenarios, DHC used the ClimateNA software (Wang, Hamann, Spittlehouse, & Carroll, 2016)[1]. Edmonton was used as the point for which projections are reported and the projections are for the 2050s (2041-2070) and 2080s (2071-2100) time periods. These results are a generalization for the region given that there is localized variation in climate from east to west. The Low Emissions scenario is RCP 4.5, the High Emissions scenario is RCP 8.5. In Table 2, the minimum and maximum change is reported both in absolute values and as percent change for both emissions scenarios in the 2080s.

[1] This program downscales and integrates future climate datasets for 2020s (2011-2040), 2050s (2041-70) and 2080s (2071-2100). The climate data for future periods are from General Circulation Models (GCMs) of the CMIP5 project included in the IPCC Fifth Assessment Report. Fifteen GCMs were selected for two greenhouse gas emission scenarios (RCP 4.5 and RCP 8.5). When multiple ensembles are available for each GCM, an average was taken over the available (up to five) ensembles. A time-series of annual projections is also available for the years between 2011-2100. The output of the program includes both directly calculated and derived climate variables (source: http://www.climatewna.com/help/climateBC/help.htm#_Toc410137600).

Table 2. Climate variable values for Edmonton's historical baseline period of 1961-1990, and two potential future scenarios for Edmonton in the 2050s and 2080s.

Scenario	MAT	MAP	PAS	EMT	EXT	Eref	DD5	AHM	CMD	PPT_sp	CMD_sm
Edmonton Baseline (1961-1990)	2.3	464	101	-45.3	34.5	567	1429	26.4	198	83	86
Edmonton Low Emissions, 2050s	5.2	494	95	-40.8	37.2	621	1922	30.8	234	101	116
Edmonton Low Emissions, 2080s	5.9	499	94	-39.8	38.1	636	2063	31.9	246	103	123
Edmonton High Emissions, 2050s	6	497	91	-39.5	38.3	636	2103	32.2	247	104	125
Edmonton High Emissions, 2080s	8.2	501	81	-36	41	712	2558	36.3	305	113	169
Min. Change (2080s)	3.6	35	7	5.5	3.6	69	634	5.5	48	20	37
Max. Change (2080s)	5.9	37	20	9.3	6.5	145	1129	9.9	107	30	83
Range	2.3	2	13	3.8	2.9	76	495	4.4	59	10	46
% Change Min.	**156.5**	**7.5**	**6.9**	**12.1**	**10.4**	**12.2**	**44.4**	**20.8**	**24.2**	**24.1**	**43**
% Change Max.	**256.5**	***8***	**19.8**	**20.5**	**18.8**	**25.6**	**79**	**37.5**	**54**	**36.1**	**96.5**

Variables shown are the following: MAT = Mean Annual Temperature (°C); MAP = Mean Annual Precipitation (mm); PAS = Precipitation as Snow (mm); EMT = Extreme Minimum Temperature (°C); EXT = Extreme Maximum Temperature (°C); Eref = Hargreaves reference evaporation (mm); DD5 = degree-days above 5°C/growing degree-days; AHM = Annual Heat Moisture Index; CMD = Hargreave's Climatic Moisture Deficit (mm), PPT_sp = precipitation in spring, CMD_sm = climatic moisture deficit in summer. Low emissions scenario is RCP 4.5. High emissions scenario is RCP 8.5.

Temperature

For the future scenarios, mean annual temperature increases substantially over the baseline value of 2.3°C up to a range of 5.9°C – 8.2°C by the 2080s (Table 2). For the 2050s, the projected temperature increases by at least 126% and by up to 257% by 2085. Average temperatures will be warmer in all seasons (Figure 7).

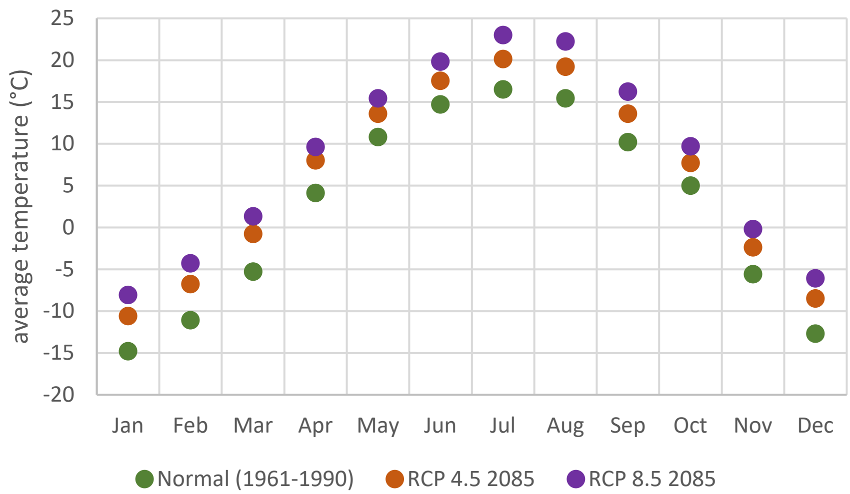

Figure 7. Average Monthly Temperature for Edmonton's current baseline climate and two GHG concentration scenarios (RCP 4.5 and RCP 8.5) in the 2080s.

Average minimum temperatures will be warmer in all seasons but by a larger magnitude in the winter months (Figure 8).

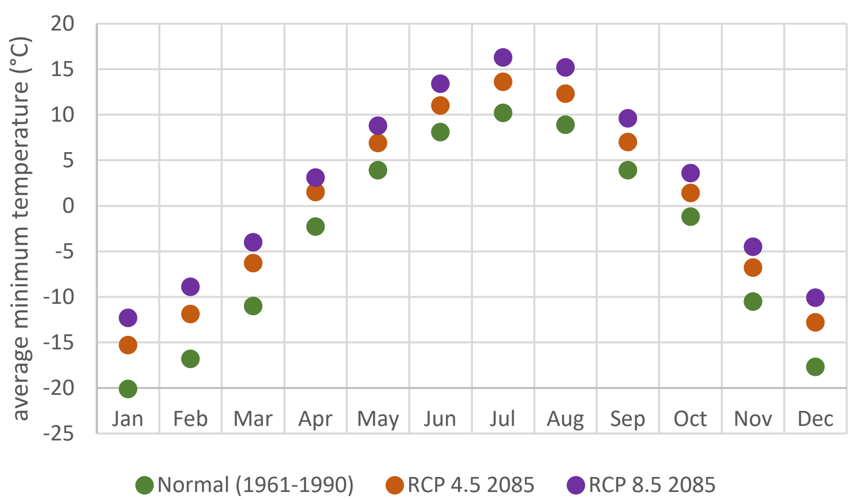

Figure 8. Average Monthly Minimum Temperature for Edmonton's current baseline climate and two GHG concentration scenarios (RCP 4.5 and RCP 8.5) in the 2080s.

Average maximum temperatures will also be warmer in all seasons (Figure 9).

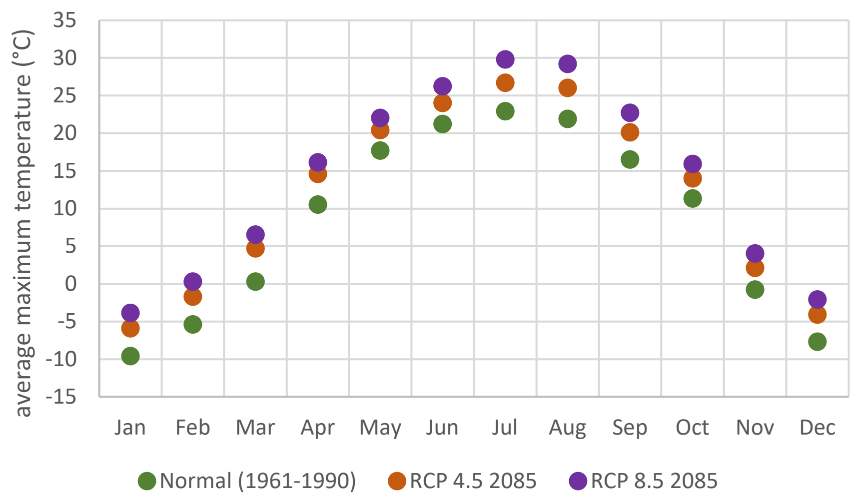

Figure 9. Average Monthly Maximum Temperature for Edmonton's current baseline climate and two GHG concentration scenarios (RCP 4.5 and RCP 8.5) in the 2080s.

Extreme maximum summer temperatures will increase from 35°C to up to 41°C (+6°C), while extreme minimum winter temperatures (extreme minimum from within the 30 year period) will increase from -45°C to as high as -36°C (+9°C) by the 2080s under the RCP8.5 scenario. The coldest minimum temperature (average of extreme minimums over 30 years) is projected to increase from -35.1°C to -28.8°C by the 2080s (Figure 10).

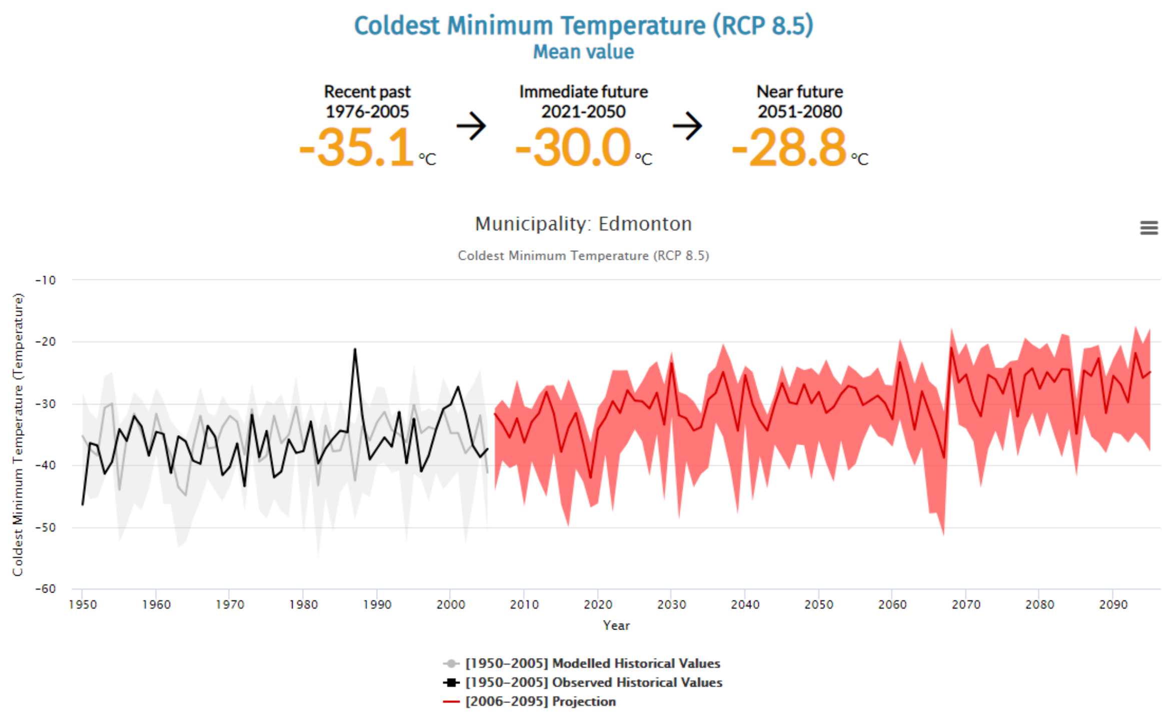

Figure 10. Coldest minimum temperature (averaged over 30 years) projected for Edmonton. (https://climateatlas.ca/data/city/466/minmin_2060_85).

Growing Season

Related to temperature, the growing season as measured by Growing Degree-days (DD5) is also set to expand considerably. 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. Growing Degree-Days (GDD) provide an index of the amount of heat available for the growth and maturation of plants and insects. Growing degree days are projected to increase from 1,429 to up to 2,558 by the 2080s in the high emissions scenario. Growing degree days are also expected to accumulate over a longer period of time and accumulate more rapidly, with the greatest increase in the summer months (Figure 11).

The beginning of the frost-free period is also expected to shift earlier, from the present average date of May 31 to as early as 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 as late as October 8 under the high emissions 2080s scenario.

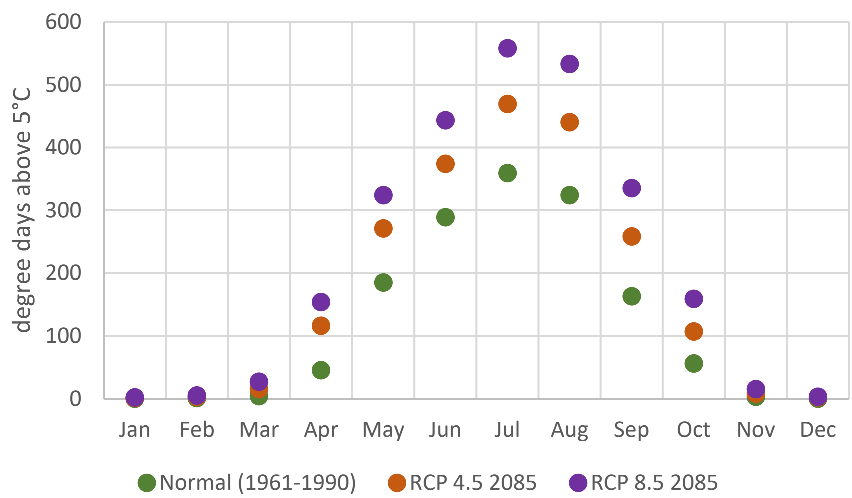

Figure 11. Degree days (above 5°C) for Edmonton's current baseline climate and two GHG concentration scenarios (RCP 4.5 and RCP 8.5) in the 2080s.

Precipitation

Mean annual precipitation is forecast to increase from 464 mm to up to 501 mm by the 2080s (Figure 12). Less precipitation is expected to fall as snow. 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 (Figure 12). 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.

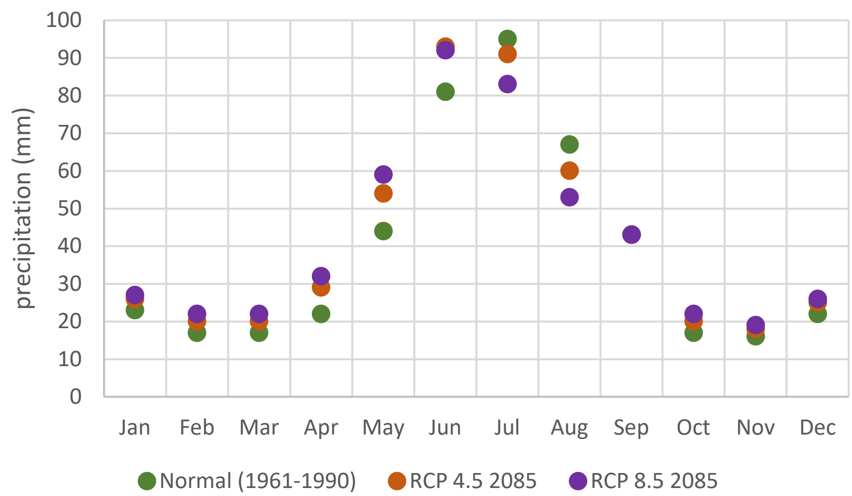

Figure 12. Precipitation (mm) for Edmonton's current baseline climate and two GHG concentration scenarios (RCP 4.5 and RCP 8.5) in the 2080s.

Moisture Availability

Evapotranspiration and climatic moisture deficits (CMD) are projected to increase in both the low or high emissions scenarios, particularly in summer. CMD is projected to increase from 198 mm to up to 305 mm (54%) in the 2080s, with the greatest increase occurring in summer and slight increases in spring and fall (Figure 13). 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 (Figure 13). These results indicate that the effect of higher temperatures driving evapotranspiration rates and the decline in summer precipitation will likely outweigh the effect of increased annual precipitation in terms of overall moisture availability. The present gradient of moisture deficit increasing from west to east will remain across the EMR (Figure 14).

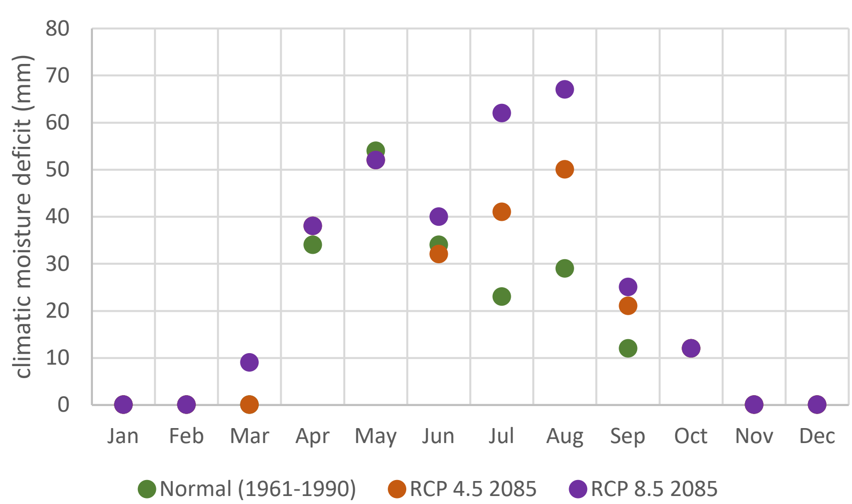

Figure 13. Climatic moisture deficit (mm) for Edmonton's current baseline climate and two GHG concentration scenarios (RCP 4.5 and RCP 8.5) in the 2080s.

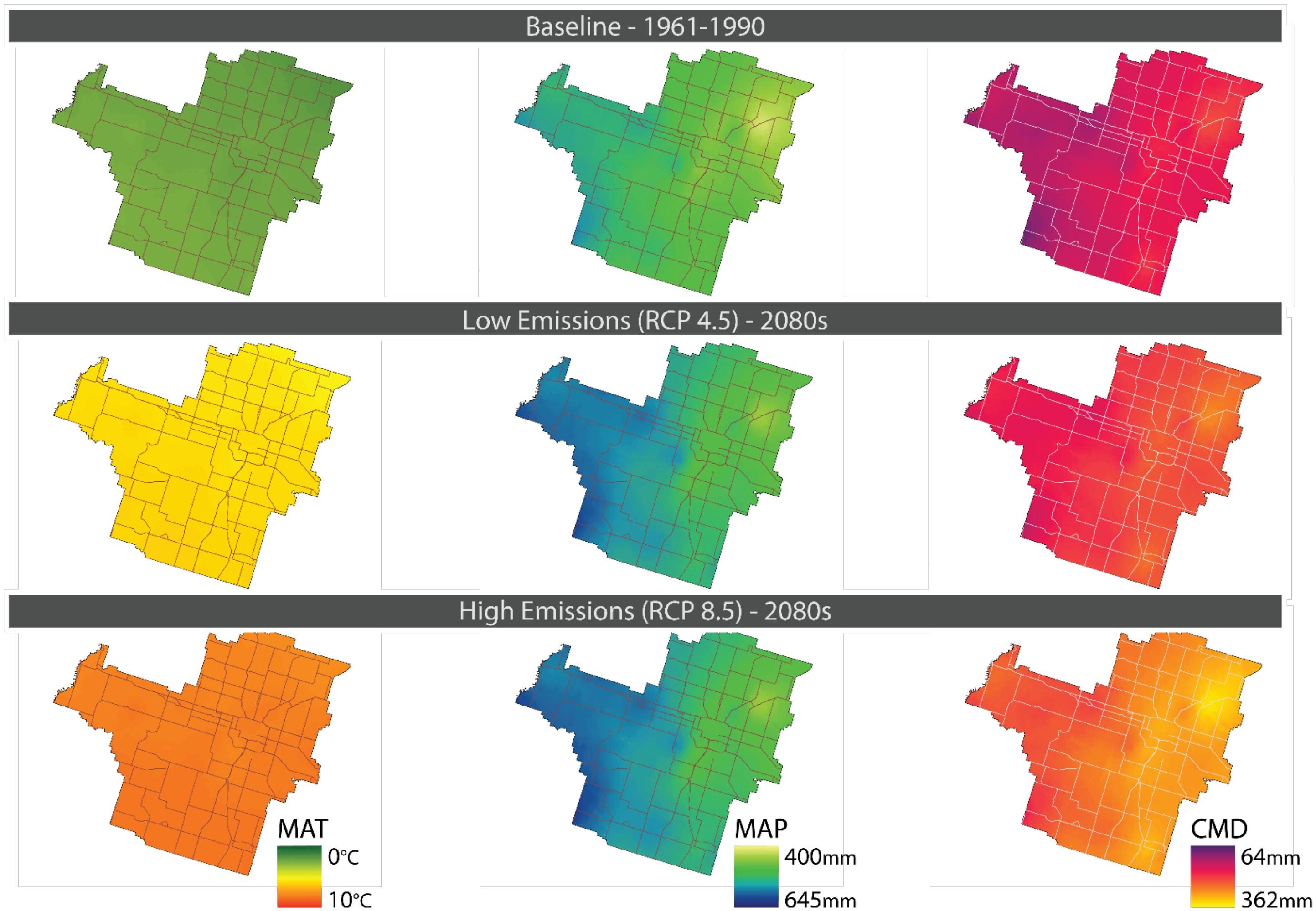

Figure 14. Mean annual temperature, mean annual precipitation and climatic moisture deficit mapped for the region with projected changes under 2080s low emission and high emission scenarios.

Similarly, modelling work to project future CMI projects substantial shifts in relative moisture across the region (Figure 15). Under the median model scenario, the CMI shifts to between -30 mm in the west and -200 mm in the east by the 2080s (Schneider, 2013). Under the hot model scenario, CMI shifts to -150 mm in the west and -300 mm in the east by the 2080s (Schneider, 2013). Under the median scenario, the EMR's 2080s CMI values are similar to those of the Calgary area currently, while under the hottest scenario, the 2080s values are similar to the current dry shortgrass prairie areas in southeastern Alberta.

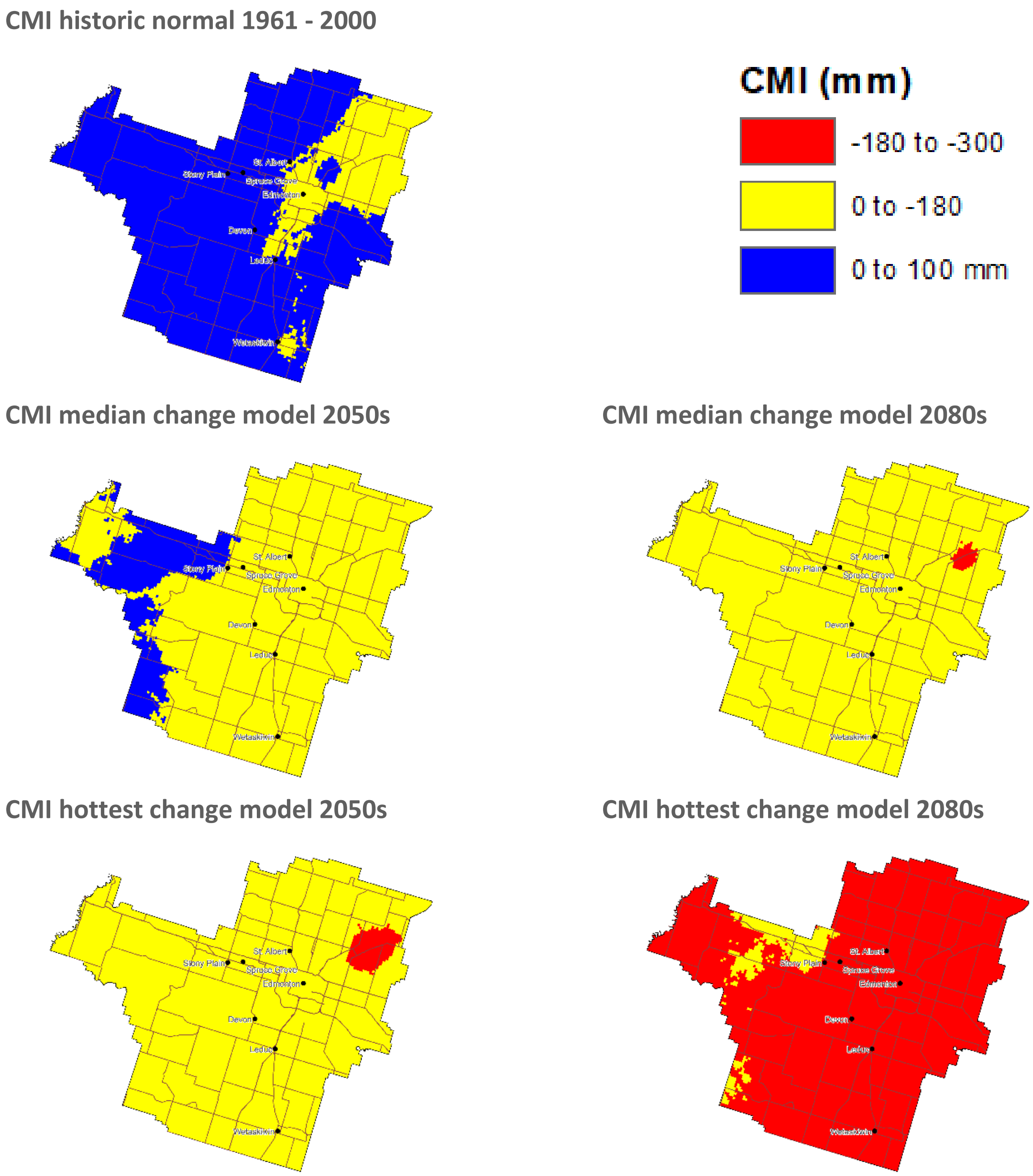

Figure 15. Climatic Moisture Index mapped for the EMR under historic normal conditions and for 2050s and 2080s projections.

Climate Analogues

An online climate analogue tool (Fitzpatrick & Dunn, 2019) recommends future analogues for high and low emissions scenarios for many cities in North America while also showing a climate similarity raster (Figure 16). The raster was used to select a range of 30 cities with similarities to Edmonton's future climate. This tool suggested that by the 2080s Edmonton's future climate would be most like Alexandria, Minnesota under a low emissions scenario, and like Minneapolis, MN under a high emissions scenario (Figure 16). However, the underlying model for this tool relies heavy on MAT and MAP. To provide a broader picture of potential climate analogues, ClimateNA was used to further compare the baseline climates of 30 cities with Edmonton's future high and low scenarios to determine which North American cities might be relevant analogues of Edmonton's future climate in terms of moisture, temperature and growing season.

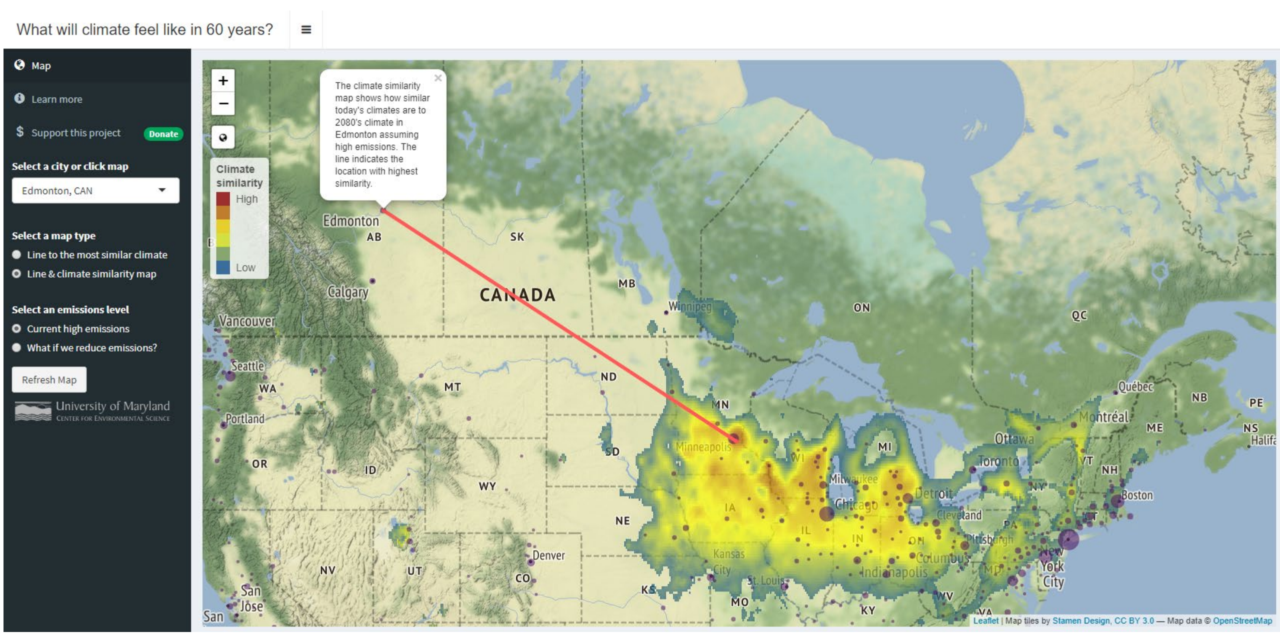

Figure 16. Screenshot of the Fitzpatrick and Dunn climate analogue tool showing a suburb of Minneapolis, MN as the best climate analogue for Edmonton in the 2080s under a high emissions scenario. (Fitzpatrick & Dunn, 2019, https://fitzlab.shinyapps.io/cityapp/)

The expanded analysis identified several other cities that might be more like the region's future climate. The ClimateNA variables for 30 cities current climates were compared with the future climate outputs for RCP 4.5 and RCP 8.5 scenarios for the 2050s and 2080s time periods. Two methods of comparison were used:

1. Principal components analysis, an automated method for grouping and visualizing quantitative data, was used to assess climate variables that most explained the differences and similarities between comparison cities' baseline climates and modeled future the EMR climates.
2. A coarse comparison of the similarity of selected climate variables further supported the above analyses to identify cities with similar temperature, growing season, and moisture values to those projected for the region.

Figure 17 shows the results of the principal components analysis (PCA), which groups variables according to how much of the variation they explain between the cities. The PC1 axis, which explains the most variation, represents a temperature/growing season gradient from colder/short on the left to warmer/longer on the right. The PC2 axis more strongly corresponds to moisture, with moisture deficit represented near the top and moisture abundance near the bottom. The region's baseline climate can be seen near the bFFP (beginning Frost Free Period) variable. Projected future climate can be seen above and to the right of the baseline climate indicating a shift towards a warmer, drier climate. The PCA analysis places the EMR's 2050s and low emissions 2080s climate in the vicinity of present-day Calgary, AB in terms of moisture and closer to Fargo, ND and Alexandria, MN in terms of temperature and growing season. By the 2080s, the EMR's predicted climate under a high emissions scenario is similar in terms of moisture to Saskatoon, SK and Regina, SK but more similar to St Could, MN, Toronto, ON and Minneapolis, MN in terms of temperature and growing season.

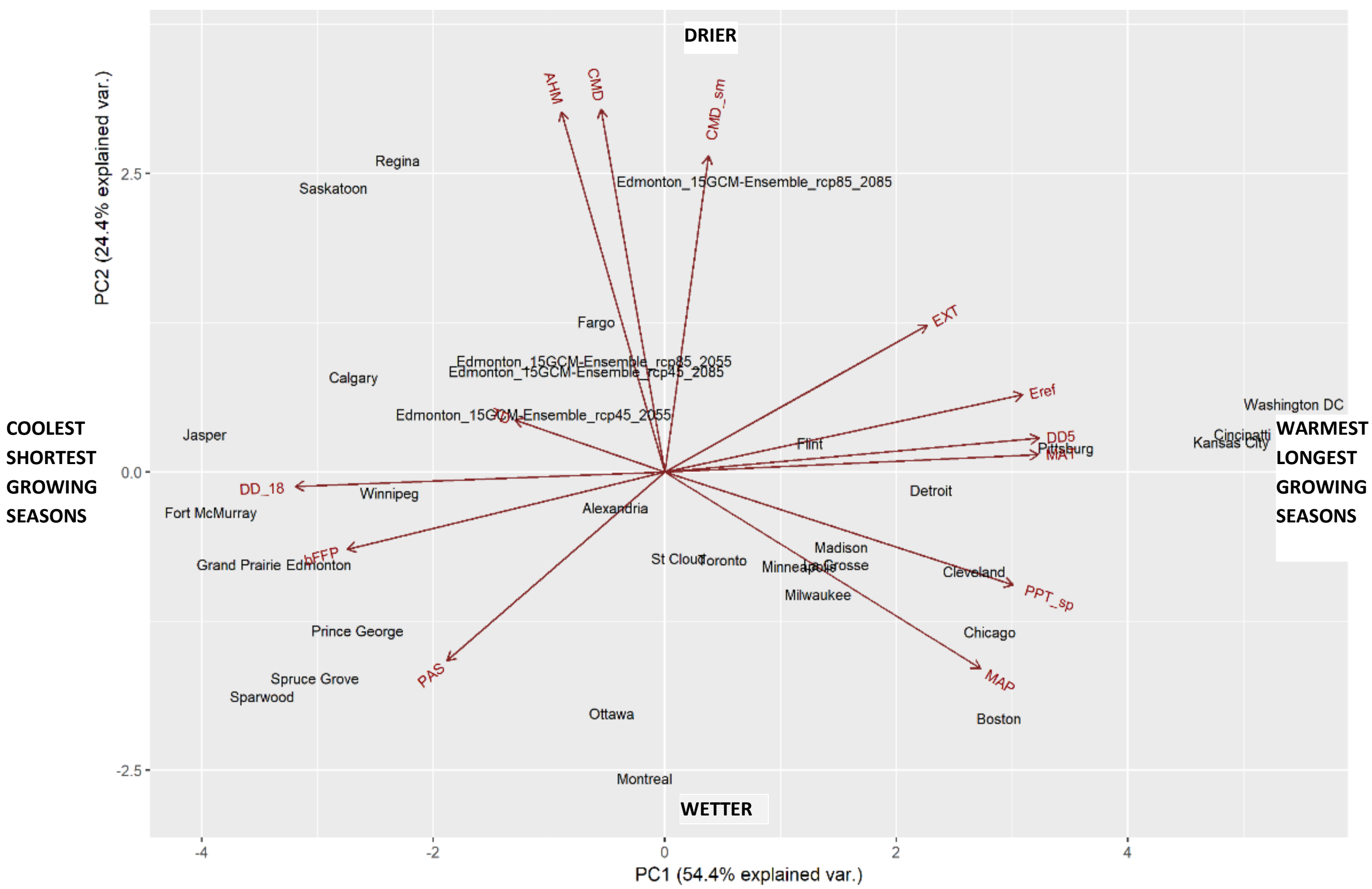

Figure 17. PCA results showing the first two principal components for 13 selected climate variables. The PC1 axis represents a temperature/growing season gradient from colder/shorter on the left to warmer/longer on the right. The PC2 axis more strongly corresponds to moisture, with moisture deficit near the top and moisture abundance near the bottom. Edmonton's baseline climate is shown near the bFFP (beginning Frost Free Period) variable. Projected future Edmonton climates can be seen above and to the right of the baseline, indicating a shift towards a warmer, drier climate.

The PCA, and comparison of individual variables suggested that future climate for both RCP 4.5 scenario time periods, and the 2050s RCP 8.5 scenario were fairly similar to one another (Figure 18). However, by the 2080s the region's climate in a high emissions world is considerably different than the other projections. When isolating variables for temperature, growing season, precipitation and moisture availability and comparing them to future climate based on the RCP4.5 scenario, different cities were highlighted as shown in Figure 18. Due to forecasting uncertainty, it is important to consider the results from climate similarity analysis as a suite of potential future conditions. No single city is likely to perfectly represent the region's future climate.

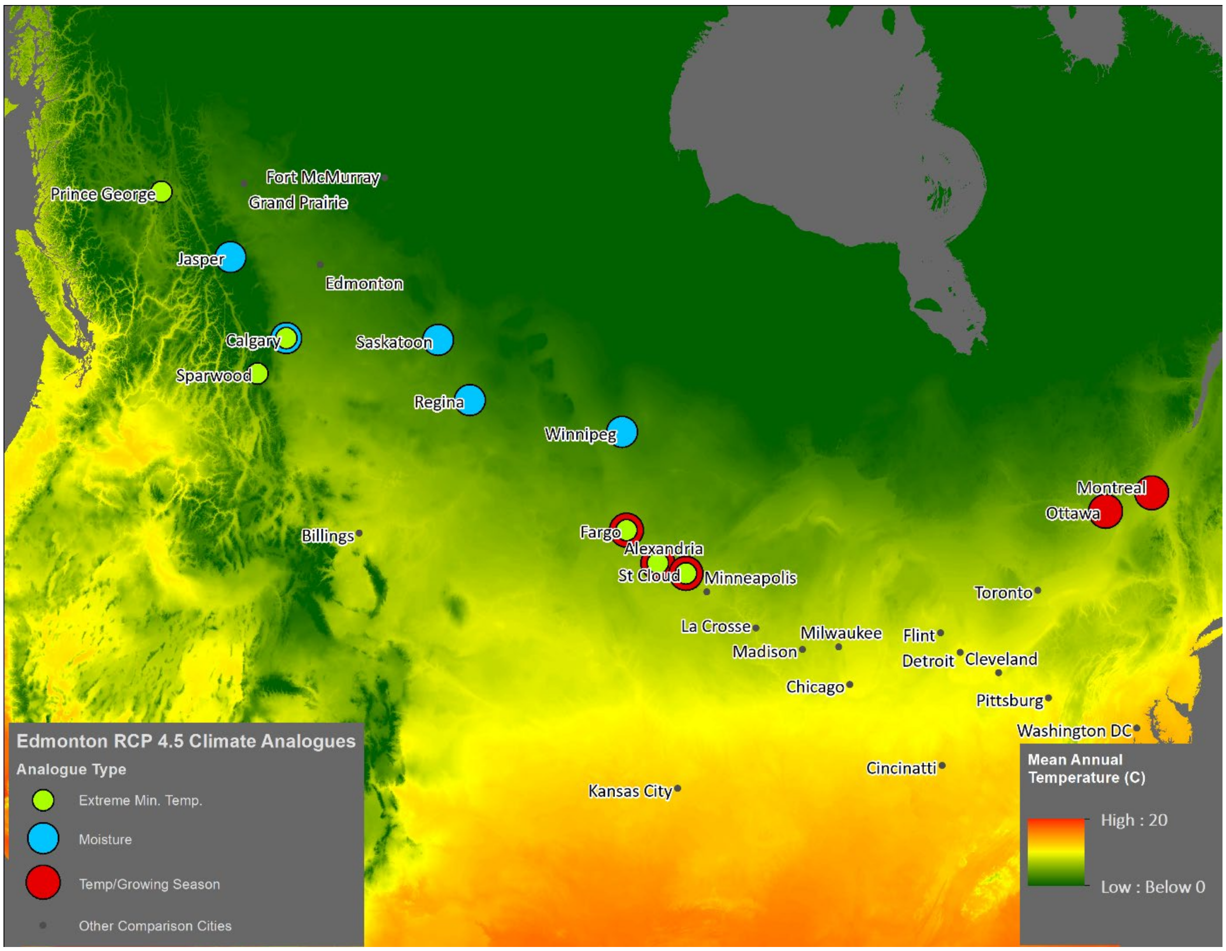

Figure 18. Analogues of future climate under the RCP 4.5 (low emissions) scenario for three variable categories : extreme minimum temperature, moisture (availability and deficit), and temperature/growing season. Moisture analogues are clustered in the Canadian prairie provinces, where there is also some overlap with extreme minimum temperature analogues. Temperature and Growing Season analogues, however, are found much further south and east, near the border of North Dakota and Minnesota and in Central Canada. Background image is Mean Annual Temperature (MAT) for the 1961-1990 baseline period.

The results of the climate analogue analysis indicate that the EMR's future climate is likely to have temperatures and a growing season more like present-day cities located much further to the south and east, but will be drier, more similar to current prairie cities slightly to the south. The combination of increased temperature and reduced moisture is distinct from all of the comparison cities. However, these warmer cities may provide potential sources of new urban species or genotypes and, in some cases, native species genotypes suited to the EMR's future climate if also tolerant of drought.

The EMR's climate in the 2080s under a high emissions scenario is an outlier when compared with 30 years prior or either time period in the low emissions scenario. This supports the idea that climate change may produce novel climate combinations with no clear analogues using historical data.

These findings are consistent with reports on the EMR and Alberta as a whole, which note that temperature is expected to increase significantly while precipitation is set to increase in the spring, but stagnate or decline in the summer months (All One Sky Foundation, 2018; Zukiwsky & Boyd, 2014).

4.2.2 Projected Changes in Extreme Weather

In general, members of the scientific community believe that climate change is likely to bring changes in the frequency and characteristics of extreme weather events globally (Seneviratne, et al., 2012). However, modelling difficulties and uncertainties around which emissions pathways will be realized cause predictions of event frequency to have varying confidence, with confidence decreasing as specificity in location, duration, and intensity increase (Diffenbaugh, et al., 2017). Extreme events that are strongly driven by temperature, such as hot nights, are better understood than events shaped by multiple factors or of longer duration, such as heat waves (Seneviratne, et al., 2012). In North America, there is high confidence that maximum summer temperature and minimum winter temperature have increased since the 1960s for most inland areas (Romero-Lankao, et al., 2014). Additionally, there is high confidence that loss of glacial and snow cover in temperate montane environments is related to climate warming and that these losses threaten summertime water availability in western North America (Romero-Lankao, et al., 2014).

In western Canada, modelling of future weather conditions has been focused on wildfire prediction, though most models use standard temperature and precipitation indicators to extrapolate seasonal fire activity (Wang, et al., 2015; Kirchmeier-Young, Zwiers, Gillett, & Cannon, 2017; Tan, Chen, Yew, Liu, & Chen, 2019; Flannigan, et al., 2001). Historical observation of precipitation variables for the period 1950-2010 shows a declining trend in the EMR but this may not be statistically significant (Jiang, Gan, Xie, Wang, & Kuo, 2017; All One Sky Foundation, 2018; Mekis, Vincent, Shephard, & Zhang, 2015). The climate of the EMR is surprisingly diverse for its muted topography, showing a wide gradient of moisture and temperature that is perhaps suggestive of the region's location at a zone of interacting climate drivers (cf. Kienzle, 2018). Increased evapotranspiration was a contributing factor to the major precipitation and flooding event in southern Alberta in 2013, raising the risk of similar events in a future climate with higher temperatures and incidental atmospheric moisture (Teufel, et al., 2017; Milrad, Gyakum, & Atallah, 2015).

Overall, 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 atmospheric moisture (Lemmen, Warren, Lacroix,

& Bush, From Impacts to Adaptation: Canada in a Changing Climate, 2007; Zukiwsky & Boyd, 2014; Prairie Climate Centre, n.d.). Municipalities in the region are preparing for a range of potential weather conditions, including winter storms; extreme precipitation and consequent flooding; water scarcity; convective storms with impacts such as hail, lightning, and tornadoes; strong winds; heat waves; grass and forest fires; and destructive freeze-thaw cycles (Zukiwsky & Boyd, 2014).

4.3 Summary of Climate Projections

Climate changes are expected to result in:

- Average temperatures increasing in all seasons by between 5 and 7 °C with winter showing the largest increase, followed by spring and summer. Temperature will increase the least in fall.
- Longer growing seasons.
- Mean annual precipitation increasing modestly, with more precipitation falling in spring and winter, while summer changes are negligible.
- Hotter summers with higher evapotranspiration and moisture deficits in spring and summer.
- Potential but uncertain changes in the frequency and intensity of extreme weather events including winter storms, flooding, extreme drought, convective storms, lightning, tornadoes, wind storms, heat waves, wildfire and destructive freeze-thaw cycles.

5.0 How Climate Change May Impact Invasive Species and Pests in the EMR

5.1 Overview

Climate change affects the distribution, spread, abundance, and impact of invasive species (Gritti, Smith, & Sykes, 2006). Many invasive species are expected to expand their ranges into new areas (Smith, et al., 2012) because invasive species tend to have characteristics that facilitate rapid shifts and traits that favour them in a changing environment. These include large geographic ranges, broad climatic tolerances, short juvenile periods, long-distance dispersal mechanisms, the ability to adapt to new conditions faster than native species, (Hellmann, Byers, Bierwagen, & Dukes, 2008) (Clements & Ditommaso, 2011), and growth strategies such as allelopathy which can permanently alter soil chemistry rendering it inhospitable to native species.

Although many studies have drawn connections between the direct effects of climate change and the invasion rates of exotic species, the primary driver of invasion remains human-facilitated dispersal (Settele, et al., 2014). Changed climates can set the stage for invasion if facilitated dispersal continues unregulated. There is broad agreement that climate novelty can facilitate the establishment of novel invasive species once dispersal occurs (Masters & Norgrove, 2010).

It is hypothesized that the four main climate change related drivers increasing the likelihood of invasion and disturbance by invasive species are:

1. **Warming and precipitation** changing population dynamics and species distributions;
2. **Elevated CO_2** enhancing competitiveness of exotic species;
3. Sudden onset impacts increasing native ecosystem **disturbance frequency and intensity** (e.g. extreme storms, wildfire); and
4. Slow and sudden onset impacts increasing **stress and mortality rates in native species and ecosystems** (Breshears, et al., 2005) (Dukes & Mooney, 1999) (Pauchard, et al., 479-486) (Ziska & Dukes, Weed Biology and Climate Change, 2011).

Climate change impacts: slow-onset and sudden-onset
The State of Knowledge Summary describes climate change impacts as “sudden-onset” or “slow-onset”. Sudden-onset impacts, also called “climate hazards”, are discrete events associated with extreme weather. Extreme rainfall events, blizzards, wildfires, windstorms, and heat waves can have impacts on the health of ecological resources in the EMR. Through impacts like cuts and wounds to plant tissue or newly exposed mineral soil, climate hazards can provide conditions that favour rapid colonization by invasive species and pests. Slow-onset impacts result from predicted changes to the regional climate. They represent the changing suitability of the region’s climate and habitats for invasive species and pests as a function of trends in seasonal and annual climate variables – such as minimum and maximum annual temperatures, growing degree days, and monthly rainfalls. The State

of Knowledge Summary identifies that the consequences of slow-onset impacts can be significant and widespread because they are distributed broadly and act over a long timeframe.

Further to the above noted drivers of change, mounting evidence indicates many invasive species are capable of relatively rapid genetic change, enabling them to expand ranges and invade new areas in response to anthropogenic ecosystem change. This has been documented for some individual invasive plant species including purple loosestrife, spotted knapweed, jimsonweed, St. John's wort, and Japanese knotweed (Clements & Ditommaso, 2011).

The subsections below provide a literature review of how climate change is anticipated to impact regional vulnerability to invasive plants, animals, insect pests, and diseases. The drivers of change noted above are a reoccurring theme in the description of anticipated vulnerabilities. It should be noted that although scientists have used experimental field and observational studies as well as simulation models to try to assess the effects of climate change on invasive species, considerable uncertainty remains and much more research is still needed (Olatinwo, et al., 2014)

5.2 Invasive Plants

The EMR is host to dozens of invasive plant species including agricultural species (e.g. Canada thistle, common tansy, scentless chamomile, leafy spurge, etc.), riparian species (e.g. Himalayan balsam, purple loosestrife), and species that impact infrastructure (e.g. knotweed) or recreation opportunities (e.g. flowering rush). All of these species have the potential to pose significant ecological impacts (e.g. garlic mustard, common buckthorn, etc.).

General Impacts: Invasive plants often have traits that allow them to outcompete native species in new environments, such as higher metabolic rates and nutrient uptake (Leishman, Haslehurst, Ares, & Baruch, 2010; Matzek, 2012).

Temperature: Later arrival of freezing and increasing winter temperatures may allow some invasive plants to survive the winter when they previously could not (Dukes & Mooney, 1999).

Precipitation: In grassland ecosystems, increases in winter precipitation combined with either no change or a decrease in summer precipitation favours invasive grasses (e.g. cheatgrass) over native grasses. The invasive species bloom earlier resulting in decreases of available soil resources for native plants that emerge later in the season (Prevey & Seastedt, 2014).

Growing degree days: Longer growing degree days may shift first flowering dates of some plants. Multiple studies have found that purple loosestrife changes its flowering times in order to adapt to local climates (Dech & Nosko, 2004) (Colautti & Barrett, 2013). It is able to do this because of high genetic variability (Kiesel, 2014). Adaptation of bloom timing could have significant impact for species like loosestrife which have biological control programs.

Elevated CO_2: It is widely known that elevated levels of CO_2 stimulate plant growth. One study compiled evidence that elevated CO_2 favours invasive plant growth (particularly those in managed agricultural settings) and that under elevated CO_2 control through herbicide will be less effective on some invasive plants. Among the invasive plants species documented to undergo significant growth response to elevated CO_2 are: Canada thistle, leafy spurge, jimsonweed, spotted knapweed, yellow starthistle, field bindweed, field sowthistle, and kudzu (Ziska & George, 2004).

Elevated CO_2 is anticipated to hinder the speed of recovery of native ecosystems after major disturbance, increasing the likelihood of colonization by invasive species (Dukes & Mooney, 1999).

Extreme weather: Extreme weather can provide opportunities for invasion by degrading ecosystem structure and assisting dispersal (Diez, et al., 2012). An example is the well documented connection between wildfire and the spread of invasive plants (D'Antonio, 2000). Disturbance, both natural and human caused, alters resource availability. In a forest setting this may include increases in light from canopy openings and increased exposure of mineral soil, both of which provide opportunities for plant invasion.

The likelihood of invasion increases when disturbance occurs adjacent to invasive plant seed sources, key vectors, or dispersal pathways. This brings up the concept of propagule pressure. When an area is significantly infested with invasive plants, there are ample seed sources. This is called high propagule pressure. Climate change is expected to alter propagule supply and pressure through potential changes in human activities such as transportation, tourism, and commerce as well as changes in atmospheric patterns (Eschtruth & Battles, 2009) (Hellmann, Byers, Bierwagen, & Dukes, 2008) .

Stresses to native species and ecosystems: Changes in temperature, precipitation and CO_2 concentrations are anticipated to stress native species and ecosystems. These changes may lead to resource scarcity and increased competition which in turn increase vulnerability to invasion (Dukes & Mooney, 1999) (Simberloff D. , 2000). With the rapid pace of climate change, species that cannot quickly extend their range or have long generation times will be at a disadvantage. Species with large latitudinal ranges, tolerating a range of climates, are likely to be the most successful invaders (Rajmanek, 1995).

5.3 Invasive Animals

The most prominent non-native invasive animals currently in the EMR are several species of fish including goldfish, koi and suspected Prussian carp (genetic testing is currently underway at the University of Alberta to confirm species identification of the carp). There are several populations of wild boar throughout the province. Alberta has several programs to detect or control invasive animals including watercraft inspection stations to prevent the introduction of zebra and quagga mussels and a successful decades-old rat control program which has largely kept the province rat free.

General Impacts: Although climate change continues to open new suitable habitats for species not currently present in the Edmonton Metropolitan Region, with the exception of aquatic animals there is little research to confirm or deny the vulnerability of the region to invasion by specific animal species

(Smith, et al., 2012). As with vascular plants, the invasiveness of an animal species is a composition of its intrinsic attributes and the structure of the ecosystem where it is introduced. Climate change appears likely to increase rates of establishment and invasion, assuming the rate of facilitated dispersal remains high (Walther, et al., 2009).

Temperature: Increasing winter temperatures mean warmer water temperatures and shorter periods of ice cover. This will allow aquatic species that were previously limited to expand their range (Rahel & Olden, 2007). The same is true for terrestrial animals for which cold winters may have prevented establishment or kept populations in check.

Growing degree days: Increasing water and air temperature are expected to extend the growing season of aquatic species. This will provide time for invasive species such as zebra and quagga mussels (not currently present in Alberta) to maximize the use of their main competitive advantage: high reproductive rates (Rahel & Olden, 2007).

5.4 Insect Pests

Insect pests in the EMR include both native and introduced species that target trees either in the native forest, urban forest, or both (e.g. mountain pine beetle, emerald ash borer, poplar borer, etc.).

General Impacts: Scientists have expected the population dynamics of insect pests to vary with climate change effects for several decades (Harrington, Woiwod, & Sparks, 1999). Climate change is likely to increase survival of insect pests leading to population expansion and outbreaks (Rustad, et al., 2012).

Where insect pests expand their range, even conspecific hosts may have few selective defenses against infestation, allowing ranges to rapidly increase (Cudmore, Björklund, Carroll, & Lindgren, 2010). Similarly to the spread of invasive animals and plants, insect pests under climate change are expected to shift their ranges uphill and poleward, with local range contractions and a mix of beneficial and harmful effects specific to pests and regions (Régnière, St-Amant, & Duval, 2010).

Temperature: Insects, dependent on external temperature sources for regulating metabolism, display high responsiveness to climate change in terms of their growth and reproductive cycles (Bale, et al., 2002; Fleming & Volney, 1995).

The indirect impacts of climate change are difficult to predict but include changes in the nutrient content of foliage and the weakening of trees and plants via drought or other slow-onset climate hazards, increasing host susceptibility to pest attack (Jamieson, Trowbridge, Raffa, & Lindroth, 2012; Netherer & Schopf, 2010). In northwestern Alberta, aspen dieback across large areas resulted from successive years of drought and springtime thaw-freeze cycles weakening trees and supporting infestations by wood-boring insects and fungi (Hogg, Brandt, & Kochtubajda, 2002).

In British Columbia, the native mountain pine beetle (*Dendroctonus ponderosae*) has historically gone through cycles of endemic and epidemic population, but its most recent outbreak has been exacerbated by a succession of warm years such that the insect displayed invasive behaviour in its native environment and now in Alberta's lodgepole pine forests. Most recently the beetle has been detected just outside of the EMR in Lac Ste. Anne County.

Growing Degree Days: The measure of growing degree days is highly relevant to changes in the population of insect pests, because it represents the excess thermal capacity in an ecosystem that drives forward many pest life cycles (Robinet & Roques, 2010; Battisti & Larsson, 2015).

Phenology: Herbivorous insects can be indirectly impacted by changes in the phenology of their host plants, with a variety of effects depending on the interruption of timing between the emergence and maturation of pests and their food sources (Cornelissen, 2011; Bale, et al., 2002). Earlier budbreak in host plants can reduce the quality or otherwise disrupt larval feeding or allow multiple generations of breeding within a single year (Jamieson, Trowbridge, Raffa, & Lindroth, 2012).

Precipitation: Precipitation regulates insect pests, largely through moderating the interactions between insects and their preferred food species or predators. Early research in the Canadian prairies established that soil moisture can delay, accelerate, or terminate the development of many grassland insects that experience some phase of their growth and development below ground (Beirne, 1970). Additionally, all insects can be impacted by mechanical damage from precipitation events that exceed their survivability, such as hail storms or violent rains. The relationship between moisture and insect development is less researched than the influence of temperature (Jamieson, Trowbridge, Raffa, & Lindroth, 2012; Bale, et al., 2002). Effects of an extreme event can be delayed on insect populations, particularly for insects that have one or fewer broods per year (Boggs & Inouye, 2012).

Winds: There is evidence that winds have assisted the long-range dispersal of forest pests in Canada, including species found in Alberta, mountain pine beetle (*Dendroctonus ponderosae*) and eastern spruce budworm (*Choristoneura fumiferana*) (Huapeng & Jackson, 2017; de la Giroday, Carroll, Aukema, & McGeoch, 2012; Sturtevant, et al., 2013; Anderson & Sturtevant, 2010). Conditions for insect emergence and dispersal via this method depend on multiple factors, both decreasing the likelihood of long-range wind dispersal events and their predictability. It seems likely that facilitated dispersal will continue to be the dominant factor determining the spread of invasive insects and forest pests.

5.5 Plant Diseases

Plant diseases typically refer to fungal, bacterial, and viral pathogens that impact the health and vigour of plants. In the EMR plant diseases include native species which attack natural and urban forest species (e.g. black knot and fire blight) as well as clubroot, an introduced pathogen that attacks certain agricultural crops. Dutch elm disease has not yet been detected in the EMR but is regularly monitored as it poses a significant risk to elms in the urban forest.

General Impacts: The distribution and effects of plant diseases under changed climates are dynamic, responding to abiotic and biotic factors that are unique to regions and species. The historical record of infestations by plant diseases is poor, limiting our ability to assess the risk of novel cases (Shaw & Osborne, 2011).

The severity and range of diseases depends in large part on a reading of the climate effects on pathogen vectors and hosts, adding a layer of complexity to assessing the risk of invasion relative to invasion by plants and animals. Climate change may also result in a rebalancing of phenology or resources in the ecosystem such that an endemic pathogen becomes a disruptive force.

Much of the research surrounding the vulnerability of plants to disease under changed climates focuses on changes to the architecture of the hosts, rather than the attributes of the pathogens themselves.

Precipitation: Foliar density tends to create humid microclimates on the leaf surface which may further favour pathogens which target leaf surface. This effect could be counteracted by prolonged summer drought; however, the single rain events may be sufficient to allow infection as pathogen phenological cycles can be very short (Harvell, et al., 2002).

Temperature: Increasing winter temperatures are a crucial variable likely to increase the severity and spread of plant diseases. Winter is the major period of pathogen mortality in temperate climates – higher winter temperatures result in a greater overwintering success for inoculum and release diseases from population bottlenecks (Harvell, et al., 2002).

Growing degree days: As with insects, higher growing degree days each year support “polycyclic” plant pathogens to exponentially increase their inoculum, with the potential for greatly increased infection and dispersal rates (Boland, Melzer, Hopkin, Higgins, & Nassuth, 2004).

Elevated CO_2: Increased levels of carbon dioxide in the atmosphere result in increased leaf area, thickness, and density, which suggests foliar pathogens will benefit from climate change through increased host availability (Garrett, Dendy, Frank, Rouse, & Travers, 2006).

Extreme weather: Extreme weather hazards are also likely to have an effect on infection rates, though this is difficult to quantify. Rosenzweig, et al. (2001) found that floods and heavy rains could increase humidity and favour foliar pathogens, induce soil transport and therefore disperse soil-borne pathogens, and foment root rot; drought will diminish plant vigour; and larger storm events and storm tracks have the potential to provide large-scale transportation for disease agents on air currents.

Many pathogens require entry pathways, such as cuts or wounds in vascular plant tissue, to establish an infection site on new hosts (Boland, Melzer, Hopkin, Higgins, & Nassuth, 2004). It is widely expected that as climate variability increases, damage to plants will result in physical wounds as well as decreased vigour, thereby increasing host susceptibility (Pautasso, Döring, Garbelotto, Pellis, & Jeger, 2012; Rosenzweig, Iglesius, Yang, Epstein, & Chivian, 2001).

Stress and mortality rates in native species and ecosystems: The complex of climate hazards and biotic pathogens has been held responsible for many otherwise unexplained "declines" in tree species across Canada. Aspen dieback in northwestern Alberta in the 1980s and the current decline of yellow-cedar and paper birch throughout their native ranges in British Columbia are thought to result from the interactions of disease factors with climate change (Hogg, Brandt, & Kochtubajda, 2002; Sturrock, et al., 2011).

6.0 Invasive Species and Pests of Concern to the EMR

6.1 Pathway of Invasion

In order for a species to invade a new landscape, it must pass through a variety of environmental filters (Hellmann, Byers, Bierwagen, & Dukes, 2008):

1. Geography: Travel across geographic barriers
2. Abiotic conditions: Species must survive and tolerate new environmental conditions
3. Biotic conditions: Species must acquire critical resources, survive interactions with natural enemies, and possibly form mutualistic relationships at the new site
4. Landscape factors: The species must spread, establishing populations in new sites across the landscape

Given all the right conditions, over time an invasive species will spread and distribute across a landscape, passing through four stages of invasion (Figure 19). The risk of significant ecological, social and economic impacts grows with increased distribution and abundance of invasive species while the cost of control increases and feasibility of control decreases.

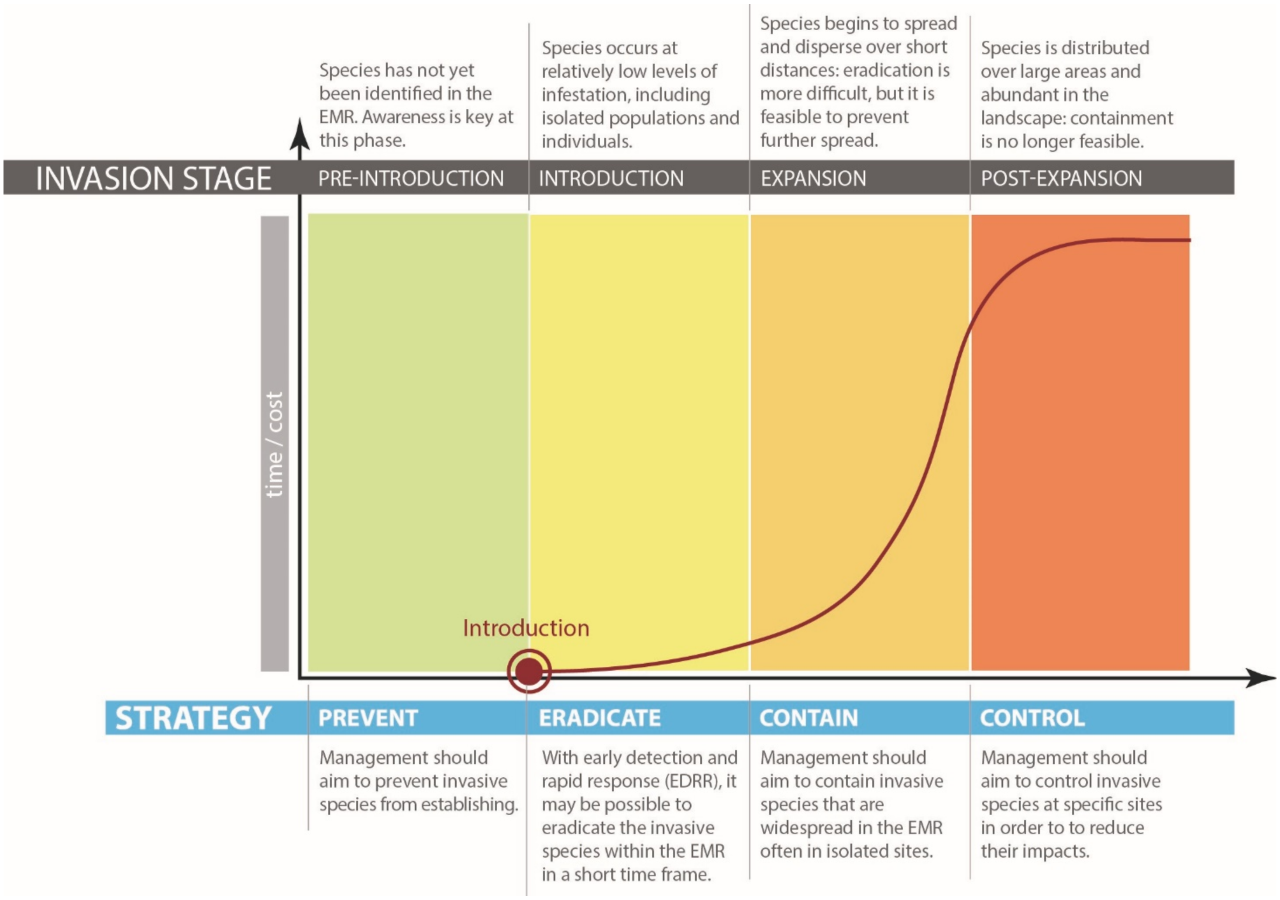

Figure 19. Stages of invasion

There is often lag time observed between when a species appears on a landscape and when it starts exponentially expanding. It is hypothesized that this may frequently represent the time it takes for the invader to evolve to fit the new habitat (Clements & Ditommaso, 2011). Concurrent with changing climate conditions, many invasive species populations in the EMR may be developing adaptations that will lead to rapid population growth in the future. This underscores the importance of early detection and rapid response to new invasive species in the region.

6.2 Predicting Invasive Species and Pest Concerns

The reasons a particular species will successfully establish and spread depend both on the existing ecosystem structure and a unique set of site factors and conditions. **This makes it very difficult to predict the outcome of specific introductions** (Parmesan & Yohe, 2003; Smith, et al., 2012; Walther, et al., 2009; Jamieson, Trowbridge, Raffa, & Lindroth, 2012; Robinet & Roques, 2010). Chai et al. (2014) assessed the threat from 16 invasive plant species found in neighbouring provinces and states moving into Alberta under modelled climates. The comprehensive assessment used a combination of an invasiveness ranking system, climate matching, and habitat suitability modelling. Their research suggests that by the 2050s Alberta, particularly in the south, will be highly suited to invasion by giant knotweed (*Fallopia sachalinensis*), tamarisk (*Tamarix chinensis*), and alkali swainsonpea (*Sphaerophysa salsula*).

Given the myriad of factors involved in predicting whether a species will both arrive and successfully invade a new landscape, and given the uncertainty of predicting how a particular species will respond to climate change, we have taken the following approach to highlighting the top species of concern for the region:

- Top invasive species and pests of **current concern** are based largely on the number of mentions from the EMR staff survey combined with the species targeted in EMR municipal Integrated Pest Management Plans.

- Top invasive species and pests of **future concern**: Given that facilitated dispersal is the main driver of invasive species introduction, we looked at species present in neighbouring jurisdictions which are currently designated high risk/high priority for management. This includes BC, Saskatchewan, and Montana. Based on the results of our climate analogue analysis of Edmonton's future climate we also looked at invasive species present in North Dakota and Minnesota (the region's of Edmonton's future climate analogue cities) which are currently designated high risk/high priority for management. Species had to have habitat types which exist in the EMR and have impacts of consequence for the EMR in order to be included.

It should be emphasized that 'species of concern' lists do not quantify actual risk to the region. A risk assessment would take an in-depth objective examination of a variety of characteristics (e.g. ecological factors, social and economic factors, biological characteristics, distribution characteristics, feasibility of control[2]), in order to determine the relative risk a specific species poses to the region.

The results of the exercise to determine species of current and future concern are provided in Tables 3 (invasive plants), 4 (invasive animals), 5 (insect pests), and 6 (plant diseases). Each table provides the following information:

1. Stage of infestation (approximation based on available information) or nearest known occurrence to the EMR

2. Habitat type in the EMR (or target species in the case of insect pests and plant diseases)
    a. Natural forest
    b. Urban forest
    c. Grasslands/open range
    d. Shrubland
    e. Riparian
    f. Aquatic

[2] Two example invasive species risk assessments: Invasiveness Ranking Tool for Non-Native Plants of Alaska (USDA Forest Service, 2008); Minnesota's Top Invasive Threats (University of Minnesota, 2018); the Alberta government uses the Invasive Species Risk Assessment Tool (RAT), however the tool has not been found to be accessible online.

3. Type of impact in the EMR
    a. Agricultural
    b. Ecological
    c. Infrastructure
    d. Recreation
    e. Public health/safety

4. Regulatory status in Alberta:
    a. Nox.Weed: noxious weed Alberta *Weed Control Act*
    b. Proh.Nox.Weed: prohibited noxious weed under the Alberta *Weed Control Act*
    c. Prop.Proh.Nox.Weed: proposed prohibited noxious weed Alberta *Weed Control Act*
    d. Pest.Fish.Act: pest under the Alberta *Fisheries Act*
    e. Pest.Agri.Pest.Act: pest under the Alberta *Agricultural Pests Act*

5. List of provinces or states where species is a priority for management (limited to BC, SK, MO, ND, MN)

Information Sources for Tables 5-6 include:

- Integrated Pest Management Plans: St. Albert, Leduc, Devon, Red Deer, Calgary
- EMR municipal websites
- Canada, BC, Alberta government websites
- Alberta Invasive Species Council Factsheets
- Invasive Species Council of British Columbia Factsheets
- Alberta Native Plant Council Rogues Gallery
- EDDMapS Alberta
- Montana Management Assessment of Invasive Species (Creative Resource Strategies, 2016)
- North Dakota Department of Agriculture – Weed Survey Report 2018 (North Dakota Department of Agriculture, 2018)
- Minnesota’s Top Invasive Threats (University of Minnesota, 2018)
- Minnesota Noxious Weed List (Minnesota Department of Agriculture, 2019)

Table 3. Invasive plants of concern to the EMR.

Common name (aquatic species)	Scientific name	Stage of infestation or nearest known occurrence	Habitat type	Type of impact	Regulatory status (Alberta)	Jurisdiction(s) where designated a priority species
CURRENT CONCERNS						
Canada thistle	*Cirsium arvense*	Post-expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	MO; MN
Caragana (Siberian peashrub)	*Caragana arborescens*	Introduction	Shrubland; forest	Ecological		
Common buckthorn	*Rhamnus cathartica*	Expansion	Shrubland	Ecological	Proh.Nox.Weed	
Common burdock	*Arctium minus*	Post-expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	ND
Common reed	*Phragmites australis subsp. australis*	Introduction	Aquatic/Riparian	Ecological; Agricultural Infrastructure; Public health/safety	Pest.Fish.Act	MO; MN
Common tansy	*Tanacetum vulgare*	Post-expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	MO; MN
Field scabious	*Knautia arvensis*	Post-expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	
Flowering rush	*Butomus umbellatus*	Introduction	Aquatic	Ecological; Recreation	Proh.Nox.Weed Pest.Fish.Act	MO
Garlic mustard	*Alliaria petiolata*	Introduction	Forest	Ecological	Proh.Nox.Weed	BC; MN
Himalayan balsam	*Impatiens glandulifera*	Introduction	Riparian	Ecological	Proh.Nox.Weed Pest.Fish.Act	BC
Japanese knotweed	*Fallopia japonica*	Introduction	Various	Ecological; Infrastructure	Proh.Nox.Weed	BC; MN
Jimsonweed	*Datura stramonium*	Introduction	Open grassland/range	Ecological; Agricultural; public health/safety	Prop.Proh.Nox. Weed	
Leafy spurge	*Euphorbia esula*	Post-expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	MO; MN
Orange hawkweed	*Pilosella aurantiaca*	Introduction	Open grassland/range	Ecological; Agricultural	Proh.Nox.Weed	BC; MO
Perennial sow thistle	*Sonchus arvensis*	Expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	
Purple loosestrife	*Lythrum salicaria*	Introduction	Riparian	Ecological	Proh.Nox.Weed Pest.Fish.Act	BC

Common name (💧 aquatic species)	Scientific name	Stage of infestation or nearest known occurrence	Habitat type	Type of impact	Regulatory status (Alberta)	Jurisdiction(s) where designated a priority species
Scentless chamomile	*Tripleurospernum inodorum*	Post-expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	ND
Toadflax, Dalmatian and yellow	*Linaria dalmatica* *Linaria vulgaris*	Post-expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	MO
White cockle	*Silene latifolia Poir. ssp. alba*	Post-expansion	Open grassland/range	Ecological; Agricultural	Nox.Weed	
FUTURE CONCERNS						
Absinthe wormwood	*Artemisia absinthium*	Montana, Saskatchewan	Open grassland/range	Ecological; Agricultural		
Alkali swainsonpea	*Sphaerophysa salsula*	Montana, Saskatchewan	Open grassland/range	Ecological; Agricultural	Prop.Proh.Nox. Weed	
Chinese Tamarisk	*Tamarix chinensis*	Montana	Riparian	Ecological	Proh.Nox.Weed	
Curly leaf pondweed 💧	*Potamogeton crispus*	BC, Montana	Aquatic	Ecological; recreation	Pest.Fish.Act	MO; ND; MN
Eurasian watermilfoil 💧	*Myriophyllum spicatum*	BC, Montana	Aquatic	Ecological; recreation	Proh.Nox.Weed Pest.Fish.Act	BC; MO; ND; MN
Giant hogweed	*Heracleum mantegazzianum*	BC	Various	Ecological; public health/safety	Proh.Nox.Weed	BC
Hydrilla 💧	*Hydrilla verticillata*	Washington, Great Lake states	Aquatic	Ecological; recreation	Pest.Fish.Act	MO; MN
Knotweed, Bohemian and giant	*Fallopia x bohemica* *Fallopia sachalinensis*	BC, Montana	Various	Ecological; infrastructure	Proh.Nox.Weed	BC
Palmer amaranth	*Amaranthus palmeri*	North Dakota	Open grassland/range	Ecological; Agricultural		MN
Saltcedar	*Tamarix ramosissima*	Montana	Riparian	Ecological	Proh.Nox.Weed	MO; ND

Table 4. Invasive animals of concern to the EMR.

Common name (💧 aquatic species)	Scientific name	Stage of infestation or nearest known occurrence	Habitat type	Type of impact	Regulatory status (Alberta)	Jurisdiction(s) where designated a priority species
CURRENT CONCERNS						
Crayfish 💧	*Oronectes spp.*	Introduction	Aquatic	Ecological		MO; MN
Goldfish 💧	*Carassius auratus*	TBD	Aquatic	Ecological		MN
Koi 💧	*Cyprinus carpo*	TBD	Aquatic	Ecological		MN
Norway rat	*Rattus norvegicus*	Introduction	Various	Agricultural; ecological; public health/safety	Pest.Agri.Pest .Act	
Prussian carp (suspected; genetic testing underway)	*Carassius gibelio*	TBD	Aquatic	Ecological		MN
Threespine stickleback 💧	*Gasterosteus aculeatus*	TBD	Aquatic	Ecological		
Wild boar	*Sus scrofa*	Expansion	Open grassland/range Shrubland	Agricultural; ecological; public health/safety	Pest.Agri.Pest .Act	SK
FUTURE CONCERNS						
American bullfrog 💧	*Lithobates catesbeianus*	Montana; BC (Okanagan)	Aquatic	Ecological		BC; MO
Asian carp (bighead, black, silver) 💧	*Hypophthalmichthys nobilis* *Mylopharyngodon piceus* *Hypophthalmichthys harmandi*	Minnesota	Aquatic	Ecological	Pest.Fish.Act	MN
Asian clams 💧	*Corbicula fluminea*	Ontario, including Great Lakes	Aquatic	Ecological; infrastructure	Pest.Fish.Act	MO
Black bullhead catfish 💧	*Ameiurus melas*	Fort McMarray	Aquatic	Ecological		
Channeled applesnail 💧	*Pomacea canaliculata*	TBD	Aquatic	Ecological; agricultural	Pest.Fish.Act	

Common name (💧 aquatic species)	Scientific name	Stage of infestation or nearest known occurrence	Habitat type	Type of impact	Regulatory status (Alberta)	Jurisdiction(s) where designated a priority species
Faucet snail 💧	*Bithynia tentaculata*	Montana; Great Lakes	Aquatic	Ecological; infrastructure; recreation	Pest.Fish.Act	MN
Jumping worms 💧	*Amynthas spp.*	Minnesota	All terrestrial habitat	Agricultural; Ecological		MN
New Zealand mudsnail 💧	*Potamophyrgus antipodarum*	Great Lakes; BC (west coast)	Aquatic	Ecological		MO
Northern snakehead 💧	*Channa argus*	Virginia/Arkansas	Aquatic	Ecological		MN
Round goby 💧	*Neogobius melanostomus*	Ontario, including Great Lakes	Aquatic	Ecological	Pest.Fish.Act	MN
Spiny water flea 💧	*Bythotrephes longimanus*	Minnesota; Great Lakes	Aquatic	Ecological; recreation	Pest.Fish.Act	MN
Zebra and quagga mussels 💧	*Dreissena polymorpha* *Dreissena rostriformis bugensis*	Montana; Winnipeg	Aquatic	Ecological; infrastructure; recreation	Pest.Fish.Act	BC; SK; MO, ND; MN

Table 5. Insect pests of concern to the EMR.

Common name	Scientific name	Stage of infestation or nearest known occurrence	Habitat type	Host species	Regulatory status (Alberta)	Jurisdiction(s) where designated a priority species
CURRENT CONCERNS						
Cottony ash psyllid	*Psyllopsis discrepans*	Post-expansion	Urban forest	Ash		
Elm bark beetle, banded	*Scolytus schevyrewi*	Introduction	Urban forest	Elm		
Elm bark beetle, European	*Scolytus multistriatus*	Post-expansion	Urban forest	Elm		MN
Elm bark beetle, native*	*Hylurgopinus rufipes*	N/A	Urban forest	Elm		
European elm scale	*Gossyparia spuria*	Post-expansion	Urban forest	Elm		
Forest tent caterpillar*	*Malacosoma disstria*	N/A	Natural and urban forest	Aspen and other deciduous spp.		
Gypsy moth, Asian and European	*Lymantria dispar asiatica* *Lymantria dispar dispar*	Introduction	Natural and urban forest	Deciduous spp.	Pest.Agri.Pest .Act	BC; MO; MN
Lilac/ash borer*	*Podosesia syringae*	N/A	Urban forest	Ash and lilacs		
Poplar borer*	*Saberda calcarata*	N/A	Natural and urban forest	Poplars/aspen		
Western spruce budworm*	*Choristoneura occidentalis*	N/A	Natural forest	Douglas-fir		
Yellow-headed spruce sawfly*	*Pikonema alaskensis*	N/A	Natural and urban forest	Spruce		
FUTURE CONCERNS						
Asian longhorned beetle	*Anoplophora glabripennis*	Mississauga, ON (controlled) Ohio	Natural and urban forest	Broad range of hosts		BC; MN
Brown marmorated stinkbug	*Halyomorpha halys*	BC (Okanagan)	Open grassland/range	Fruiting agricultural crops (170 confirmed hosts)		BC; MN
Emerald ash borer	*Agrilus planipennis*	Winnipeg	Urban forest	Ash		MO; MN

Common name	Scientific name	Stage of infestation or nearest known occurrence	Habitat type	Host species	Regulatory status (Alberta)	Jurisdiction(s) where designated a priority species
Japanese beetle	*Popillia japonica*	Vancouver/ Montana	Urban areas	Turf grass, over 300 plant species (incl. agricultural crops)		BC; MO; ND
Mountain pine beetle*	*Dendroctonus ponderosae*	Lac Ste. Anne County	Natural forest	Pine		BC
Sirex woodwasp	*Sirex noctillo*	Southern Ontario	Natural forests	Spruce, pine, true fir		MN
Spotted wing drosophila	*Drosophila suzukii*	BC, Manitoba	Open grassland/range	Agricultural fruit crops		MN

* Native species

Table 6. Plant diseases of concern to the EMR.

Common name	Scientific name	Stage of infestation or nearest known occurrence	Habitat type	Host species	Regulatory status (Alberta)	Jurisdiction(s) where designated a priority species
CURRENT CONCERNS						
Black knot*	*Dibotryon morbosum*	N/A	Urban forest	Cherry family		
Bronze leaf disease	*Apioplagiostoma populi*	Post-expansion	Natural and urban forest	Poplar and aspen		
Canker	*Cytospora*	Post-expansion	Urban forest	Various tree species		
Clubroot	*Plasmodiophora brassicea*	Post-expansion	Open grassland/range	Canola, mustard, cabbage family	Pest.Agri.Pest .Act	
Fire blight*	*Erwinia amylovora*	N/A	Natural and urban forest	Rose family trees and shrubs		
Fusarium head blight	*Fusarium spp.*	Post-expansion	Open grassland/range	Wheat, barley, oats, rye		MN
Spruce needle rust	*Chrysomyxa ledi*	TBD	Natural and urban forest	Spruce		
FUTURE CONCERNS						
Dutch elm disease (DED)	*Ophiostoma ulmi* *Ophiostoma himal-ulmi* *Ophiostoma novo-ulmi*	Saskatchewan and Montana	Urban forest	Elm	Pest.Agri.Pest .Act	MO; MN

* Native species

7.0 Conclusions and recommendations for management

In summary, the EMR's vulnerability to invasive species and pests is anticipated to increase with climate change, leading to increased ecological, social, and economic impacts. Human facilitated dispersal will remain the primary driver of introduction and spread. However, climate change may increase the potential for introduction of new species, the expansion of existing species, and alter the effectiveness of control strategies through the following mechanisms:

1. Changes in temperature and precipitation which invasive species will be able to adapt to more quickly. This will enable them to reproduce earlier and more often, putting native species at a disadvantage. These changes will also remove climatic barriers for some species not previously able to tolerate the EMR climate.
2. Elevated CO_2 is expected to favour the growth rates of some invasive plants and may decrease the effectiveness of herbicide in some cases.
3. Increased frequency and intensity of disturbance may provide more opportunities for invasion and assist in dispersal.
4. Increased stress and mortality of native species and ecosystems may favour that competitive advantages of many invasive species which have wider tolerances than native species. Pests may take advantage of stress and weakened host species.

These effects are more certain for terrestrial and aquatic invasive plant and animal species than they are for insect pests and plant diseases since the impact of climate change on host species and the potential for interrupted synchronicities of lifecycle stages add a level of complexity.

Although changing climatic conditions may harm certain invasive species and pests in specific circumstances, the overwhelming trend is expected that warming will remove climatic barriers previously inhibiting growth or survival, that slow and sudden onset climate impacts will provide new and more frequent opportunities to establish and spread, and that native species are less likely to be able to adapt as quickly as non-native, invasive species.

Alberta currently has a relatively low number of invasive species and pests in comparison to eastern Canada and the northeastern US. Neighbouring jurisdictions are host to many high-risk species that could have devasting impacts in the EMR. Given that climate change is likely to increase the risk of new introductions and expand the invasion of existing invasive species and pests, the optimal strategy in the EMR should be a focus on prevention backed by a coordinated and cohesive management approach across all EMR municipalities.

It is important to note that there is a high level of uncertainty in both the global climate models that predict future climate, as well as the assessment of invasive species and pests impacts and their relative risk and vulnerability to the EMR. Due to the complexity of possible interactions and the unexpected possibilities that could occur as change advances, it is essential to continue to monitor and study climate change impacts on invasive species and pest. Adaptive management must underpin management responses to ensure impacts are not missed or misunderstood, as well as enabling rapid course corrections if required.

Municipalities in the EMR have begun to plan for long-term changes to the region's climate (Chai & Staley, 2018). The State of Knowledge Summary identifies many plans either currently existing or under development in the region that address aspects of climate change (All One Sky Foundation, 2018). Although it is now customary for communities to consider climate change in strategic planning, the field of climate adaptation remains novel for many and requires new management tools (Chai, Nixon, Zhang, & Nielsen, 2014).

See Phase 2 report for recommendations for management to reduce vulnerability to the climate impacts of concern.

8.0 Key to Acronyms

- BMP Best Management Practice
- CANUFNET Canadian Urban Forest Network
- CFIA Canadian Food Inspection Agency
- CMD Climate Moisture Deficit
- CMI Climate Moisture Index
- DED Dutch Elm Disease
- EAB Emerald Ash Borer
- EDRR Early Detection Rapid Response
- EMR Edmonton Metropolitan Region
- GDD Growing Degree-Days
- IPM Integrated Pest Management
- IPMP Integrated Pest Management Plan
- ISA International Society of Arboriculture
- IVMAA Industrial Vegetation Management Association of Alberta
- LANTA Landscape Alberta Nursery Trades Association
- MAT Mean Annual Temperature
- NGO Non-Governmental Organization
- PVMA Professional Vegetation Managers Association
- StopDED Society to Prevent Dutch Elm Disease

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Appendix 1 Staff Survey Results

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
Please list the invasive species and pests of top concern for your jurisdiction: **Plants**	buckthorn Canada thistle caragana common burdock common tansy field scabious garlic mustard Himalayan balsam common Japanese knotweed leafy spurge orange hawkweed perennial sow thistle scentless chamomile white cockle yellow toadflax	Canada thistle common tansy purple loosestrife	Canada thistle common tansy Himalayan balsam mountain ash scentless chamomile toadflax	bird's foot trefoil caragana common burdock common tansy common toadflax creeping thistle field scabious flowering rush garlic mustard Himalayan balsam leafy spurge Manitoba maple mountain ash orange hawkweed ox-eye daisy perennial sow thistle purple loosestrife quack grass reed canary grass scentless chamomile		Common reed common tansy Flowering rush garlic mustard Japanese knotweed leafy spurge nodding thistle spotted knapweed Yellow flag iris	Canada thistle Scentless chamomile	scentless chamomile Himalayan balsam cow cockle purple loosestrife

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
				smooth brome tufted vetch watermilfoil				
Please list the invasive species and pests of top concern for your jurisdiction: **Animals**	feral cats goldfish mice rabbits raccoons rats three-spine stickleback	badgers beavers coyotes Gophers gulls pigeons rabbits voles	beavers rabbits Richardson ground squirrels voles	coyotes goldfish magpies Norway rats pocket gophers Prussian carp raccoons snails snakehead three-spine stickleback wild boar zebra mussels		Canada geese feral cats goldfish Prussian carp wild boar zebra/quagga mussels	beavers coyotes mice rabbits voles	gophers
Please list the invasive species and pests of top concern for your jurisdiction: **Insect pests**	aphids Asian long-horned beetle Aspen tortrix cottony psyllid elm bark beetle elm scale emerald ashborer forest tent caterpillar gypsy moth lilac ashborer oyster scale poplar borer	elm scale emerald ashborer poplar and willow borer yellowheaded spruce sawfly	poplar and willow borer spruce budworm yellowheaded spruce sawfly	ash leaf caterpillar ash plant bug cottony psyllid elm bark beetle emerald ashborer lilac ash borer mountain pine beetle poplar borer wasps		emerald ashborer mountain pine beetle pea leaf weevil ticks	ants spruce budworm wasps	mosquitos ticks yellow headed sawfly ash psyllid

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
Please list the invasive species and pests of top concern for your jurisdiction: **plant diseases**	black knot Canker Clubroot Dutch elm disease Fire blight Pseudomonu syringae Spruce needle rust	Black knot Dutch elm disease	Black knot	Black knot Bronze leaf disease Dutch elm disease Fire blight		Black knot Bronze leaf disease Clubroot Fusarium	Black knot Fire blight	Black knot Bronze leaf disease
Whose job is it to manage invasive species and/or pests?	integrated pest management (pests) Natural areas operations (plants) Planning and Development Services Pest Management and Forestry Parks and Roads (City Operations) Community Standards & Neighborhoods Weed Inspectors Infrastructure Operations Open Space Operations	Public Services - Parks Department	Parks and Open Spaces Operations Parks – Public Works	Public Works Department Parks and open Spaces Sturgeon River and Natural Areas Coordinator Development Engineering Capital Projects	Parks Turf and Horticulture	Recreation Parks and Culture Transportation and Agricultural Services	Parks Department Peace Officers (enforcement)	Parks Department

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
	Department for Public land Environmental Services Lab							
Does this same department manage pests of urban trees? If no, which department manages tree pests?	Pest Operations Integrated Pest Management Urban Forestry Transportation and Agricultural Services Citizen Services Parks and Roads – Forestry Section	Public Services - Parks Department	Parks and Open Spaces Operations Parks – Public Works	Public Works Department Parks and open Spaces	Parks Turf and Horticulture	Recreation Parks and Culture Transportation and Agricultural Services	Parks Department Peace Officers (enforcement)	Parks Department
Does your jurisdiction regulate invasive species and pests through bylaws or enforce any aspect of the Weed Control Act?	Yes All IPM is done in accordance with Weed Control Act. City of Edmonton IPM Policy relates back to Weed Control Act and also a City bylaw to manage lands.	Yes	Yes	Yes City of St. Albert has an integrated pest management plan and an unsightly property bylaw.		Yes	Yes Control of Weeds and Unmaintained Vegetation on Premises or Property by Peace officers.	Yes Working closely with our bylaw and weed inspectors.

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
	Biologists with Pest Management Lab act as Inspectors under the Agricultural Pest Act, are certified as Inspectors for Watercraft Inspection for Zebra/Quagga mussels, and as Inspectors under Community Standards Bylaw 14600 Municipal Enforcement Officers act as authority for rat control under Agricultural Pest Act	By-law can enforce the Community Standards By-law or the Weed Control Act. The City also has a tree inspector that is used for new development plantings - they have the ability to approve or reject the stock. The Parks department uses Clean Certified Stock in all their plantings.				Weed inspector program - inspects all public and private lands for noxious and restricted weeds, respond to and follow up on complaints, issue weed notices in accordance with the Weed Control Act and follow through on compliance Rural Roadside Vegetation Control Program Annual Weed Control Program		

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
Does your jurisdiction have pesticide or herbicide related bylaws that impact the control of invasive species and pests?	Yes	No	No	Yes		No	No	No
Does your jurisdiction have any guidebooks, management plans, strategies or best practices related to invasive species and pests?	Yes C501 Integrated Pest Management Plan "Operational Management of Integrated Pest Management in Open Space Operations" Natural Areas Management Plan	Yes Integrated Pest Management Plan Urban Forestry Plan City Landscaping Guidelines	No	Yes Integrated pest Management Plan		Yes Weed and Pest Control policy Rural Roadside Vegetation Control Program Country Talk Newsletter Biosecurity Guide for Light and Heavy industrial Operations	Yes Urban Forest Management Plan	Yes Integrated pest Management Plan
Does your jurisdiction have any inventory data related to invasive species and pests?	Yes Forestry inventory Prohibited Weed Control Mapping EDDMapS Alberta	Yes City GIS Inventory Cityworks Contractor Data	Maybe Forest Management Inventory	Yes City GIS Database EAB Surveillance		Yes Invasive Species Mapping	Yes Edmonton Beetle Trap Data	No
Does your jurisdiction collaborate or partner with any invasive species and pest organizations or groups?	Yes Alberta Invasive Species Council International Society of Arboriculture	Yes Alberta Invasive Species Council Regional Integrated Pest Management Group	Yes IPM Group Capital Region	Yes Alberta Invasive Species Council StopDED LANTA ISA		Yes Alberta Invasive Species Council Alberta Agriculture and Forestry	Yes Capital Region Integrated Pest Management	Yes Dutch Elm Society Lanta Organizations

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
	StopDED CFIA			PVMA		Alberta Environment And Parks Professional Vegetation Managers Association		
Does your jurisdiction provide or receive training or workshops with regard to management of invasive species or pests?	Yes Weed pull workshops Conferences and training sessions IPM training orientation Integrated Pest Management workshops Public education events Critical pest training (Pest Management Lab) IVMAA Staff ID training	Yes Olds College workshops StopDED meetings City regional IPM meetings ISC conferences	Yes StopDED workshops PVMA CANUFNET ISA	Yes ISC conferences Employee orientation training		Yes Alberta training workshops Public outreach events Conferences and workshops	Yes Capital Region Integrated Pest Management trainings (twice annually)	Yes Arboriculture Canada training & education limited, ISA local chapter, Lanta Workshops
Do any of the following people carry out invasive species or pest control? (Staff, Contractors, Stewardship/Community Volunteers, Other)	Staff - mechanical and chemical weed control	Staff - conduct spot treatment applications of pesticides and herbicides.	Staff – herbicide application, manual control, monitoring	Staff – chemical and manual control Contractors - chemical and manual control		Staff – chemical and manual control, monitoring	Staff – invasive mapping, chemical and manual control Contractors	Staff Contractors

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
	Contractors - administer pest chemical applications, tree removals Volunteers - Staff coordinate volunteer events for weed pulling	Contractors - hired to apply the pesticides and herbicides on the large scale	Contractors - herbicide application, manual control, monitoring	Stewardship/Community Volunteers – annual weed pulling events		Contractors – chemical control, aquatic chemical control Stewardship/Community Volunteers – annual weed pull events		
Please let us know if you have any additional comments		data on trends or appropriate species, local information on species to avoid, or species that should be re-established. A list of certified nurseries in the area would be helpful. A forecast of future issues. We are interested in seeing the survey responses of each municipality.					The Edmonton capital region has a great collaboration of municipalities who get together to talk about current issues related to integrated pest management twice a year.	

Survey question	Summary of Responses							
	Edmonton	Leduc	Spruce Grove	St Albert	Stony Plain	Strathcona	Devon	Wetaskiwin
		A communication tool/one page fact sheet to present to Council would be helpful i.e. economic impact, what would the City look like if we lost 30-40% of boulevard trees to pest/disease						

Appendix 2 Summary of Relevant Policy and Planning Documents and Initiatives for Invasive Species and Integrated Pest Management

Municipalities (in order of population)	Relevant Invasive Species and Pest Policy, Planning or Initiatives
City of Edmonton	1. Integrated Pest Management Policy (2019) 2. Natural Areas Management Plan 3. Urban Forest Management Plan (2012) 4. Site specific plans 5. Management plans from other jurisdictions and federal and provincial emergency response plan 6. Resources and information on city website are provided for European elm scale, mosquitoes and weeds.
Strathcona County	1. Best practices manual for clubroot 2. Weed and pest control policy 3. Rural roadside vegetation control program 4. Use BMPs from Alberta Invasive Species Council 5. Strathcona County has been involved in various capacities with the North Saskatchewan Watershed Alliance since 2004 6. Resources and information on the website are provided for general weed control, flowering rush, Japanese knotweed, jimsonweed, Phragmites, Giant hogweed, ornamental invasive plants, tree pests, and animal pests
City of St. Albert	1. Integrated Pest Management Plan (2018) 2. Urban Forest Management Plan (2017) 3. Natural Areas Assessment and Management Plan (2015) 4. Invasive fish management procedure document 5. Dutch Elm Disease Bylaw 6. Unsightly Property Bylaw 7. Community Standards Bylaw 8. Landscape and Engineering Standards 9. Community events and programs such as River Edge Enhancement Project, Clean, Green River Fest, naturalization projects and Arbour Day 10. The city is part of the Sturgeon River Watershed Alliance 11. Resources and information on the website are provided for weed control
City of Spruce Grove	1. Climate Resilience Express Action Plan (2018) 2. Urban Forest Management Plan (2004) 3. The city is conducting a natural areas assessment that reviews and assesses forest stands and current management practices in natural areas 4. The city has a web page on Black Knot disease
City of Leduc	1. Integrated Pest Management Plan (2017) 2. Weather and Climate Readiness Plan (2014) 3. Urban Forest Management Plan (2010) 4. Community Standards Bylaw 995 (2018) 5. Minimum Landscape Design and Construction Standards (property owners are compelled to keep all areas free of weeds during construction)

Municipalities (in order of population)	Relevant Invasive Species and Pest Policy, Planning or Initiatives
	6. Telford Lake Master Plan (2012) describes the maintenance and protection of lake fringe vegetation and wildlife along the shores of Telford Lake 7. Guidelines for Area Structure Plans require a biophysical assessment to be conducted in order to build houses in newly developed areas 8. Leduc hosts an annual Arbour day, contributing to a greener and more attractive City 9. The City of Leduc worked with the University of Alberta on a Wildlife Corridor Study, connecting Telford and Saunders Lake 10. Resources and information on the website are provided for weed control
Town of Stony Plain	1. Land Use Bylaw (2017) 2. Municipal Development Plan (2013) 3. Environmental Stewardship Strategy (2007) 4. Regional rain barrel program 5. The town hosts Arbour Day events 6. The town participates in the Capital Region Municipal Sustainability Group
Wetaskiwin County	1. Per the 2015-2018 Strategic Plan, the city plans to 'review and update policies for environmental sustainability 2. Resources and information on the website are provided for weed, animal, and insect pest control
Town of Devon	1. Integrated Pest Management Plan (2018) 2. Urban Forest Management Plan (2015) 3. Living Together in Devon Community Standards brochure (2017) 4. Information on tree diseases (black knot and Dutch elm disease) is provided.