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DRAFT
Supplemental Climate Information for Nahanni National Park Reserve

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Contents

Preface

This is a supplement to the "Let's Talks about Climate Change: Northwest Region" (Parker, 2017) report and is intended to support climate change discussions at Nahanni National Park Reserve.

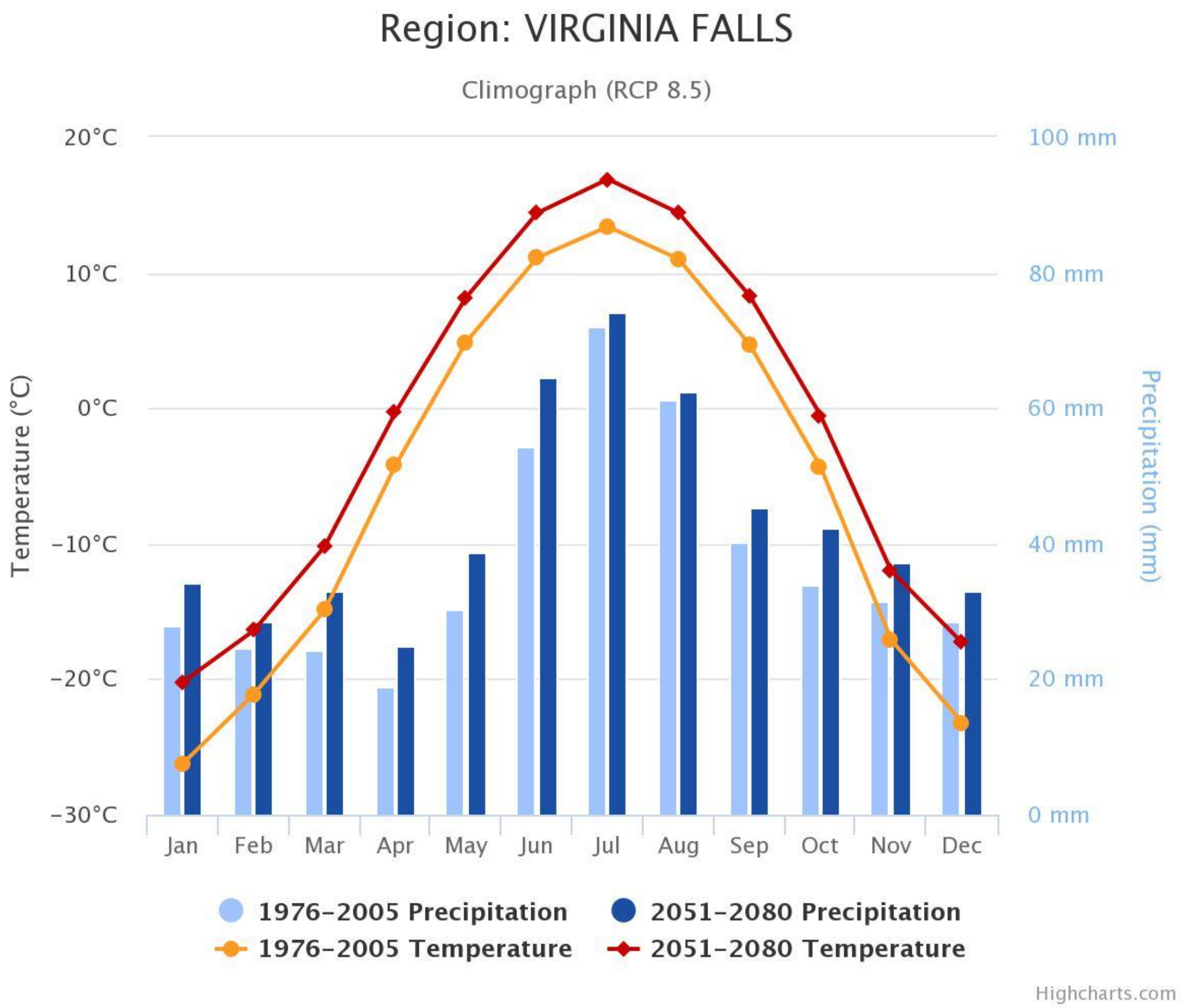
Future climate projections are modelled with several different greenhouse gas concentration trajectories called **Representative Concentration Pathways (RCP)** (Vuuren *et al.*, 2011). They describe possible climate futures and are named after respective radiative forcing values in the year 2100 relative to pre-industrial values (i.e., +2.6, +4.5 and +8.5 watts/m^2). **RCP 2.6** assumes we take action and greenhouse gas emissions peak in 2010-2020 and decline thereafter. **RCP 4.5** assumes emissions peak around 2040 and then decline. **RCP 8.5** assumes we take no action and emissions continue to rise "status quo" throughout the 21st century. We are currently tracking RCP 8.5.

This is a site focussed document and to understand the larger climate change context please review Canada's Changing Climate assessment reports (e.g., Warren and Lemmen, 2014) and the Intergovernmental Panel on Climate Change assessment reports (e.g., IPCC, 2014). With respect to adaptation options, consider Gross *et al.* (2016), Parker *et al.* (2018), or Rockman *et al.* (2016).

Disclaimer
Views, statements, findings and conclusions are solely those of the author and do not necessarily reflect the views and policies of Parks Canada. Although the author has made every effort to ensure that the information is accurate, complete and correct, neither Parks Canada nor the author can guarantee its integrity. Readers are encouraged to verify with original sources.

Highlights

- Current climate is generally subarctic, and considered to be Dfc type (D = Cold; f = without dry season c = cold summer) (Peel *et al.*, 2007).
- Mean annual temperature has increased 3°C since 1950, over twice the global average (ACIA, 2005; IPCC, 2014), and is projected to continue to warm, perhaps as much as 8°C.
- Total annual precipitation has increased 59% since 1950 and is projected to increase.
- "Elders advised that in the 1960's when they would go trapping in January-February, temperatures would get as low as -50°C. Now, temperatures are typically only as low as -30°C. A general consensus is that there is less snow now than 20-30 years ago, and that it melts earlier. Evidence of permafrost thaw has been seen." (CZC, 2015).

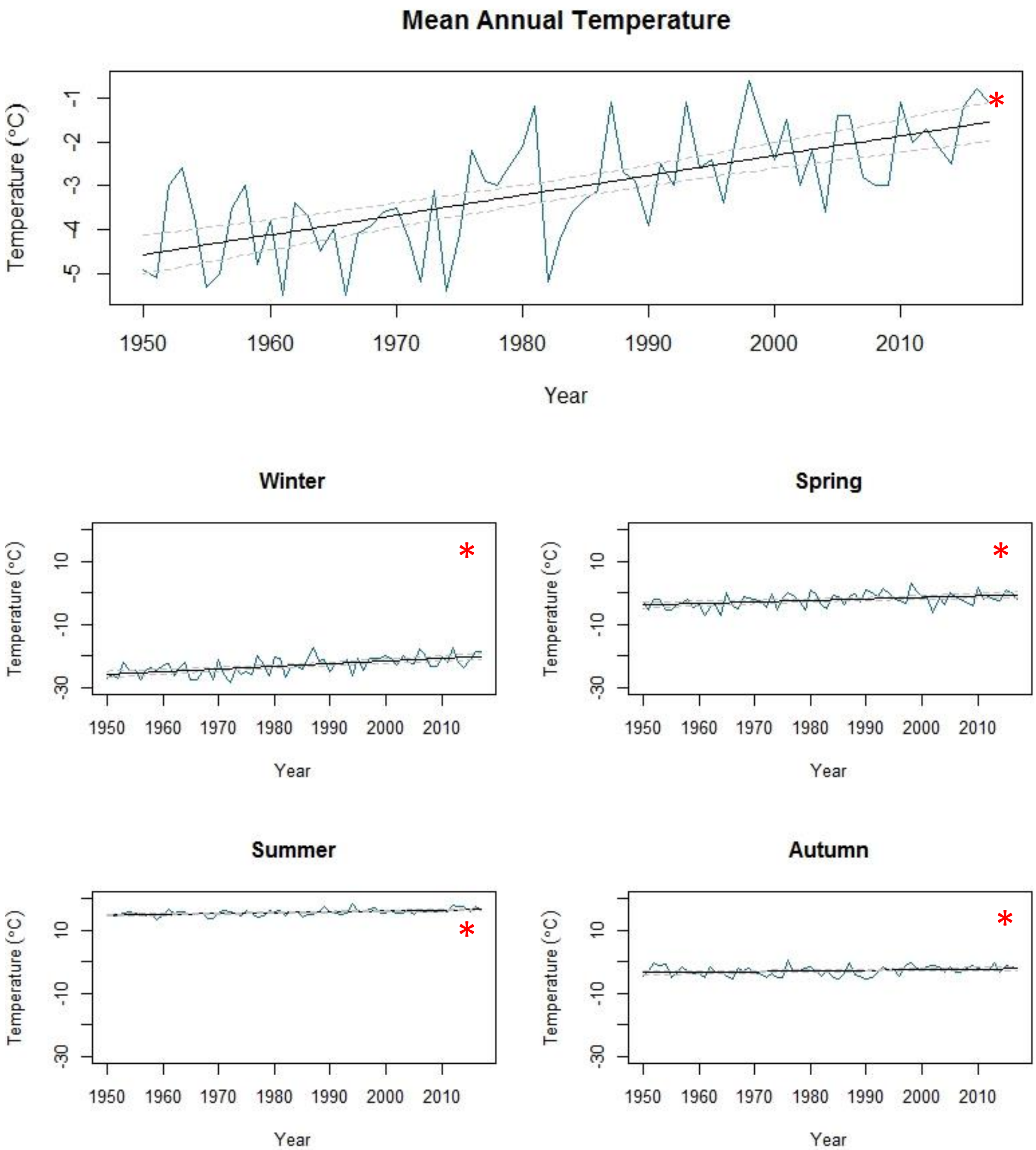


Climograph for the Virginia Falls region. Monthly mean temperature and total precipitation for 1976-2005 baseline and 2051-2080 future projection (RCP 8.5). Figure source: Climate Atlas of Canada (https://climateatlas.ca/).

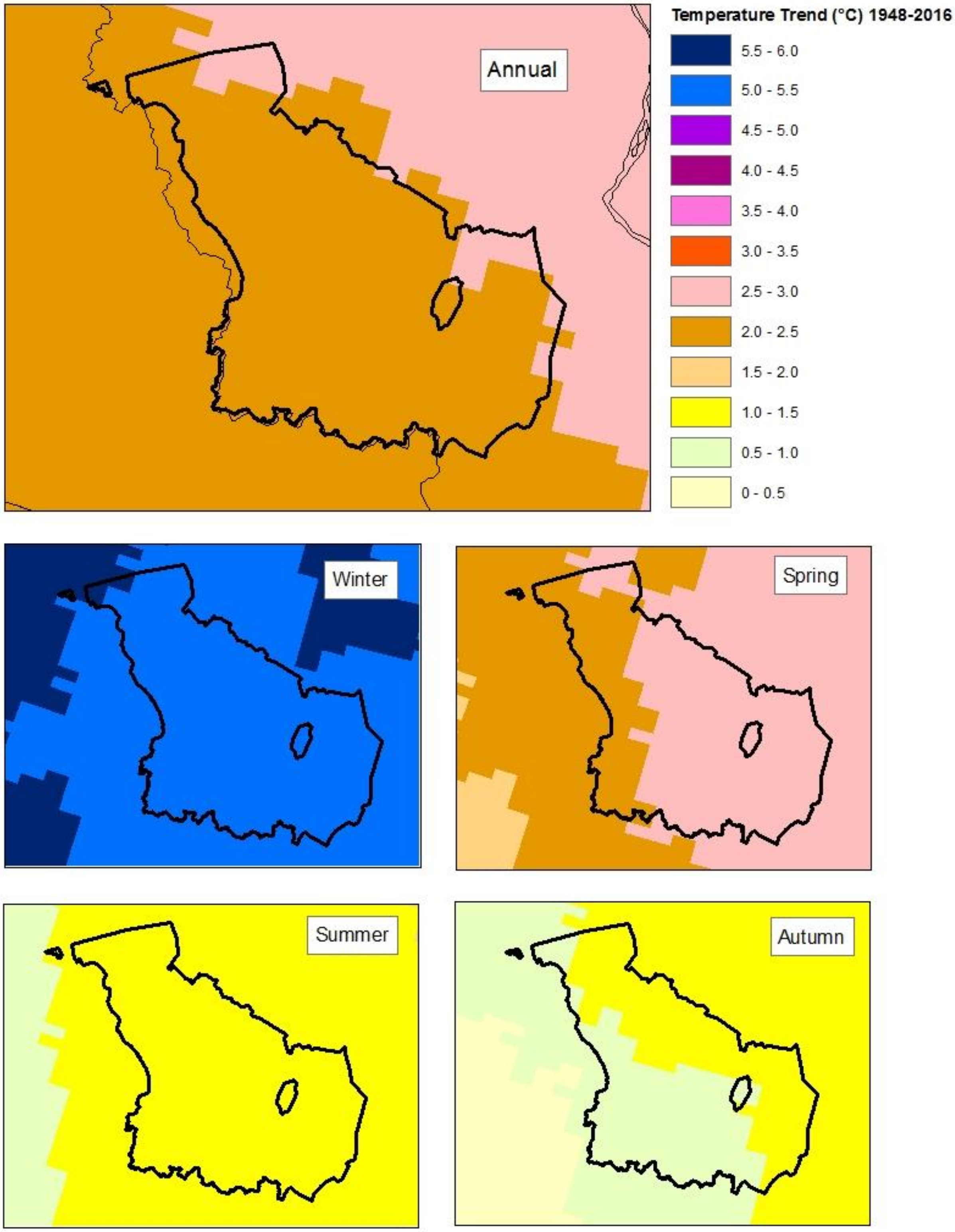
1. Historic Climate

1.1 Temperature

Fort Simpson is the closest meteorological station with long term temperature data (ECCC, 2017). Trends from 1950 to 2017 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend (P<0.05).



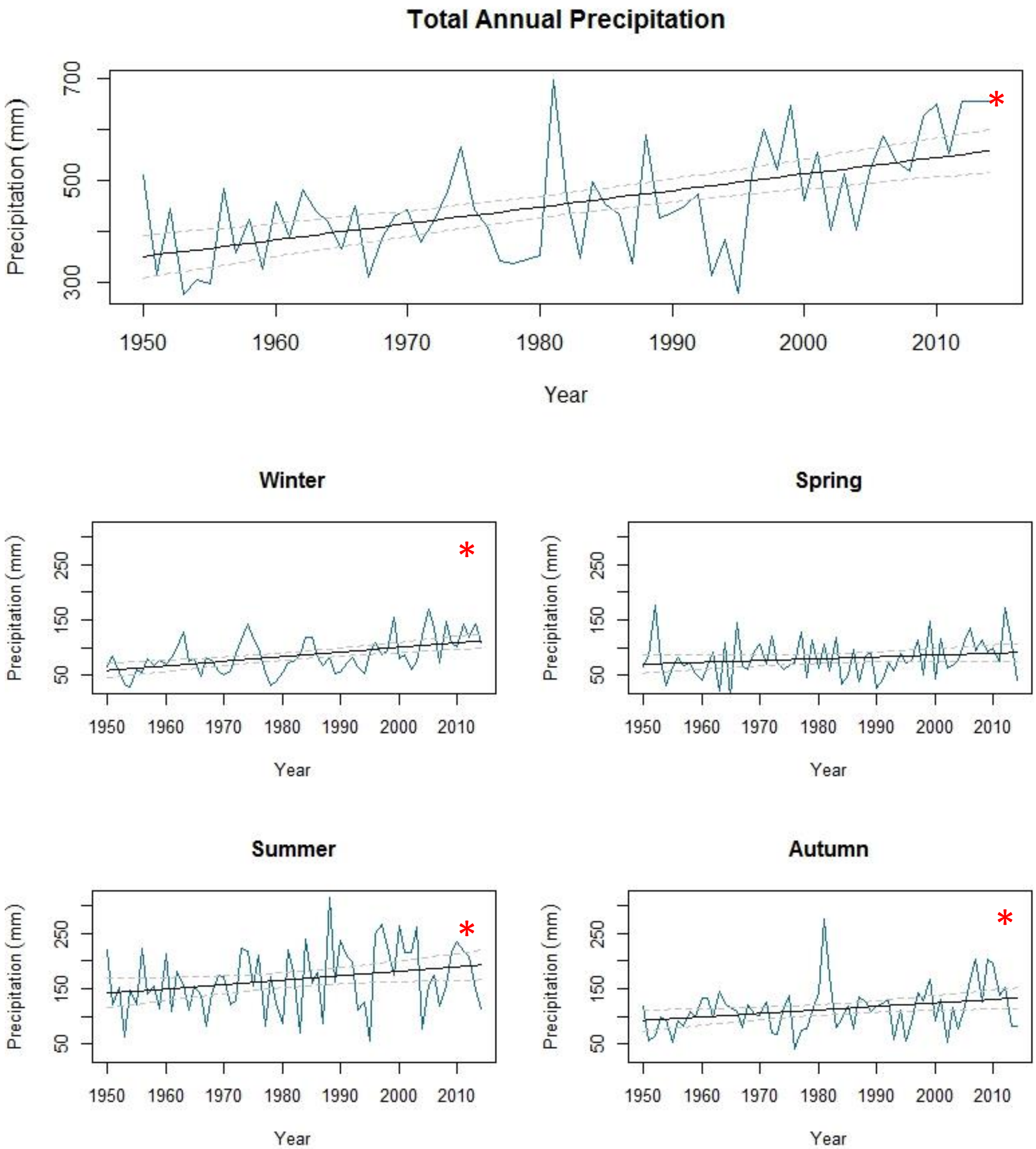
Fort Simpson mean annual and seasonal temperature. A statistically significant (P<0.05) increase observed in mean annual and all seasons. Mean annual temperature has increased by 3.0°C since 1950 and winter (Dec, Jan, Feb) has increased the most of all the seasons, by 5.7°C since 1950.



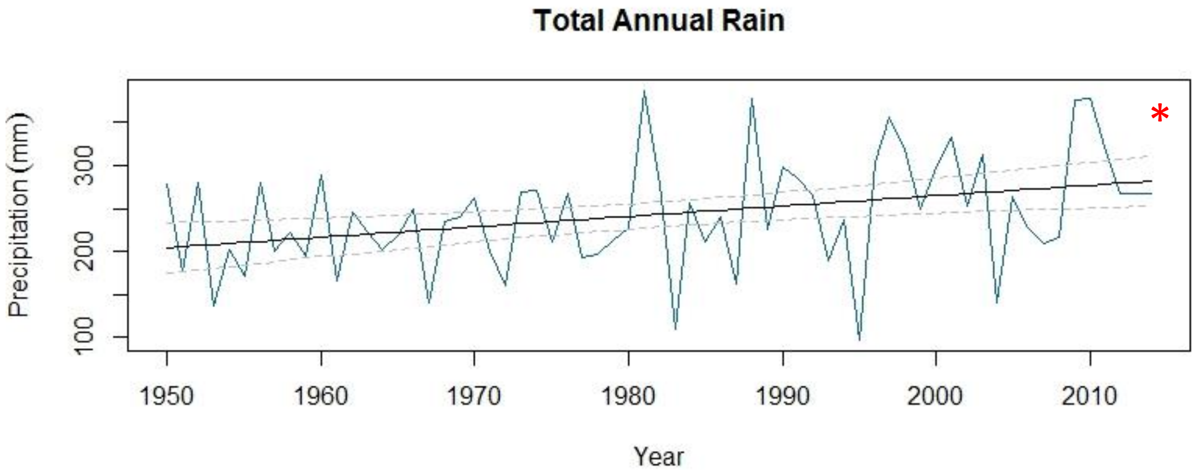
Mean annual and seasonal temperature trends (˚C) for Nahanni NPR from 1948 to 2016. Based on Canadian gridded data (CANGRD) it represents the change in temperature over the period of record (1948-2016). Data source: https://climate-change.canada.ca/climate-data/#/historical-gridded-data.

1.2 Precipitation

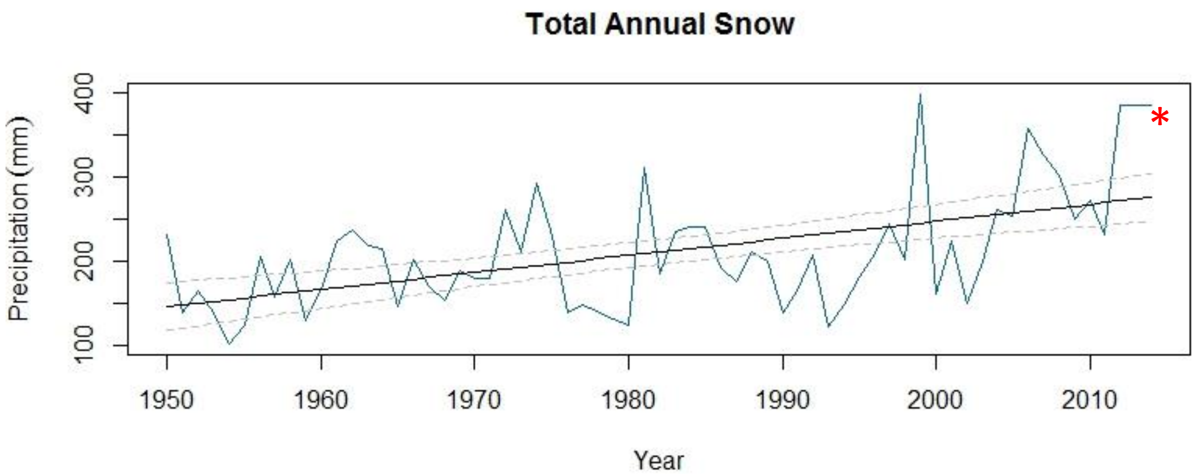
Fort Simpson is the closest meteorological station with long term precipitation data (ECCC, 2017). Trends from 1950 to 2014 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend ($P<0.05$).



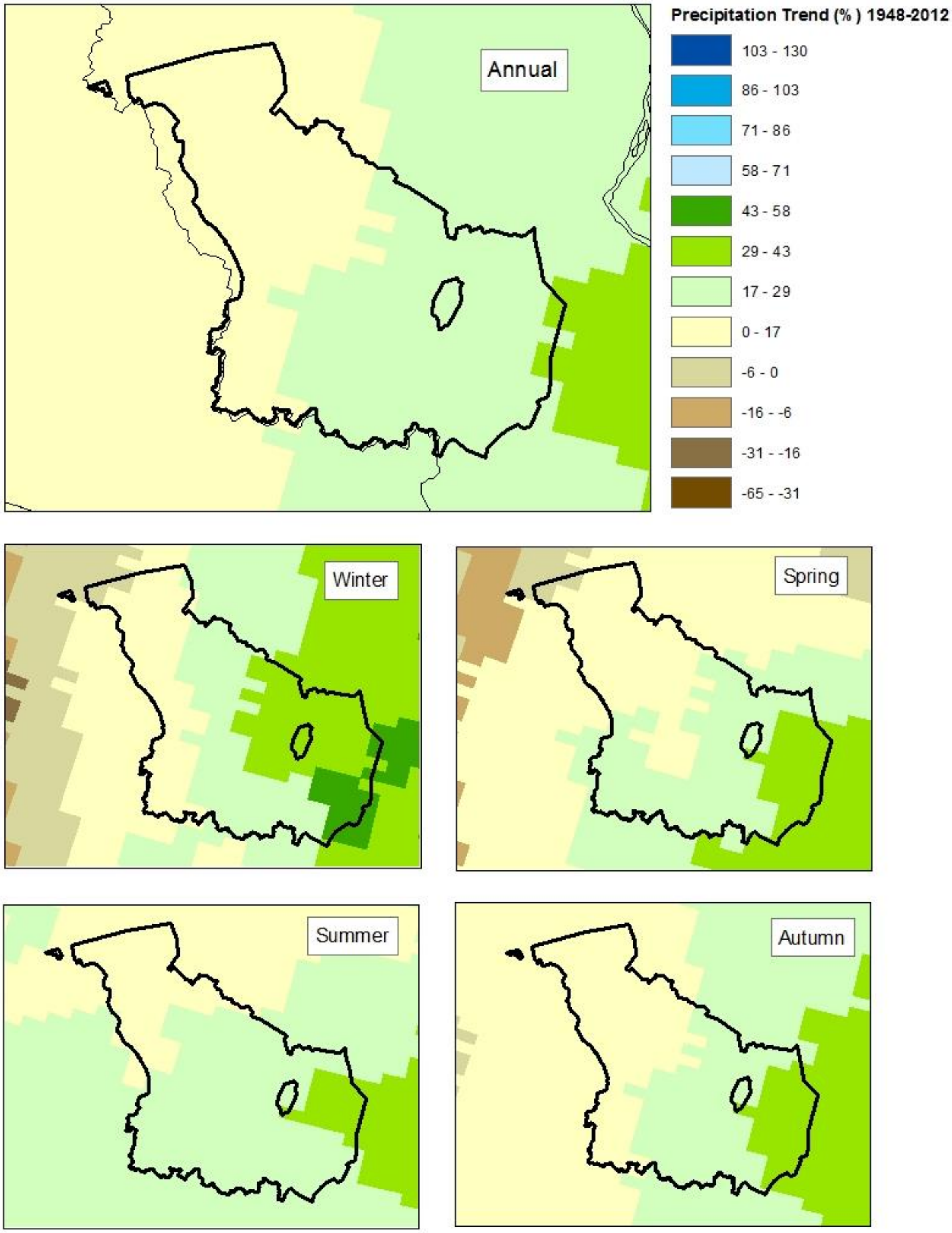
Fort Simpson total annual and seasonal precipitation. Total annual precipitation demonstrated a statistically significant increase ($P<0.05$), +206 mm (59%), between 1950 and 2014. All seasons except spring (Mar, Apr, May) demonstrated a statistically significant ($P<0.05$) increase, the greatest being observed for winter, +53 mm (90%).



Fort Simpson total annual rain demonstrated a statistically significant (P<0.05) increase between 1950 and 2014, +77 mm (38%).



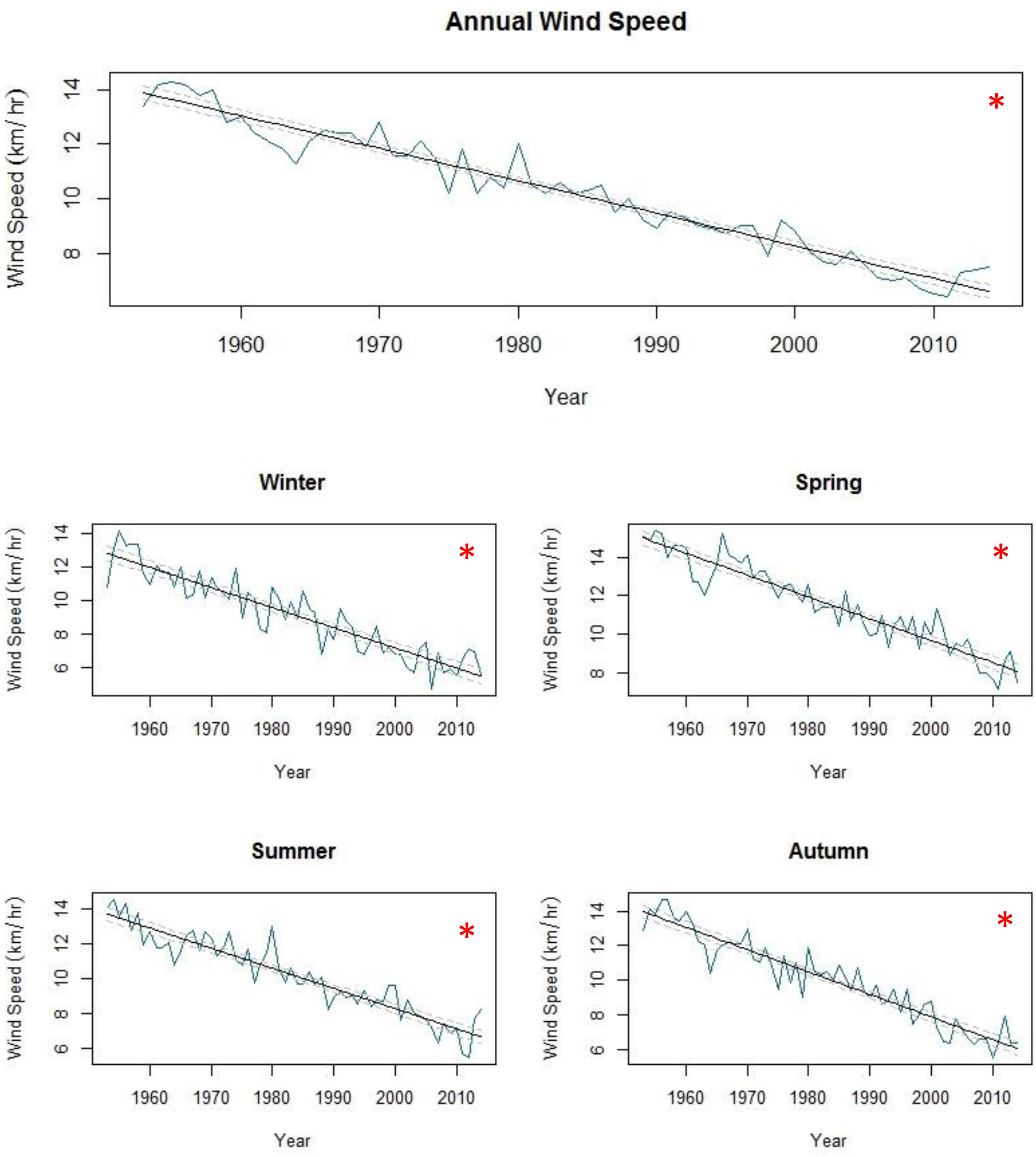
Fort Simpson total annual snow demonstrated a statistically significant (P<0.05) increase between 1950 and 2014, +129 mm (88%).



Total annual and seasonal precipitation trends (%) for Nahanni NPR for 1948-2012. Based on Canadian gridded data (CANGRD) the relative trends reflect the percent change in total precipitation over the period of record (1948-2012). Data source: https://climate-change.canada.ca/climate-data/#/historical-gridded-data.

1.3 Surface Wind Speed

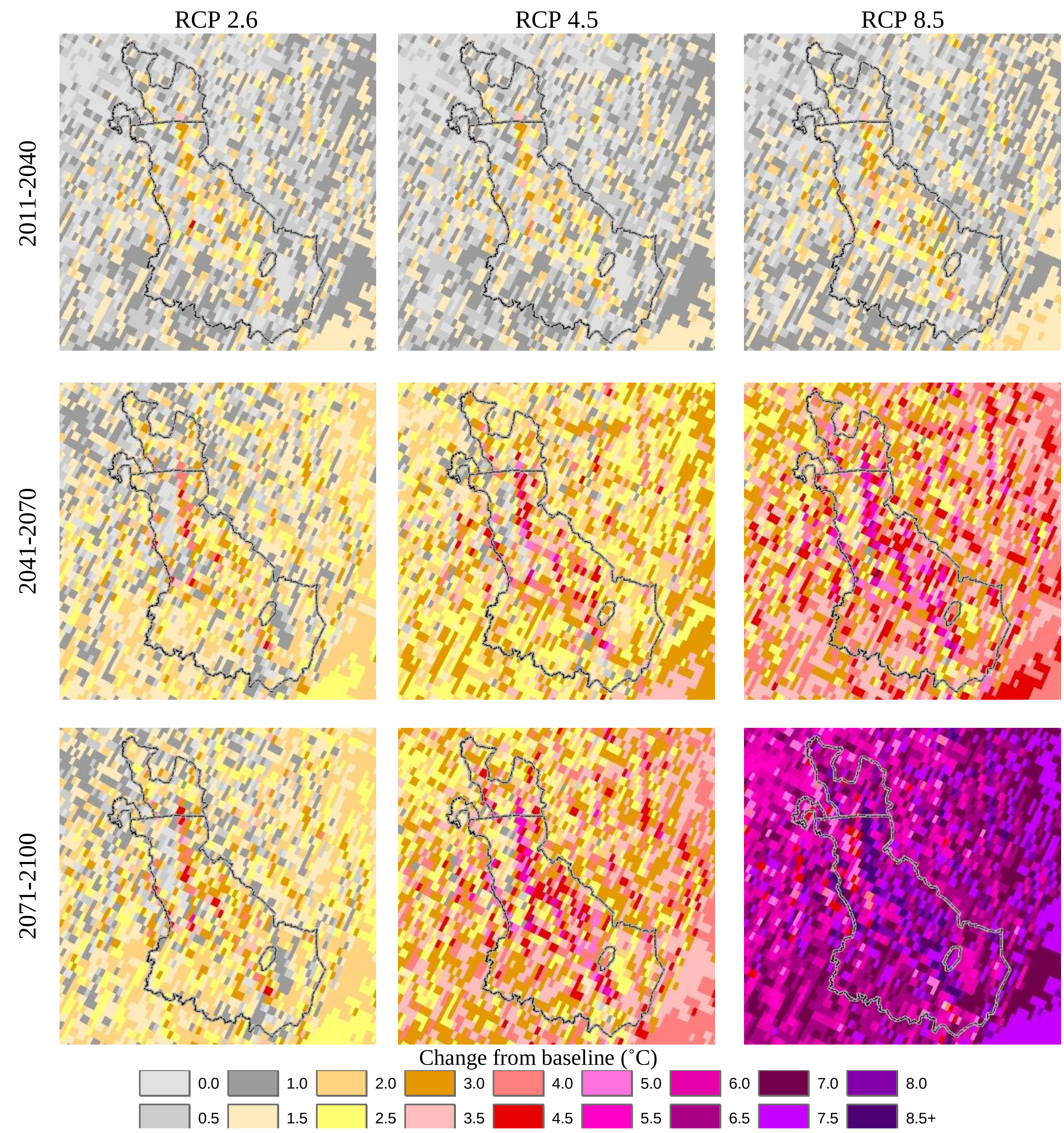
Fort Simpson is the closest meteorological station with long term wind data (ECCC, 2017). Trends from 1953 to 2014 determined using a generalized linear model (R Core Team, 2017) including 95% confidence intervals. "*" = statistically significant trend (P<0.05).



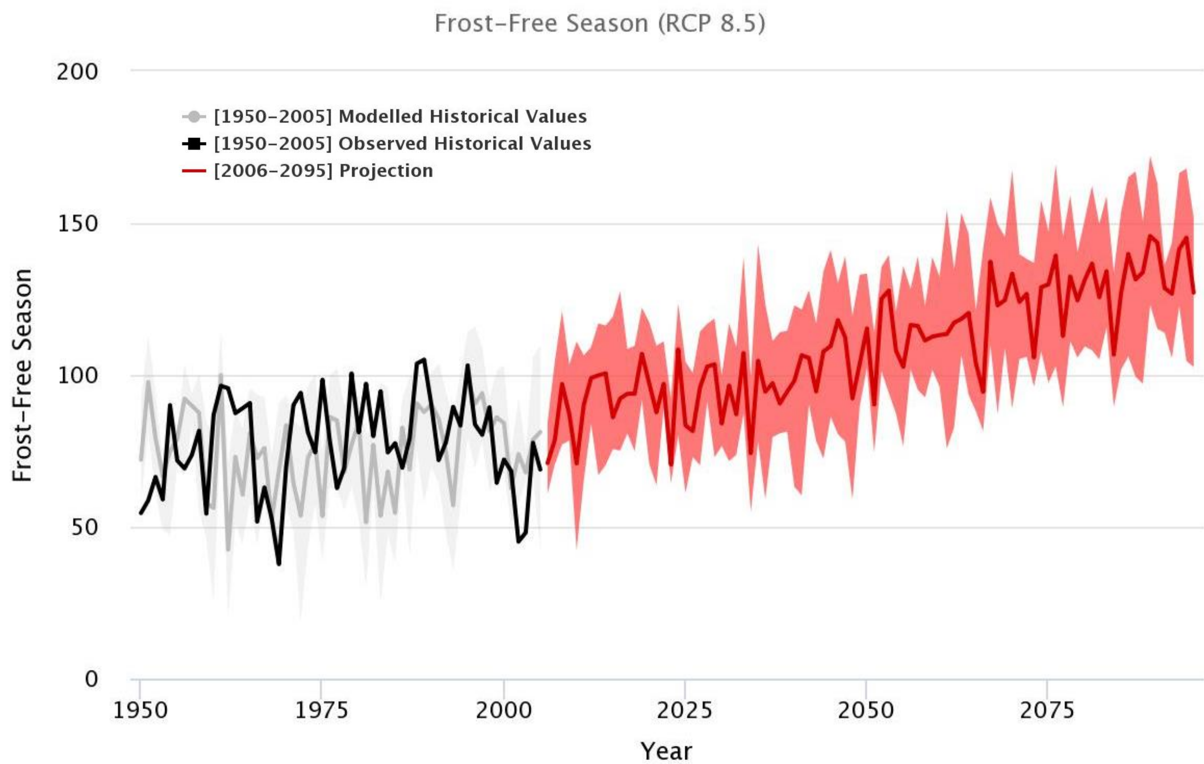
Fort Simpson mean annual and seasonal wind speeds. Mean annual wind speeds have demonstrated a statistically significant (P<0.05) decrease, -7.2 km/hr (-53%) between 1953 and 2014. All seasons have demonstrated a statistically significant (P<0.05) decrease as well.

2. Projected Climate Trends

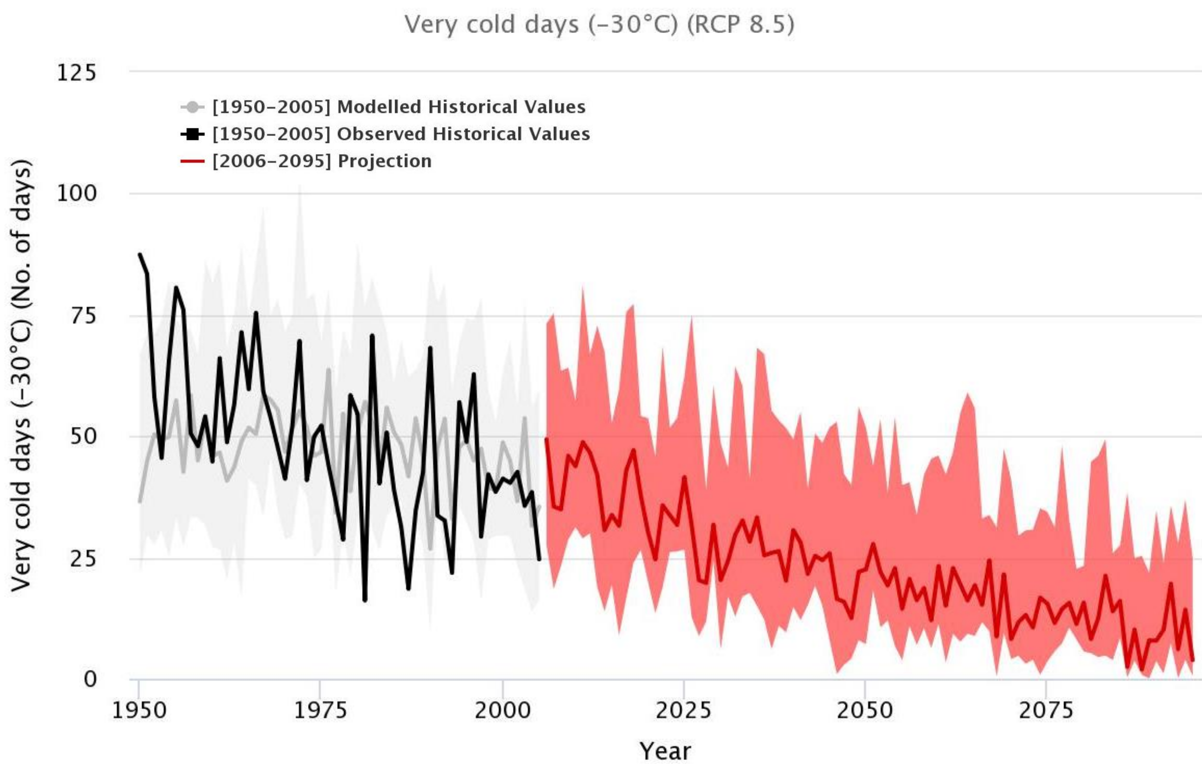
2.1 Temperature



Projected mean annual temperature increase for Nahanni National Park Reserve from a 1980-2010 baseline. Composite projection of CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM. Data source: Natural Resources Canada, Canadian Forest Service, http://cfs.nrcan.gc.ca/projects/3 (Price *et al.*, 2011). Depending on the RCP scenario and location, mean annual temperatures could increase by 8.0 °C by 2071-2100.

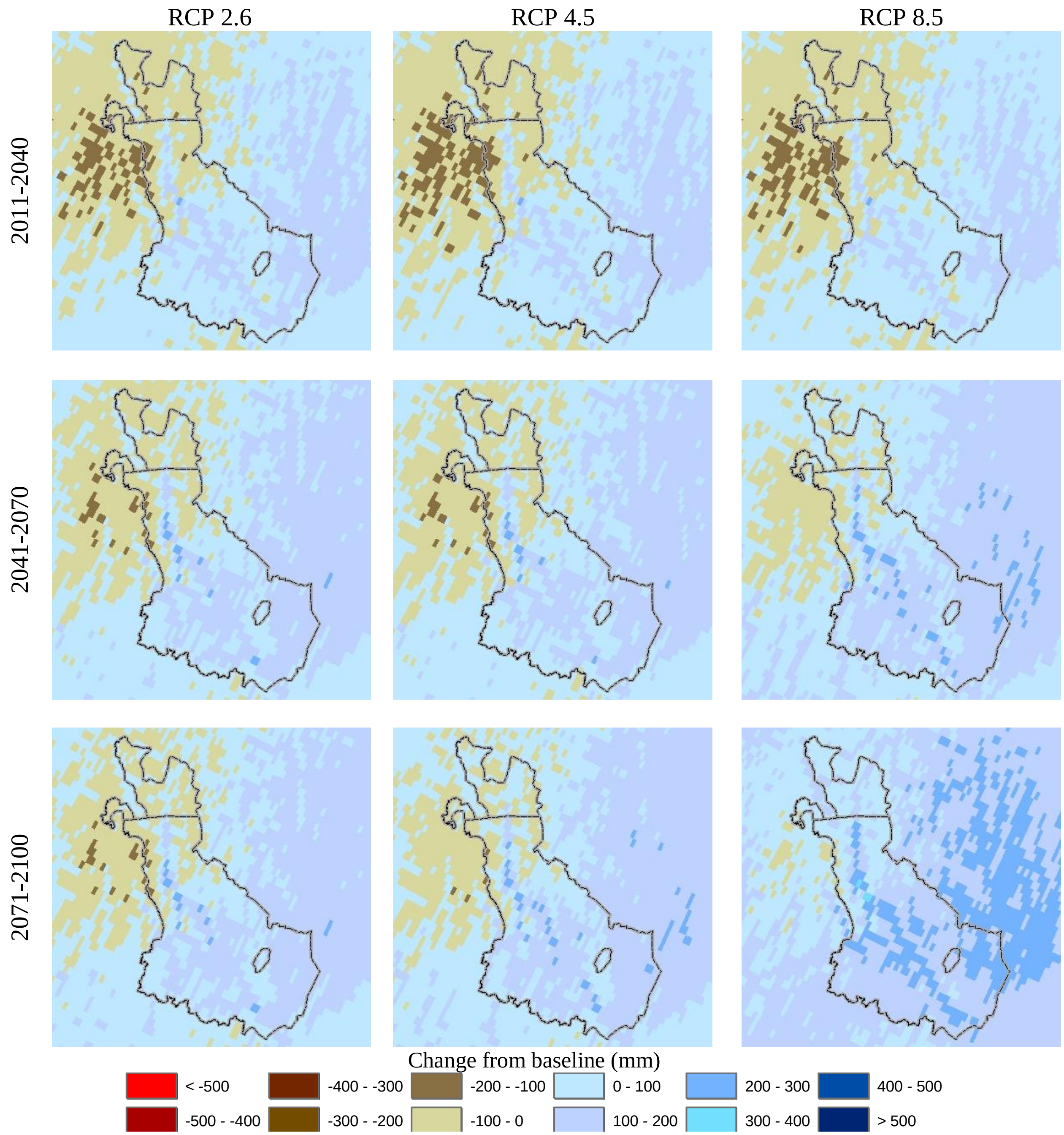


Frost-free season (days) for the Virginia Falls region is projected (RCP 8.5) to increase by 41 days by 2051-2080. Figure source: Climate Atlas of Canada (https://climateatlas.ca/).



Very cold days (-30˚C) for the Virginia Falls region is projected to decrease by 30 days/year by 2051-2080. Figure source: Climate Atlas of Canada (https://climateatlas.ca/).

2.2 Precipitation



Projected total annual precipitation change for Nahanni National Park Reserve from a 1980-2010 baseline. Composite projection of four spatially interpolated downscaled Global Circulation Models: CanESM2, CESM1CAM5, HADGEM2ES and MIROCESM. Data source Natural Resources Canada, Canadian Forest Service, http://cfs.nrcan.gc.ca/projects/3 (Price *et al.*, 2011). Depending on the RCP scenario and location, total annual precipitation is projected to change from -100 mm to + 200 mm by 2071-2100.

Rainfall Intensity, Duration and Frequency (IDF)

The rainfall IDF values in the following tables are calculated with IDF_CC Tool 3.0 (http://www.idf-cc-uwo.ca/) using Generalized Extreme Values (Simonovic *et al.*, 2017).

Baseline total precipitation amounts (mm) for Fort Simpson from 1969-2009.

T (years)	2	5	10	25	50	100
5 min	4.34	6.62	8.26	11.50	14.90	17.63
10 min	6.41	10.20	13.07	18.77	24.16	28.91
15 min	7.98	13.00	16.80	22.97	27.09	31.30
30 min	10.34	16.37	20.71	26.78	30.17	35.32
1 h	12.26	18.85	23.46	29.42	32.96	37.96
2 h	15.82	22.66	27.24	32.69	36.04	40.47
6 h	24.92	32.72	38.05	42.79	45.69	49.23
12 h	32.14	41.89	48.60	54.22	57.51	61.58
24 h	40.94	55.76	65.90	75.32	81.43	88.70

Projected (2050-2100) precipitation (mm) for Fort Simpson using an ensemble of models and **RCP 4.5**.

T (years)	2	5	10	25	50	100
5 min	4.54	6.98	9.18	12.58	15.59	19.16
10 min	6.70	10.80	14.42	20.19	25.27	31.40
15 min	8.26	13.75	18.63	25.33	31.39	38.46
30 min	10.63	17.34	23.11	29.90	36.03	42.75
1 h	12.57	20.02	26.15	33.08	39.14	45.58
2 h	16.22	24.19	30.40	37.02	42.54	48.15
6 h	25.44	35.45	42.38	48.63	53.40	57.79
12 h	32.75	45.50	54.06	61.51	67.11	72.14
24 h	41.75	60.24	73.31	85.65	95.25	104.29

Projected (2050-2100) precipitation (mm) for Fort Simpson using an ensemble of models and **RCP 8.5**.

T (years)	2	5	10	25	50	100
5 min	4.92	7.70	10.21	12.64	16.86	23.34
10 min	7.27	11.90	16.08	20.24	27.34	38.02
15 min	9.05	15.22	20.43	25.54	34.08	46.16
30 min	11.75	19.23	25.09	30.39	38.85	49.67
1 h	13.94	22.20	28.44	33.75	42.52	53.76
2 h	17.98	26.76	33.14	37.92	44.78	53.98
6 h	28.29	39.24	46.23	50.40	56.25	65.53
12 h	36.48	50.39	59.01	63.94	70.11	80.55
24 h	46.50	66.75	79.98	88.62	100.37	118.08

Fort Simpson observations and projections. Today's "one in 100 year" rainfall event (i.e., 37.96 mm/hr) is projected to be closer to a "one in 25 - 50 year" event by 2050-2100 for both RCP scenarios and the future "one in 100 year" rainfall event is projected to increase in intensity (i.e., between 45.58 – 53.76 mm/hr).

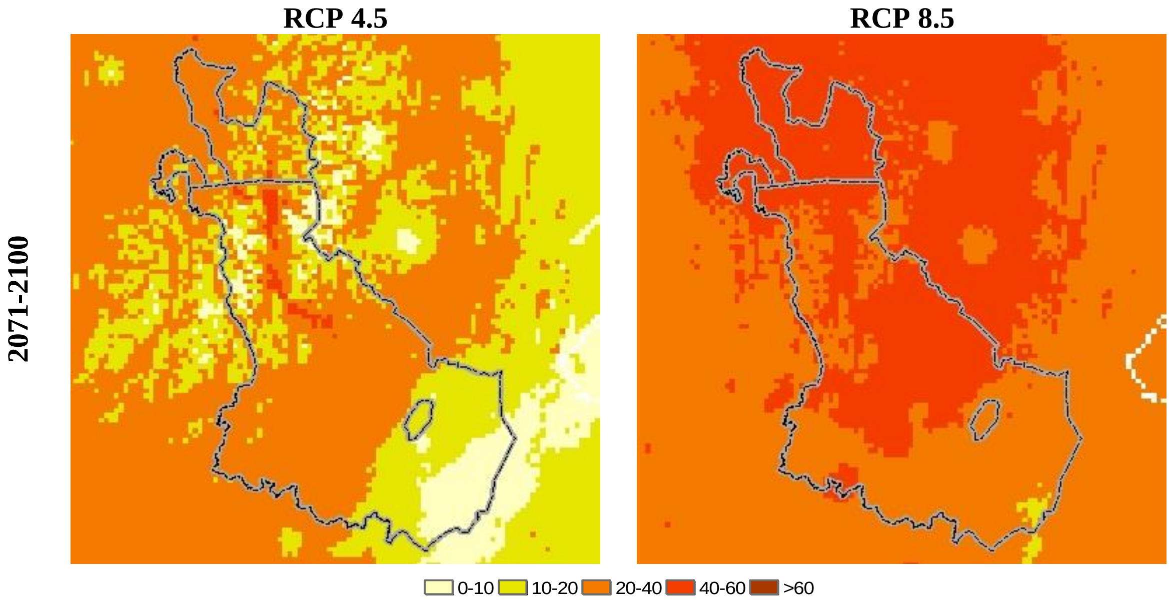
The Climate Atlas of Canada (https://climateatlas.ca/) for Virginia Falls projects that the number of heavy precipitation (>20mm) days/year will increase from the 1976-2005 baseline of 0.6 days to 0.8 days by 2051-2080.

3. Climate Change Impacts

Climate change is also reported in the State of the Park Report (Haggarty and Tate, 2009).

3.1 Wildfire

- The frequency, seasonality, extent and severity of wildfires is closely tied to climatic conditions (e.g., Westerling *et al.*, 2006).
- Wildfire season length and frequency of extreme fire weather are expected to increase (Jain *et al.*, 2017).
- Wotton *et al.* (2017) project a future increase in the number of days where crown fires are likely to occur as well as an increase in the number of days when fire intensities (e.g., head fire intensity above 10,000 kW/m) could exceed the capabilities of suppression resources (doubling in some end of century scenarios).
- Wang *et al.* (2017) project an increase in the number of active burning days (i.e., spread days as related to daily fire weather).
- Lightening is cited as a driver of recent fire activity (Veraverbeke *et al.*, 2017).

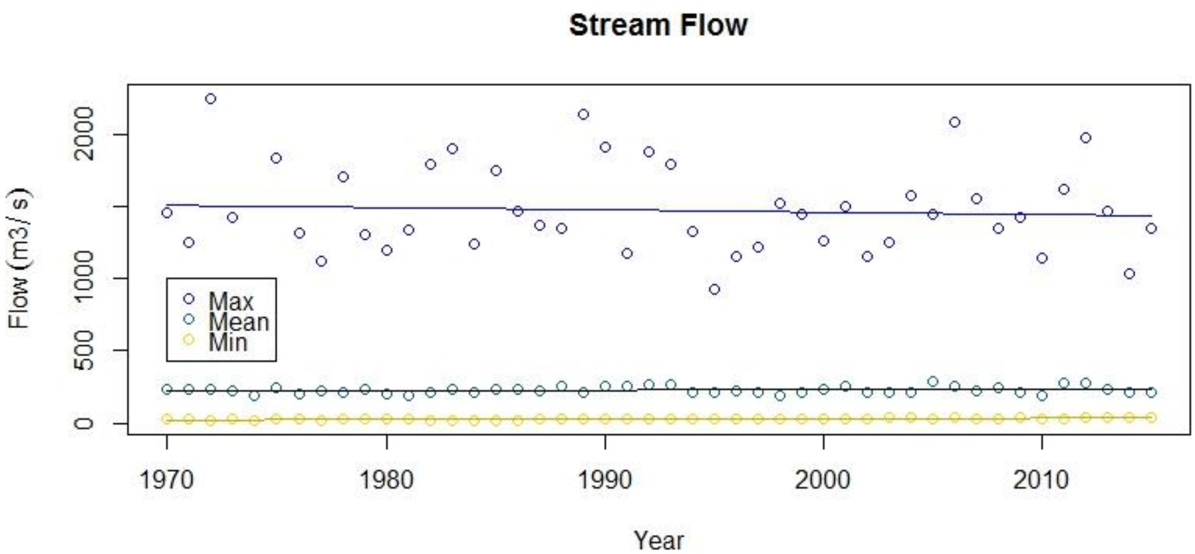


Projected increase in wildfire season for Nahanni National Park Reserve. Increased length in days from baseline (1981-2010) under RCP 4.5 and RCP 8.5 scenarios. Depending on the RCP scenario and location, an increase of 5-50 days is projected by 2071-2100. Data source: Natural Resources Canada, http://cfs.nrcan.gc.ca/fc-data-catalogue.

Staple and Wall (1996) discuss that increased wildfire activity due to climate change will affect visitor experience along the river.

3.2 Hydrological Regimes

Changes to temperature (e.g., snowmelt) and precipitation (e.g., intensity, duration, frequency, rain vs snow) affects stream hydrology.



South Nahanni River above Virginia Falls annual flow data (Station 10EB001) for 1970 to 2015. A statistically significant (P<0.05) increase observed for minimum flow. Maximum flow appears to demonstrate a slight decreasing trend but it is not statistically significant (P<0.05) and mean flow appears to demonstrate a slight increasing trend but it is not statistically significant (P<0.05). The majority of peak flows occur in June. Trend determined using a generalized linear model (R Core Team, 2017) and data from EC Data Explorer, HYDAT (July 16, 2018) (https://ec.gc.ca/rhc-wsc/). Additional analysis is recommended and could reveal patterns in minimum, maximum, and mean flows and levels, as well as timing and seasonal patterns.

Historic hydrometric station data is also available on-line from the Government of Canada, https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html.

Halliwell and Catto (2003) examined water quality in Nahanni and their analysis also includes observations on hydrology.

Brook and Ford (1980) discuss the complexity of hydrological activity including karst drainage and flooding.

3.3 Glaciers and Permafrost

Between 1982 and 2008 the glacial covered area (e.g., Ragged Range, Brintnell-Bologna icefields) in the Greater Nahanni Ecosystem contracted by 30% (from 262 to 184 km^2) (Demuth and Ednie, 2016; Demuth *et al.*, 2014). For western Canada most studies report a 25% decline in glacier area (DeBeer *et al.*, 2016) and this is consistent with the general decline in glaciers globally (e.g., IPCC, 2013; UNEP, 2008).

Nahanni is an area of discontinuous permafrost (IPA, 2010; Smith, 2010). Observations have shown that ground temperatures are increasing and that there has also been an increase in the depth of the active layer as the permafrost thaws (DeBeer *et al.*, 2016; Mamet *et al.*, 2017; Smith *et al.*, 2010). The Scotty Creek Research Station (http://www.scottycreek.com/) is located 50 km south of Fort Simpson in the lower Liard River valley, NT. For over two decades has been investigating vegetation and permafrost dynamics and the effects on hydrological cycles. For instance, analysis has shown an increase in the rate of permafrost thaw and forest plateau loss. For more information, please review associated publications (e.g., Baltzer *et al.*, 2014; Connon *et al.*, 2014; Haynes *et al.*, 2018; Quinton and Baltzer, 2013; Quinton *et al.*, 2009). In addition, Walvoord and Kurylyk (2016) provide a review of the hydrological impacts of thawing permafrost.

3.4 Biodiversity

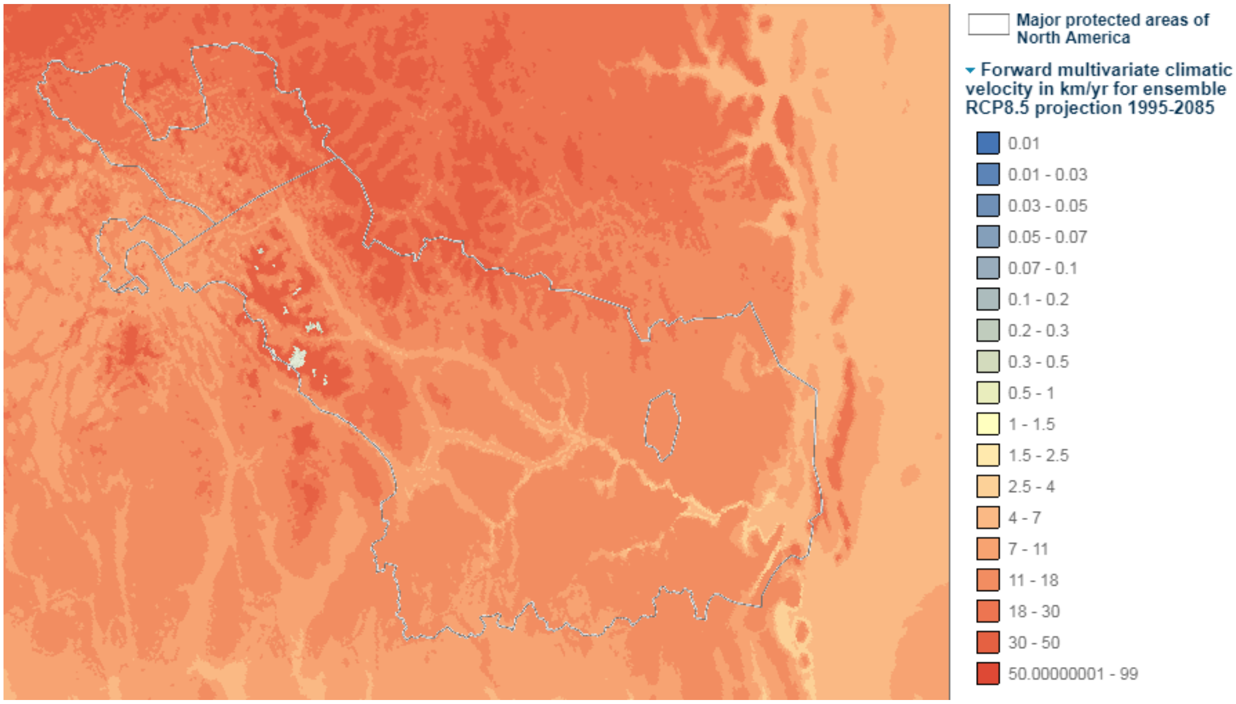
Schock *et al.* (2010) report on the presence of amphibian pathogens in the area and the potential effects of climate change on increasing its distribution.

Climate change is predicted to have negative effects on caribou populations, including impacts related to a change in forest habitat due to permafrost thaw and wildfire activity; longer periods of insect harassment; and winter weather that may make travel, foraging and predator avoidance more difficult (Species at Risk Committee, 2012; Witter *et al.*, 2012).

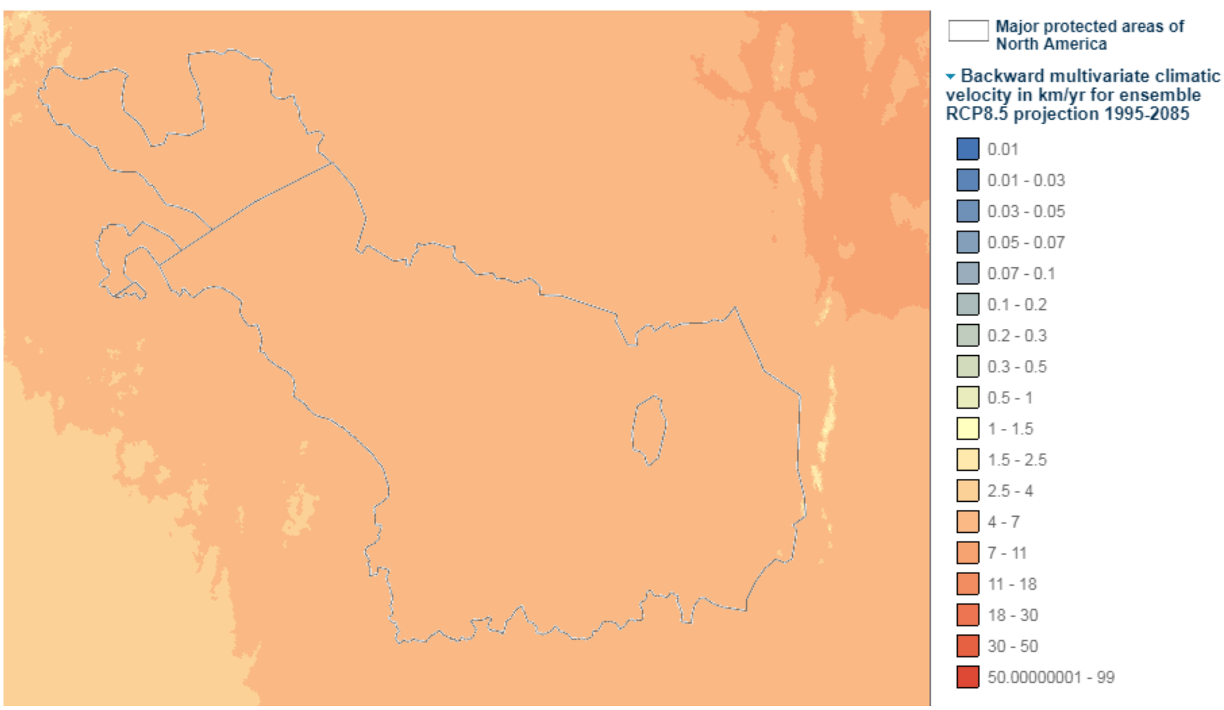
Climate change is likely impacting wolverine in the southern part of their range, and this impact is expected to increase northward (COSEWIC, 2014). It is uncertain how it will affect this species in Nahanni.

Climate Velocity

Climate velocity for Nahanni region from AdaptWest (https://adaptwest.databasin.org/).



Forward climate velocity (km/yr). The rate at which an organism in the current landscape has to migrate to maintain constant climate conditions. At Nahanni the projected rate is **5-34 km/yr** for the 2071-2100 (RCP 8.5) period. The river valleys appear to have a slower velocity.



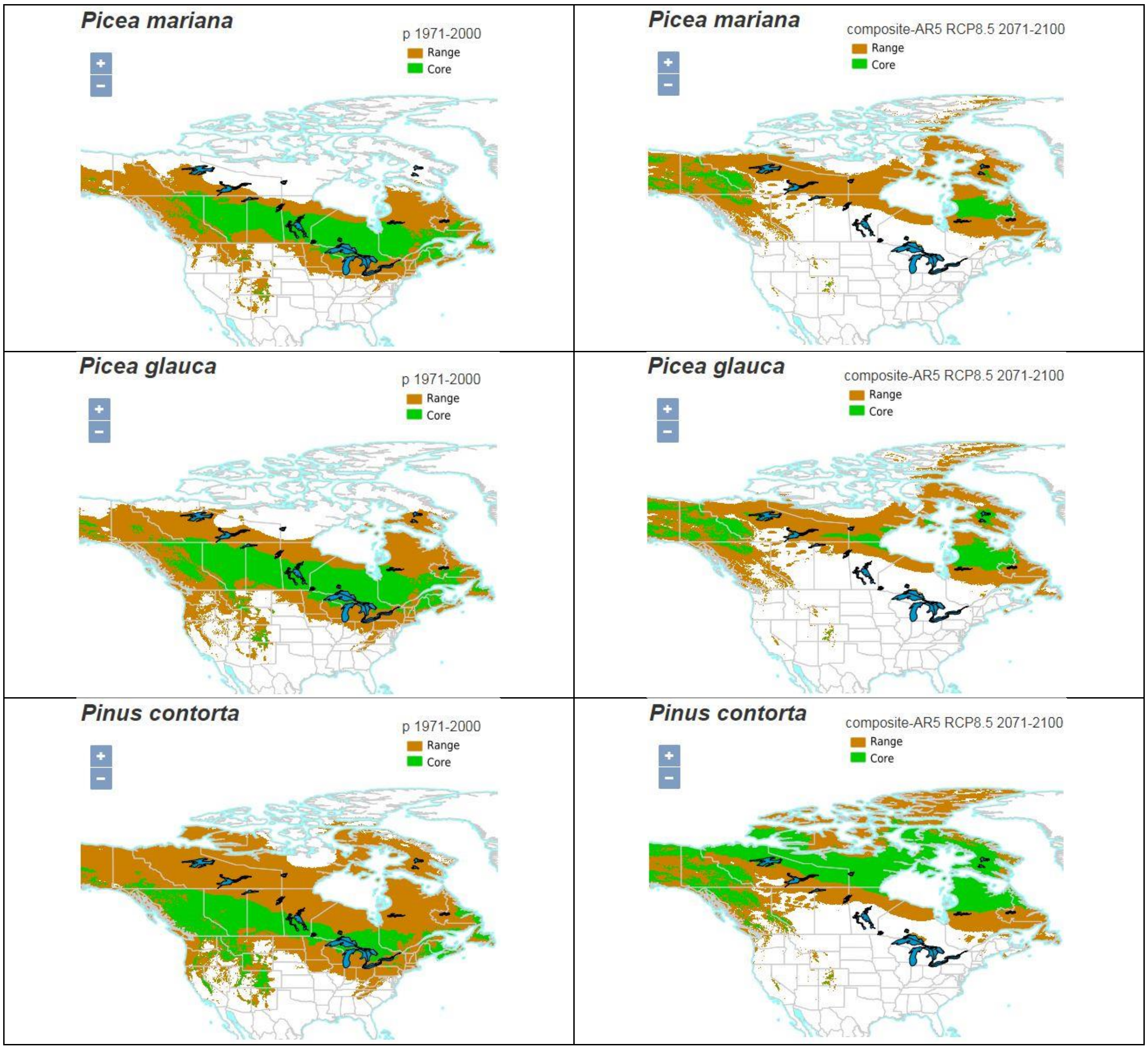
Backward climate velocity (km/yr). Given the projected future climate habitat of a grid cell, it is the minimum rate of migration for an organism from equivalent climate conditions to colonize this climate habitat. At Nahanni NPR the projected rate is **5-6 km/yr** for the 2071-2100 (RCP 8.5) period.

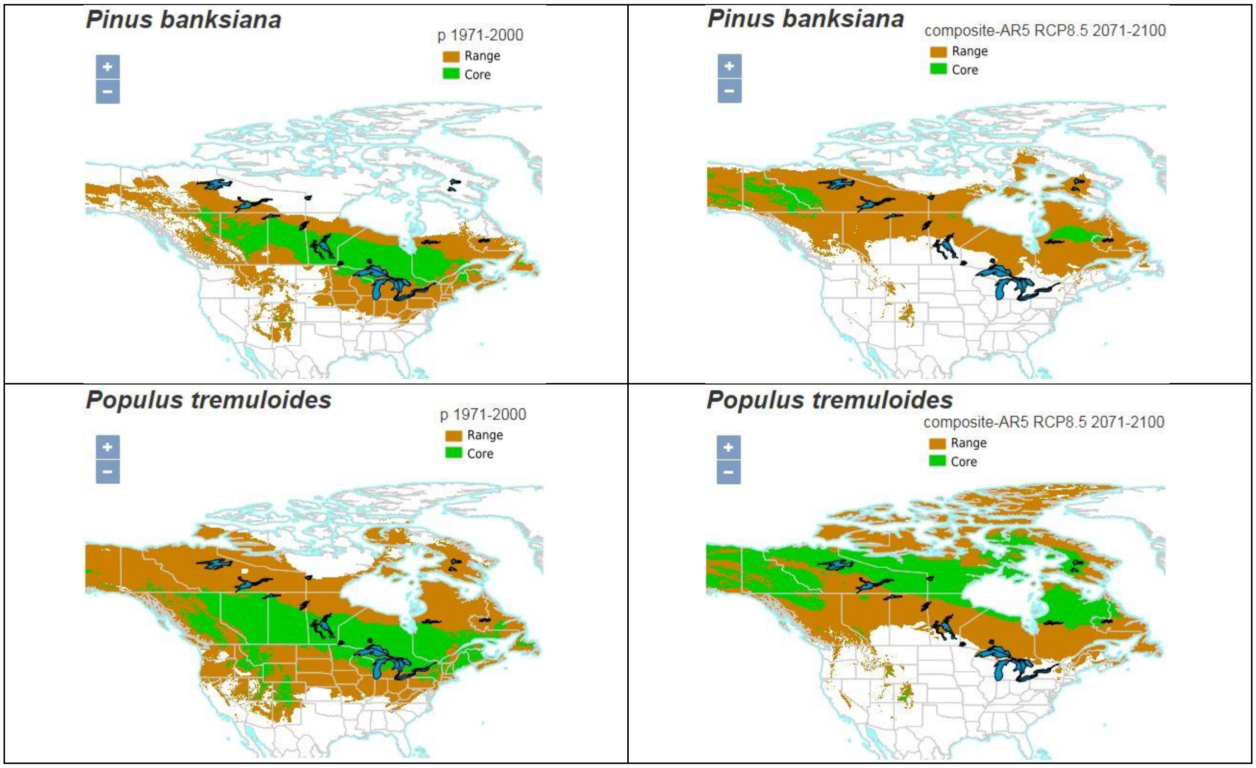
Plant Hardiness

Plant Hardiness is associated with probabilities of plant survival in relation to average, broad scale climatic conditions. As the climate changes, habitat suitability for plant species also changes. Natural Resources Canada maintains a database that includes future projections of plant hardiness (http://www.planthardiness.gc.ca/). A query of this database revealed a future decline in the number of species in Nahanni NPR (61.59N, -125.75W), see following table.

Potential plant species richness for Nahanni NPR based on current and future plant hardiness projections.

	1971-2000	2011-2040	2041-2070	2071-2100
Full Range	369	495	702	1169
Core Range	73	131	301	491





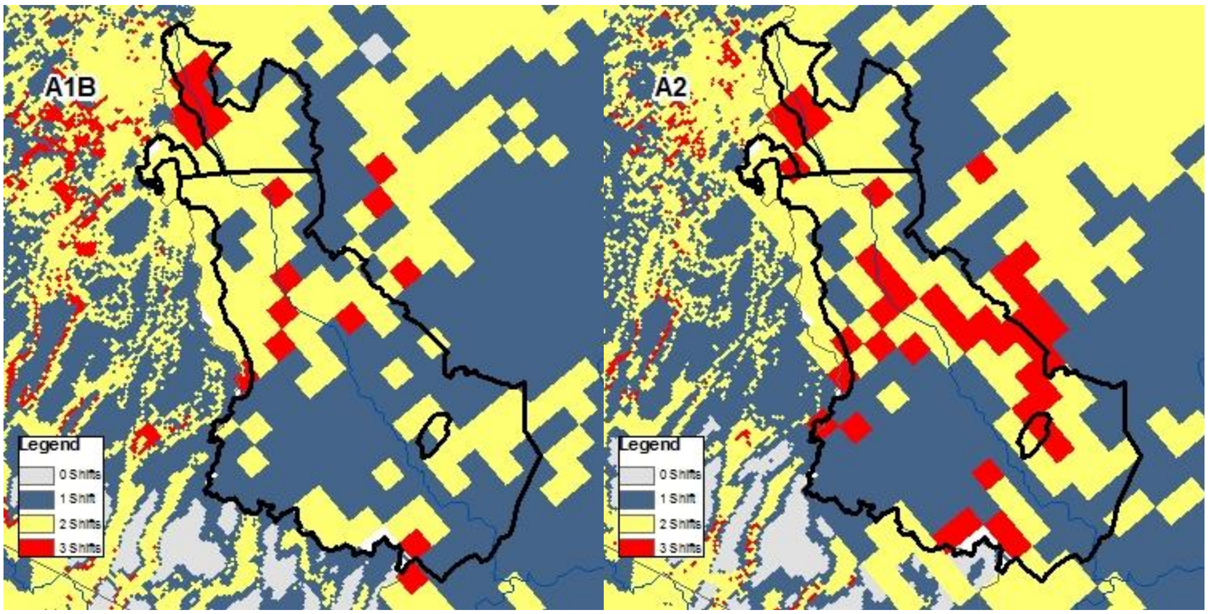
Change in core and full range for example tree species from a 1971-2000 baseline to 2071-2100 future projection (RCP 8.5) based on plant hardiness.

Other vegetation comments:

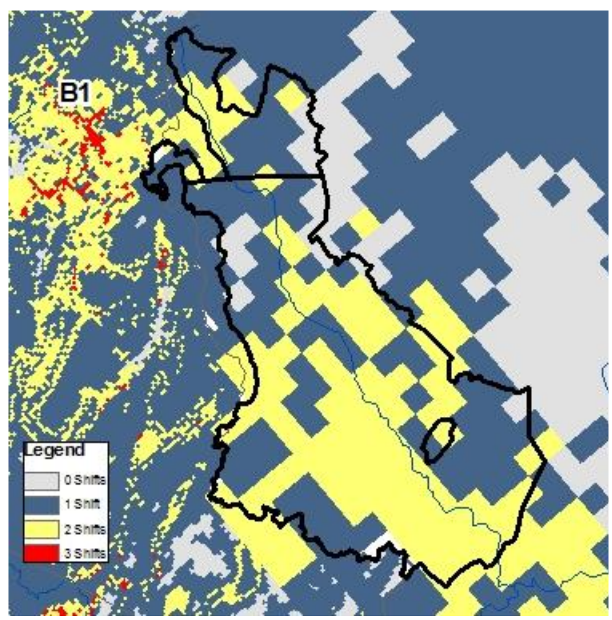
- The alpine treeline is found at high elevations (1101 -1115 m) in the Mackenzie Mountains. Although region specific evidence is not cited, alpine treelines are generally moving upwards with warming conditions (IPCC, 2014).
- A baseline Normalized Difference Vegetation Index (NDVI) has been established for Nahanni and can be used for monitoring ecosystem change (He *et al.*, 2012).

Climate-Biomes

"Cliomes" are broadly defined regions based on temperature and precipitation patterns and associated vegetation communities. Using climate models the Scenarios Network for Alaska and Arctic Planning (SNAP) projected future cliome shifts for the region (SNAP and EWHALE lab, 2012). "This analysis can assist with: planning connectivity between protected areas; identifying novel conservation zones to maximize representation of habitats during the emerging changes; designing plans, management and monitoring for individual protected areas" (Rowland *et al.*, 2016).



Projected change and resilience under three emission scenarios. These maps depict the total number of times models predict a shift in cliome between the 2000's and the 2030's, the 2030's and the 2060's, and the 2060's and the 2090's. This reflects an ensemble of five different climate models for three different greenhouse-gas emissions scenarios (A1B, A2 and B1). Outputs can be considered in terms of areas of resilience (i.e., lack or projected cliome shift) and vulnerability (i.e., multiple cliome shifts over time). Yukon is at 2 km resolution and NT is at 18.4 km resolution.



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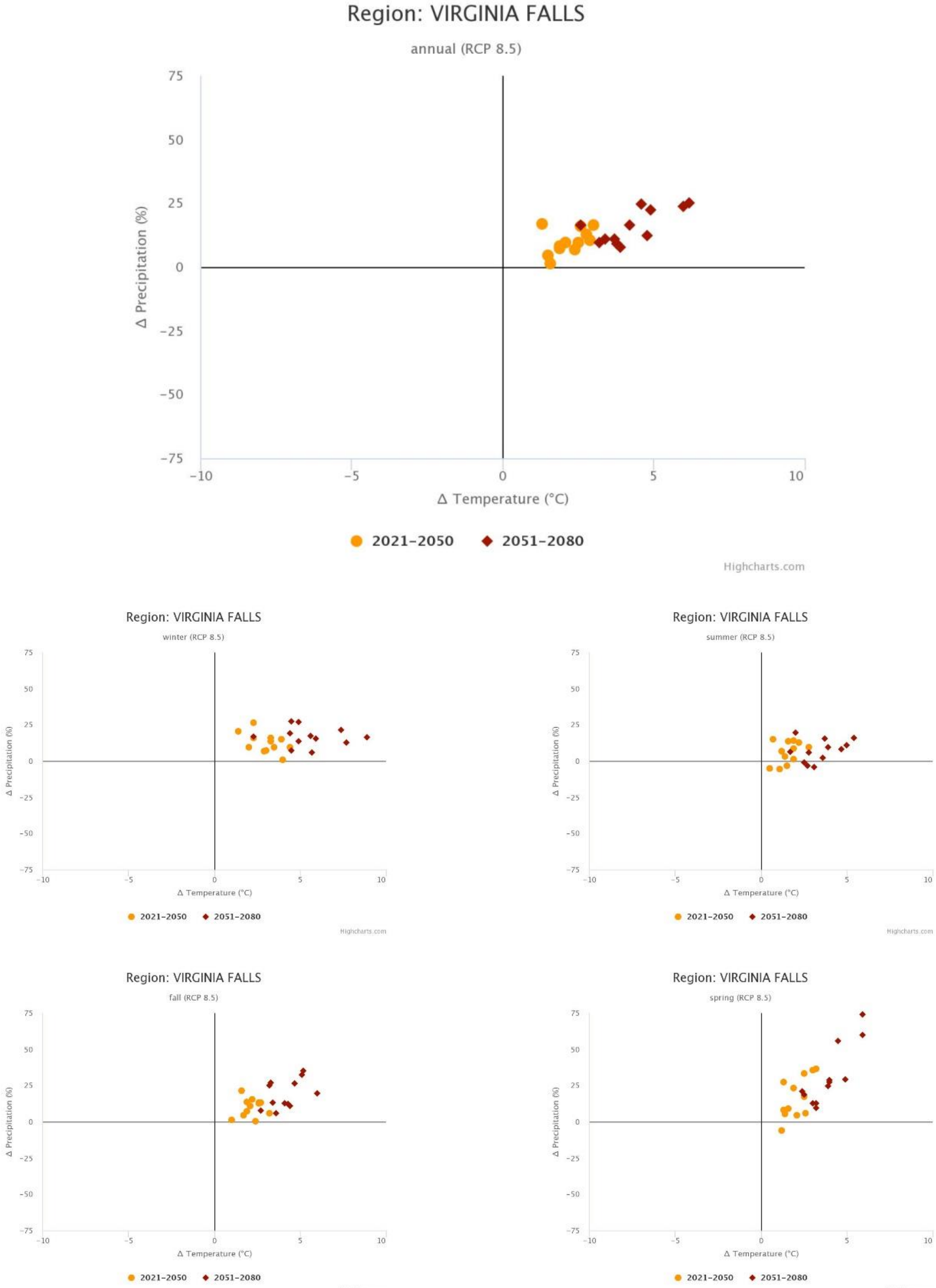
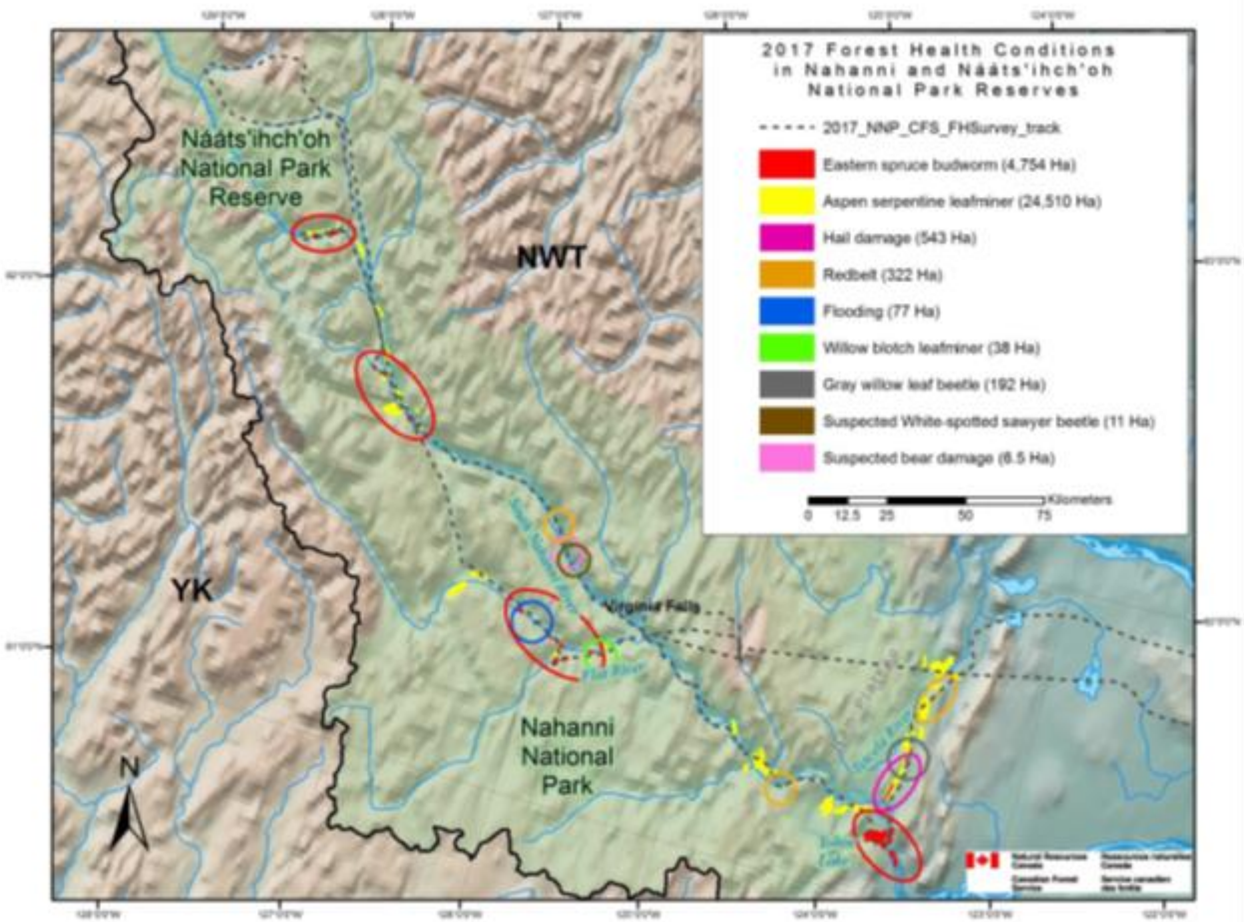
Appendix 1. Model Scatterplots for Temperature and Precipitation



Climate models for the ###### Region. Each point represents a single model-simulated temperature/precipitation response to the RCP 8.5 scenario. Statistically downscaled data (Bias Corrected Spatial Disaggregation; BCSD) derived from 12 CMIP5 global climate models (PCIC, 2014). Models generally project warmer and wetter conditions.

Appendix 2. Related Information

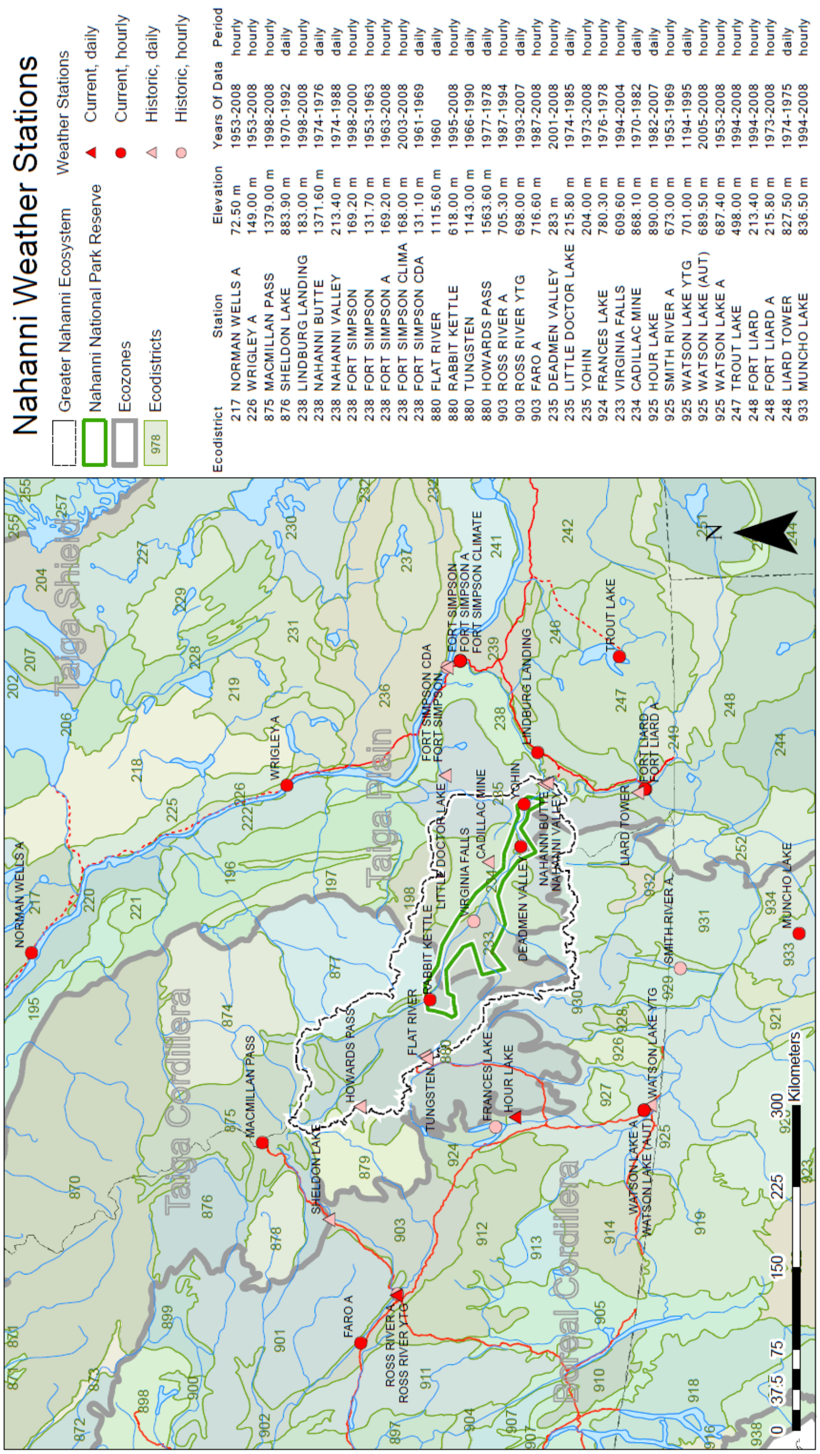
Forest Health Conditions



Forest health condition in Nahanni NPR in 2017 (Brett, 2018).

Spruce budworm is the primary agent affecting white spruce throughout the region and the area affected increased from 2016 to 2017. Aspen serpentine leafminer continues to cause moderate to severe defoliation to trembling aspen in Nahanni (Brett, 2018).

Nahanni Weather Stations



Ecodistrict	Station	Elevation	Years Of Data	Period
217	NORMAN WELLS A	72.50 m	1953-2008	hourly
226	WRIGLEY A	149.00 m	1953-2008	hourly
875	MACMILLAN PASS	1379.00 m	1998-2008	hourly
876	SHELDON LAKE	883.90 m	1970-1992	daily
238	LINDBURG LANDING	183.00 m	1998-2008	hourly
238	NAHANNI BUTTE	1371.60 m	1974-1976	daily
238	NAHANNI VALLEY	213.40 m	1974-1988	daily
238	FORT SIMPSON	169.20 m	1998-2000	hourly
238	FORT SIMPSON	131.70 m	1953-1963	hourly
238	FORT SIMPSON A	169.20 m	1963-2008	hourly
238	FORT SIMPSON CLIMA	168.00 m	2003-2008	hourly
238	FORT SIMPSON CDA	131.10 m	1961-1969	daily
880	FLAT RIVER	1115.60 m	1960	daily
880	RABBIT KETTLE	618.00 m	1995-2008	hourly
880	TUNGSTEN	1143.00 m	1966-1990	daily
880	HOWARDS PASS	1563.60 m	1977-1978	daily
903	ROSS RIVER A	705.30 m	1987-1994	hourly
903	ROSS RIVER YTG	698.00 m	1993-2007	daily
903	FARO A	716.60 m	1987-2008	hourly
235	DEADMEN VALLEY	283 m	2001-2008	hourly
235	LITTLE DOCTOR LAKE	215.80 m	1974-1985	daily
235	YOHIN	204.00 m	1973-2008	hourly
924	FRANCES LAKE	780.30 m	1976-1978	hourly
233	VIRGINIA FALLS	609.60 m	1994-2004	hourly
234	CADILLAC MINE	868.10 m	1970-1982	daily
925	HOUR LAKE	890.00 m	1982-2007	daily
925	SMITH RIVER A	673.00 m	1953-1969	hourly
925	WATSON LAKE YTG	701.00 m	1194-1995	daily
925	WATSON LAKE (AUT)	689.50 m	2005-2008	hourly
925	WATSON LAKE A	687.40 m	1953-2008	hourly
247	TROUT LAKE	498.00 m	1994-2008	hourly
248	FORT LIARD	213.40 m	1994-2008	hourly
248	FORT LIARD A	215.80 m	1973-2008	hourly
248	LIARD TOWER	827.50 m	1974-1975	daily
933	MUNCHO LAKE	836.50 m	1994-2008	hourly

Map Produced by: Parks Canada Agency, Southwest NWT Field Unit, Resource Conservation. May, 2008. UTM 10N, WGS84
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