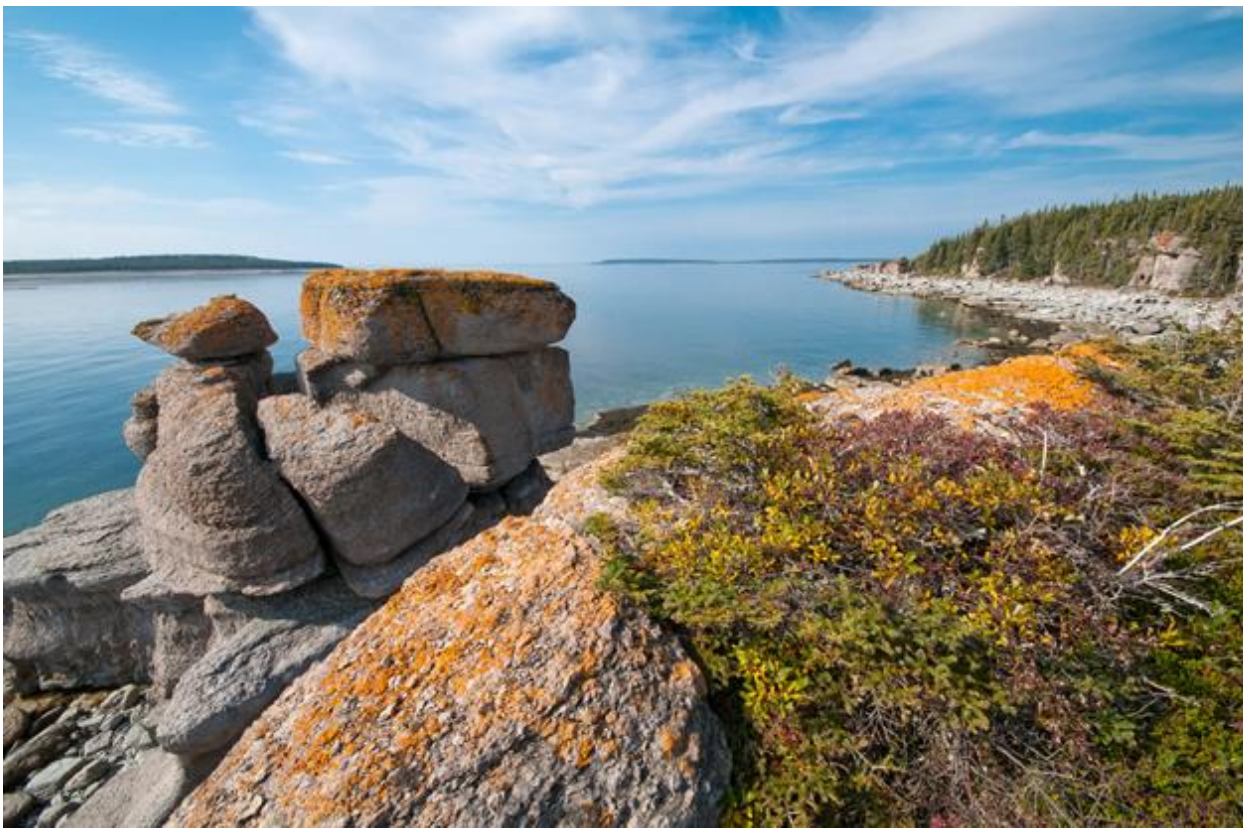
Let’s Talk about Climate Change: Québec Region



Office of the Chief Ecosystem Scientist

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Let’s Talk about Climate Change: Québec 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) Québec 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.

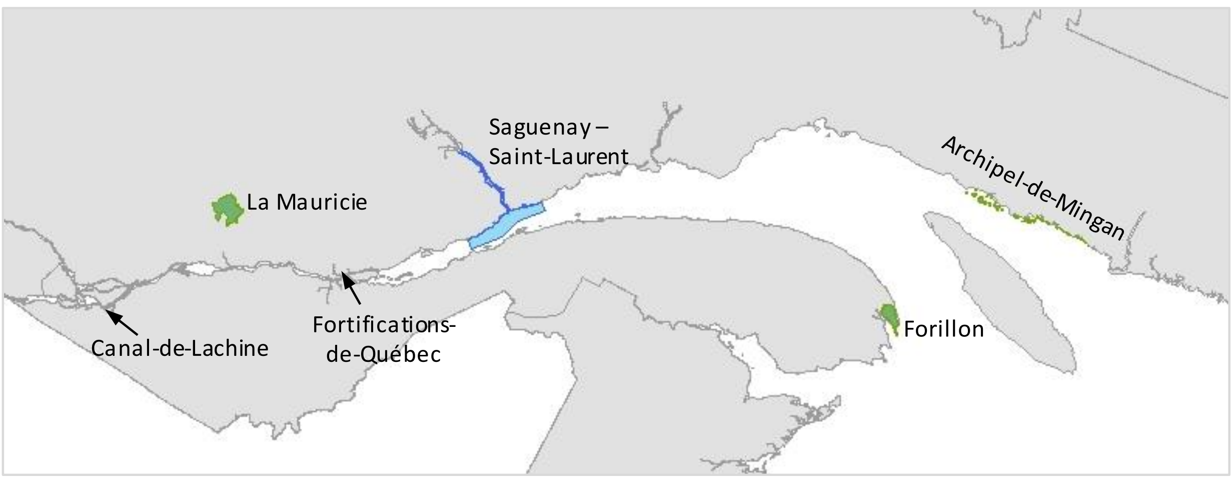


Figure 1. National Parks, Marine Parks and National Historic Sites included in this regional assessment.

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. 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.

Vertical allowances for each site were acquired from the Canadian Extreme Water Level Adaptation Tool (CAN-EWLAT, http://www.bio.gc.ca/science/data-donnees/index-en.php). The vertical allowances are “recommended changes in the elevation of coastal infrastructure required to maintain the current level of flooding risk in a future scenario of sea level rise”. These estimates are based on a future projection of regional sea level rise using the RCP 4.5 and RCP 8.5 scenarios and the historical water level records, including both tides and storm surge. The historical records do not incorporate predicted changes in storm tides.

2.2 Regional Climate Change Summaries

2.2.1 Physical Effects

- Since 1950, average annual air temperatures in the region have increased by 1 to 3˚C (Ouranos, 2015). This warming trend is projected to continue and model results indicate a further increase of 3 to 8˚C by 2100, depending on the location and RCP scenario used.

- The projected poleward migration of isotherms show the dramatic extent and speed of climate change in Québec. For instance, the 5˚ isotherm, which characterizes the mean annual temperature of Montreal, is projected to move up to 240 km north by 2080 (Figure 7). The spatial pattern of precipitation (isohyetes) is however expected to be more stable.
- The warming will be much more rapid toward Northwest Québec (up to 0.05˚/yr) compared to the Southeast Québec (up to 0.035˚/yr; Figure 8; Berteaux *et al.*, 2014).
- Precipitation patterns have been variable, with a general increase in spring and autumn and a slight decrease in winter precipitation in southern Québec since 1950 (Ouranos, 2015). Total annual precipitation is projected to increase with some seasonal and regional variability (e.g., an exception to the increase is a decrease in snow amounts in some areas of southern Québec) (Logan *et al.*, 2011; Ouranos, 2015).
- Winter river flows are projected to increase throughout Québec (e.g., more freeze/thaw events). Spring and autumn flows are projected to increase in the north and decrease in the south (e.g., greater evotranspiration) (Logan *et al.*, 2011; Ouranos, 2015). Summer drought conditions are also projected to increase in southern Québec (IPCC, 2012; Ouranos, 2015).
- For the 1979-2009 period surface-water temperatures have increased by 0.55 ˚C/decade in the Northeast Gulf of St. Lawrence and by 0.36 ˚C/decade in the St. Lawrence Estuary (Loder *et al.*, 2013). Projections generally indicate further warming of 1 to 3˚C by 2100 (Capotondi *et al.*, 2012).
- Saltwater intrusion of groundwater is expected to become more of a concern with higher sea levels (Chang *et al.*, 2011; Rasmussen *et al.*, 2013).
- For the period 1998-2013, average annual sea-ice cover in the east coast region has decreased by 1.53%/yr (Lemmen *et al.*, 2016). Within the Gulf of St. Lawrence maximum annual ice concentrations are projected to decrease by 67% and the number of days the protective ice-foot that develops along much of the regions coastline is also projected to decrease by ~33 days by 2041-2070 (Senneville *et al.*, 2014).
- A northward shift in storm track is expected to increase storm frequency in the region (Loder *et al.*, 2013).
- Although there are local difference in the magnitude of sea level change, regionally mean sea levels are rising faster than global average (Church *et al.*, 2013; Ouranos, 2015). Projections for the region indicate another 30-100cm in relative sea level rise by 2100 (James *et al.*, 2014; Zhai *et al.*, 2015).
- Rates of coastal erosion will vary with landform. While cliffs or bluffs will only recede, marshes, sand dunes and beaches are more dynamic and have the capacity to re-establish and undergo morphological change (e.g., landward migration, overwash and erosion)(e.g., Nye, 2010). Coastal dynamics at Forillon NP were examined by a research team from the Université du Québec à Rimouski (e.g., Bernatchez *et al.*, 2013). For example, it was concluded that climate change (sea level rise) may progressively drown the salt marsh at Penouille (Gibeault *et al.*, 2016). Given the concerns and impacts of coastal erosion, restoration activities have been initiated at Forillon including roadway and historic monument relocation, shoreline naturalization, and replacing a paved trail with a raised boardwalk (https://www.pc.gc.ca/en/pn-np/qc/forillon/info/cote-coastal).

Mean Annual Temperature

Change from 1980-2010 Baseline

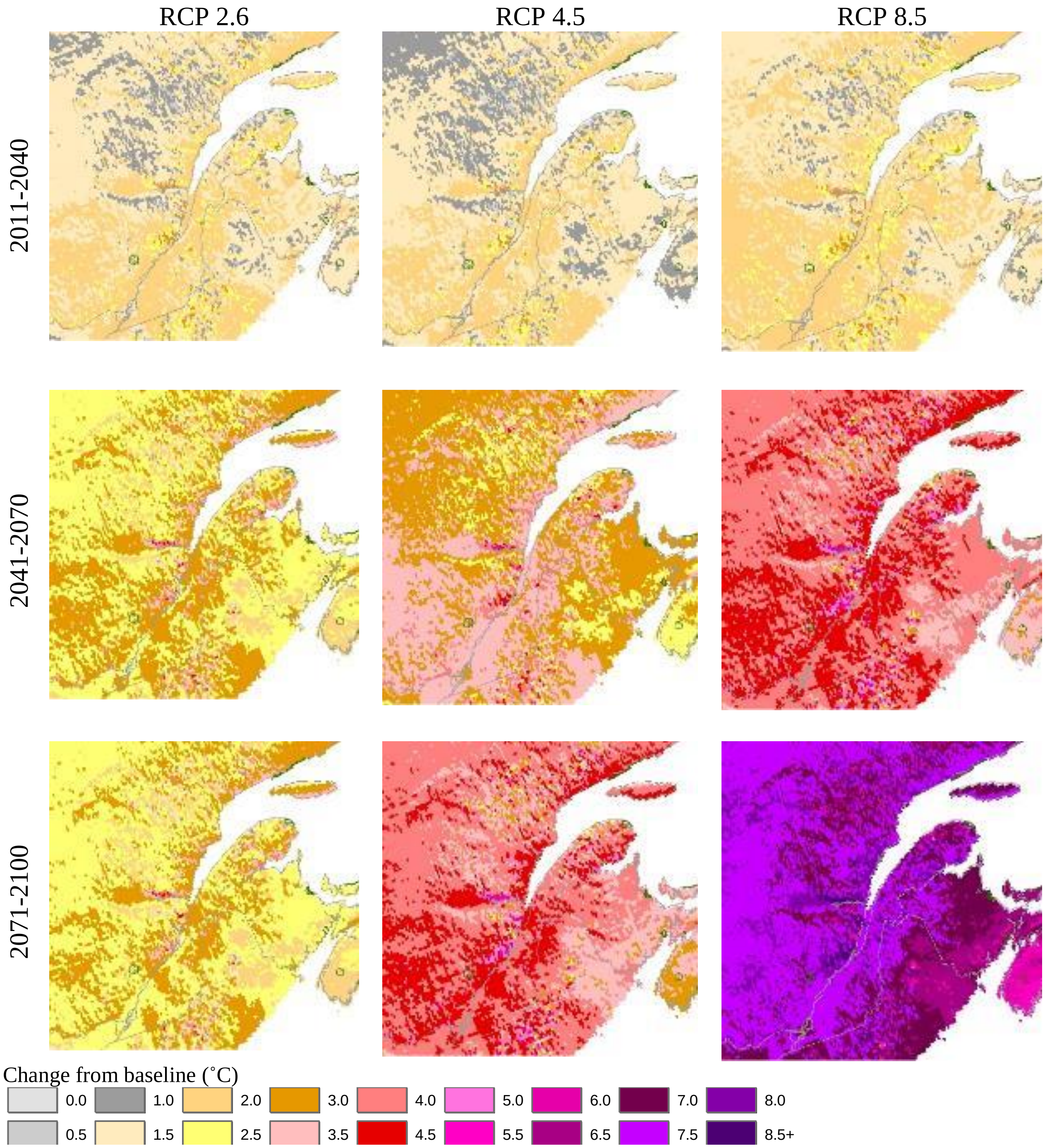


Figure 2. Temperature projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada,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

Total Annual Precipitation

Change from 1980-2010 Baseline

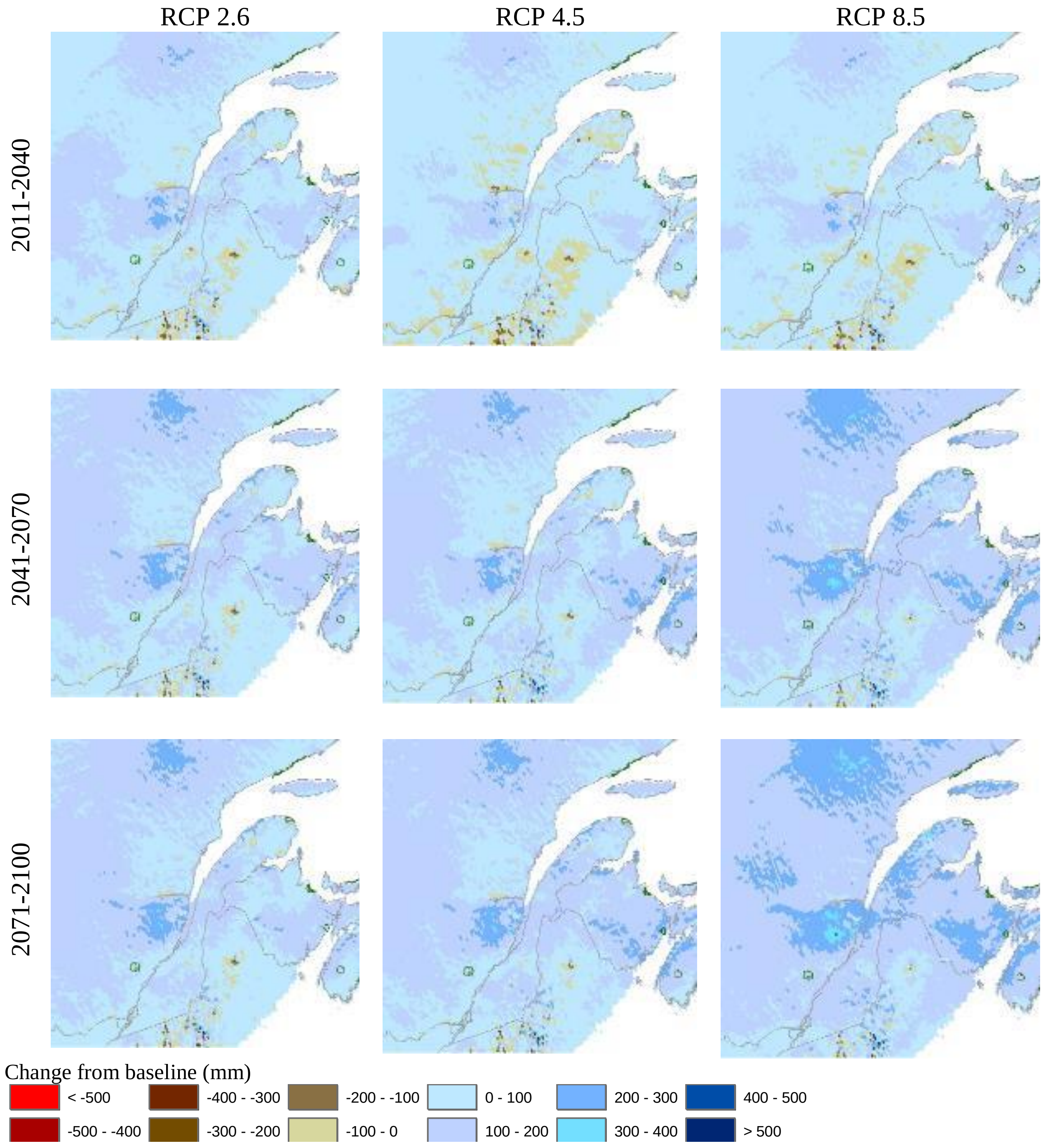
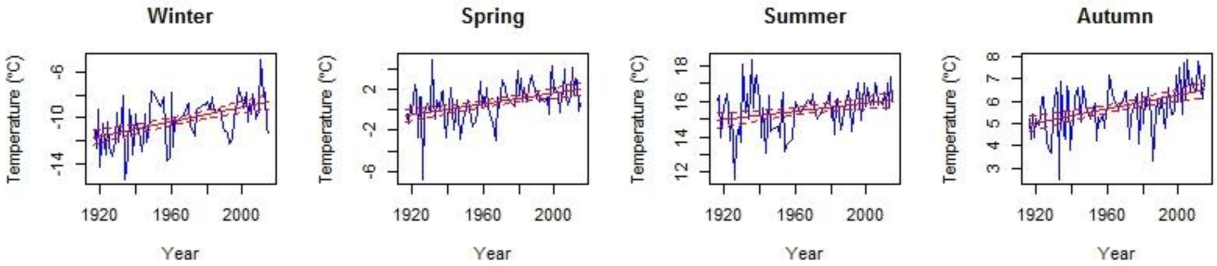


Figure 3. Precipitation projections represent a composite (average) of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM, using three greenhouse gas scenarios (RCPs) for three future time periods. Climate data provided by Natural Resources Canada,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

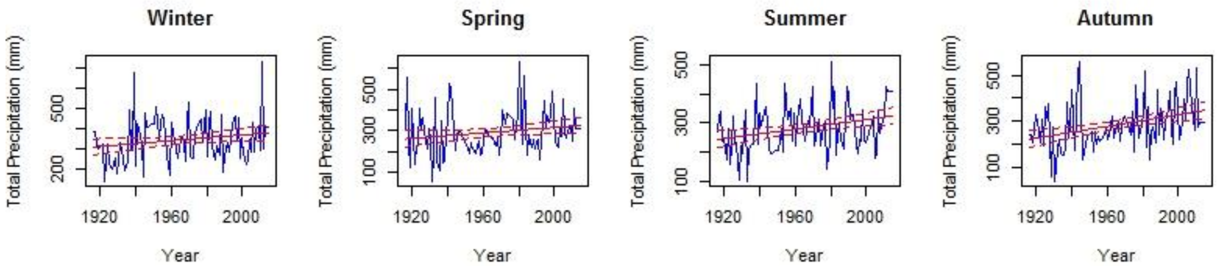
Forillon National Park

A. Mean Temperature



Seasonal mean temperature at Gaspe Climatological Station (7052601) from 1916 to 2015. A significant trend (P<0.05) observed for winter (0.032°C/yr), spring (0.026°C/yr), summer (0.011°C/yr) and autumn (0.016°C/yr).

B. Total Precipitation

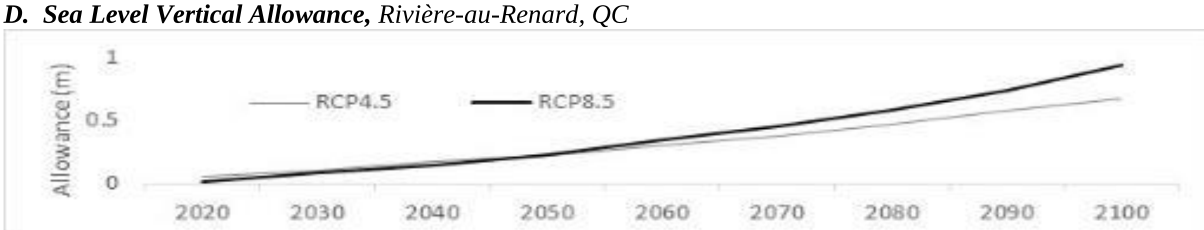


Seasonal total precipitation at Gaspe Climatological Station (7052605) from 1916 to 2013. A significant trend (P<0.05) observed for winter (0.72mm/yr), summer (0.81mm/yr) and autumn (1.26mm/yr). No significant trend (P<0.05) observed for spring.

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

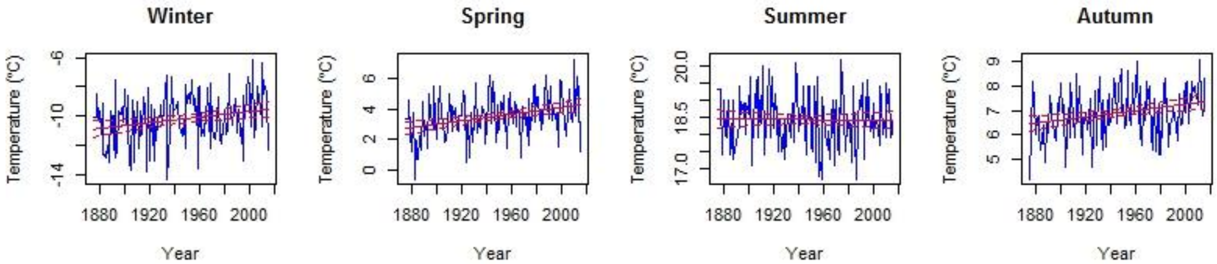
Increase / decrease in:	**2011-2040**			**2041-2070**			**2071-2100**		
Mean Winter Temperature (°C)	2.6	to	2.9	3.9	to	5.2	3.9	to	8.0
Mean Spring Temperature (°C)	2.1	to	2.1	3.5	to	4.5	3.4	to	7.5
Mean Summer Temperature (°C)	2.1	to	2.1	3.0	to	4.5	2.9	to	7.4
Mean Autumn Temperature (°C)	1.6	to	1.6	2.3	to	3.6	2.4	to	6.5
Precipitation in Winter	4%	to	6%	12%	to	13%	9%	to	23%
Precipitation in Spring	2%	to	7%	7%	to	15%	4%	to	20%
Precipitation in Summer	5%	to	9%	9%	to	12%	11%	to	11%
Precipitation in Autumn	-3%	to	-6%	-2%	to	-3%	-4%	to	-7%
Number of days of growing season	21.0	to	22.0	32.0	to	43.0	32.0	to	72.0
Growing degree-days during growing season	27%	to	27%	43%	to	66%	43%	to	122%
Advance in start of growing season (days)	8.0	to	8.0	15.0	to	21.0	16.0	to	40.0
Climate Moisture Index (sum May-Sept)	12.8	to	14	10.1	to	11.5	2.0	to	12.0

D. Sea Level Vertical Allowance, *Rivière-au-Renard, QC*



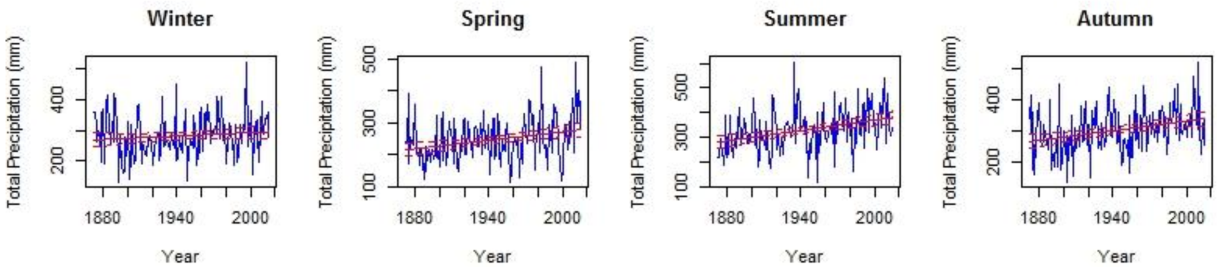
Fortifications of Québec National Historic Site

A. Mean Temperature



Seasonal mean temperature at Québec Climatological Station (701S001) from 1875 to 2015. A significant trend ($P<0.05$) observed for winter (0.009°C/yr), spring (0.011°C/yr) and autumn (0.006°C/yr). No significant trend ($P<0.05$) observed for summer.

B. Total Precipitation

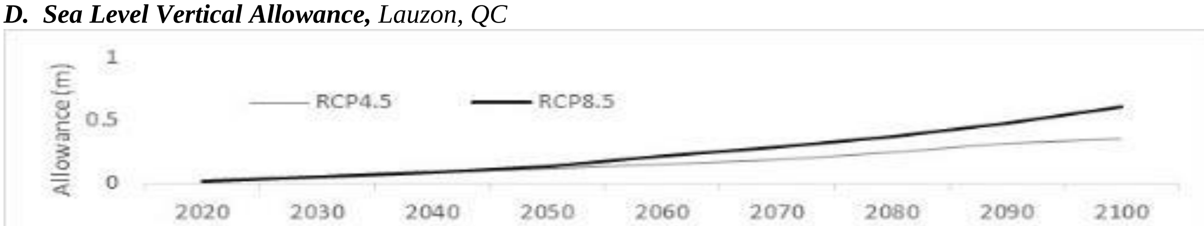


Seasonal total precipitation at Lauzon Climatological Station (7024254) from 1872 to 2015. A significant trend ($P<0.05$) observed for spring (0.44mm/yr), summer (0.7mm/yr) and autumn (5.3mm/yr). No significant trend ($P<0.05$) observed for winter.

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

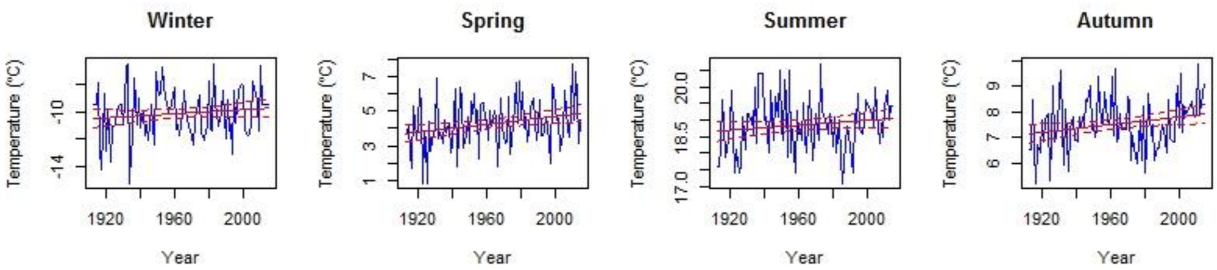
Increase / decrease in:		**2011-2040**			**2041-2070**			**2071-2100**	
Max Winter Temperature (°C)	8.3	**to**	8.4	9.1	**to**	10.5	9.1	**to**	13.3
Max Spring Temperature (°C)	2.5	**to**	2.6	3.7	**to**	4.9	3.3	**to**	7.8
Max Summer Temperature (°C)	1.8	**to**	1.9	2.5	**to**	4.4	2.4	**to**	7.5
Max Autumn Temperature (°C)	9.2	**to**	9.4	10.0	**to**	11.5	9.9	**to**	14.9
Min Winter Temperature (°C)	2.6	**to**	2.9	3.8	**to**	5.7	3.9	**to**	9.4
Min Summer Temperature (°C)	1.6	**to**	1.7	2.3	**to**	4.0	2.4	**to**	7.0
Precipitation in Winter	9%	**to**	10%	16%	**to**	20%	15%	**to**	29%
Precipitation in Spring	8%	**to**	11%	4%	**to**	22%	11%	**to**	29%
Precipitation in Summer	5%	**to**	8%	8%	**to**	8%	5%	**to**	12%
Precipitation in Autumn	0%	**to**	36%	2%	**to**	2%	-2%	**to**	2%
Advance in start of growing season (# of days)	14.6	**to**	20.0	9.4	**to**	11.2	13.6	**to**	35.4

D. Sea Level Vertical Allowance, *Lauzon, QC*



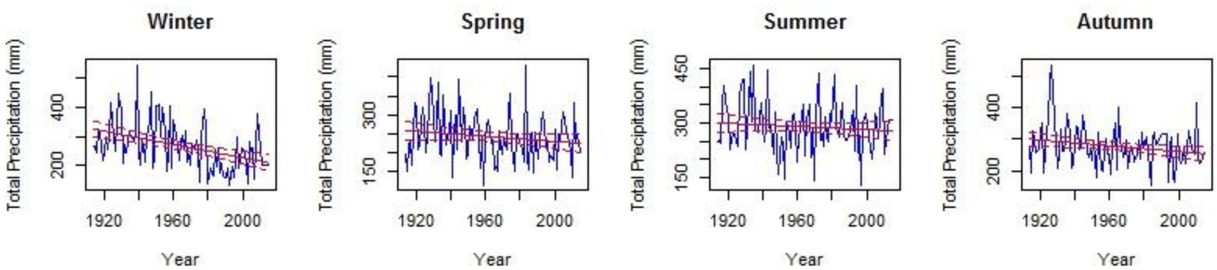
La Maurice National Park

A. Mean Temperature



Seasonal mean temperature at Nicolet Climatological Station (7025440) from 1913 to 2015. A significant trend ($P<0.05$) observed for spring (0.011°C/yr) and autumn (0.007°C/yr). No significant trend ($P<0.05$) observed for winter or summer.

B. Total Precipitation



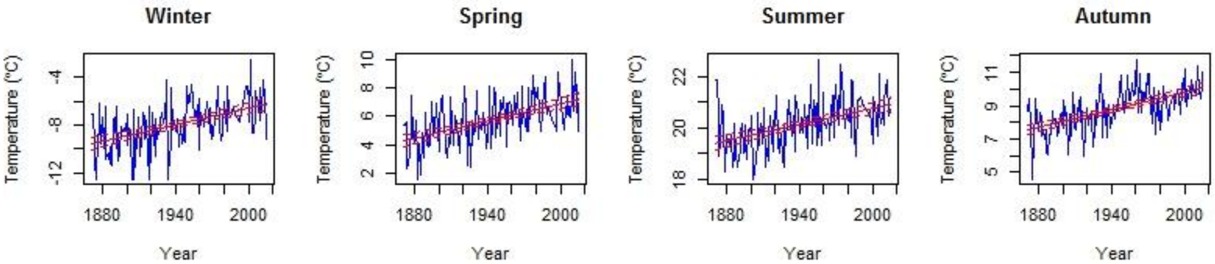
Seasonal total precipitation at Nicolet Climatological Station (7025440) from 1914 to 2015. A significant trend ($P<0.05$) observed for winter (-1.14mm/yr) and autumn (-0.46mm/yr). No significant trend ($P<0.05$) observed for spring or summer.

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)	2.3	to	2.6	3.4	to	5.0	3.4	to	8.4
Mean Spring Temperature (°C)	2.3	to	2.4	3.5	to	4.8	3.2	to	7.9
Mean Summer Temperature (°C)	1.6	to	1.6	2.3	to	4.0	2.2	to	7.2
Mean Autumn Temperature (°C)	1.7	to	1.8	2.5	to	3.9	2.4	to	7.4
Precipitation in Winter	6%	to	7%	12%	to	17%	11%	to	26%
Precipitation in Spring	9%	to	13%	14%	to	24%	15%	to	32%
Precipitation in Summer	0%	to	2%	1%	to	2%	-2%	to	7%
Precipitation in Autumn	-2%	to	-2%	-1%	to	0%	0%	to	-4%
Number of days of growing season	23.0	to	25.0	32.0	to	42.0	31.0	to	66.0
Growing degree-days during growing season	20%	to	22%	32%	to	55%	31%	to	106%
Advance in start of growing season (days)	10.0	to	10.0	14.0	to	20.0	14.0	to	33.0
Climate Moisture Index (sum May-Sept)	10.6	to	11.3	5.1	to	9.7	-7.4	to	11.7

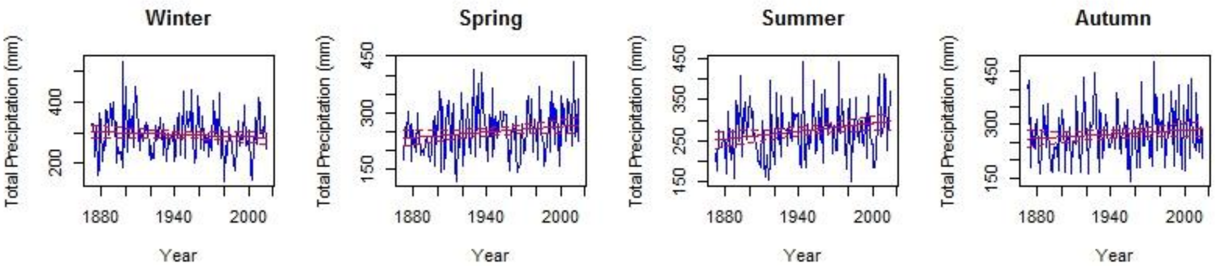
Lachine Canal National Historic Site

A. Mean Temperature



Seasonal mean temperature at Montreal Climatological Station (7024740) from 1871 to 2015. A significant trend (P<0.05) observed for winter (0.023°C/yr), spring (0.02°C/yr), summer (0.01°C/yr) and autumn (0.02°C/yr).

B. Total Precipitation



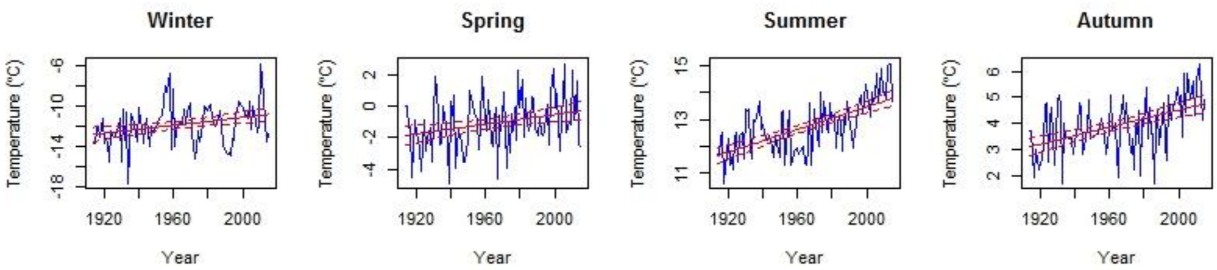
Seasonal total precipitation at Montreal Climatological Station (7025250) from 1872 to 2015. A significant trend (P<0.05) observed for spring (0.24mm/yr) and summer (0.32mm/yr). No significant trend (P<0.05) observed for winter or autumn.

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)	7.4	**to**	7.4	8.1	**to**	9.5	8.1	**to**	12.3
Max Spring Temperature (°C)	2.3	**to**	2.5	3.5	**to**	4.7	3.1	**to**	7.3
Max Summer Temperature (°C)	2.0	**to**	2.0	2.6	**to**	4.5	2.6	**to**	7.7
Max Autumn Temperature (°C)	9.2	**to**	9.4	10.0	**to**	11.5	9.9	**to**	15.0
Min Winter Temperature (°C)	2.0	**to**	2.3	3.1	**to**	5.0	3.2	**to**	8.4
Min Spring Temperature (°C)	2.1	**to**	2.1	3.2	**to**	4.4	2.8	**to**	7.2
Min Summer Temperature (°C)	1.1	**to**	1.2	1.8	**to**	3.5	1.9	**to**	6.5
Min Autumn Temperature (°C)	11.0	**to**	11.2	11.9	**to**	13.2	11.8	**to**	16.6
Precipitation in Winter	2%	**to**	2%	9%	**to**	12%	7%	**to**	22%
Precipitation in Spring	4%	**to**	8%	-6%	**to**	18%	10%	**to**	24%
Precipitation in Summer	5%	**to**	6%	4%	**to**	4%	2%	**to**	9%
Precipitation in Autumn	-1%	**to**	-50%	-1%	**to**	1%	-5%	**to**	2%
Advance in start of growing season (# of days)	13.4	**to**	16.8	7.6	**to**	9.4	10.6	**to**	31.8

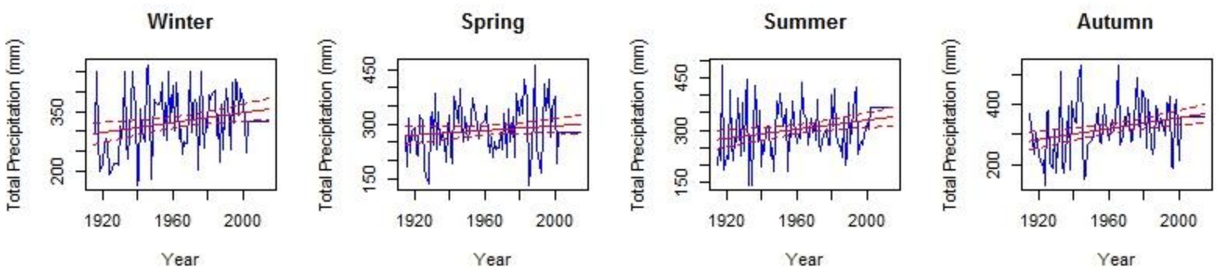
Mingan Archipelago National Park Reserve

A. Mean Temperature



Seasonal mean temperature at Natashquan Climatological Station (7045401) from 1914 to 2015. A significant trend (P<0.05) observed for winter (0.019°C/yr), spring (0.015°C/yr), summer (0.021°C/yr) and autumn (0.016°C/yr).

B. Total Precipitation

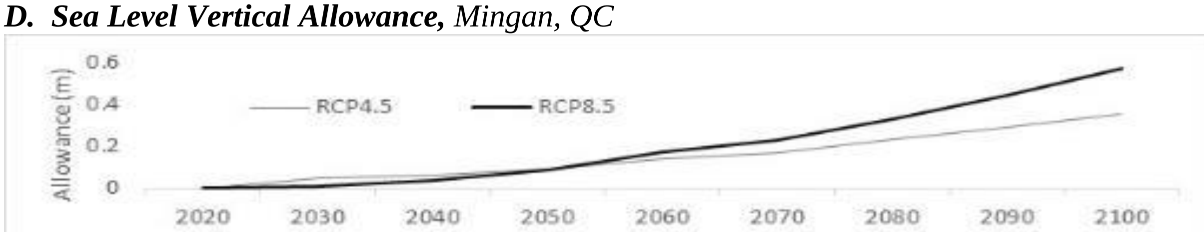


Seasonal total precipitation at Natashquan Climatological Station (7045400) from 1915 to 2003. A significant trend (P<0.05) observed for winter (0.63mm/yr), summer (0.66mm/yr) and autumn (0.9mm/yr). No significant trend (P<0.05) observed for spring.

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

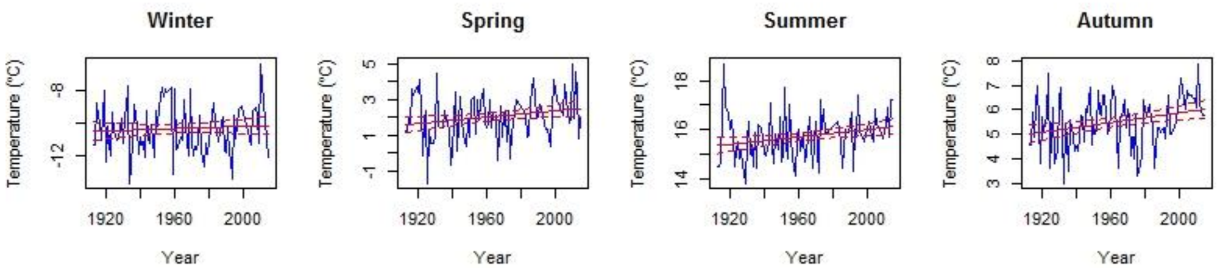
Increase / decrease in:	2011-2040			2041-2070			2071-2100		
Mean Winter Temperature (°C)	2.8	to	3.1	4.2	to	5.5	4.2	to	8.5
Mean Spring Temperature (°C)	2.2	to	2.2	3.8	to	4.8	3.7	to	8.0
Mean Summer Temperature (°C)	2.1	to	2.2	3.0	to	4.5	2.9	to	7.4
Mean Autumn Temperature (°C)	1.6	to	1.6	2.3	to	3.7	2.4	to	6.6
Precipitation in Winter	6%	to	6%	11%	to	16%	11%	to	26%
Precipitation in Spring	2%	to	-2%	3%	to	10%	2%	to	16%
Precipitation in Summer	9%	to	6%	11%	to	15%	10%	to	16%
Precipitation in Autumn	7%	to	3%	6%	to	10%	8%	to	3%
Number of days of growing season	21.1	to	21.4	32.4	to	45.4	33.6	to	72.7
Growing degree-days during growing season	34%	to	34%	52%	to	82%	53%	to	150%
Advance in start of growing season (days)	10.1	to	10.6	17.7	to	24.7	18.9	to	41.4
Climate Moisture Index (sum May-Sept)	20.3	to	19.0	18.6	to	17.3	18.2	to	10.7

D. Sea Level Vertical Allowance, *Mingan, QC*



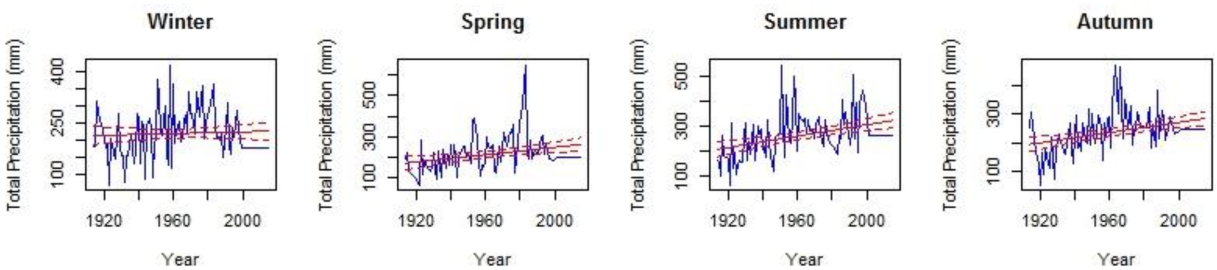
Saguenay-St. Lawrence Marine Park

A. Mean Temperature



Seasonal mean temperature at Tadoussac Climatological Station (7042840) from 1913 to 2015. A significant trend ($P<0.05$) observed for spring (0.009°C/yr), summer (0.007°C/yr) and autumn (0.01°C/yr). No significant trend ($P<0.05$) observed for winter.

B. Total Precipitation

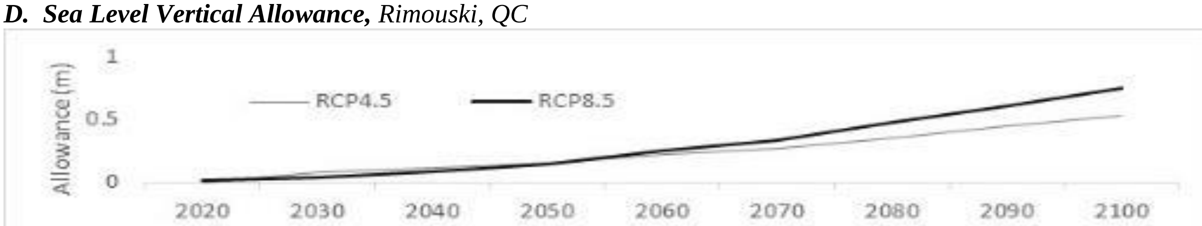


Seasonal total precipitation at Tadoussac Climatological Station (7025440) from 1914 to 2004. A significant trend ($P<0.05$) observed for spring (0.9mm/yr), summer (1.15mm/yr) and autumn (0.89mm/yr). No significant trend ($P<0.05$) observed for winter.

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)	2.1	to	2.4	3.3	to	4.8	3.3	to	8.2
Mean Spring Temperature (°C)	2.5	to	2.5	3.8	to	5.0	3.5	to	8.3
Mean Summer Temperature (°C)	2.5	to	2.6	3.2	to	4.9	3.2	to	8.1
Mean Autumn Temperature (°C)	1.8	to	1.9	2.6	to	4.0	2.6	to	7.4
Precipitation in Winter	17%	to	18%	23%	to	28%	22%	to	38%
Precipitation in Spring	14%	to	18%	21%	to	31%	19%	to	41%
Precipitation in Summer	5%	to	6%	7%	to	8%	5%	to	10%
Precipitation in Autumn	2%	to	4%	6%	to	7%	3%	to	5%
Number of days of growing season	21.0	to	23.0	30.0	to	41.0	30.0	to	64.0
Growing degree-days during growing season	32%	to	34%	46%	to	71%	46%	to	129%
Advance in start of growing season (days)	12.0	to	12.0	18.0	to	24.0	18.0	to	38.0
Climate Moisture Index (sum May-Sept)	10.0	to	10.1	5.8	to	9.3	-4.3	to	10.4

D. Sea Level Vertical Allowance, *Rimouski, QC*



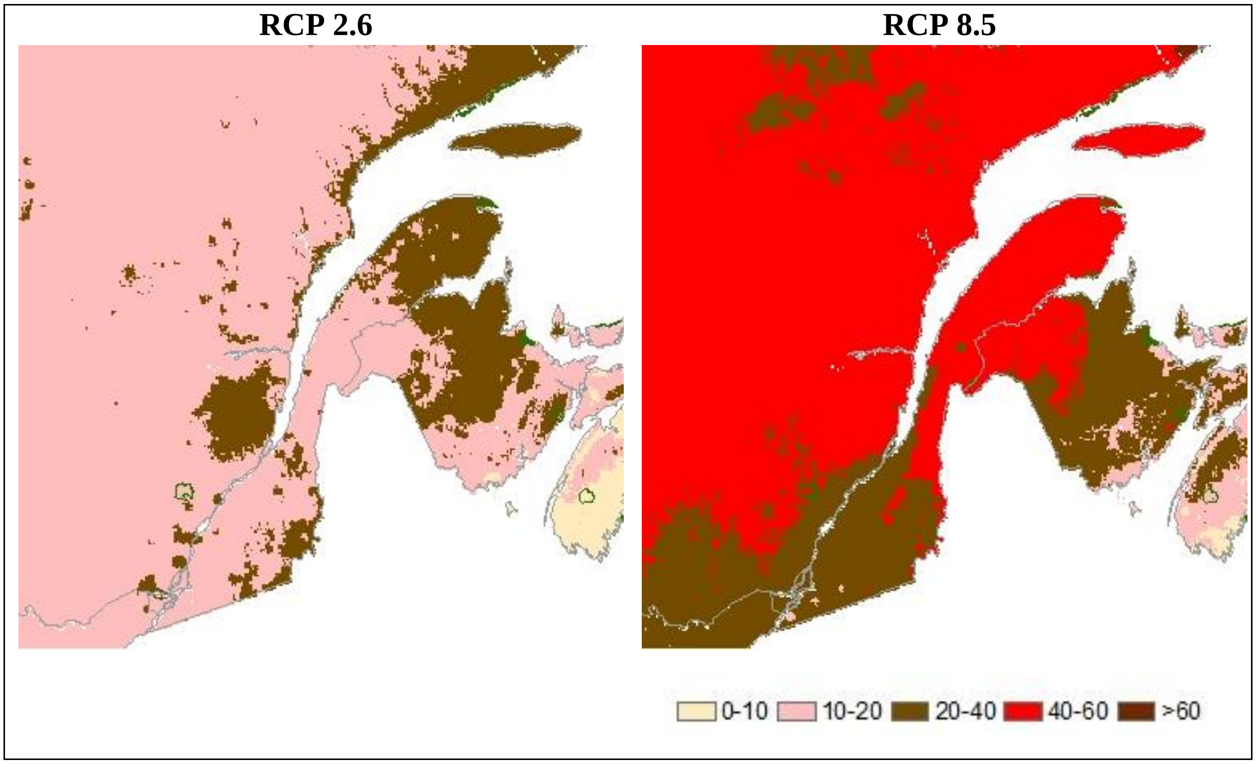


Figure 4. Increase in wildfire season length (days) under RCP 2.6 and 8.5 scenarios.

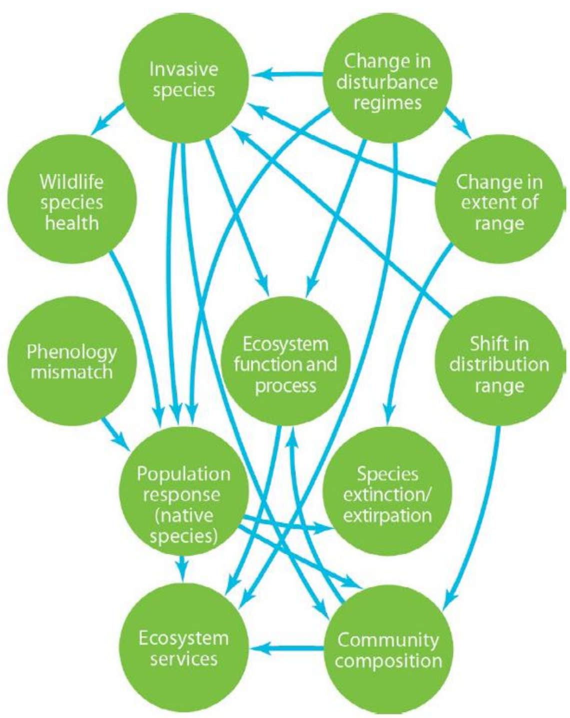


Figure 5. The complex ecosystem linkages and interactions to climate change (from Nantel *et al.*, 2014).

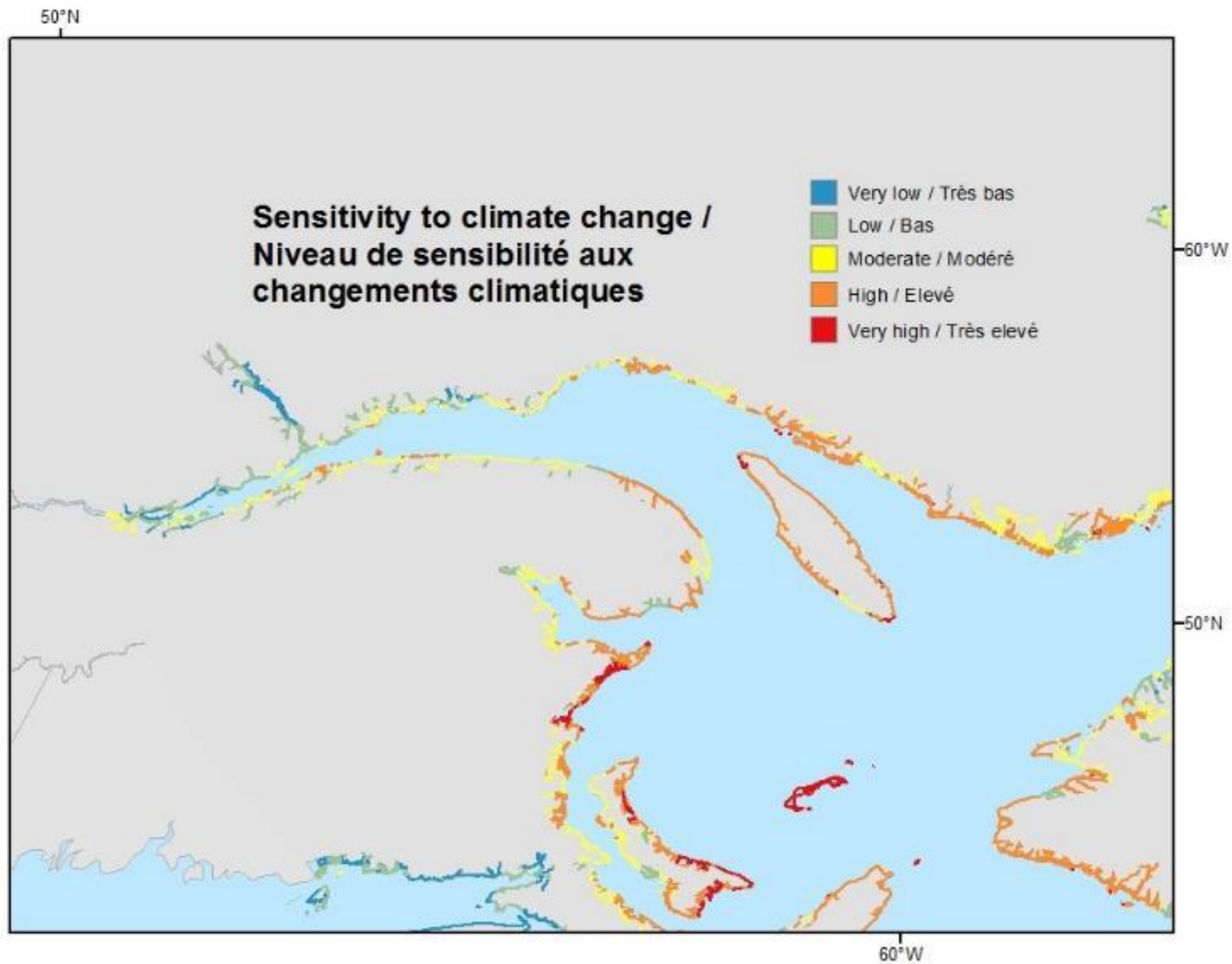


Figure 6. Preliminary map of coastal sensitivity to climate change. Sensitivity is based on coastal materials, landforms, relief, ground ice, wave height, tidal range, recent trends in sea ice concentration, and projected sea level rise to 2050. Data provided by Natural Resources Canada (Couture and Manson, 2016).

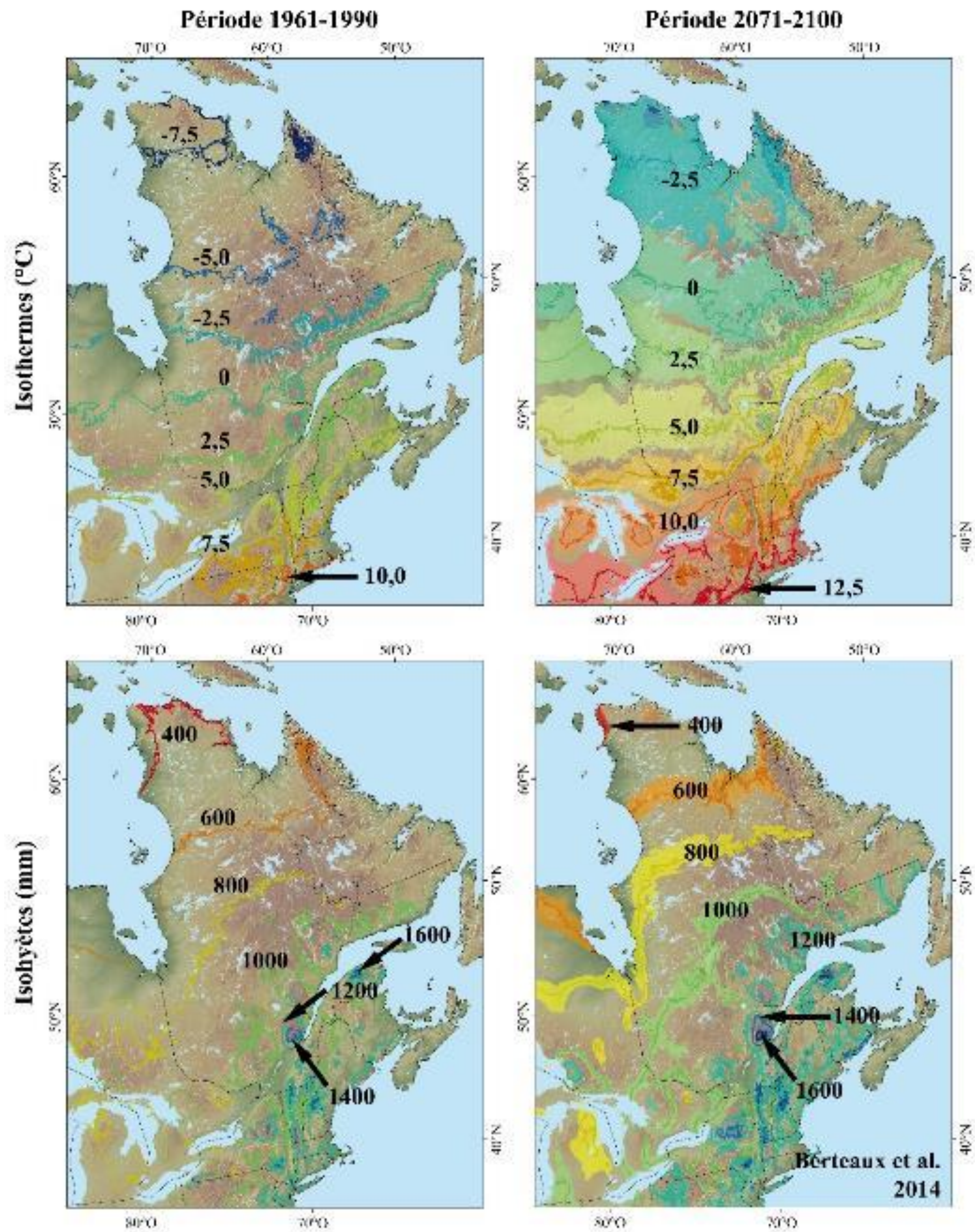


Figure 7. Isotherms and isohyets for annual mean temperature and total precipitation in the past (1961-1990) vs. future (2071-2100), for Québec and periphery (Berteaux *et al.*, 2014).

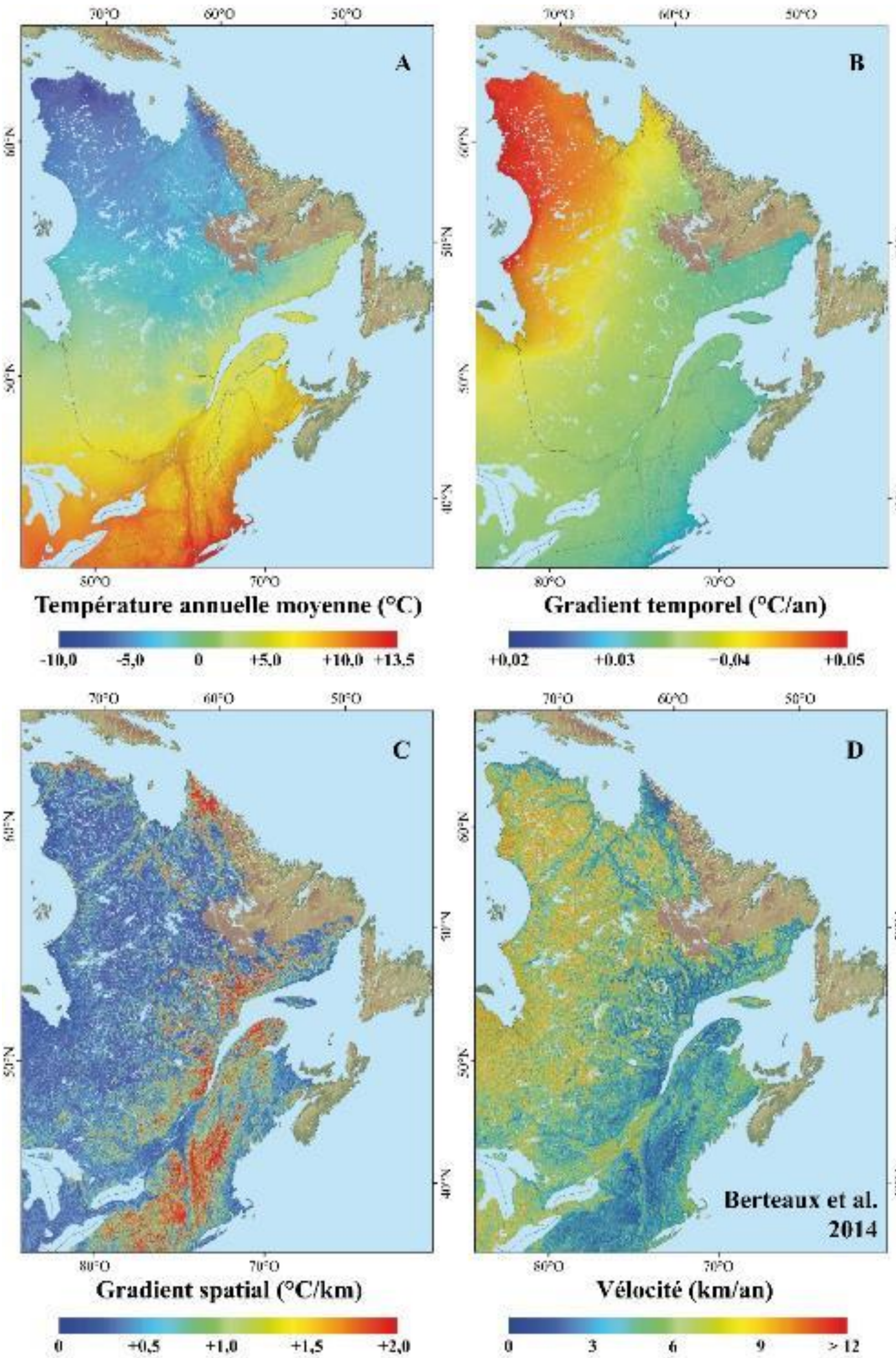


Figure 8. Spatial and temporal temperature gradients and climatic velocity for Québec and periphery, from 1961-1990) to 2071-2100 (Berteaux *et al.*, 2014). Velocity combines temporal and spatial gradients, being larger where warming is faster, but decreasing where spatial gradients are strong.

2.2.2 Other Effects

Ecosystems and Biodiversity

- Based on climate niche models for 765 species of vascular plants, amphibians, and birds, the future climates of Québec will become suitable for many more species of those taxa (Figure 9), but the range of many species presently established are expected to contract. Overall, climate niches are projected to shift north by 45 to 70 km/decade; very few species will be able to actually adjust their range at that speed (Berteaux *et al.*, 2014).
- On the long term, shifts in climate niches will potentially entail major species turn-over in large parts of Québec, especially in the boreal region (Figure 10; Berteaux *et al.*, 2014).
- Species and ecosystems in areas with large climatic velocity (Figure 8) will be the most exposed to climate change; those areas will likely see more profound ecological changes, depending on the sensitivity of their component species.
- 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).
- 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).
- Ocean primary productivity in the region is declining and appears linked to warming waters and less sea ice (i.e., sea ice releases salt, which sinks, setting up a convective process that brings less dense, nutrient-rich waters to surface) (Dufour and Ouellet, 2007; Hoegh-Guldberg and Bruno, 2010). No significant change in the regions ocean surface water pH has been observed since 1934 (DFO, 2012a).
- Small changes in ocean temperature are known to influence the abundance and distribution of aquatic vegetation (e.g., eelgrass), finfish and shellfish (Burkett and Davidson, 2012; DFO, 2012b; Shackell *et al.*, 2013). There is a general trend towards commercial marine species losses in the Gulf of St. Lawrence and gains on the Newfoundland and Labrador Shelf due to thermal tolerances (Khan, 2013).
- Increasing inland water temperatures may exceed the thermal regime for cold-water species (Poesch *et al.*, 2016).
- Sea-level rise and increases in the frequency and magnitude of storm surges are potential threats to waterbird nests and breeding habitat on low-lying landforms, such as barrier islands and beaches (e.g., Bourque *et al.*, 2015; Craik *et al.*, 2015; Tremblay *et al.*, 2006). Populations of rare arctic-alpine plants, including some endemics, established on the upper beaches in Mingan Archipelago NPR are losing habitat due to stronger and more frequent winter storms. At least one endemic species is projected to disappear from the park within the next 50 yrs.
- As the climate envelope for boreal forest tree species (e.g., black spruce, white spruce, jack pine, balsam fir, trembling aspen) becomes less suitable along the forests southern boundary, conditions are becoming more favourable for Great Lakes-St. Lawrence forest

species (e.g., white pine, red pine, sugar maple, red oak) (McKenney *et al.*, 2010; Sittaro *et al.*, 2017; Walker *et al.*, 2002; Warren *et al.*, 2013). Forest yields could potentially decrease in the maple, balsam fir and spruce forests due to decreased soil moisture (projected to be 20-40% less by 2041-2070) (Houle *et al.*, 2012; Ouranos, 2015).

- The change in boreal forest composition to more deciduous species may offset some of the concerns associated with climate change and wildfires (Terrier *et al.*, 2013).
- Asynchrony between life history events has been observed. Although photoperiod is not changing, other ecological cues are changing, such as temperature, river flow, heat accumulation, etc. About 80% of migratory bird species (for which there are sufficient data) are arriving earlier now than 40 years ago in Québec (Berteaux *et al.*, 2014). On average, those species are arriving 3.5 days earlier; short distance migrants have brought forward their dates of arrival by more days than long-distance migrants. Because of much earlier peaks in insect and plant biomass have been observed, this may mismatch migrant bird hatchling growth and development (e.g., asynchrony between wood warbler and eastern spruce budworm) (Knudsen *et al.*, 2011; Nituch and Bowman, 2013).
- Plant productivity may increase due to increased CO_2, that is, if species are not otherwise limited by habitat conditions (e.g., soil, moisture, nutrients, light) or disturbances (e.g., fire, flooding, or drought) (Warren *et al.*, 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). For example, in some areas moose population decline has been attributed to the transmission of the deadly brain worm (*Parelaphostrongylus tenuis*) from range expanding white tailed deer (Pickles *et al.*, 2013).
- Conditions, including milder winters and 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 and gypsy moth) (Warren and Lemmen, 2014). Beech bark disease and Emerald Ash Borer will soon reach La Mauricie NP region.

Visitor Experience

- Seasonal recreational and nature-based activities are affected by climate change and unreliable weather (Scott and Jones, 2006; Scott *et al.*, 2007). In particular decreased snowpack will negatively impact winter recreational activities such as snowshoeing, cross-country skiing and ice fishing.
- According to an assessment for the Eastern Township and Laurentian regions summer socioeconomic gains may not compensate for winter losses (Bleau *et al.*, 2012).
- Park visitation may increase due to an earlier spring and warmer summer and autumn conditions, therefore it may be necessary to extend the operating season to accommodate visitor safety and demand.
- 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 more common in southern Quebec (Ouranos, 2015). As well, increasing incidences of West Nile virus (mosquito vector) have been linked to climate change (Soverow *et al.*, 2009).

- A longer and more intense fire season will affect visitor safety and experience (e.g., area closures, no campfires).

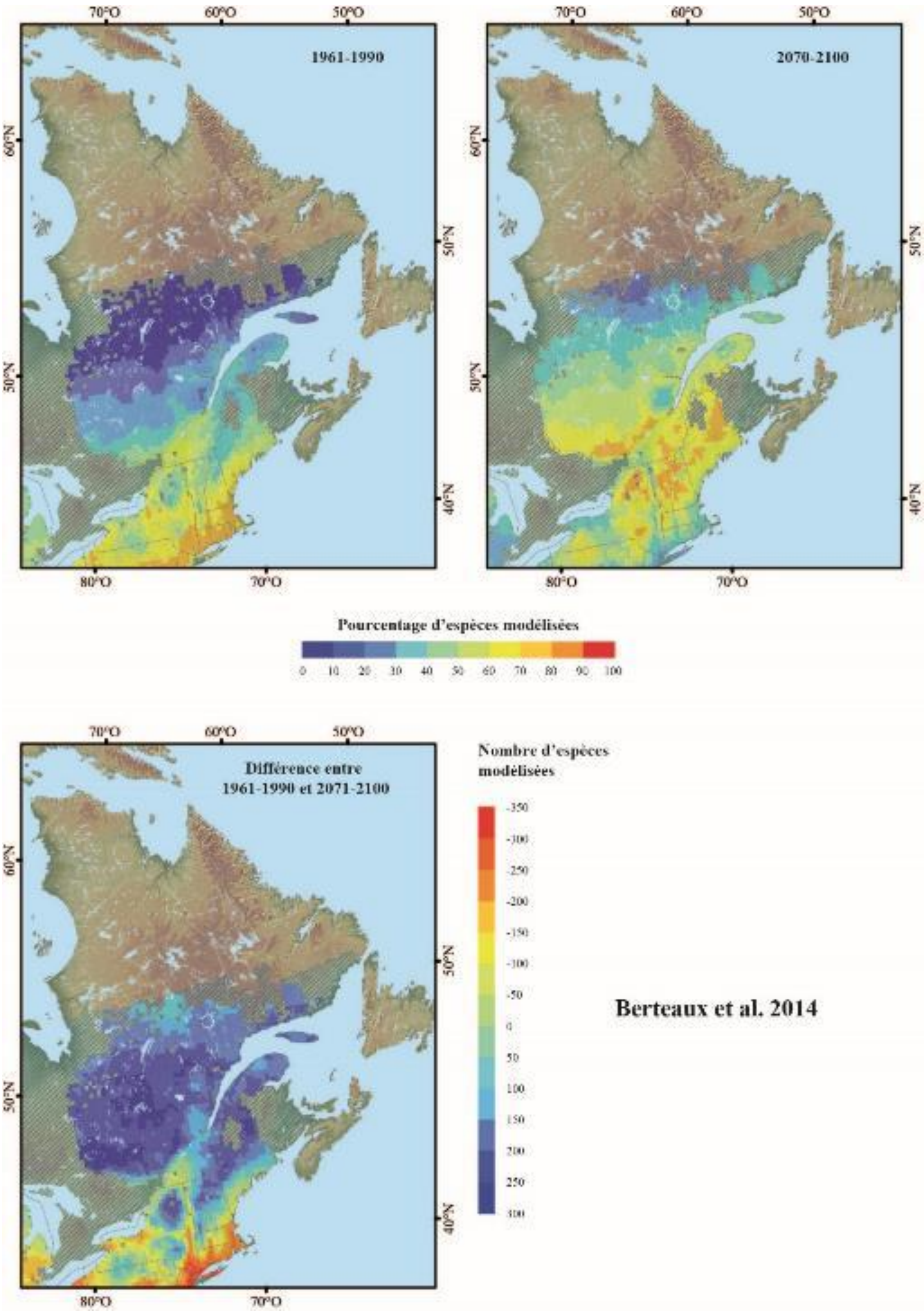


Figure 9. Distribution of richness in climate niches of native species, from past to future (Berteaux *et al.*, 2014). The upper left hand map shows the percentage of 765 modeled species for which the climate was suitable in 1961-1990 and the upper right map shows the percentage among the same species for which the climate will be suitable in 2071-2100. The lower map shows the distribution of increase in climate niche richness.

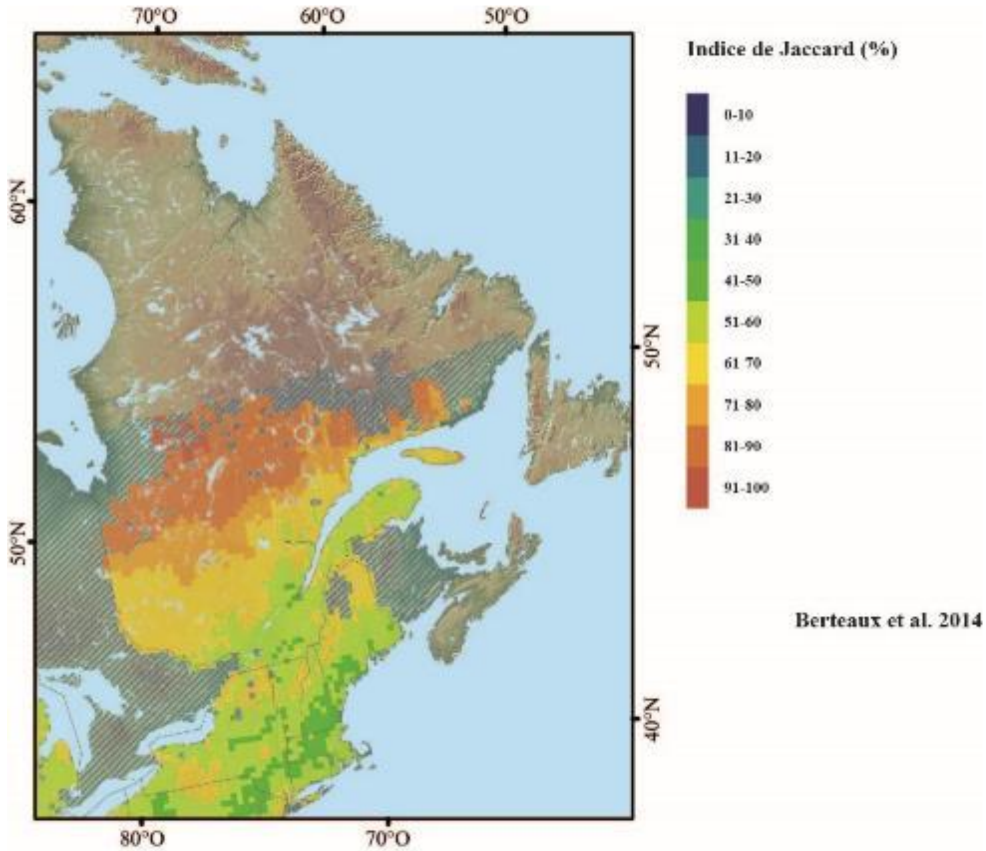


Figure 10. Distribution of projected turn-over in climate niches of native species, from 1961-1990 to 2071-2100 (Berteaux *et al.*, 2014). The Jaccard index is a measure of dissimilarity between current and projected future species composition, so that the larger the value, the more different the future composition will be compared to present.

Assets and Infrastructure

- Increased storm intensity and less ice cover increases the risk of coastal flooding and erosion. For instance, a comprehensive study of the coastal dynamics of the Penouille Peninsula in Forillon NP has identified vulnerable areas and informed, among other things, the re-location of the building and trail (Bernatchez *et al.*, 2013).
- Projected sea level rise (see vertical allowance projection within each site summary) will damage and destroy coastal infrastructure (Lemmen *et al.*, 2016), with associated maintenance or relocation costs.
- Saltwater intrusion of aquifers may impact potable water sources.
- Flooding from extreme events may overwhelm stormwater system capacities.
- There is an increasing risks to assets and infrastructure associated with wildfire in some areas. Although fire is generally not recognized as a significant ecosystem driver in the Carolinian or Great Lakes-St. Lawrence forests as compared to the boreal forest, more severe fire weather (heat and drought) may create conditions where fire suppression is no longer feasible or effective (Colombo, 2008; Flannigan *et al.*, 2005).
- An engineering assessment confirmed the vulnerabilities of Montreal's (proximate to Lachine Canal NHS) drainage system to climate change (Engineers Canada, 2015).

Cultural Resources

- Flood, storm surge, and wildfire may damage some archaeological sites.
- 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).

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 (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 (e.g., structures that improve drainage and serve as "ecopassages"; communicating climate change through park programs and exhibits; and, responding to changing visitor interests and needs.

Regional adaptation resources:

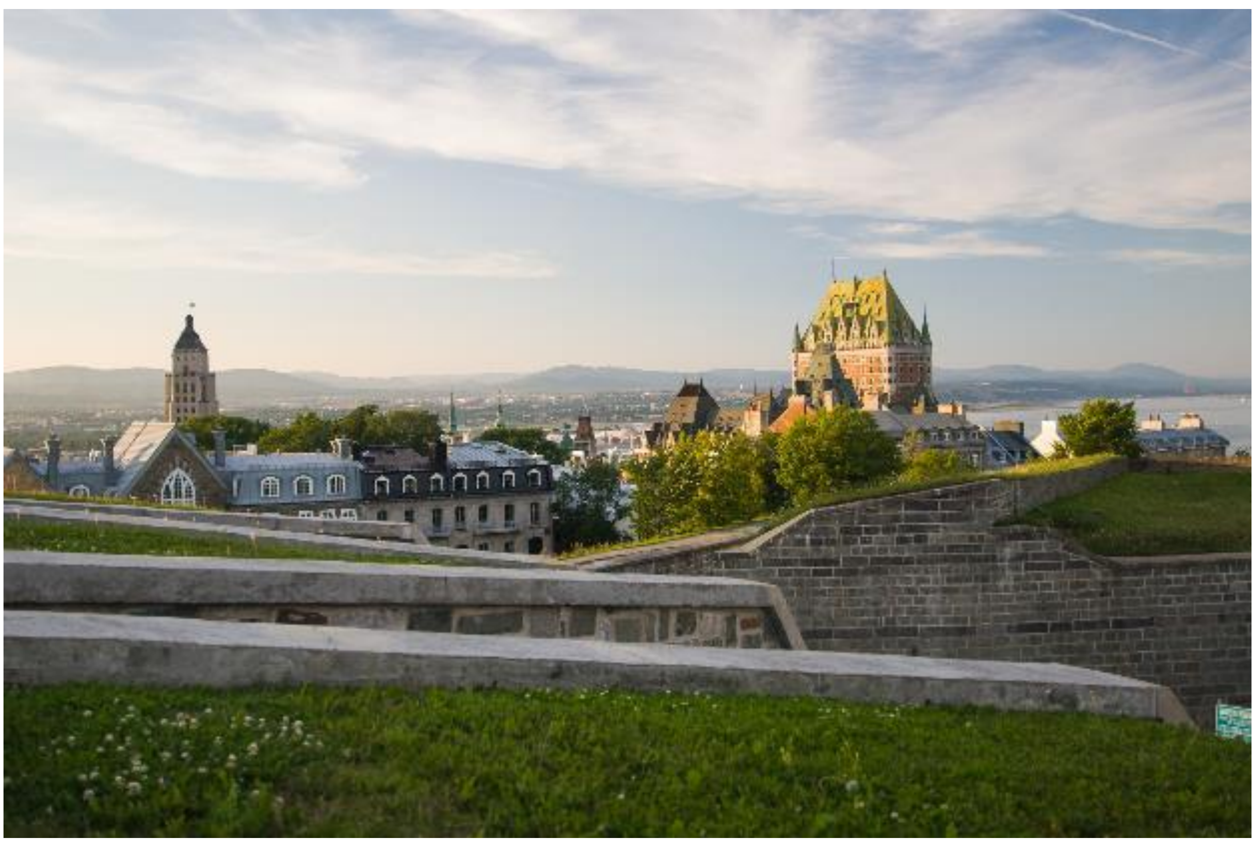
- A key organization for informing and guiding climate change adaptation in the region is Ouranos (https://www.ouranos.ca). Their "*Synthesis on Climate Change Knowledge in Québec*" report is an excellent resource (Ouranos, 2015).
- The Coastal Archaeological Resources Risk Assessment (CARRA) project helps managers respond to coastal hazard impacts to archaeological resources (Pollard-Belsheim *et al.*, 2014).
- Berteaux *et al.* (2014) provides an analysis of projected change to biodiversity and a discussion of adaptation strategies and knowledge gaps.

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.
- Have services and infrastructures adapted and welcoming to cyclists and hikers, and promote zero-emission activities, such as hiking, canoeing, kayaking and sailing.
- Review Parks Canada (2015) and US NPS (2012a).



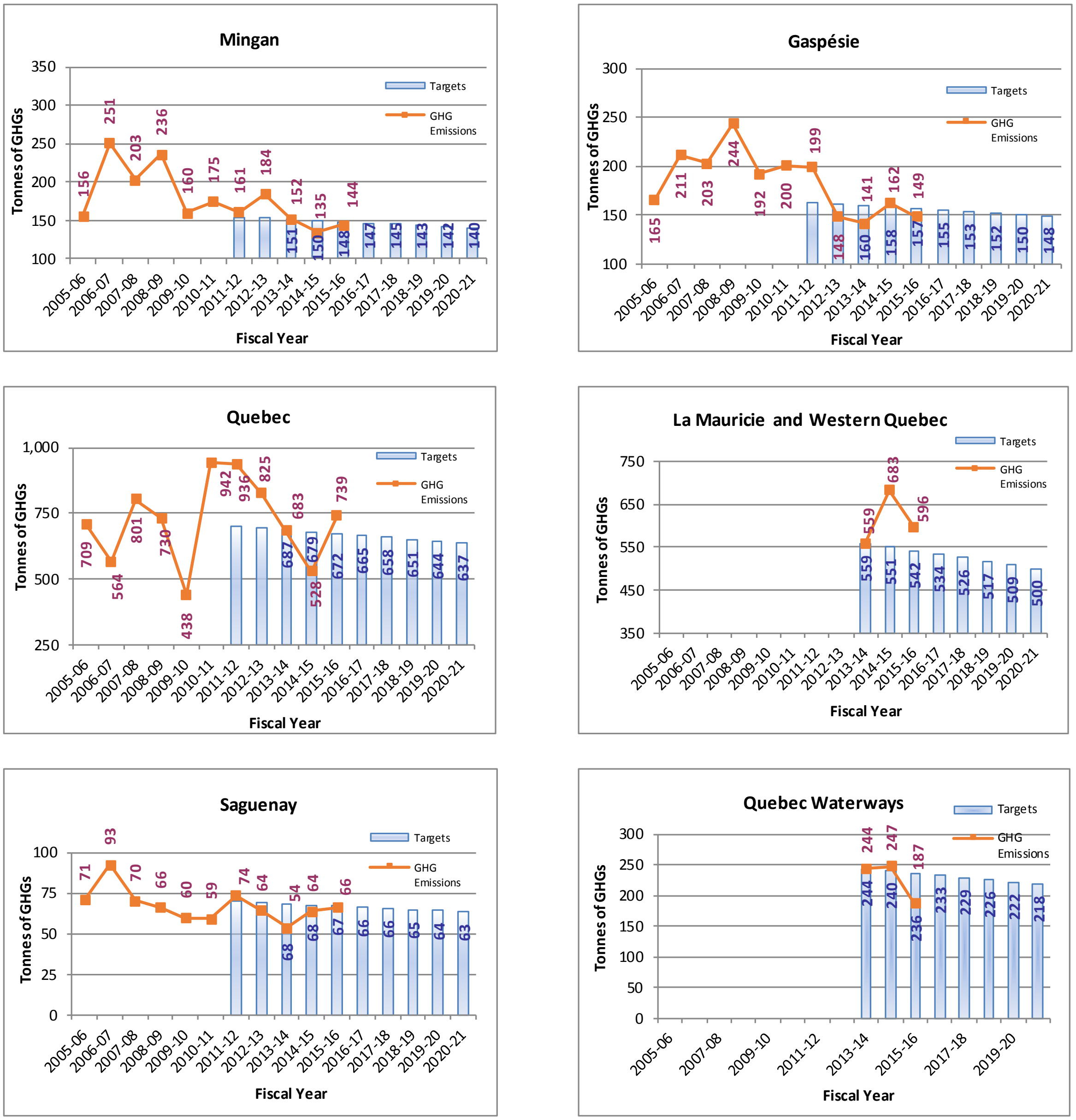


Figure 11. Greenhouse Gas Emissions per Field Unit. Emissions are calculated from energy (e.g., heating, electricity) and fuel expenditures, excluding travel, air charters, and some other sources. GHG emissions from energy cost are adjusted for source (e.g., coal, hydro, diesel, etc...). The targets in these figures are from 2015 reduction targets (Parks Canada, 2015). Revised, lower targets to be communicated in 2017 (Canada, 2016).

3.3 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). In locations with appropriate facilities, consider diversifying visitor experiences to provide alternatives to weather-dependent activities.
- ☑ Quantify 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).
- ☑ 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.

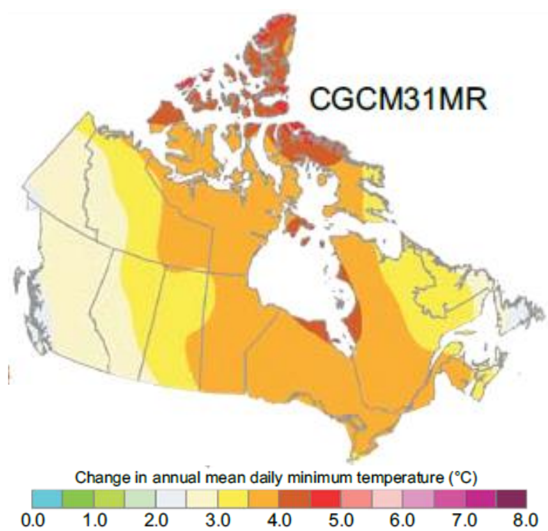

Figure A1. Projected change in annual daily minimum temperature for 2041-2070, relative to 1961-1990 (Price *et al.*, 2011).

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.