Let's Talk about Climate Change: Prairie and Boreal Plains Region

Office of the Chief Ecosystem Scientist

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Parks Canada Parcs Canada

Canada

Let’s Talk about Climate Change: Prairie and Boreal Plains Region

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This report is one in a series that provides a regional summary of observed and projected climate change trends and impacts facing all of Canada’s national parks, national marine conservation areas and certain national historic sites. This is an internal document to Parks Canada and is intended to encourage and inform broader conversations and support place–based actions on climate change.

The “Let’s Talk about Climate Change” series regions are defined by biogeoclimatic and operational similarities, and include: 1) Atlantic Region; 2) Quebec Region; 3) Great Lakes Region; 4) Prairie and Boreal Plains Region; 5) Mountain Region; 6) Pacific Region; 7) Northwest Region; and, 8) Arctic and Hudson Plains Region.

This report and others in the series are available at the Parks Canada Climate Change SharePoint Website: http://collaboration/sites/PD010/SitePages/Home.aspx

Contents

1. Introduction

The fifth and most recent report from the Intergovernmental Panel on Climate Change (IPCC, 2014) establishes with certainty that the Earth's climate system is warming, "and since the 1950's, many of the observed changes are unprecedented over decades to millennia". Human activity has increased atmospheric concentrations of greenhouse gas (GHG) to levels not observed in at least the last 800,000 years. Worldwide, a rapidly changing climate is having profound impact on our social-ecological systems, amplifying existing risks and creating new ones.

Canada's rate of warming is about double the global rate (even greater in the north) and the last three decades have been the warmest 30-year period in at least 1,400 years. Some of the observed changes include shifts in species distribution and abundance, glacier loss, thawing permafrost, decreasing sea ice, earlier ice break-ups, increasing wildfires, sea level rise along some coasts, changes to phenology, and an increase in extreme weather events such as heat waves, droughts, heavy rainfall and more (e.g., Lemmen *et al.*, 2016; Warren and Lemmen, 2014). The risks and impacts are felt across Parks Canada, from the ecosystems and cultural resources we protect, to the facilities and infrastructure we build and maintain, to the visitor experiences we offer - and most concerning, these impacts are projected to increase for decades to come. It is an uncertain and complex context, one which will test the adaptive capacity and effectiveness of policy, planning, and management frameworks.

To advance place-based climate response efforts, this document is one in a series of regional reports that provides accessible summary information about climate change in Canada's national parks, national marine conservation areas (NMCAs) and certain national historic sites. For some sites this will support preliminary conversations on climate change and for others the content will be eclipsed by a need for more detailed vulnerability assessments, adaptation strategies and decision support tools. Regardless, the intent is to encourage and equip individuals and sites to talk about climate change, both internally and externally, and consider the challenges in their own context.

1.1. "Natural Solution" Concept

As a lead conservation and protected area agency, and the largest federal land owner and third largest federal asset manager in the country, Parks Canada's response to climate change is a matter of importance. Part of the response will involve recognizing and positioning protected areas as a "natural solution" to climate change in regional, national and international plans and programs (e.g., Dudley *et al.*, 2010; Lopoukhine *et al.*, 2012; NAWPA, 2012).

As a "natural solution", well-designed and effectively managed protected areas:

- Mitigate climate change through the sequestration and storage of carbon in forests, coastal wetlands ("blue carbon") and other natural ecosystems.
- Protect biodiversity by providing a safe haven for species.
- Enhance connectivity and species movements within and across protected area networks.

- Provide essential ecosystem goods and services, such as clean water, erosion control, flood/storm water protection, genetic diversity, cultural opportunities, etc…
- Serve as a benchmark for climate change related research and monitoring.
- Provide a context for social learning, good governance, and adaptive management.
- Help people and communities cope by supporting sustainable and resilient economies in and around protected areas and promoting social well-being (e.g., healthy parks – healthy people).
- Demonstrate environmental stewardship through "green" design and conservation practices.
- Create and facilitate meaningful experiences that help to inspire, inform, and guide actions in response to climate change.

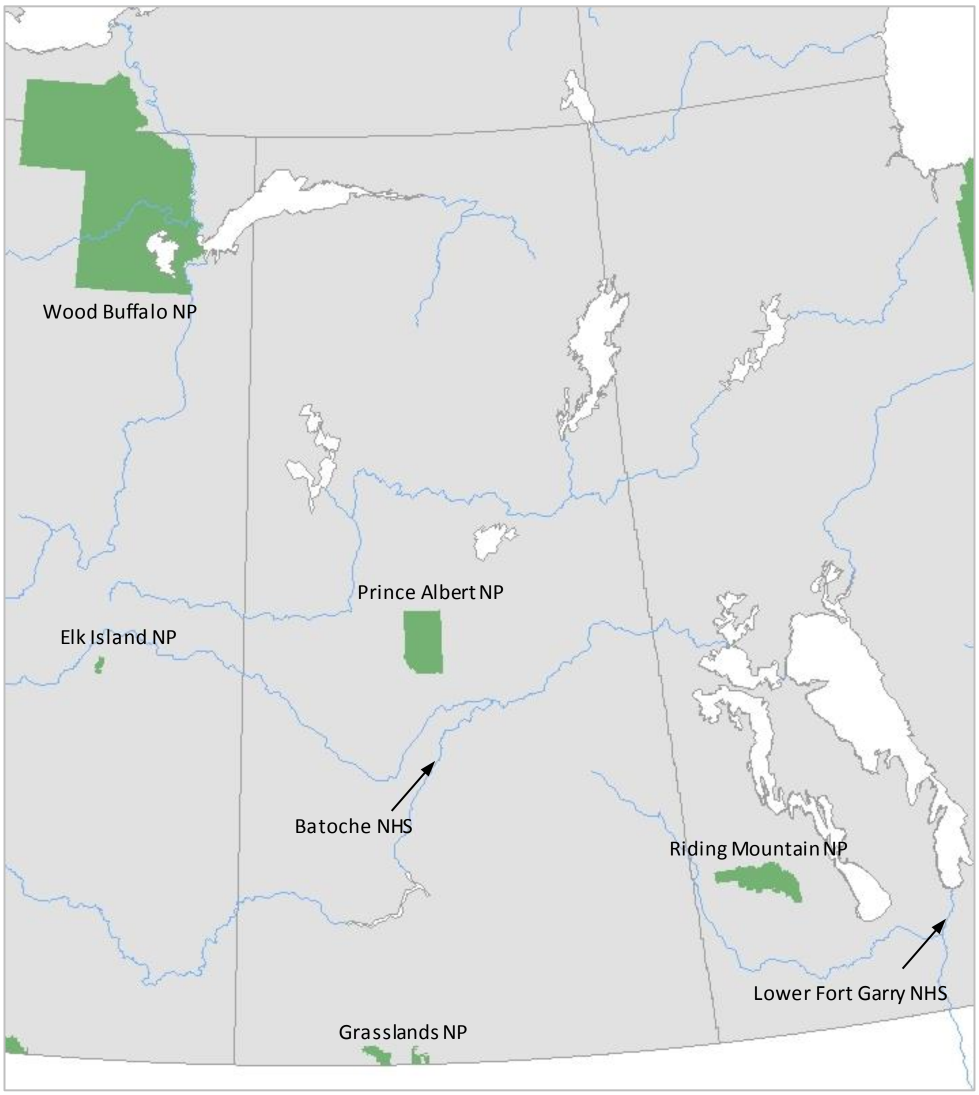


Figure 1. National Parks (NP) and National Historic Sites (NHS) included in this regional assessment.

2. Observed and Projected Climate Trends

This section provides site specific summaries of historic observed temperature and precipitation trends as well as future climate projections. These are only a subset of the climate variables available for analysis and presentation (see Appendix 1).

2.1 Methods

Historic observed mean monthly temperature and total precipitation data was accessed from the Adjusted and Homogenized Canadian Climate Data website (http://www.ec.gc.ca/dccha-ahccd) for the climatological stations within or closest to each protected area. Temperature and precipitation stations were not always in the same location and preference was given to selecting stations with the longest and most current data for a protected area. All available years were plotted and the trend was determined using a generalized linear model (R Core Team, 2014) including 95% confidence intervals. For the analysis, winter = December, January and February; spring = March, April and May; summer = June, July and August; and, autumn = September, October and November.

A table with future climate change projections was determined for the centre of each protected area. Season by season descriptions were provided to complement the earlier park-based assessments by Scott and Suffling (2000) and to help inform seasonal operations and activities. The climate projections were determined following Price *et al.* (2011) and used the average of four General Circulation Models (GCMs) and the lowest and highest Representative Concentration Pathway (RCP) GHG scenarios (Vuuren *et al.*, 2011). The RCP 2.6 (lowest) scenario assumes that we take action and GHG emissions peak in 2010-2020 and decline thereafter. The RCP 8.5 (highest) scenario assumes we take no action and emissions continue to rise throughout the 21st century. Figures 2 and 3 also include a projection based on the RCP 4.5 scenario, where emissions peak around 2040 and then decline.

2.2 Regional Climate Change Summaries

2.2.1 Physical Effects

- On average, annual air temperature for the region has increased by 2˚C since the 1950's, which exceeds the global land surface average increase of 1.2˚C (DeBeer *et al.*, 2016). The warming has been slightly greater for the nighttime versus daytime period (Vincent *et al.*, 2012). Seasonally, the greatest warming has occurred in the winter (~3.9˚C) with spring arriving as much as 5 to 20 days earlier (Vincent *et al.*, 2015). This warming trend is projected to continue and model results indicate a further increase of 2-8˚C by 2100, depending on the location and RCP scenario used.
- Extreme heat events have increased in many areas, while extreme cold events have decreased in virtually all areas (Mekis *et al.*, 2015). This trend is expected to increase, in particular the frequency, intensity and duration of heat events (IPCC, 2012). For instance, the 1 in 20 year extreme heat event is projected to become a 1 in 5 year event by mid-century (Kharin *et al.*, 2007).

- Precipitation patterns have been variable, with a general increase in total annual precipitation of ~14% (50 mm) being observed in most areas in the region (Chun *et al.*, 2013; DeBeer *et al.*, 2016; Millett *et al.*, 2009). In winter there is a clear distinction between an increase in precipitation in the north and a decrease in the south (as much as 50%). Increasing temperatures have resulted in an increase in the fraction of precipitation that falls as rain versus snow. Change in frequency and intensity of heavy rainfall events are difficult to identify at the regional scale given the highly localized nature of such events and the low density of climate stations in the region (Mekis *et al.*, 2015). However, the persistence of multi-day rainfall storms at many sites has increased and the number of single day events has decreased (Shook and Pomeroy, 2012).
- Prairie hydrology (including flood regimes) appears to be changing with a greater contribution of rain-on-snow (Buttle *et al.*, 2016; Dumanski *et al.*, 2015).
- Drought conditions appear to be variable on a decadal-scale. In 2015, severe drought conditions resumed following a few years of record wet conditions in the prairies. In the future, the southern prairies in particular are expected to have a higher likelihood of drought conditions (Bonsal *et al.*, 2013; Sushama *et al.*, 2010).
- Permafrost is sporadic in Wood Buffalo NP and there is evidence of its on-going degradation (Smith, 2010; Warren and Lemmen, 2014). Thawing permafrost is generally leading to decreased substrate stability, surface subsidence, waterlogging, thermokarst development and collapse of forested peat plateaus, as well as an associated release of GHG (e.g., Baltzer *et al.*, 2014; Walvoord and Kurylyk, 2016; Warren *et al.*, 2013).
- Snow cover duration and extent has declined in recent decades (e.g., Derksen and Brown, 2012).
- Since the mid-20th century the duration of ice cover on lakes and rivers has generally reduced and spring breakup is occurring one to several weeks earlier (Beltaos and Prowse, 2009; Prowse, 2012). This trend is expected to continue with breakup dates advancing by 1 to 3½ weeks and freeze-up dates being delayed by up to 2 weeks (Dibike *et al.*, 2012; Warren and Lemmen, 2014).
- Trends in river flow vary regionally and over time. A general increase in autumn and winter flows, especially in the more northern parts of the region, have been observed. Spring and summer flows appear to be inconsistent across the region. Future decreased flows are expected in the Athabasca River, tributaries of the Saskatchewan River and other rivers draining the eastern slopes of the Rocky Mountains (Kerkhoven and Gan, 2011; Kienzle *et al.*, 2012; Peters *et al.*, 2013; St Jacques *et al.*, 2013; St Jacques *et al.*, 2010). Increased total runoff and earlier discharge peaks are expected in the Lake Winnipeg (Upper Assiniboine) watershed (Shrestha *et al.*, 2012). The Mackenzie River shows an increasing long-term trend in its discharge, the contribution of permafrost degradation may be a factor (Dery *et al.*, 2016; Rood *et al.*, 2017).
- Adding to the complexity of climate trends, decreased river flows appear to be associated with positive phases of the Pacific Decadal Oscillation (~60year cycle) and the El Niño-Southern Oscillation, as well as with strong Aleutian lows (St Jacques *et al.*, 2014).

Mean Annual Temperature

Change from 1980-2010 Baseline

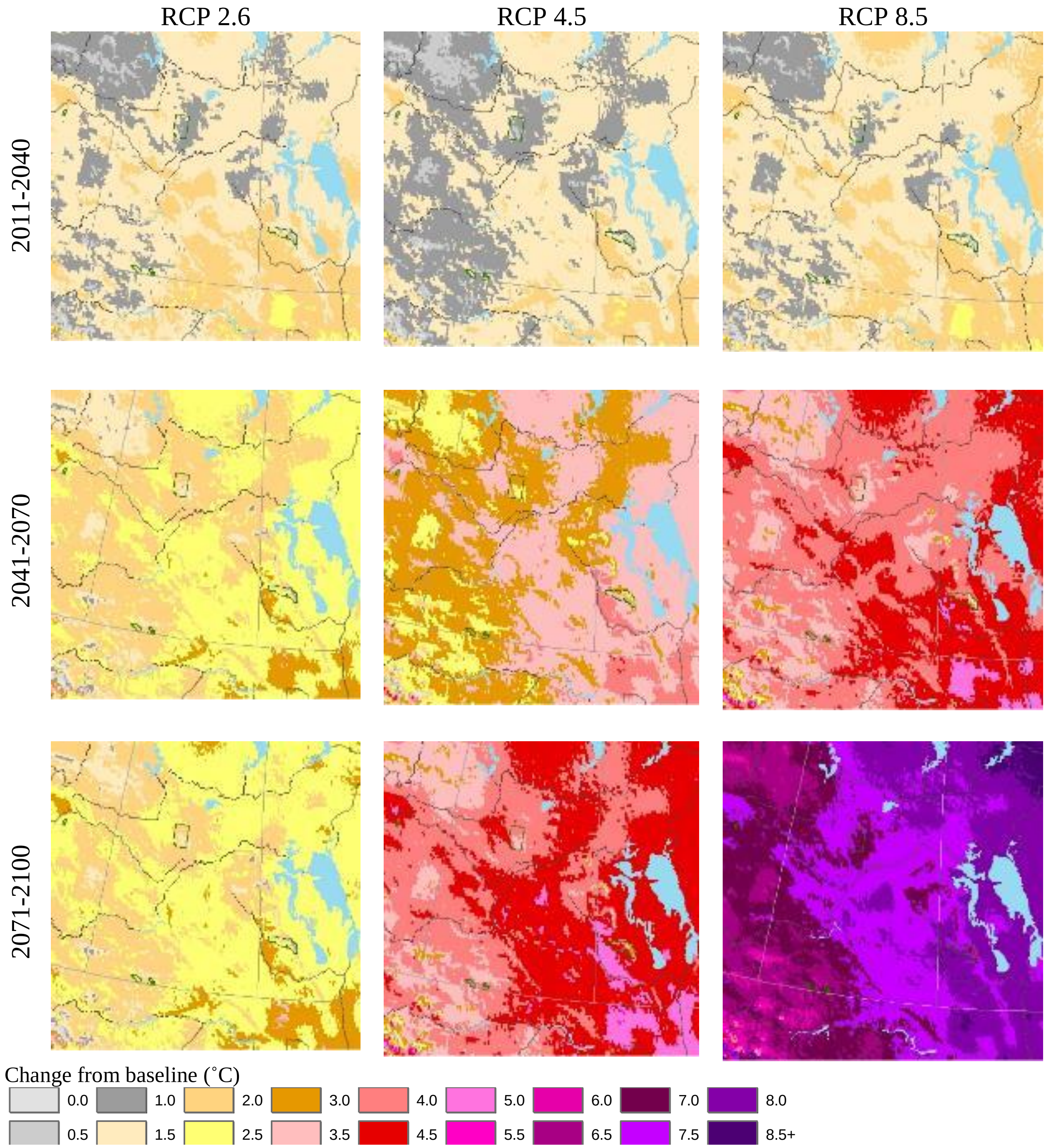


Figure 2a. Elk Island, Prince Albert, Riding Mountain and Grasslands NPs and Lower Fort Garry NHS. Temperature projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie (http://cfs.nrcan.gc.ca/projects/3).

Mean Annual Temperature

Change from 1980-2010 Baseline

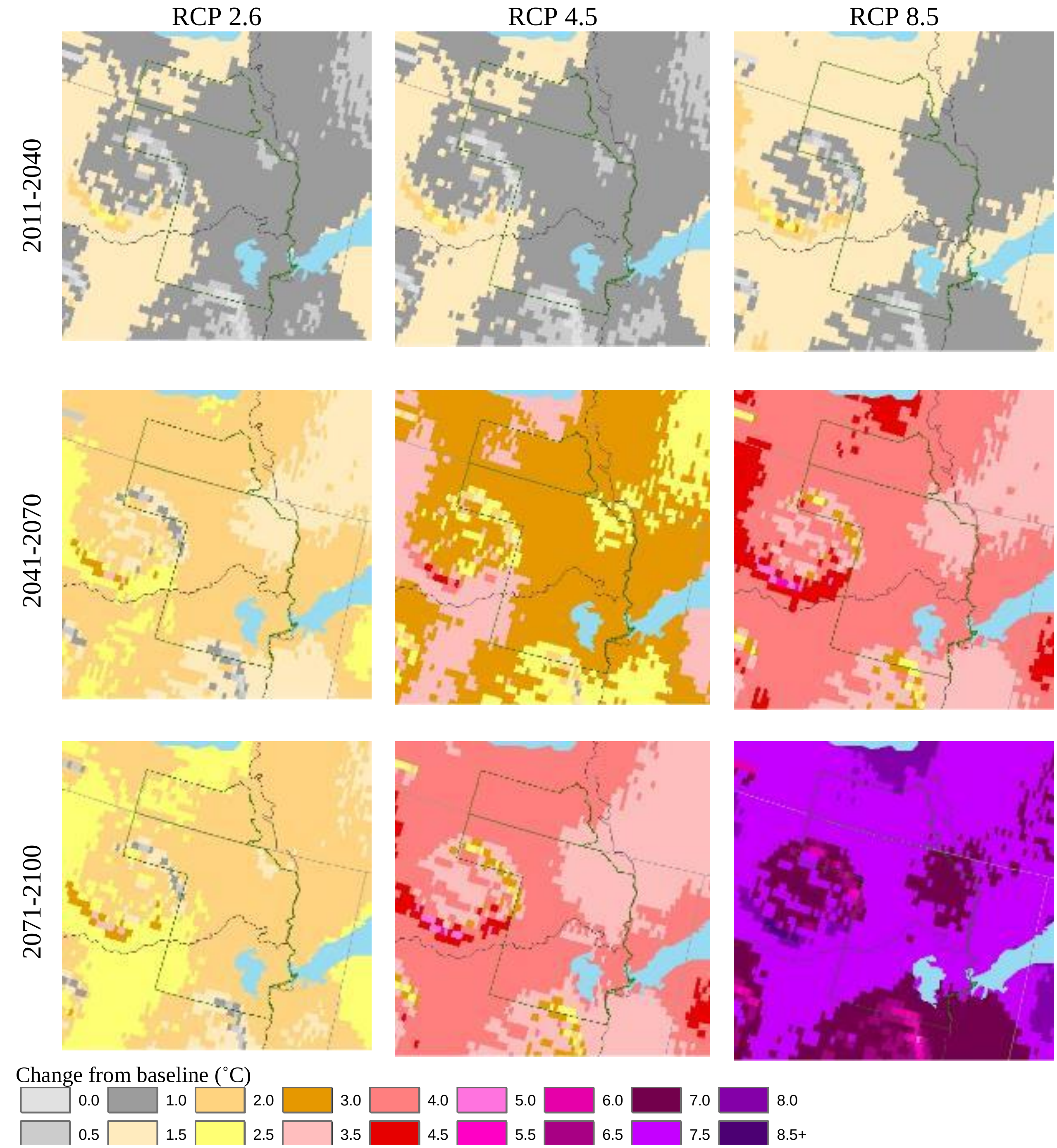


Figure 2b. Wood Buffalo NP. Temperature projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie (http://cfs.nrcan.gc.ca/projects/3).

Total Annual Precipitation

Change from 1980-2010 Baseline

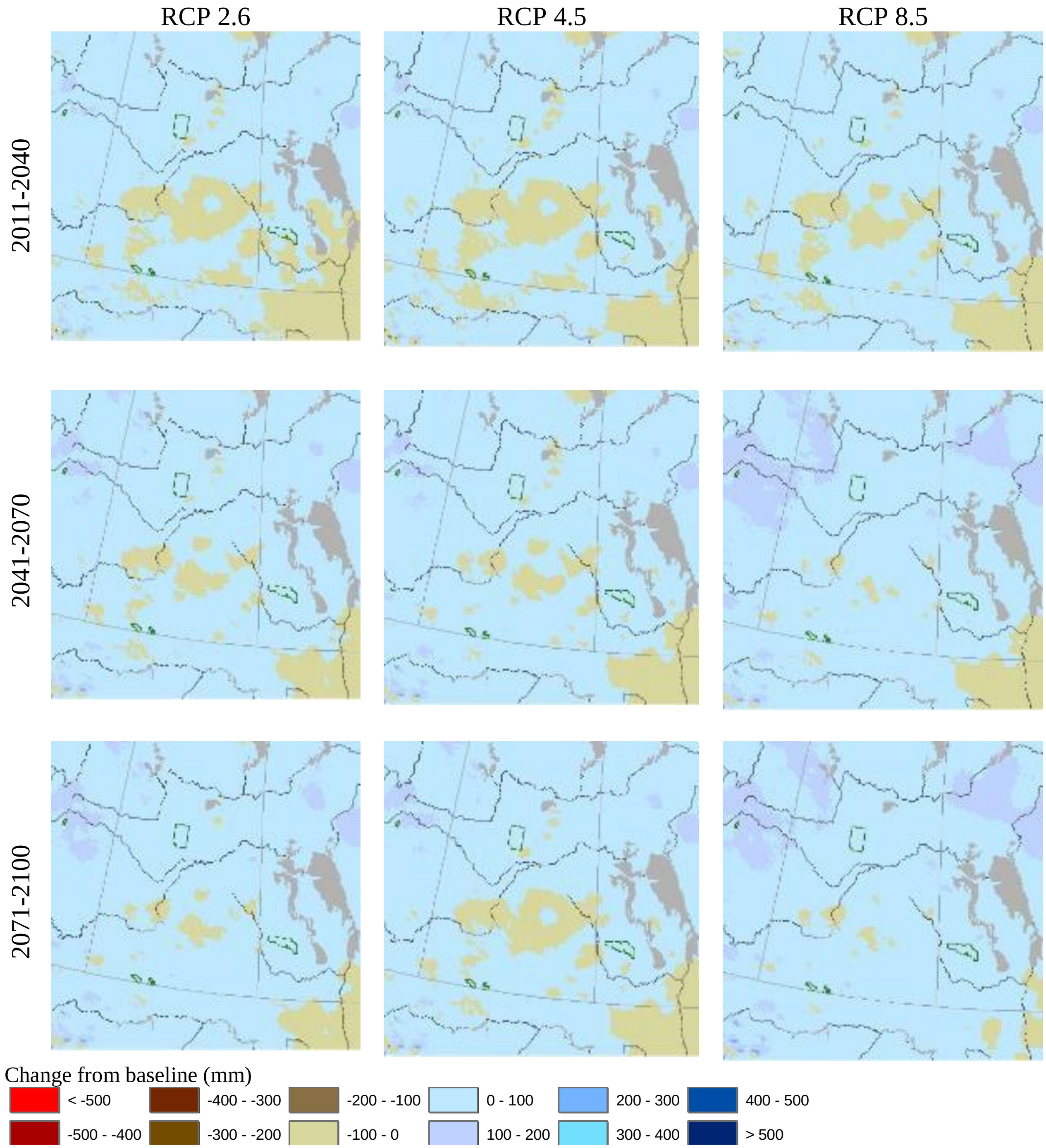


Figure 3a. Elk Island, Prince Albert, Riding Mountain and Grasslands NPs and Lower Fort Garry NHS. Precipitation projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie (http://cfs.nrcan.gc.ca/projects/3).

Total Annual Precipitation

Change from 1980-2010 Baseline

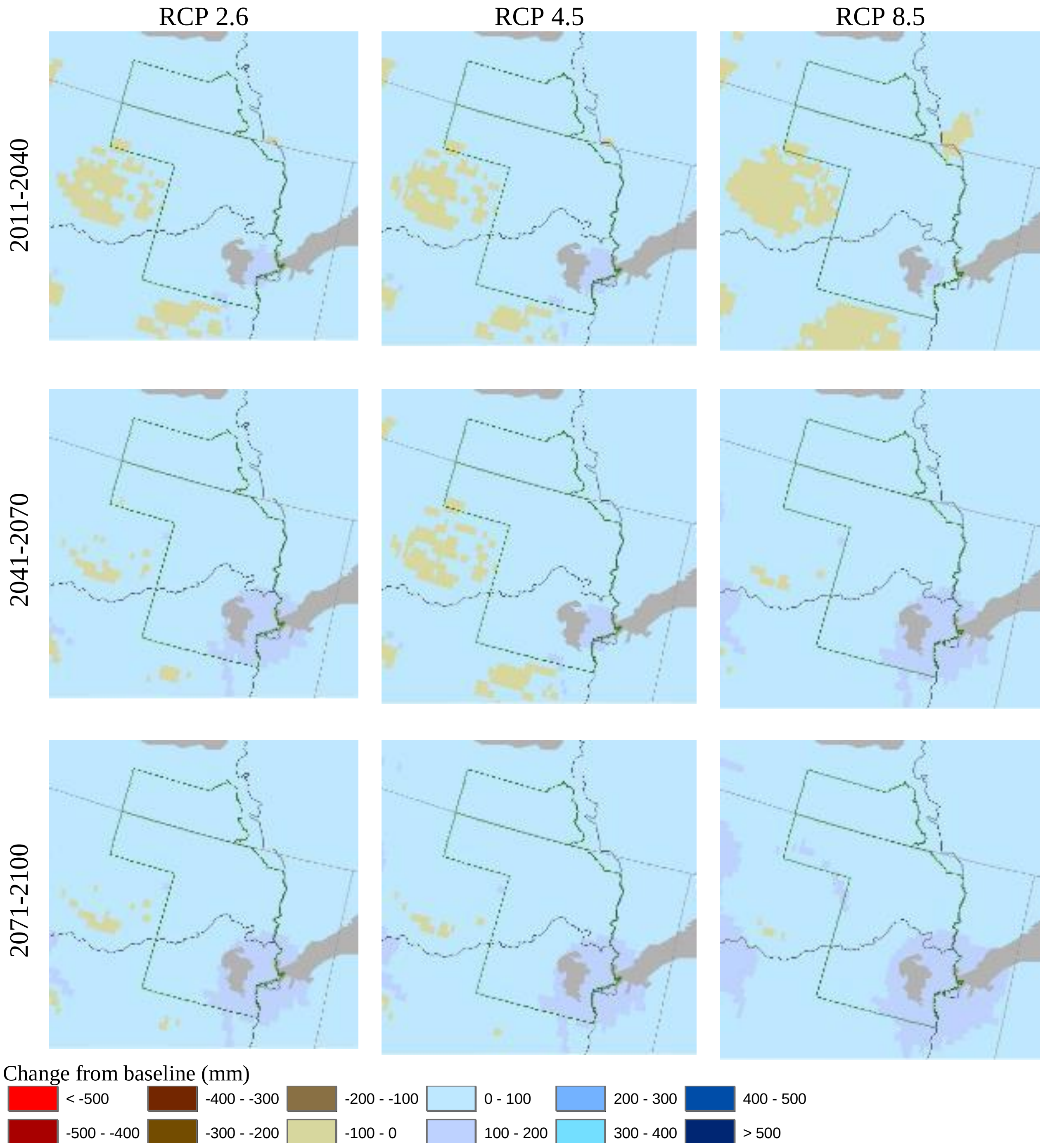
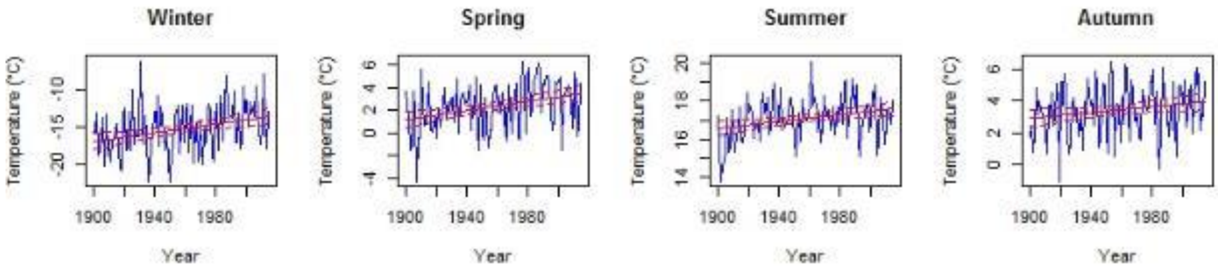


Figure 3b. Wood Buffalo NP. Precipitation projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada, Canadian Forest Service, Sault Ste. Marie (http://cfs.nrcan.gc.ca/projects/3).

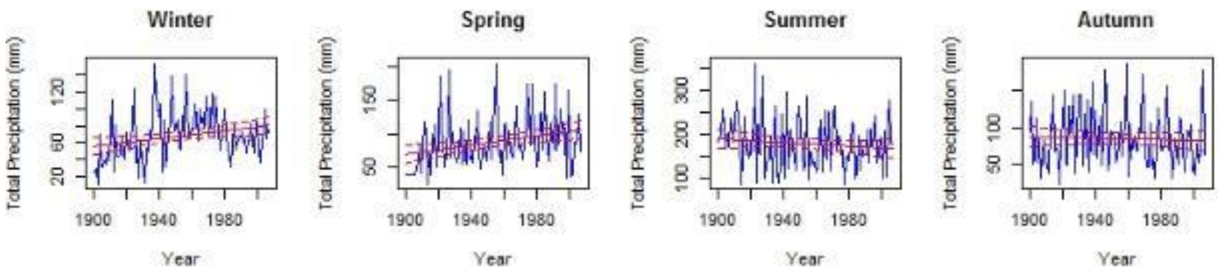
Batoche National Historic Site

A. Mean Temperature



Seasonal mean temperature at Saskatoon Climatological Station (4057165) from 1900 to 2015. A significant trend (P<0.05) observed for winter (0.03°C/yr), spring (0.02°C/yr), summer (0.009°C/yr) and autumn (0.009°C/yr).

B. Total Precipitation



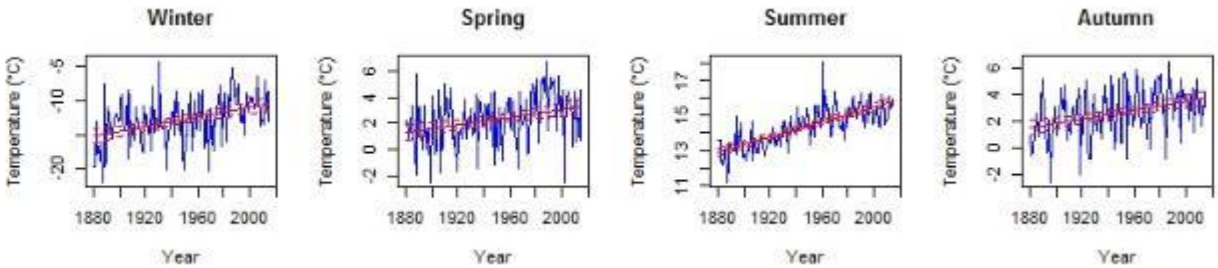
Seasonal total precipitation at Saskatoon Climatological Station (4057120) from 1900 to 2007. A significant trend (P<0.05) observed for winter (0.23mm/yr) and spring (0.34mm/yr). No significant trend (P<0.05) observed for summer or autumn.

C. Climate Change Projection for Centre of Historic Site Relative to 1981-2010 Baseline Mean (Appendix 1)

Increase / decrease in:	**2011-2040**			**2041-2070**			**2071-2100**		
Max Winter Temperature	10.7	to	11.0	11.6	to	14.0	12.1	to	17.1
Max Spring Temperature	1.4	to	1.7	2.5	to	3.8	2.2	to	7.2
Max Summer Temperature	2.2	to	2.3	2.8	to	4.5	2.7	to	8.1
Max Autumn Temperature	10.9	to	11.2	11.7	to	13.1	11.7	to	16.6
Min Winter Temperature	1.2	to	1.6	2.3	to	5.2	2.9	to	9.2
Min Spring Temperature	1.9	to	2.0	2.8	to	4.4	2.5	to	7.8
Min Summer Temperature	2.1	to	2.2	2.6	to	4.3	2.6	to	7.5
Min Autumn Temperature	-3.2	to	-3.3	-1.2	to	-2.7	-2.7	to	2.2
Precipitation in Winter	42%	to	45%	45%	to	55%	49%	to	63%
Precipitation in Spring	12%	to	16%	-25%	to	34%	16%	to	38%
Precipitation in Summer	-1%	to	-3%	2%	to	3%	-8%	to	4%
Precipitation in Autumn	-6%	to	39%	-7%	to	2%	-2%	to	1%
Advance in start of growing season (# of days)	8.4	to	12.4	5.8	to	6.6	7.6	to	23.2

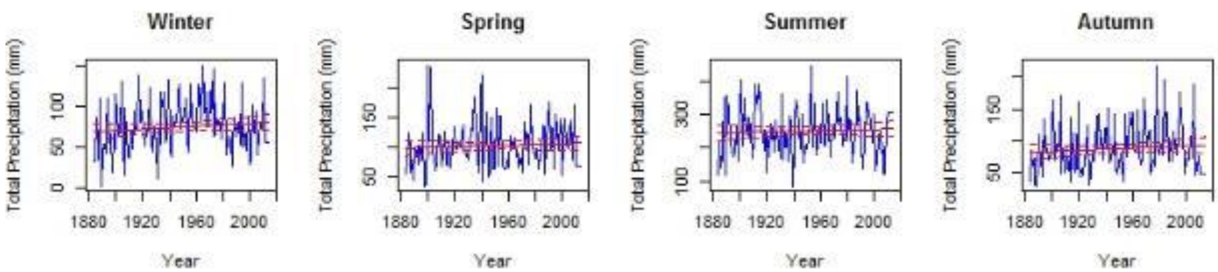
Elk Island National Park

A. Mean Temperature



Seasonal mean temperature at Edmonton Climatological Station (3012216) from 1880 to 2015. A significant trend ($P<0.05$) observed for winter (0.035°C/yr), spring (0.015°C/yr), summer (0.021°C/yr) and autumn (0.017°C/yr).

B. Total Precipitation



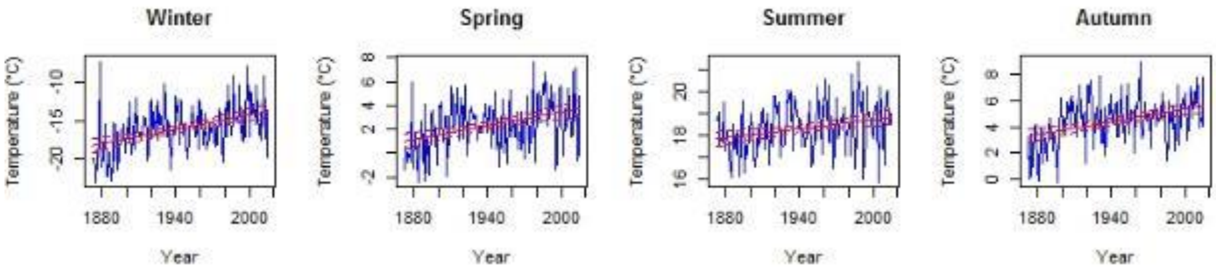
Seasonal total precipitation at Edmonton Climatological Station (3012205) from 1883 to 2012. No significant trend ($P<0.05$) observed for winter, spring, summer or autumn.

C. Climate Change Projection for Centre of Park Relative to 1981-2010 Baseline Mean (Appendix 1)

Increase / decrease in:	**2011-2040**			**2041-2070**			**2071-2100**		
Mean Winter Temperature (°C)	1.5	to	1.9	2.5	to	4.9	3.1	to	7.7
Mean Spring Temperature (°C)	2.1	to	2.2	2.9	to	4.5	3.0	to	7.4
Mean Summer Temperature (°C)	1.6	to	2.0	2.3	to	4.0	2.2	to	7.4
Mean Autumn Temperature (°C)	1.6	to	1.7	2.2	to	3.7	2.2	to	7.0
Precipitation in Winter	18%	to	21%	25%	to	31%	25%	to	42%
Precipitation in Spring	6%	to	7%	10%	to	27%	10%	to	38%
Precipitation in Summer	8%	to	18%	19%	to	19%	6%	to	23%
Precipitation in Autumn	7%	to	8%	12%	to	20%	15%	to	25%
Number of days of growing season	18.0	to	19.0	23.0	to	34.0	23.0	to	54.0
Growing degree-days during growing season	26%	to	28%	35%	to	60%	34%	to	116%
Advance in start of growing season (days)	9.0	to	10	12.0	to	19.0	13.0	to	32.0
Climate Moisture Index (sum May-Sept)	-5.0	to	-7.6	-5.6	to	-8.8	-4.7	to	-22.7

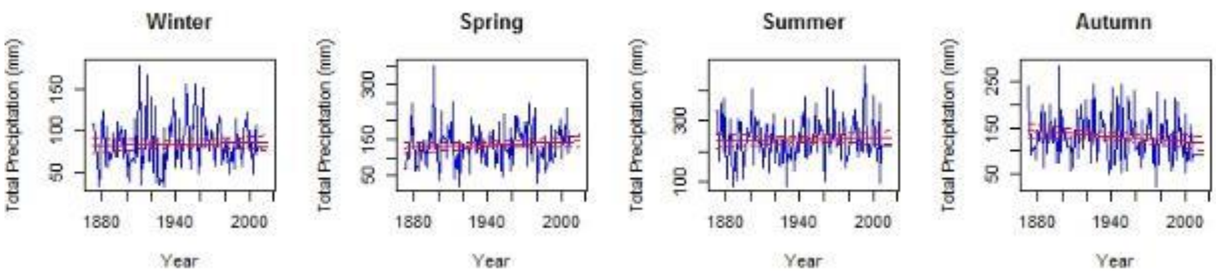
Lower Fort Garry National Historic Site

A. Mean Temperature



Seasonal mean temperature at Winnipeg Climatological Station (502S001) from 1872 to 2015. A significant trend (P<0.05) observed for winter (0.032°C/yr), spring (0.019°C/yr), summer (0.007°C/yr) and autumn (0.016°C/yr).

B. Total Precipitation



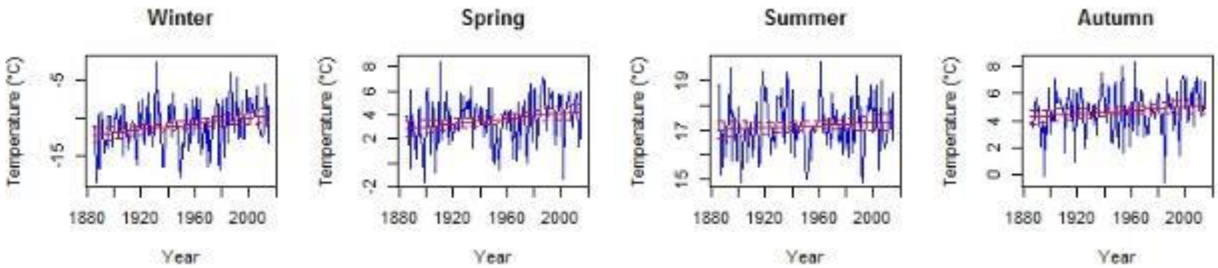
Seasonal total precipitation at Winnipeg Climatological Station (5023222) from 1872 to 2007. No significant trend (P<0.05) observed for winter, spring, summer or autumn.

C. Climate Change Projection for Centre of Historic Site Relative to 1981-2010 Baseline Mean (Appendix 1)

Increase / decrease in:	**2011-2040**			**2041-2070**			**2071-2100**		
Max Winter Temperature (°C)	9.8	to	10.1	10.6	to	13.1	11.0	to	16.5
Max Spring Temperature (°C)	2.0	to	2.4	3.2	to	4.6	2.8	to	8.2
Max Summer Temperature (°C)	2.6	to	2.6	3.1	to	5.0	3.1	to	8.3
Max Autumn Temperature (°C)	11.7	to	11.9	12.4	to	13.9	12.4	to	17.6
Min Winter Temperature (°C)	0.9	to	1.3	1.9	to	5.0	2.4	to	9.2
Min Spring Temperature (°C)	1.6	to	1.9	2.7	to	4.3	2.5	to	8.0
Min Summer Temperature (°C)	1.6	to	1.6	2.1	to	3.9	2.2	to	6.9
Min Autumn Temperature (°C)	0.9	to	0.9	1.5	to	3.1	1.6	to	6.4
Precipitation in Winter	7%	to	9%	9%	to	17%	9%	to	23%
Precipitation in Spring	2%	to	9%	-40%	to	19%	7%	to	39%
Precipitation in Summer	-14%	to	-16%	-10%	to	-18%	-8%	to	-21%
Precipitation in Autumn	-14%	to	-19%	-11%	to	-16%	-7%	to	-13%
Advance in start of growing season (# of days)	9.8	to	14.2	6.8	to	7.0	9.0	to	28.4

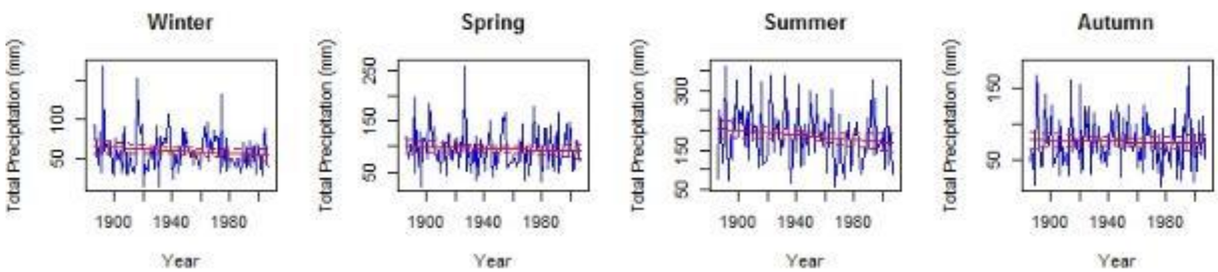
Grasslands National Park

A. Mean Temperature



Seasonal mean temperature at Swift Current Climatological Station (4028038) from 1885 to 2015. A significant trend (P<0.05) observed for winter (0.032°C/yr), spring (0.019°C/yr), summer (0.007°C/yr) and autumn (0.016°C/yr).

B. Total Precipitation



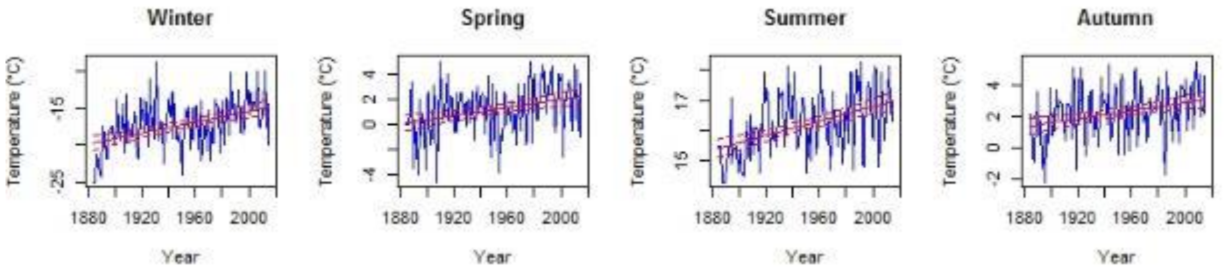
Seasonal total precipitation at Swift Current Climatological Station (4028060) from 1886 to 2007. No significant trend (P<0.05) observed for winter, spring, summer or autumn.

C. Climate Change Projection for Centre of Park Relative to 1981-2010 Baseline Mean (Appendix 1)

Increase / decrease in:	2011-2040			2041-2070			2071-2100		
Mean Winter Temperature (°C)	0.9	to	0.9	1.6	to	4.0	2.3	to	6.6
Mean Spring Temperature (°C)	1.2	to	1.6	2.1	to	3.6	2.0	to	5.9
Mean Summer Temperature (°C)	1.8	to	2.0	2.4	to	4.3	2.2	to	7.6
Mean Autumn Temperature (°C)	1.5	to	1.6	2.2	to	3.6	2.1	to	7.0
Precipitation in Winter	31%	to	35%	38%	to	44%	34%	to	63%
Precipitation in Spring	17%	to	18%	21%	to	33%	23%	to	46%
Precipitation in Summer	-5%	to	1%	-3%	to	2%	-9%	to	6%
Precipitation in Autumn	-3%	to	-11%	-6%	to	-14%	-2%	to	-6%
Number of days of growing season	14.0	to	15.0	18.0	to	32.0	17.0	to	58.0
Growing degree-days during growing season	21%	to	22%	28%	to	50%	26%	to	96%
Advance in start of growing season (days)	6.0	to	7.0	8.0	to	18.0	8.0	to	34.0
Climate Moisture Index (sum May-Sept)	-38.7	to	-39.3	-40.7	to	-47.8	-37.9	to	-64.0

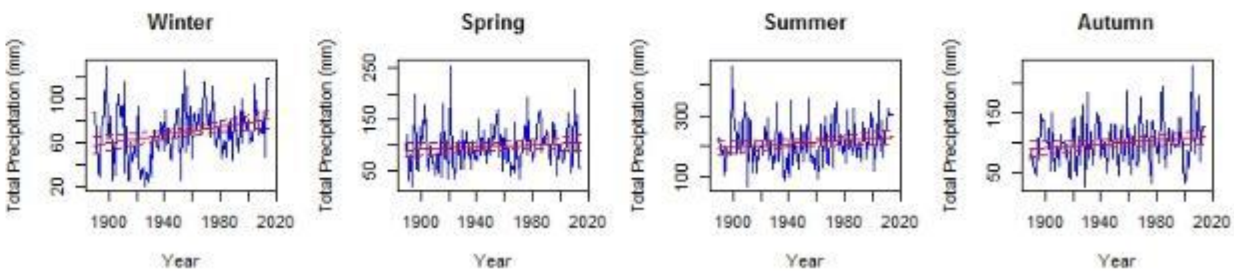
Prince Albert National Park

A. Mean Temperature



Seasonal mean temperature at Prince Albert Climatological Station (4056241) from 1884 to 2015. A significant trend ($P<0.05$) observed for winter (0.036°C/yr), spring (0.016°C/yr), summer (0.012°C/yr) and autumn (0.013°C/yr).

B. Total Precipitation



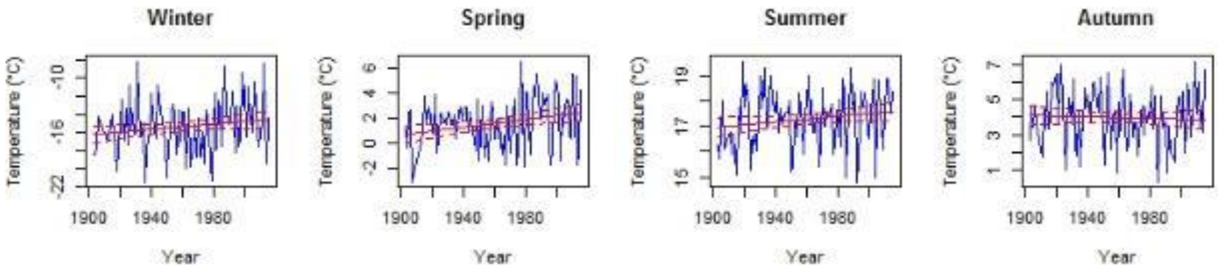
Seasonal total precipitation at Prince Albert Climatological Station (4056240) from 1989 to 2013. A significant trend ($P<0.05$) observed for winter (0.19mm/yr). No significant trend ($P<0.05$) observed for spring, summer or autumn.

C. Climate Change Projection for Centre of Park Relative to 1981-2010 Baseline Mean (Appendix 1)

Increase / decrease in:	2011-2040			2041-2070			2071-2100		
Mean Winter Temperature (°C)	0.7	to	1.0	1.6	to	4.3	2.2	to	7.8
Mean Spring Temperature (°C)	1.2	to	1.3	2.2	to	3.6	2.0	to	7.0
Mean Summer Temperature (°C)	1.7	to	1.8	2.3	to	4.0	2.3	to	7.4
Mean Autumn Temperature (°C)	1.5	to	1.7	2.3	to	3.8	2.3	to	7.2
Precipitation in Winter	25%	to	26%	30%	to	37%	30%	to	42%
Precipitation in Spring	-1%	to	2%	0%	to	16%	1%	to	20%
Precipitation in Summer	4%	to	5%	8%	to	9%	-1%	to	10%
Precipitation in Autumn	3%	to	4%	-2%	to	10%	4%	to	11%
Number of days of growing season	15.0	to	16.0	21.0	to	31.0	19.0	to	51.0
Growing degree-days during growing season	26%	to	27%	36%	to	60%	35%	to	121%
Advance in start of growing season (days)	7.0	to	8.0	11.0	to	17.0	10.0	to	28.0
Climate Moisture Index (sum May-Sept)	-11.0	to	-11.5	-12.2	to	-15.0	-11.4	to	-27.8

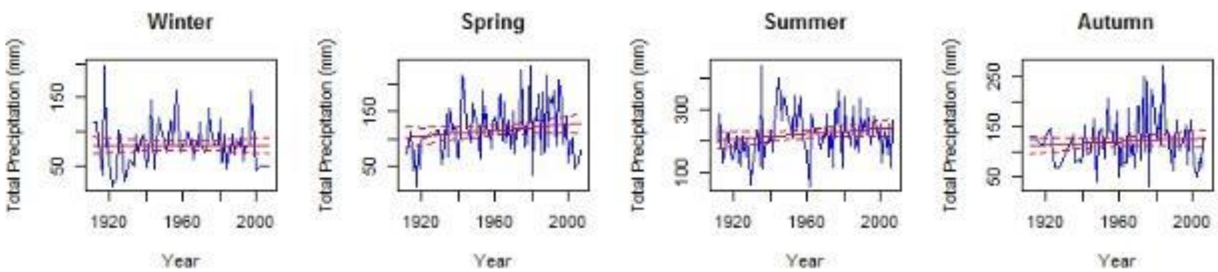
Riding Mountain National Park

A. Mean Temperature



Seasonal mean temperature at Dauphin Climatological Station (5040689) from 1903 to 2015. A significant trend ($P<0.05$) observed for spring (0.015°C/yr). No significant trend ($P<0.05$) observed for winter, summer or autumn.

B. Total Precipitation



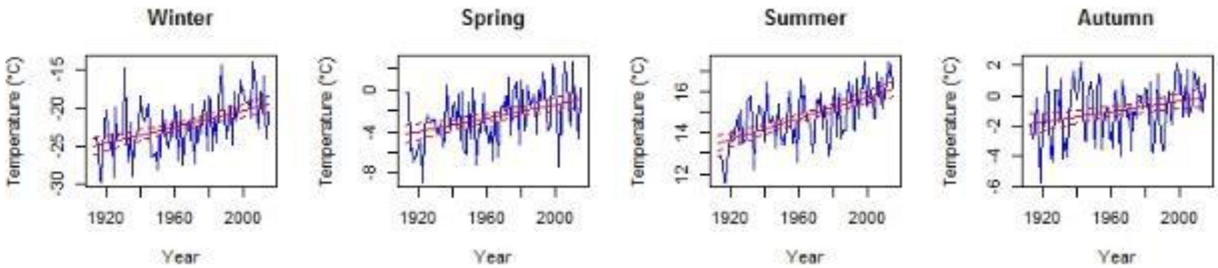
Seasonal total precipitation at Dauphin Climatological Station (5040681) from 1911 to 2007. No significant trend ($P<0.05$) observed for winter, spring, summer or autumn.

C. Climate Change Projection for Centre of Park Relative to 1981-2010 Baseline Mean (Appendix 1)

Increase / decrease in:	**2011-2040**			**2041-2070**			**2071-2100**		
Mean Winter Temperature (°C)	1.3	to	1.6	2.2	to	5.0	2.7	to	8.8
Mean Spring Temperature (°C)	1.9	to	2.3	3.1	to	4.6	2.7	to	8.2
Mean Summer Temperature (°C)	2.3	to	2.4	2.8	to	4.6	2.8	to	7.9
Mean Autumn Temperature (°C)	2.0	to	2.2	2.8	to	4.3	2.8	to	7.7
Precipitation in Winter	5%	to	6%	6%	to	11%	7%	to	22%
Precipitation in Spring	1%	to	2%	4%	to	15%	2%	to	29%
Precipitation in Summer	-2%	to	-3%	-5%	to	5%	-10%	to	6%
Precipitation in Autumn	6%	to	17%	10%	to	16%	17%	to	19%
Number of days of growing season	19.0	to	19.0	25.0	to	34.0	23.0	to	57.0
Growing degree-days during growing season	30%	to	33%	40%	to	63%	38%	to	119%
Advance in start of growing season (days)	10.0	to	10.0	14.0	to	20.0	13.0	to	33.0
Climate Moisture Index (sum May-Sept)	-14.9	to	-16.5	-15.8	to	-21.8	-14.2	to	-34.5

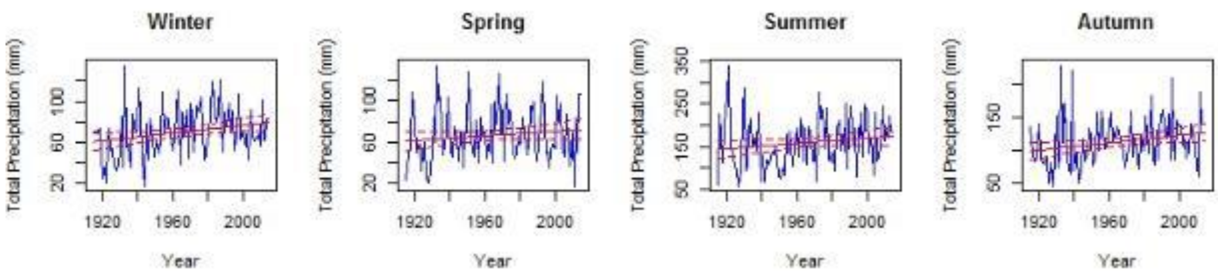
Wood Buffalo National Park

A. Mean Temperature



Seasonal mean temperature at Fort Smith Climatological Station (2202201) from 1913 to 2015. A significant trend (P<0.05) observed for winter (0.05°C/yr), spring (0.032°C/yr), summer (0.027°C/yr) and autumn (0.018°C/yr).

B. Total Precipitation



Seasonal total precipitation at Fort Smith Climatological Station (2202200) from 1915 to 2014. A significant trend (P<0.05) observed for winter (0.19mm/yr) and autumn (0.28mm/yr). No significant trend (P<0.05) observed for spring or summer.

C. Climate Change Projection for Centre of Park Relative to 1981-2010 Baseline Mean (Appendix 1)

Increase / decrease in:	2011-2040			2041-2070			2071-2100		
Mean Winter Temperature (°C)	0.5	to	1.1	1.7	to	4.7	2.4	to	8.8
Mean Spring Temperature (°C)	1.3	to	1.4	2.2	to	3.6	2.3	to	7.2
Mean Summer Temperature (°C)	1.6	to	1.8	2.1	to	4.0	2.2	to	6.9
Mean Autumn Temperature (°C)	2.0	to	2.1	2.7	to	4.3	2.6	to	7.6
Precipitation in Winter	13%	to	19%	23%	to	31%	22%	to	36%
Precipitation in Spring	13%	to	13%	17%	to	26%	13%	to	42%
Precipitation in Summer	10%	to	11%	12%	to	19%	11%	to	20%
Precipitation in Autumn	6%	to	11%	16%	to	20%	22%	to	22%
Number of days of growing season	21.0	to	22.0	27.0	to	34.0	27.0	to	53.0
Growing degree-days during growing season	24%	to	25%	33%	to	58%	34%	to	111%
Advance in start of growing season (days)	10.0	to	11.0	14.0	to	18.0	15.0	to	29.0
Climate Moisture Index (sum May-Sept)	-14.2	to	-14.5	-13.5	to	-18.9	-13.7	to	-27.3

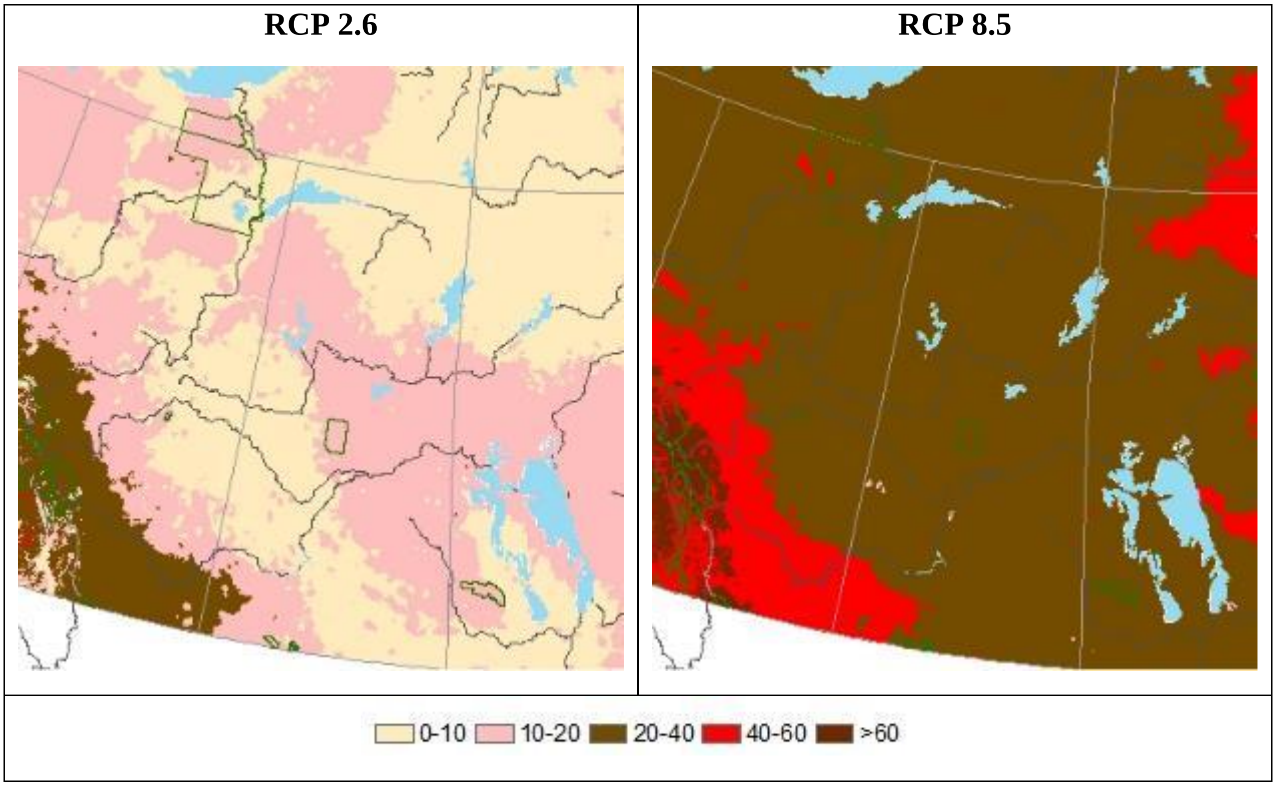


Figure 4. Projected increase in wildfire season length in days from baseline (1981-2010) by 2071-2100 under RCP 2.6 and 8.5 scenarios (data source: http://cfs.nrcan.gc.ca/fc-data-catalogue).

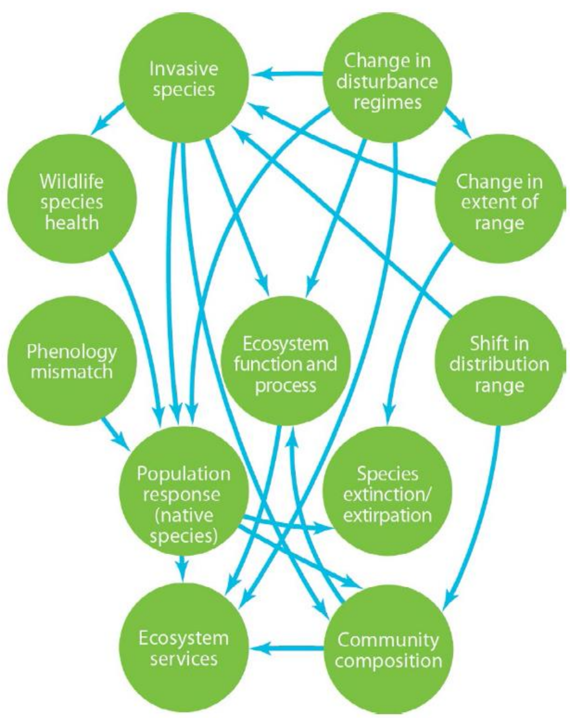
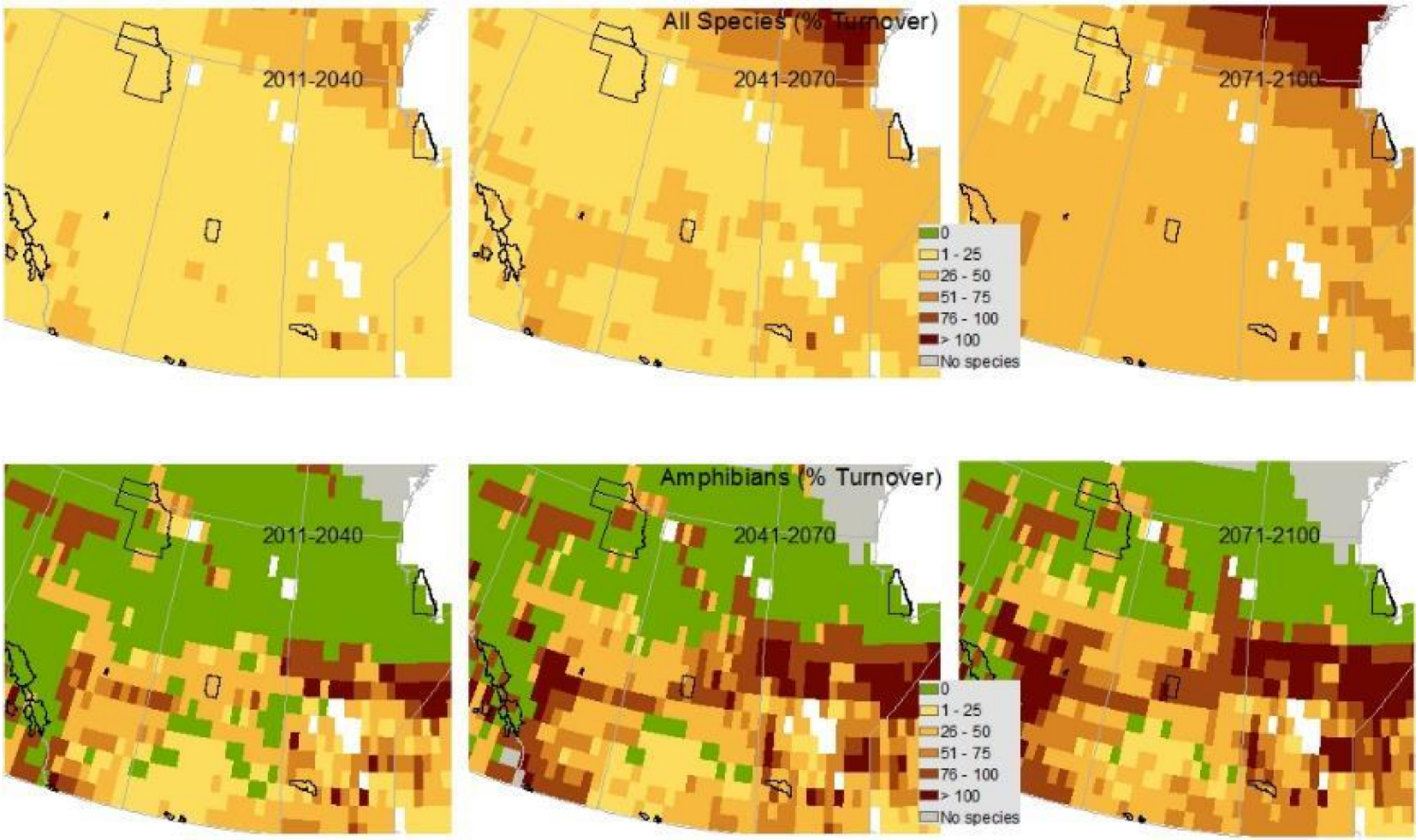


Figure 5. The complex ecosystem linkages and interactions to climate change (from Nantel *et al.*, 2014)


All Species (% Turnover)
2011-2040
2041-2070
2071-2100
0
1 - 25
26 - 50
51 - 75
76 - 100
> 100
No species
Amphibians (% Turnover)
2011-2040
2041-2070
2071-2100
0
1 - 25
26 - 50
51 - 75
76 - 100
> 100
No species

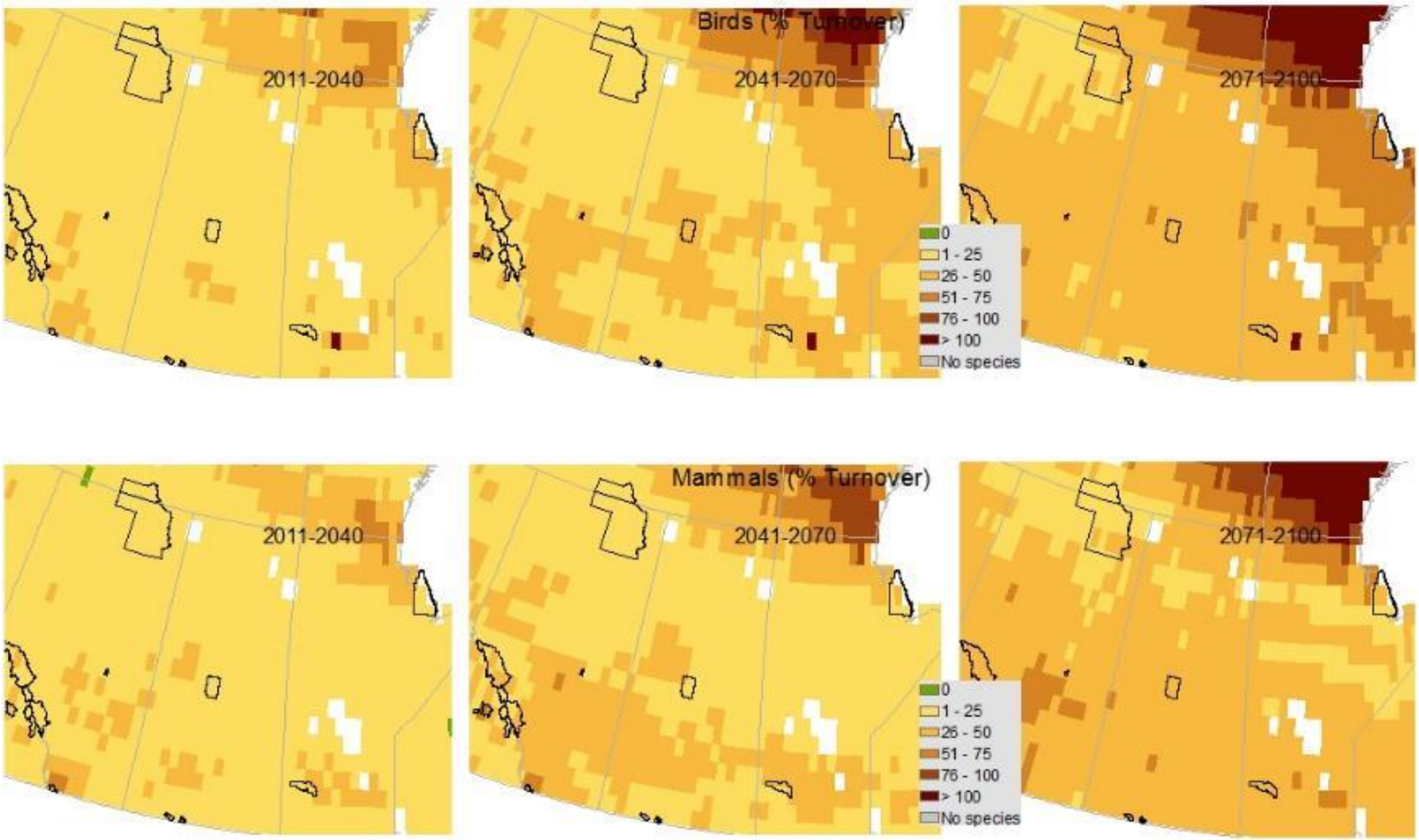


Figure 6. Percentage of projected species turnover (50 km x 50 km grid) relative to current species occurrence, assuming full dispersal (i.e., species can move into new areas) using ten coupled atmosphere-ocean general circulations models (AOGCMS) as in Lawler *et al.* (2009) and the A2 emission scenario. **Species turnover** is calculated as a composite measure of **species loss** (i.e., % of species currently in a cell whose projected future range does not include the cell) and **species gain** (i.e., % increase in species due to range expansion). Data and analysis discussed further in Lindsay *et al.* (2016).

2.2.2 Other Effects

Ecosystems and Biodiversity

- Altered flood regimes in the Peace-Athabasca Delta (Monk *et al.*, 2012) will affect its ecological composition, structure and function (Peters *et al.*, 2016; Timoney, 2009).
- While earlier snow melt and increased air temperatures should improve food availability for whopping cranes in Wood Buffalo NP, increased precipitation and altered fire regimes may reduce habitat quality (Chavez-Ramirez and Wehtje, 2012).
- Vegetation phenology has increased slightly in Grasslands NP with recent climate trends (Li and Guo, 2012).
- Climate change will influence environmental chemistry and pollutants, including an exacerbation of the effects of acid deposition (lower pH due to higher CO_2 levels), nutrient loading (precipitation events), and mercury toxicity (released under anoxic conditions, warmer waters increase the rate of methylation) (e.g., Michalak, 2016; Noyes *et al.*, 2009). Phosphorus concentrations in some lakes may increase with changes to thermal stratification (e.g., at Wood Buffalo NP, Moser *et al.*, 2002).
- Species response to climate change will vary with abiotic (e.g., isolated by fragmented landscape or island context, thermal conditions, etc…), biotic (e.g., competition, habitat) and physiological stresses. Some species, or variant forms, will survive and adapt, while others may move or face extinction (e.g., Pecl *et al.*, 2017).
- From a global perspective, vertebrate population abundances have declined by 58% between 1970 and 2012 (WWF, 2016). Projections estimate that ~60% of plants and ~35% of animals will lose over half of their range by 2080 due to climate change (Warren *et al.*, 2013). The median rate of northward migration, for those species where migration is even attainable, is ~16.9 km/decade (Chen *et al.*, 2011).
- Increasing inland water temperatures may exceed the thermal regime for cold-water species (Poesch *et al.*, 2016) and enable the colonization of warmer water species (e.g., smallmouth bass) (Sharma *et al.*, 2007).
- "Temperature velocities" for forest biomes are estimated to move northward at the rate of 0.43 km/yr for the boreal forest and 0.35 km/yr for the temperate broadleaf forest (McKenney *et al.*, 2011; Warren *et al.*, 2013). However, colonization success will vary with (micro)topography, permafrost conditions, dispersal competition, soil, precipitation patterns, disturbance regimes, pollinators and many other factors (e.g., Jacobs *et al.*, 2014; Lafleur *et al.*, 2010; McKenney *et al.*, 2007; Warren *et al.*, 2013). Nationally, it is suggested that vegetation distribution (biomes) will change in over half of Canada`s national park (Scott *et al.*, 2002).
- Langdon and Lawler (2015) found that projected climate change, biome shifts and species turnover in protected areas increased along a longitudinal gradient from low along the Pacific Coast, to highest in the Boreal Plains.
- Wildlife species will continue to experience range shifts and changes in abundance. (e.g., National Audubon Society, 2015).
- Length of the wildfire season and area burned is expected to increase (Boulanger *et al.*, 2013; Wang *et al.*, 2015; Whitman *et al.*, 2015).
- Asynchrony between life history events has been observed. Although photoperiod is not changing, other ecological cues are changing, such as temperature, river flow, etc. For

example, earlier peaks in insect and plant biomass have been observed and this may mismatch migrant bird hatchling growth and development (Knudsen *et al.*, 2011; Nituch and Bowman, 2013).

- The distribution and impacts of pathogens and parasites are expected to increase with warmer temperatures and the northward migration of species (Marcogliese, 2008; 2016; Pickles *et al.*, 2013).
- Conditions, including milder winters and summer drought, may be more favourable for invasive species colonization (Langor *et al.*, 2014; Walther *et al.*, 2009) and for more extensive forest insect and disease outbreaks (e.g., spruce budworm, forest tent caterpillar, gypsy moth) (Warren and Lemmen, 2014; Warren *et al.*, 2013; Weed *et al.*, 2013).
- The Boreal Ecosystem Research and Monitoring Sites (BERMS) project includes a flux tower in the old aspen community of Prince Albert NP. Some results include:
    - This site is highly productive, with an annual C uptake of ~120 g C /m^2/yr.
    - In May 2016, the site was completely defoliated by forest tent caterpillar and became a significant source of C to the atmosphere.
    - Spring warming has increased growing length and positively impacted C uptake.
    - The severe drought of 2001-03 caused a large and sustained increase in annual tree mortality (e.g., increased from ~2%/yr to ~7%/yr from 2004-2010), highlighting the potential for future loss of aspen stands at the forest-grassland transition zone due to climate change.

- The Changing Cold Regions Network (http://www.ccrnetwork.ca/) will conclude a 5 year research program of climate change in the region in the spring of 2018 (see report to Parks Canada; CCRN, 2017).

Visitor Experience

- The length of the visitor season and number of visitors may increase due to an earlier spring and warmer summer and autumn conditions. For instance, a study in Prince Albert NP projected that visitation will increase by 6–10% in the 2020s, 10-36% in the 2050s and 14-60% in the 2080s (Scott and Jones, 2006).
- When temperatures exceeded 25-30˚C, a strong decrease in visitation has been observed in some parks (Fisichelli *et al.*, 2015; Hewer *et al.*, 2016).
- Recreational beaches may face increased closures due to water quality from warmer waters and increased nutrient and bacteria loads (stormwater runoff). Harmful algal blooms and filamentous algae growth will increase under such conditions as well (Barton *et al.*, 2013; Reavie *et al.*, 2014).
- Decreased snowpack will negatively impact recreational activities such as snowshoeing, skiing, ice fishing, ice travel and snowmobiling.
- In terms of human health, there may be heat related concerns during extreme temperature events, as well there may be concerns due to increases in disease risks. For example, Lyme disease (bacterial disease transmitted by an infected tick) which was formerly

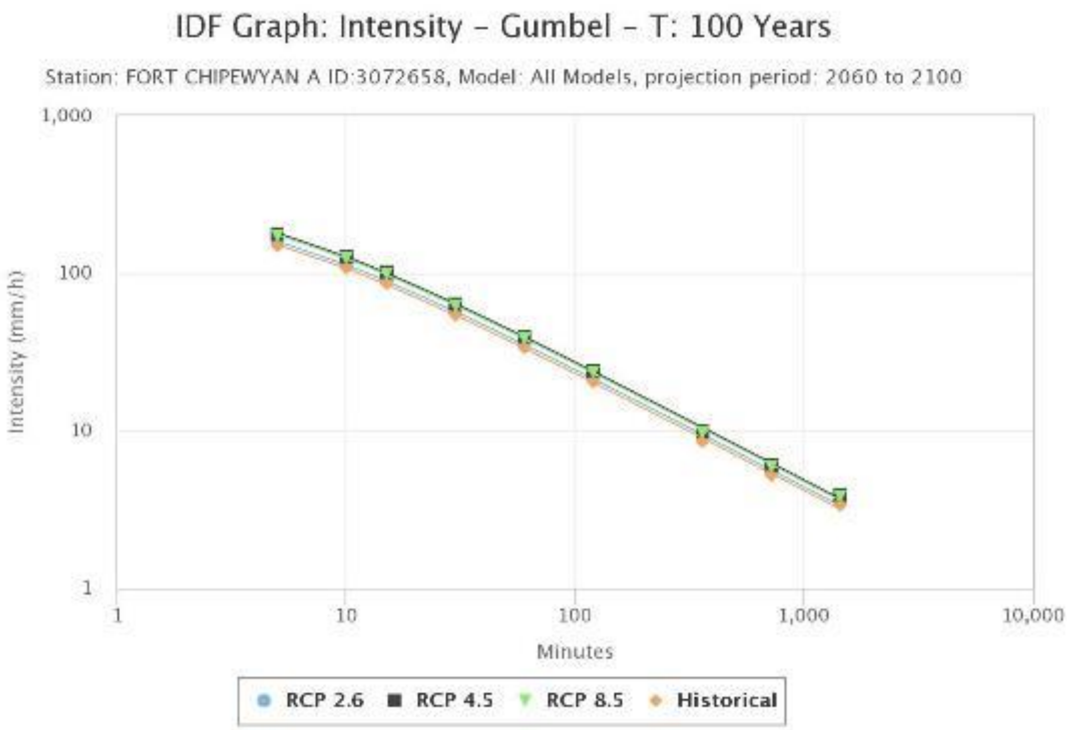
restricted to localized areas by temperature and relative humidity, is expected to expand by mid-century (Eisen *et al.*, 2016; Ogden *et al.*, 2006). Some mosquito-borne diseases also show a connection to climate change, including West Nile virus (note: besides humans it can infect over 140 species including horses, crows, ravens, etc…) (Chen *et al.*, 2013; Kulkarni *et al.*, 2015).
- A longer and more intense fire season will affect visitor safety and experience (e.g., possible area closures, no campfires, or evacuations).

Assets and Infrastructure

- Flooding from extreme rainfall events may overwhelm stormwater system capacities and damage or destroy infrastructure.
- There is an increasing risk to assets and infrastructure by wildfire damage in some areas. More severe fire weather (heat and drought) may also create conditions where fire suppression is no longer feasible or effective (Colombo, 2008; Flannigan *et al.*, 2005).
- Some facilities may be more vulnerable to the expected increase in wind gust events (Cheng *et al.*, 2014).
- The length of season and reliability of winter roads will be reduced (Lemmen *et al.*, 2008).

Cultural Resources

- Increased damage or loss of cultural resources is possible during and post- flood, wind and wildfire events (Marissa *et al.*, 2016). Erosion plays both a disturbance and discovery role with archaeological sites, raising fundamental issues about salvage, identification, protection and site management.
- There is a potential for increased deterioration of facilities and collections (e.g., non-mechanically ventilated interiors, HVACs) from increased temperature, humidity, and precipitation, e.g., increased mold, rot and fungal decay; increased corrosion, etc… (Brimblecombe, 2014; Brimblecombe and Brimblecombe, 2016; Horowitz *et al.*, 2016; Marissa *et al.*, 2016)
- Socio-economic impacts through lose or damage to cultural resources may occur.
- Micro-climates which allow historic gardens to flourish at some cultural sites (Beinn Bhreagh Hall e.g., Percy *et al.*, 2015) may be affected.



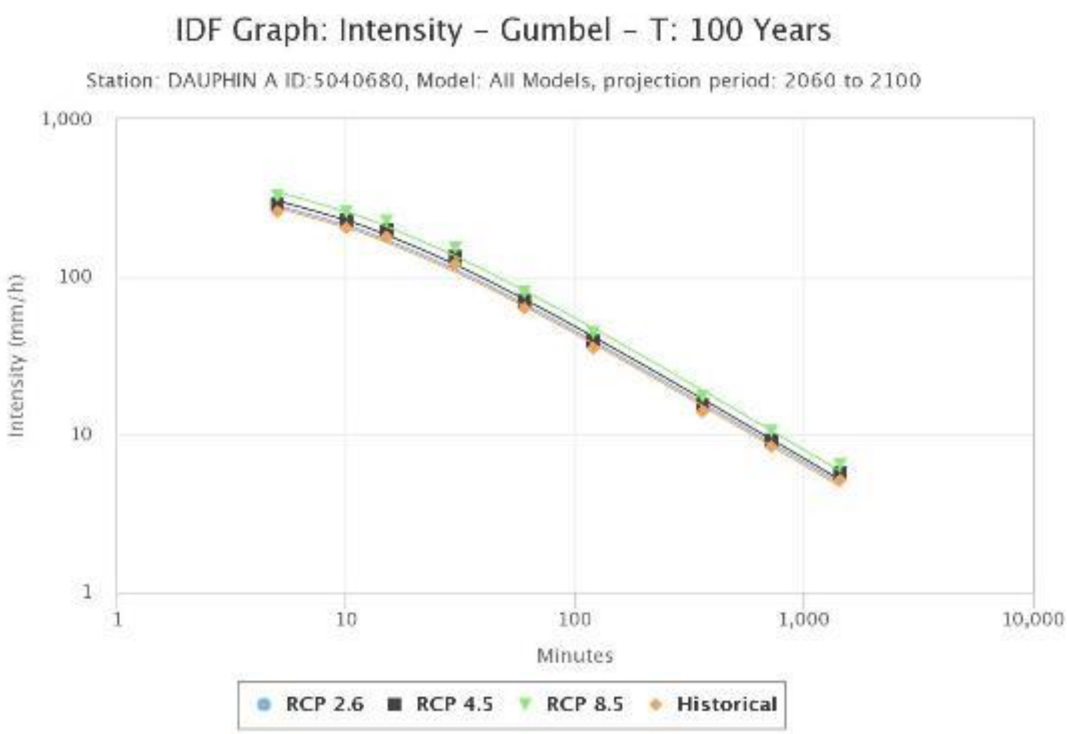


Figure 7. Example of rainfall intensity-duration-frequency curves for future climate scenarios. As illustrated, rainfall intensity for the “1 in a 100 year” event at Fort Chipewyan (Wood Buffalo NP) is projected to increase from 150mm/hr to as much as 180mm/hr (5 minute duration) and at Dauphin (Riding Mountain NP) from 259mm/hr to as much as 345mm/hr (5 minute duration). The IDF_CC Tool (https://www.idf-cc-uwo.ca) permits user driven analysis of future projections for climatological stations across the country.

3. Climate Change Actions

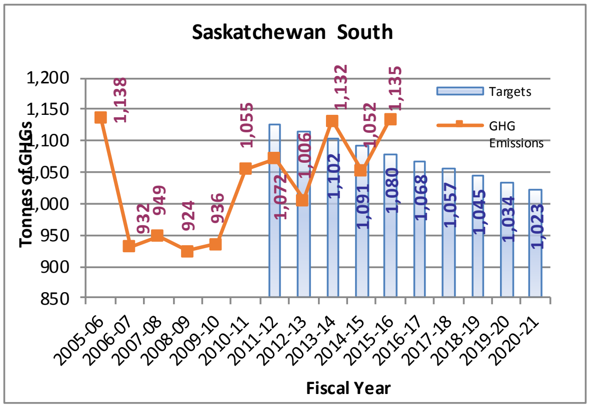
In general, most protected area agencies in Canada are only beginning to consider and develop climate change policies, planning tools, and management frameworks (Gray *et al.*, 2017; Lemieux *et al.*, 2011) (note: a draft Parks Canada climate change strategy, version 4.4, was last revised in 2008). There are, however, examples of adaptation and mitigation actions already underway in individual sites and within other jurisdictions that may inspire and guide actions (e.g., Gross *et al.*, 2016; Lemieux *et al.*, 2010; US NPS, 2010).

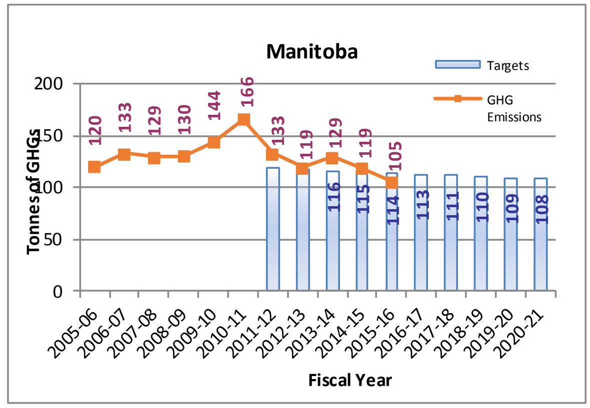
3.1 Adaptation

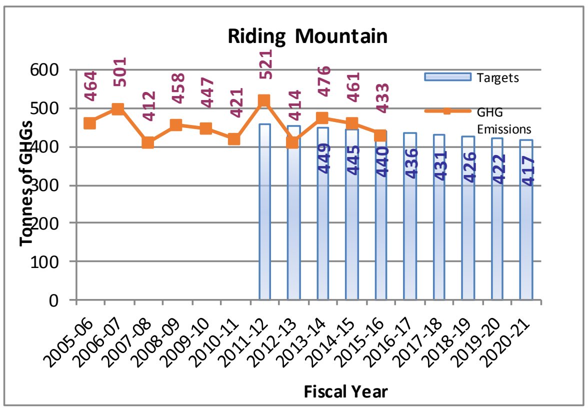
Adaptation is an adjustment in natural or human systems in response to actual or expected climate change impacts. Adaptation in protected areas often involves the implementation of established ecosystem-based management practices. These actions can represent "**no regrets**" since they broadly benefit the ecological and commemorative integrity at a site, regardless of the rate of climate change. This includes working with regional partners to manage landscape level disturbances; protecting and restoring ecosystems to build resilience; preventing the spread of invasive species; protecting species at risk; conserving built heritage at historic sites; replacing storm damaged resources and infrastructure with more sustainable and resilient designs; and, responding to changing visitor interests and needs.

Other more regionally specific examples:

- Lister et al. (2015) discuss climate change and wildlife-crossing infrastructure, emphasizing an integrated and adaptive approach.
- Hood and Bayley (2008) discuss how beaver's may help to mitigate climate effects by maintaining wetlands.
- Design or retrofit stormwater systems and hydraulic structures to accommodate new "normal" precipitation and temperature patterns. For example, replacing "like with like" culverts is ineffective if they remain undersized or continue to fill with debris. Larger structures can serve both a drainage and road "ecopassage" function, thus making landscape more permeable to water flow and species movements.







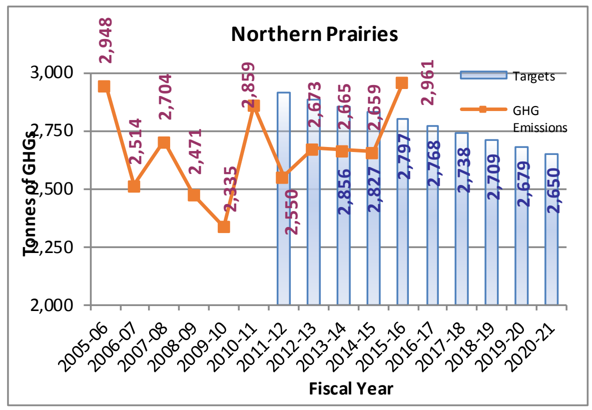
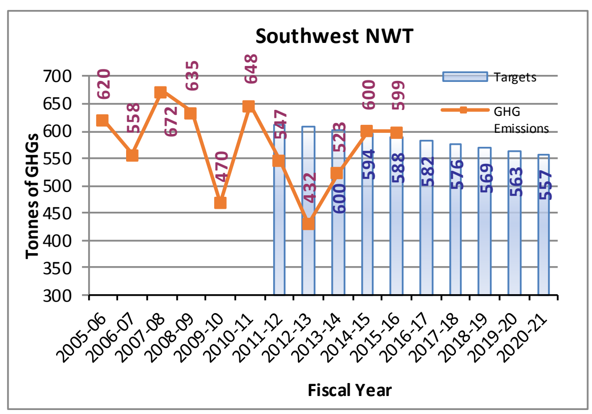


Figure 8. Greenhouse Gas Emissions per Field Unit. Emissions are calculated from energy (e.g., heating, electricity) and fuel expenditures, excluding travel, air charters, and some other sources. GHG emissions from energy cost are adjusted for source (e.g., coal, hydro, diesel, etc...). The targets in these figures are from 2015 reduction targets (Parks Canada, 2015). Revised, lower targets to be communicated in 2017 (Canada, 2016).



3.2 Mitigation

Mitigation refers to human interventions that reduce the source or enhance the sinks of GHG emissions. Carbon dioxide, methane, nitrous oxide, water vapour and ozone are the primary GHGs in the earth's atmosphere, in addition to human-made chlorine- and bromine-containing substances. Parks Canada's Asset and Environmental Management team provides national functional leadership, expertise and support related to GHG reductions. Sites interested in working on GHG reduction and more sustainable operations should confer with this team. As an example, this team annually tracks all Field Unit energy expenditures and GHG emissions and reports progress towards federal government reduction targets. The current target is 40% reduction in GHG emissions from federal buildings and fleets below the 2005 levels by 2030 (Canada, 2016); it is clear that this will require an ambitious and concerted effort on the part of all.

Mitigation examples include:

- Evaluate progress towards Parks Canada / Field Unit GHG reduction targets.
- Specify "green" and energy efficient designs for construction and renovation projects.
- Reduce the number and/or size of park vehicles and vessels to match need and maximize efficiency. Provide hybrid or electric where possible.
- Electric utility and lawn vehicles for campground maintenance.
- Anti-idling and cabin heat-recovery systems in trucks.
- Use energy efficient products, promote energy efficiency and water conservation, reduce waste and support alternative transportation.
- Review Parks Canada (2015) and US NPS (2012a).

3.3 Possible Next Steps

This report is intended to be a stepping off point, from here individuals and sites are encourage to consider how best to advance climate change actions in their own context. Here is a checklist of ideas that others have considered that may be of particular interest or relevance.

☑ Enhance workforce climate literacy (e.g., Peterson *et al.*, 2011; US NPS, 2012b).

☑ Undertake more detailed analysis of climate trends, including impact models (e.g., hydrology, wildfire, infrastructure at risk, coastal visualization) and extreme weather events (e.g., Charron, 2016).

☑ Conduct future scenario planning and explore operations under novel and equally plausible future conditions. Use scenarios to test ("wind tunnel") strategic decisions and inform contingency plans (e.g., Gross *et al.*, 2016; US NPS, 2013).

☑ Conduct vulnerability assessments of species, ecosystems or governance structures. Vulnerability is the degree to which a system is susceptible to, and unable to cope with, the impacts of climate change (e.g., Edwards *et al.*, 2015; Gleeson *et al.*, 2011; Gross *et al.*, 2016).

☑ Incorporate climate change impacts and adaptation strategies into management planning. Recalibrate management objectives in the face of ecosystem change, system novelty and loss of resilience (e.g., Lemieux *et al.*, 2011).

☑ Revise visitor management and operational plans in response to changing visitor patterns and use (e.g., Fisichelli *et al.*, 2015; Hewer *et al.*, 2016). Diversify visitor experiences to provide alternatives to weather-dependent activities.

☑ Quantify and understand carbon stocks and dynamics (e.g., US NPS, 2012a).

☑ Evaluate and communicate the value of ecological goods and services (e.g., clean water/air, provision of food, maintain biodiversity, nature-based tourism, carbon storage, etc…) and manage for the sustainability of these services (e.g., Gross *et al.*, 2016).

☑ Maintain a list of climate science and management actions to help inform and influence park messaging.

☑ Build networks and collaborate across multiple scales (e.g., Waterton Lakes NP, crownmanagers.org).

☑ "FireSmart" facilities and infrastructure (Hirsch *et al.*, 2001).

☑ Consider the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol (https://pievc.ca/protocol) in climate change vulnerable infrastructure projects.

☑ "Explicitly recognize climate change as a management issue in state of the park reporting and monitoring frameworks". This adaption option was one of two from 165 options deemed as necessary and "definitely implementable" by senior decision-makers for the Ontario park system (Lemieux and Scott, 2011).

Please contact the Office of the Chief Ecosystem Scientist if you have any questions or would like to explore any of these next steps further. In addition, PDF copies of all references and the climate data are freely available upon request.

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Appendix 1. Climate Change Projections

Climate change summaries were determined for the geo-centroid[1] of each national park and national marine conservation area. The method used to prepare the map followed Price *et al.* (2011) and used greenhouse gas (GHG) concentration scenarios adopted by the IPCC (2014) and General Circulation Models (GCMs)[2].

Of the four IPCC GHG concentration scenarios, the lowest and highest Representative Concentration Pathways (RCP), RCP 2.6 and RCP 8.5 were chosen. These are named after possible radiative forcing values in the year 2100 relative to pre-industrial values (i.e., +2.6 and +8.5 watts/m^2, respectively). RCP 2.6 assumes that global annual GHG emissions (measured in CO_2-equivalents) peak in 2010-2020, with emissions declining substantially thereafter. In RCP 8.5, emissions continue to rise throughout the 21st century.

To produce a high-resolution climate map, monthly time-series data were obtained for each GCM representing both the 20th century (1981–2010) and the scenarios of GHG concentration for the 21st century. Each monthly value at each GCM grid node was normalized either by subtracting (for temperature variables) or dividing by (for other climate variables) the mean of that month's values for the 30-year baseline period 1981–2010. The GCM projected changes in temperature and precipitation were averaged over 30-year periods and then interpolated using ANUSPLIN to the locations of climate stations in Canada and the USA. These data were then combined with observed station normals for the period 1981–2010 to create projected normals for three consecutive 30-year periods: 2011–2040, 2041–2070 and 2071–2100.

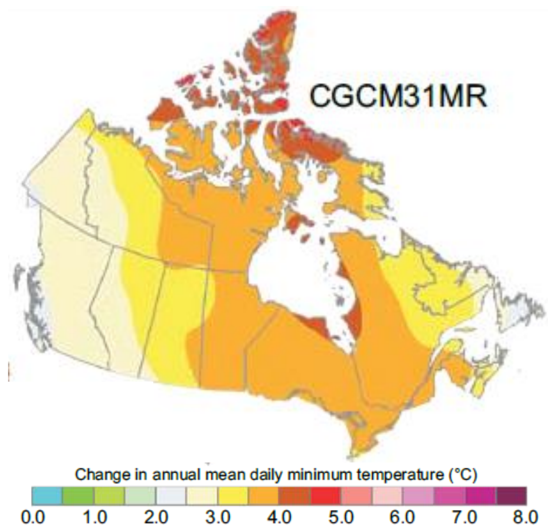

Figure A1. Projected change in annual daily minimum temperature for 2041-2070, relative to 1961-1990 (Price *et al.*, 2011).

A Bessel interpolation scheme was used to generate daily temperature and precipitation sequences that pass monotonically through the monthly values. This allowed for a suite of bioclimatic indicator variables to be estimated for these periods, including for example, mean growing season duration and precipitation during the growing season (Table A1). A set of composite maps averaging the values of the four GCMs was created and used to extract the projected climatic data for the parks and NMCAs at each geo-centroid.

No model driven by scenarios of future climate can ever provide definitive answers to questions about specific outcomes (e.g., how much change will occur at a specified location by a specified date?). However, temperature projections aligned with recent trends and there appears

[1] In the cases of parks for which the geo-centroid is located in the sea, we extracted the data for 5 sets of coordinates determined to be on the land using Google maps.
[2] CANESM2, CESM1CAM5, HADGEM2ES, and MIROCESM.

to be strong agreement on the magnitude of warming to be expected in the short term (until 2030–2040), independent of the RCP scenarios. This is because much of the warming projected for the next two to three decades is “committed warming” resulting from GHG emissions that have already occurred. It is only after ca. 2040 that the warming trajectories diverge, when early mitigation efforts (RCP 2.6 scenario) would evidently begin to have a positive effect. Further into the future, the range of possible warming increases, largely because of the divergence among the different GHG emission trajectories.

Table A1. Bioclimatic variables mapped for past and future climates[a]

No.	Variable[b]	Description
1	Annual mean temperature	Annual mean of monthly mean temperatures
2	Mean diurnal temperature range	Annual mean of monthly mean daily temperature ranges
3	Isothermality	Variable 2 ÷ variable 7
4	Temperature seasonality	Standard deviation of monthly mean temperature estimates, expressed as a percentage of their mean
5	Maximum temperature of warmest period	Highest monthly maximum temperature
6	Minimum temperature of coldest period	Lowest monthly minimum temperature
7	Annual temperature range	Variable 5 – variable 6
8	Mean temperature of wettest quarter	Mean temperature of three wettest consecutive months
9	Mean temperature of driest quarter	Mean temperature of three driest consecutive months
10	Mean temperature of warmest quarter	Mean temperature of three warmest months
11	Mean temperature of coldest quarter	Mean temperature of three coldest months
12	Annual precipitation	Sum of monthly precipitation values
13	Precipitation of wettest period	Precipitation of wettest month
14	Precipitation of driest period	Precipitation of driest month
15	Precipitation seasonality	Standard deviation of monthly precipitation estimates, expressed as a percentage of their mean
16	Precipitation of wettest quarter	Total precipitation of three wettest consecutive months
17	Precipitation of driest quarter	Total precipitation of three driest consecutive months
18	Precipitation of warmest quarter	Total precipitation of three warmest months
19	Precipitation of coldest quarter	Total precipitation of three coldest months
20	Start of growing season	Date when daily mean temperature first meets or exceeds 5°C for five consecutive days in spring
21	End of growing season	Date when daily minimum temperature first falls below –2°C after 1 August
22	Growing season length	Variable 21 – variable 20
23	Total precipitation in the three months before start of growing season	Total precipitation in the three months before variable 20
24	Total growing season precipitation	Total precipitation during variable 22
25	Growing degree-days during growing season	Total degree-days during variable 22, accumulated for all days where mean temperature exceeds 5°C
26	Annual minimum temperature	Annual mean of monthly minimum temperatures
27	Annual maximum temperature	Annual mean of monthly maximum temperatures
28	Mean temperature during growing season	Mean temperature during variable 22
29	Temperature range during growing season	Highest minus lowest temperature during variable 22
30	Climate Moisture Index (monthly)	Precipitation minus potential evapotranspiration

[a] In all cases, the descriptions should be considered estimates rather than actual values.
[b] Variables 1–19 were generated by ANUCLIM; variables 20–29 were generated by SEEDGROW. The approach used creates a daily sequence of minimum and maximum temperature and precipitation, with the values forced monotonically through the monthly values. The resulting values are intended to represent mean conditions only, as the weather in any given year would be expected to produce different results, because of interannual variability.