Climate change implications in Saskatchewan's boreal forest fringe and surrounding agricultural areas

Options and recommendations for suitable forest establishment and maintenance

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Executive Summary

This report describes the results of our investigation of the implications of climate change on the southern boreal forest fringe and adjacent parkland in Saskatchewan. The study area is the central portion of Saskatchewan between 51°N and 55°N.

We determined that, should the area undergo climate change as predicted by a particular climate change scenario, there may be significant effects on the capacity for renewal of many tree species found in the study area. White spruce, for example, is anticipated to be able to re-establish new trees in only the far north of the study area by the end of this century. The boreal forest as a whole is suggested to be in retreat.

Because of the anticipated range retreat, significant impacts on humans may occur, including changes to the forest industry, agricultural opportunities, recreation opportunities, and traditional use of the landscape. Management responses to these changes can be identified by four guiding value statements concerning the forest:

- Unmanaged Change – Accept the changes, and respond to the changes by changing our activities to match. Low cost to mitigate changes, potentially large costs from coping with change.
- Managed Retreat – Manage the changes to minimize losses to stated values, like forest cover. Significant costs associated with management actions, moderate costs of coping with changes.
- Frozen Landscape – Minimize changes to the landscape, maintaining it as in a historical condition. Large costs associated with management actions, if possible at all.
- Accelerated Capture Before Loss – Embrace the change, and assume the model predictions of change are valid. Accelerate harvest of renewable resources subject to loss in order to capture the resource before it fails to renew. Significant economic return in the short term, potentially catastrophic consequences if the assumptions are not valid. Some questions about which societal values to incorporate into the resource targets.

The risk associated with climate change is a real risk. We need to identify the consequences of prospective changes in order to manage them with minimal disruption to human systems. By investigating the individual effects of possible changes, we are able to examine coping strategies. This report identifies specific changes to values we associate with the boreal forest. What will we choose to do for ourselves for the future?

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Introduction

This report describes the results of our investigation of the implications of climate change on the southern boreal forest fringe and adjacent parkland in Saskatchewan. The study area is the central portion of Saskatchewan between 51°N and 55°N.

Some of our questions being addressed are:

- What are plausible impacts of changes in climatic conditions on tree species which are currently resident in the study area?
- What are the anticipated impacts of these changes in climatic conditions on non-resident tree species which may have potential for agroforestry and afforestation use?
- What do these impacts imply for the management of forested land and agricultural land which may plausibly be used for growing trees and forest?

The fringe forest area in Saskatchewan is potentially sensitive to climate change. Under a warmer and drier future climate, significant losses of forest cover may be anticipated due to increased severity of drought, in combination with fire, insects and other factors (Hogg 1994; Hogg and Hurdle 1995; Hogg et al, 2002).

This study is an investigation of a specific climate change scenario with respect to tree range. It is an investigation of a methodology and of one set of potential impacts on the range of existing local and candidate local tree species.

Methodology

We combined the climatic analysis documented at the Canadian Institute for Climate Studies (CICS) web site (CICS, 2003a) with forest knowledge and local condition information to model the likelihood of survival and growth of various tree species in Saskatchewan. The climate scenarios that have been developed by others were downsampled to provide higher spatial resolution information. Tree range data was combined in a Geographic Information System (GIS) with soils and topography information to produce maps describing a possible range for each species.

Study Area

The study area is the central portion of Saskatchewan between 51° and 55° N Latitude. This area has been chosen to represent the area known as the forest fringe. It includes agricultural prairie, boreal forest, and the transition between them. Figure 1 represents the study area.

The study area abuts the area of a study undertaken by the Prairie Adaptation Research Collaborative (Henderson, *et. al.*, 2002), which performed analysis on island forests on the prairies between 47.5°N and 51°N. A conclusion they reached is that there are elements of island forest ecosystems that are threatened by ongoing climate change. These ecosystems are similar in many ways to the boreal forest fringe. Both systems are located at the interface between grasslands and forest.

Climate Change Scenarios

The climate change scenario that was examined was the CGCM1, as published on the CICS web site. Within this scenario, a series of experiments has been conducted to analyse the sensitivity of the modelled system to different initial conditions and assumptions. Each experiment represents a model run for the Global Circulation Model (GCM) and suggests a future condition. The experiment provided in the appropriate form for this study was the GHG+A1 experiment.

GHG+A1 represents a scenario similar to the IPCC IS92a scenario, with an increase in the concentration of carbon dioxide and an increase in aerosols. Globally, it suggests an increase in temperature of between 2 and 6°C, and an increase in precipitation of approximately 1%. The model suggests that the temperature increases will be concentrated in continental northern latitudes (Hengeveld, 1999). The increased temperature is expected to increase evaporation, which would likely overpower the effect of increased precipitation, and reduce available soil moisture.

The Global Circulation Model scenario experiments provided us with coarse scale data for the study area, but not local variation in

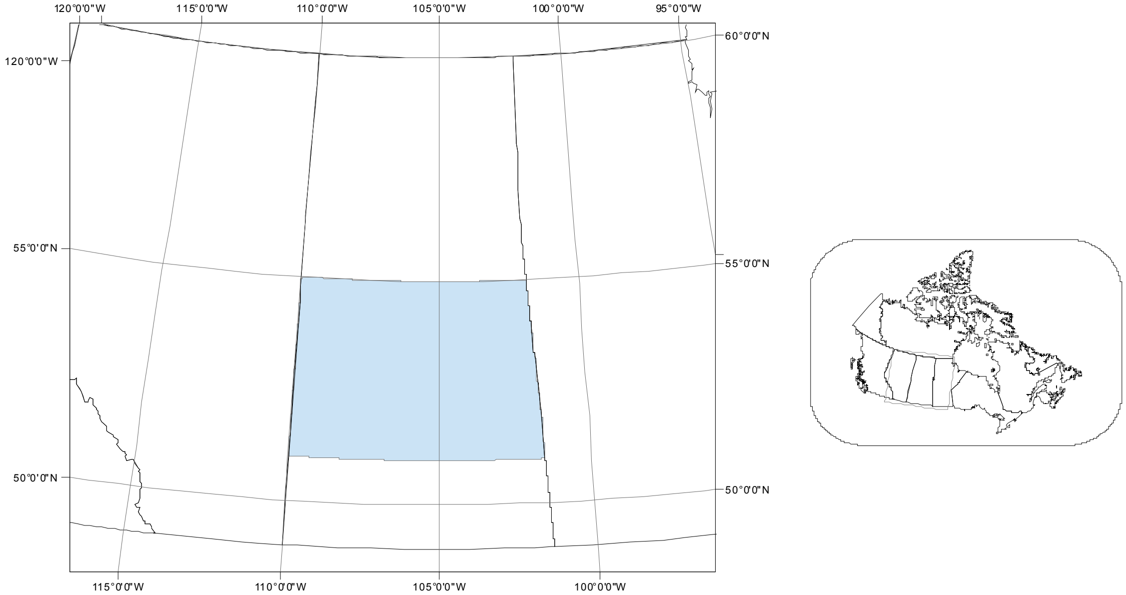


Figure 1: Study Area is from 51° to 55° N in the province of Saskatchewan

landforms and fine-scale weather patterns. In our case, we used statistical downscaling, as suggested by the CICS to generate these finer scale patterns with the SDSM package (SDSM, 2001). There are 27 weather stations used in and around the study area. The downscaling process provides possible daily weather at each of these stations. The historical training data from weather stations and atmospheric measurements sets up a model to predict station measurements with future atmospheric scenario data from a GCM.

To develop fine-scale climate models for the study area we interpolated the daily weather data from the downscaling for the weather station. At each weather station, we developed the outputs of daily minimum and maximum temperature and the amount of precipitation for the time period until 2080. This information was processed to provide information associated with plant hardiness (McKenney, *et.al.*, 2001) and the Climatic Moisture Index (Hogg 1994, 1997).

After developing these outputs from the downscaling model at the weather stations, conditions across the rest of the study area were estimated by an interpolation to a grid of points. The interpolation was a thin-plate spline, as described by Hutchinson (2002). The interpolation grid was to a resolution of 1km^2, aligned to the UTM grid.

Experiment outputs were generated for the 2020's and 2080's. These two time periods were chosen to represent a crop rotation from the present time for fast-growing species and for slower natural-forest trees.

Tree Species Analysis

We gathered tree range data, climatic factors, soil factors, and land use/cover factors in a manner similar to Prasad and Iverson (1999) but adjusted to reflect the form and availability of data in the study area.

Tree range data was adopted from Little (1971). This data represents a picture in time from the beginning or middle of the training period for the climate modelling.

Soil factors

Soils data was derived from the Soils Landscapes of Canada (SLC) soils dataset (Agriculture Canada, 2000). This was the only soils dataset which covers the entire study area consistently. The soils data was processed to represent the factors shown in Table 1.

Choice of tree species to examine

Species considered in this study were a set of locally resident trees, a set of trees found in the broader biome within North America, and a small set of trees found in other parts of the world. These trees represent boreal forest species and species that are considered potentially appropriate targets for afforestation and agroforestry.

Tree species considered in this study are shown in Table 2.

Species Adaptation to Climate Change Analysis

The main product of this project is a set of advisory maps indicating a possible range of a species of tree that may be used in agroforestry, afforestation, and the maintenance of forest in a given area.

To generate these maps, a dichotomous decision tree was developed. The decision tree consists of a series of yes/no questions based on the data available for each species. A given pixel on the map provides values for all the questions in an appropriate order to predict the likelihood that species will be able to grow on that pixel.

The prediction of future range of the various species was developed using the decision trees derived from the existing data set, with the future climate possibilities suggested by the climate model.

The prediction of range for species not known in the area, or varieties otherwise similar to species found here was generated by using the classification tree from the closest known species, and modifying the decisions based on the best available knowledge.

This suggestion of range could ultimately be used to decide which species to plant at a site, given the balance of factors. For example, on a site used for agroforestry on agricultural lands in the current forest fringe, the need might be to

Table 1: Soils factors calculated for study area

Factor Name	*Description*
pmdepaf	Proportion of Parent Material of Alluvial or Fluvioglacial origin
pmdepe	Proportion of Parent Material of Eolian origin
pmdepl	Proportion of Parent Material of Lacustrine origin
pmdepmu	Proportion of Parent Material of Morainal or Undifferentiated origin
pmdepbn	Proportion of Parent Material of Bog or Fen type
pmdepr	Proportion of Parent Material of Rock type
rootdp	Unrestricted Rooting Depth
drain	Drainage Class
calc	Calcareous Class of Parent Material
slope	Slope Class
hydro	Non-land: Lake/River

determine which species has the best possibility of surviving to a marketable age. The species chosen for this situation might be cold and drought hardy with potential for a high volume production of wood.

The forest at risk maps were derived from a difference between two sets of maps- the present situation and the possible future scenario. This will represent the areas where forest presently grows, but is not anticipated to be able to grow in the future. These may be areas where human intervention could improve the viability of the forested ecosystem.

Table 2: Species examined in this study

Resident to Study Area	***Resident to North America***	***Non-resident to North America***
Balsam fir	Lodgepole pine	Siberian larch
Manitoba maple	Red pine	European black pine
White birch	Interior Douglas fir	Scots pine
Tamarack	Ponderosa pine	
White spruce	Blue Spruce	
Black spruce		
Jack pine		
Balsam poplar		
Plains cottonwood		
Trembling aspen		
American elm		

Conceptual Background

The results presented in this report are derived from analysis based on the work of a wide range of researchers in climate change science, statistics and biology. As such, it stands on a body of knowledge. This section of the report is intended as a background document to assist the reader in understanding the material presented in the results section. For each of the sections, there is a resource list directing interested readers to further material.

Climate Change Modelling - Global Circulation Models

Climate change impacts are suggested based on models of atmospheric circulation around the world. These models are fantastically complex assessments of how energy moves through the atmosphere. They represent layers of the atmosphere and layers of the oceans as cells, typically of 2 – 5 degrees of latitude and 2 – 5 degrees of longitude. The products of climate models show how the atmosphere is moving today, and how it might move in the future.

Climate change modelling has suggested that when greenhouse gases increase in the atmosphere more energy is retained in the atmosphere. This retained energy increase can produce higher temperatures, increased turbulence, increased cloud cover, or all of these effects and more.

The process of creating future predictions of climate is based on some assumptions. Different model runs might use different assumptions. One scenario might suggest that carbon dioxide (CO_2) will double by 2080, another might suggest that CO_2 will triple by 2080. The model output results are then made as predictions of what might happen if these assumptions are valid.

The model used in this report is the Canadian Global Climate Model, version 1 (CGCM1), using the GHG+A1 scenario. This scenario is based on the historical situation (the control run) with the addition of increased greenhouse gases (GHG) and sulphate aerosols (+A1). This scenario represents conditions that represent the continued increase in CO_2 concentrations to double the 1980 concentration by 2050, and triple by 2100. The sulphate aerosol concentrations were modelled to increase until 2050 as developing regions industrialise, and then decline slowly thereafter.

The CGCM1 GHG+A1 experiment describes a global picture suggesting land surface temperatures could rise 6°C by 2100. This increased temperature and increased atmospheric energy would lead to an increase in evaporation, which would increase precipitation. The scenario prediction is that precipitation would increase by 1% globally by 2050 and 4.5% by 2100. The increases in precipitation are expected to occur mainly over the seas and land in higher latitudes of the northern hemisphere.

Increasing temperature and precipitation might seem like a good combination for forest cover, but the increased evaporation induced by temperature increase offsets the increased precipitation. The net result is that soil moisture is expected to decrease, especially in summer.

The CGCM1 GHG+A1 scenario is one of the more extreme climate change experiments among all the major GCM's and their experiments. This can be seen at the CICS website, by exploring the placement of the GHG+A1 model in relation to others. Figure 1 shows how the CGCM1 model compares to other models over Prince Albert in the years around 2080.

Resources:

CGCM1 model, GHG+A1 scenario description with technical detail:

http://www.cccma.bc.ec.gc.ca/data/cgcm1/cgcm1_gh-ga.shtml

CGCM1 model description and interpretation:

http://www.msc-smc.ec.gc.ca/saib/climate/ccd_00-01.pdf

CICS website for GCM exploration

http://www.cics.uvic.ca/scenarios/plots/select.cgi

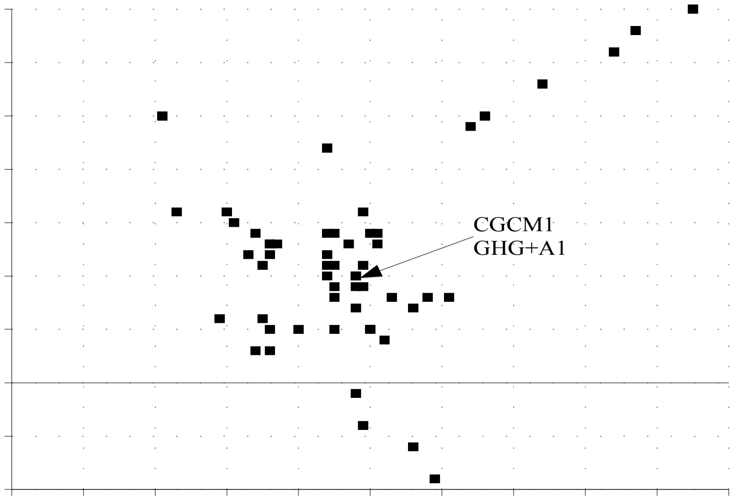


Figure 2: Placement of the CGCM1 GHG+A1 experiment in comparison to other climate change experiments. The experiment used in this study is indicated with an arrow. This GCM cell is over Prince Albert, SK for the 2080 period.

Climate Change Modelling – Downscaling

Global Circulation Models have several limitations, one of which is the resolution of the results they produce. A typical cell is on the order of several degrees of longitude by several degrees of latitude in area. Predictions of the effects of climate change are effectively rather broad predictions. For example, there are 12 cells that have a component in Saskatchewan from the model (CGCM1) used in this study. One approach to making the predictions more specific is to scale the predictions down from the GCM using local historical information. This process is called statistical downscaling.

The historical daily weather patterns at a weather station describe the minimum and maximum temperatures and the precipitation at the weather station during a training period. The usual training period is from 1961 to 1990. The data represent 10957 daily measurements over 30 years.

The historical station data can be compared to historical daily atmospheric measurements to identify a statistical model which describes the relationship between the station data and the atmospheric data. This relationship is assumed to be consistent between the historical term and potential future scenarios.

The GCM provides a set of atmospheric values for each cell for each future scenario it describes. These data are analogous to the historical measurements of atmospheric data. A scenario of predictions of daily weather can be generated from the projected atmospheric values and the relationship. These daily values incorporate the variability of natural weather and the trends derived from the GCM.

The end product of downscaling is a set of scenarios which describe the range of possible future conditions derived from the weather station and from the GCM. It can be manipulated at the station level, or summarized and interpolated to make maps, as we have done.

Resources:

Statistical Downscaling Model (SDSM) background

http://www.cics.uvic.ca/scenarios/index.cgi?More_Info-Downscaling_Background

Statistical Downscaling Model (SDSM) software and manual

https://co-public.lboro.ac.uk/cocwd/SDSM/IDLogin.html

Statistical Methods - Recursive Partitioning

Recursive partitioning is a statistical technique for investigating what differentiates the members of a group into their subgroups. It is used in this study to discern what factors make a particular location fall into a specific tree range or not. This knowledge is then used to predict what locations would be appropriate ranges for specific tree species in future scenarios.

The recursive partitioning process produces a yes/no question that distinguishes the group into two subgroups. This question will maximize the difference between the subgroups and minimize the variability within the subgroups. If a subgroup is still too variable, the process is repeated. The end result is a dichotomous key, similar to the sort used in taxonomic classification in biology.

The process of recursive partitioning divides the data by whichever predictor best splits the data into separate groups. Species presence likelihood is the response variable in this study. The statistical procedures involved will be the *rpart* program that is part of the R statistical package (Ihaka and Gentleman, 1996).

The dichotomous key which is a product of recursive partitioning may be used to predict forward for new cases, or cases from a population which is not already classified. This is what we have done in this study.

Resources:

R statistical package:

http://www.r-project.org

Introduction to recursive partitioning

http://www.mayo.edu/hsr/techrpt/61.pdf
http://www.mayo.edu/hsr/techrpt/rpartmini.pdf

Biology – Silviculture

Future climate scenarios under increasing CO_2 concentrations suggest changes to climatic conditions that may significantly affect the establishment, growth, persistence, and consequently diversity and extent of current forest cover.

We choose to look at three categories of forest tree species: 1) those resident to the study area, 2) those resident to North America, and 3) those not resident to North America. These three groups represent tree species that may react to a changing climate by adapting, migrating, or perishing, and also species that through active introduction could potentially mitigate loss of forest cover due to loss of resident species.

Information concerning the growing conditions required for each of the species examined is described in the Appendix concerning the species in question. The resident species are described in Appendix 3, and the non-resident species are described in Appendix 4.

Resources:

Silvics information:

http://www.na.fs.fed.us/spfo/pubs/silvics_manual/table_of_contents.htm
http://plants.usda.gov/

Relationship between climate variables and tree species occurrence:

http://www.ene.gov.on.ca/envision/air/climatechange/impacts.pdf
http://www.ene.gov.on.ca/envision/air/climatechange/options.pdf
http://www.fs.fed.us/ne/delaware/atlas/index.html
http://pubs.usgs.gov/pp/p1650-a/index.html

Methodology

The methodology employed in this study is best described as a series of individual model components. The major components are a climate model and a predictive model. The climate model predicts possible scenarios of weather derived from a global climate model. The predictive model uses historical climate, soil and tree species range data to develop predictions of tree species range in potential future climate scenarios. The overall methodology is graphically represented in Figure 3.

Climate Model

To predict future climate under a climate change scenario, we used a statistical downscaling approach at a series of weather stations to predict the climate at that weather station, and then interpolated the point summary statistics to the broader landscape.

Data Sources

Data used in this component of the study were derived from Environment Canada's climate data web site (Environment Canada, 2001). Daily climate records were exported from the compact disc image and converted into a format appropriate for the statistical downscaling software. Missing data were replaced with appropriate missing data markers.

Some stations in or near the study area did not have sufficient data for analysis, and were not used. The minimum number of valid days of data for a station was 8000 out of 10970 days in the period. An exception was made in the case of Cumberland House, where there were about 5000 days in the period. It is in an area under-represented by weather stations, and so was used despite the relative lack of data.

Predictors used in the downscaling were downloaded from the Canadian Institute of Climate Studies (CICS) web site, and are derived from the CGCM1 GCM, using the CGCM1 GHG+A1 scenario, which is similar to the IS92a GA1 scenario. They were formatted for SDSM by the CICS (CICS, 2003b).

Statistical Downscaling

We downscaled climate data at each station to produce synthetic daily weather data. At each station we produced 100 stochastic examples of weather for the projected period. These stochastic

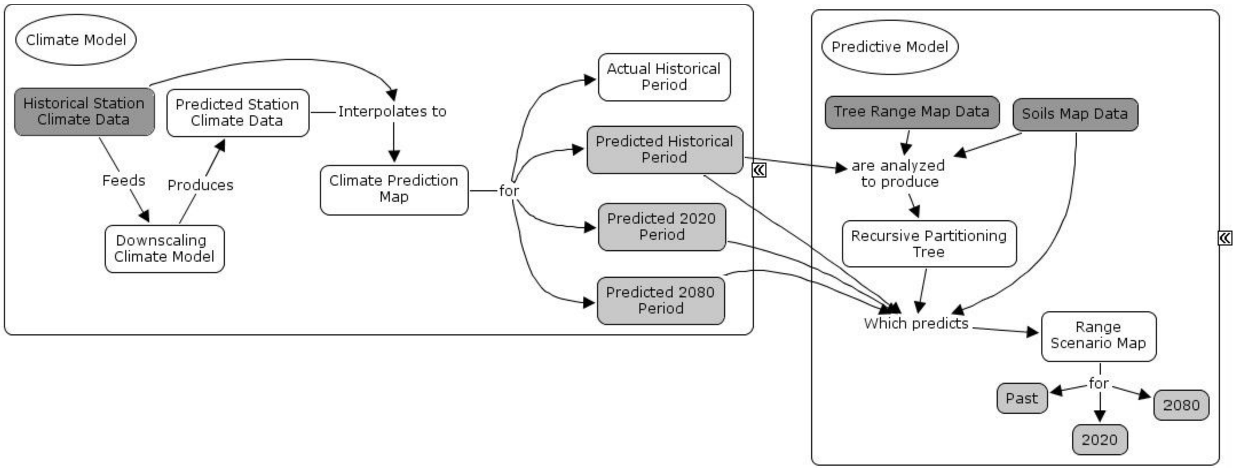


Figure 3: Concept map describing the relationship of the individual components of the model to the input data (dark grey) and the analytical steps involved in producing project output (light grey).

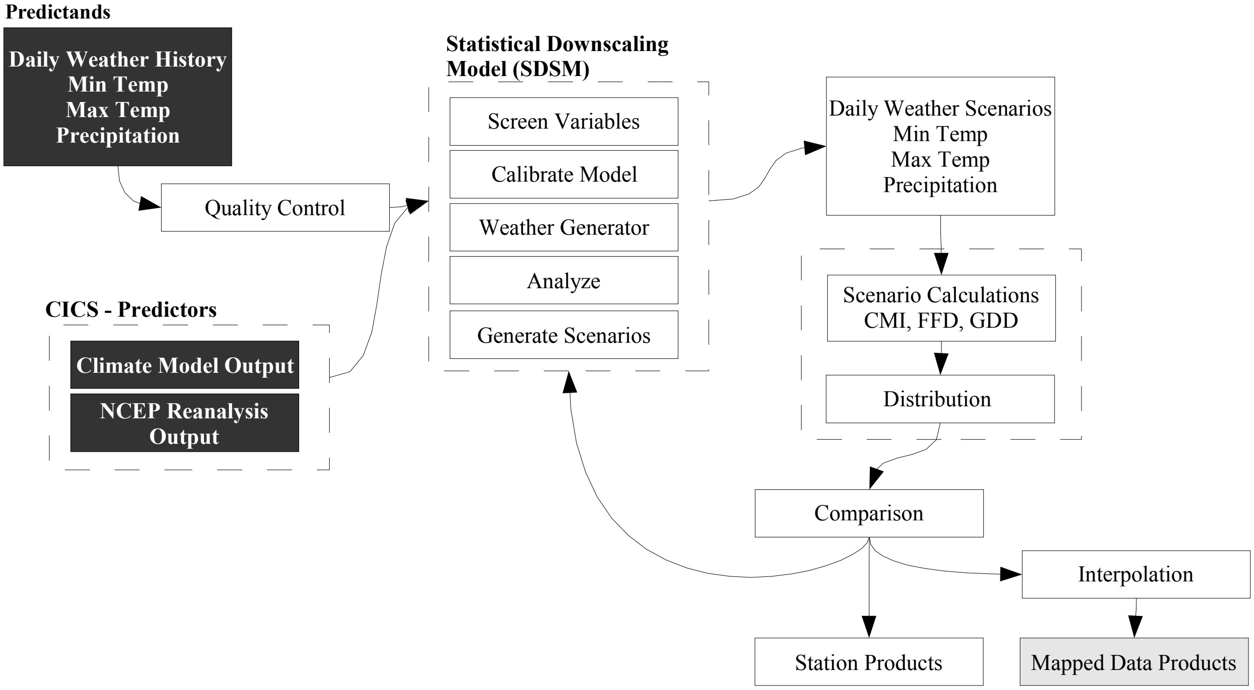


Figure 4: Block diagram of the downscaling process. Black represents data sources, while grey represents the outputs from this process.

examples were examined and summarized to the final statistics which were interpolated to the study area.

Statistical downscaling was performed using the Statistical Downscaling Model (SDSM)(Wilby, *et al.*, 2002). The five steps of the downscaling are the screening of variables to identify useful variables, the calibration of the model, the generation of historical scenario data, the comparison of the source and scenario data, and finally the generation of future scenario data (Figure 4).

The variables identified by the screening process differ by the statistic being simulated. The specific statistics are shown in Table 3.

The model calibration process develops the statistical relationship to predict the predictands from the predictors. This parameter file is used for historical weather generation and generating future scenarios.

A set of historical scenario predictions was made in order to compare the real historical data to the stochastic scenario data. This is the historical weather generation phase. The comparison of the scenario data and the real data provides a check that the choices made for predictors are appropriate.

Scenarios for future weather were generated from the parameter file and GCM data. 100 scenarios were derived for each of three time periods – Current (1961-1990), 2020's (2010-2039), and 2080's (2070 – 2099). Thirty years of data for each of daily minimum temperature (TMIN), daily maximum temperature (TMAX) and precipitation (PRCP) was generated.

From the scenario daily weather data, summaries were made. Some of the summaries are directly derived from the data, while others involve a calculation step. Table 4 shows the statistics derived from the daily data.

The temperature and precipitation summaries were generated by finding the 10th, 50th, and 90th percentiles of all scenarios and all years. Frost-free days were determined by finding the longest period in each year and scenario where the minimum temperature did not fall below 0°C. The median (50th percentile) was found among all years and scenarios.

Table 3: Predictors used to estimate each of the predictands being simulated. Predictors are atmospheric measurements used to generate the scenarios of station weather values (predictands).

Predictands	*TMAX & TMIN*	*PRCP*
Predictors	Surface airflow strength	Surface airflow strength
	500hPa geopotential height	500hPa airflow strength
	850hPa geopotential height	500hPa vorticity
	Specific humidity at 500hPa	500hPa geopotential height
	Specific humidity at 850hPa	Specific humidity at 500hPa
	Near surface specific humidity	Specific humidity at 850hPa
	Mean temperature at 2m	Near surface specific humidity
		Mean temperature at 2m

Table 4: Statistics derived from daily station predictions for each time period.

Plant Hardiness	*Climatic Moisture Index*
Median and extreme (10th percentile) daily minimum temperatures of the coldest month (° C) Median and extreme (90th percentile) daily maximum temperatures of the warmest month (°C) Median frost free period (days) Growing Degree Days, with a 5°C base Rainfall (mm) – Annual, Summer, Winter	Daily precipitation Daily maximum temperature Daily minimum temperature Mean monthly solar radiation

Growing degree days were determined by calculating the daily mean temperature and subtracting 5°C. When the resulting value is positive, it is added to an annual accumulation. The median value of the annual accumulations for each scenario was used for making predictions.

Climatic Moisture Index synthesizes the combined effect of changing temperature and rainfall as a moisture balance statement. To calculate it, a daily moisture balance is calculated. This balance is accumulated for the year, and then a median is found for making predictions. The daily moisture reduction is calculated by predicting the rate of potential evapotranspiration from the monthly mean solar energy influx and the daily mean temperature. The daily moisture input to the system is calculated from the precipitation. The difference between them is the daily moisture balance. Negative values mean a drier climate than positive values.

Interpolation was performed to derive a prediction between weather stations. The interpolation function *tps* was used from the statistics package *R* (Ihaka and Gentleman, 1996). This function is a thin-plate spline model. Low levels of smoothing were used to remove discontinuities in the interpolation.

Outputs at this stage are climate variable raster datasets across the study area for each of three climate periods.

Predictive Model

The predictive model for this analysis uses the data from the climate model, a soils layer, and existing tree range data to predict the future scenario range for individual species of trees. There is a training step and a predicting step.

The software used was a combination of the statistics package *R*, the geographical information system (GIS) package ArcGIS v. 8.3 (ESRI, 2003), and some custom-written software to direct the analysis and convert results as needed.

Training the Model

To train the predictive model, we developed a recursive partitioning tree for each of the tree species found in the study area. This recursive partitioning tree was developed from the existing range as the dependent variable. The independent variables were soil and climate factors. A ten percent selection of the data was used to minimize calculation time and provide an opportunity to develop predictions using different data than is used to verify.

The training data for climate was derived from the predicted historical period dataset. The predicted data for the initial condition was used rather than the actual historical data to minimize differences in the range suggestions.

To check the predictive power of the statistical model, a prediction was made of the historical range of the species based on a different random subset of the training data. Where this appeared similar to the training range, it was deemed appropriate, and the model was accepted. Where there was limited suitability, an investigation into the possible reasons was made and adjustments to the model structure were made.

The *R* program *rpart* was used to generate the recursive partitioning trees. It generates text that describes which factors guide the splits between species. Multiple splits are defined at each node of the tree, but only the first one is used. The lower level splits are correlated with the primary split to indicate the level of compatibility.

The prediction of future range of the various species was developed using the decision trees derived from the existing data set, with the future climate possibilities suggested by the climate model.

The prediction of range for species not currently present in the study area, or varieties otherwise similar to species found here, was generated by using the classification tree from the closest known species, and modifying the nodes based on the best available knowledge. Where that did not produce appropriate output, a new decision key was developed from published research concerning the species in question.

Tree species were examined for current suitability and suitability for each of the model outputs at each of the grid points. Suitability of a particular species was based on its ability to establish, survive and thrive.

Predicting Scenarios

Predicting the future range of tree species was a matter of reading the *rpart* output and identifying the terminal node to which each pixel classifies. The future predictions are made by using the future scenario climate data, while the historical predictions are made using the historical scenario climate data. A map was developed for each time period and species. The original training data, historical scenario data, and future scenario data are presented together to facilitate comparisons.

Software for this purpose was written expressly for this project.

The tree species examined in the study are shown in Table 5. They are species which are found in the study area, species which are resident to North America, and species resident elsewhere in the world. These choices represent species that are thought to be suitable candidates for planting in the study area.

Resident Species

Resident species' range predictions are created by simply substituting the appropriate climate data for the historical data, and then splitting up the data again at each node. In general terms, these predictions were in line with predictions made elsewhere and at a broader scale. Where they did not seem to agree with other work in the area of range change under climate change, adjustments were made to improve the fit of the model. The simplest adjustment was to identify which decision node diverged from expectations and the

Table 5. Species examined in this study.

Resident to Study Area	***Resident to North America***	***Not resident to North America***
Abies balsamea (L.) Mill. (balsam fir)	*Picea pungens* Engelm. (blue spruce)	*Larix sibirica* Ledeb. (Siberian larch)
Acer negundo L. (Manitoba maple)	*Pinus contorta Dougl.* (lodgepole pine)	*Pinus nigra* Arnold (European black pine)
Betula papyrifera Marsh. (white birch)	*Pinus ponderosa* Laws. (ponderosa pine)	*Pinus sylvestris* L. (Scots pine)
Larix laricina (Du Roi) K. Koch (tamarack)	*Pinus resinosa* Ait. (red pine)	
Picea glauca (Moench) Voss (white spruce)	*Pseudotsuga menziesii* (Mirb.) Franco (interior Douglas fir) *	
Picea mariana (Mill.) B.S.P. (black spruce)		
Pinus banksiana Lamb. (jack pine)		
Populus balsamifera L. (balsam poplar)		
Populus deltoides Bartr. (Plains cottonwood)		
Populus tremuloides Michx. (trembling aspen)		
Ulmus americana L. (American elm)		

* *Pseudotsuga menziesii* (interior Douglas fir) was not analyzed separately. The existing range of the variety is very similar to the range of *Pinus ponderosa* (Ponderosa pine), and similar assumptions of range should be made.

historical range, and choose a highly correlated secondary split instead of the original choice. The historical predicted pattern was then examined to make sure that the tree still represented the species as well as it could.

The native species are the species for which the predictions are based on analysis rather than speculation.

Non-Local Resident Species

These species are not found in the study area at present, but are found in the larger environment of mid-continental North America. If future forest policy allows it, these species may be planted in Crown forests. Many of these species have been, and continue to be, planted on private land. There is no training data to predict how these species react in this area. For some species, there is anecdotal information about specific plantings in the study area. For other species, there is nothing other than knowledge of silvics to guide the development of a decision tree. Critical silvics information was gathered on a variety of factors affecting tree establishment, growth, and survival, and is referenced in Appendix 3.

This information was used to assist in the development of decision trees for the various species. A particular focus was on how the tree species are expected to establish and develop. The data was gathered from a literature search for each of the species in question.

Some of these species are compared to a species known in the area. For example, *Pinus contorta* was compared to *P. banksiana*. Differences in growth and tolerance to growing environments were noted and compared. A decision tree was adopted from the comparison species and changed to match our expectations driven by the differences in environmental tolerance.

After a decision tree was generated, a prediction of historical range was created, and the results compared with other tree range prediction systems and the anecdotal evidence of planting survival. The process of refining the decision tree is an iterative one.

If a species is not very similar to any candidate resident species, a new decision tree may be composed for it. The same iterative process of comparison takes place.

Non-Resident Species

These species are not found in the study area, but are found in the global boreal forest or exhibit tolerance for climate extremes. There is no training data for these species, and anecdotal evidence of suitability varies by species. For these species, silvics information drives the process of preparing the decision trees and range predictions.

Results

Climate Modelling

Station-level Modelling

The climate modelling component of this study produced a set of maps indicating a general warming. This is consistent with the global circulation model upon which it was based. The individual stations deviate from the global model based on their own relationship with the training data.

Climate stations are shown in Figure 5. These stations are distributed across the study area as evenly as possible. The station choices were restricted by data availability. There are large distances between stations in the northern part of the area. In the south, some stations were dropped to reduce complexity in the agricultural area.

For each station, model output is represented in Appendix 1. As an example, a single station, Waskesiu, is discussed here. The other stations exhibit similar trends.

Table 7 shows the values for minimum temperature of the coldest month for the station in Waskesiu. These values are calculated from the annual minimum of the the daily minimum temperature values. They are accumulated over the thirty year period and over 100 stochastic scenarios. The values in this table are the 10th, 50th and 90th percentiles of the minimum temperature values. These values are abbreviated as TMIN10, TMIN50 and TMIN90 throughout the results.

The values shown for Waskesiu show that the minimum daily temperature values are expected to warm by about 10°C and that the range of variability will increase from 12°C to 17°C. This is consistent with the GCM prediction of a substantial rise in winter temperature, and an increase in variability. The amount of change seems higher than that predicted by GCM alone.

Table 6 shows the maximum temperature of the warmest month for the weather station in Waskesiu. As with TMIN, they are accumulated

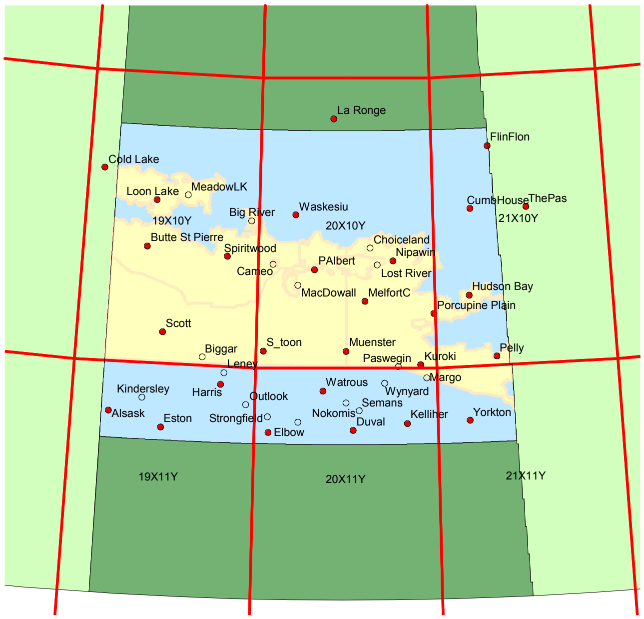


Figure 5: Climate stations used in this study are in filled circles. Alternate stations are unfilled circles. straight lines represent GCM cells. Yellow shows the area of forest fringe.

Table 6: Values of the maximum temperature of the coldest month, based on downscaled results for Waskesiu weather station. The 10th percentile, 50th percentile and 90th percentile of the annual values are shown.

	1970	***2020***	***2080***
TMAX 10	28.81	29.8	32.89
TMAX 50	31.36	32.19	35.06
TMAX 90	34.37	35.21	37.56

Table 7: Values of the minimum temperature of the coldest month, based on downscaled results for Waskesiu weather station. The 10th percentile, 50th percentile and 90th percentile of the annual values are shown.

	1970	***2020***	***2080***
TMIN 10	-47.87	-45.58	-39.07
TMIN 50	-41.32	-38.99	-30.68
TMIN 90	-35.46	-32.42	-22.1

Table 8: Values of the number of frost-free days and the number of growing-degree days with a 5°C base, based on downscaled results for Waskesiu weather station. The 10th percentile, 50th percentile and 90th percentile of the annual values are shown.

	1970	***2020***	***2080***
FFD 10	78	83	102
FFD 50	93	105	130
FFD 90	109	121	144
GDD 10	1017	1163	1561
GDD 50	1123	1272	1724
GDD 90	1236	1419	1851

Table 9: Precipitation values based on downscaled results for Waskesiu weather station. The 10th percentile, 50th percentile and 90th percentile of the annual values are shown.

	1970	***2020***	***2080***
PRCP 10	330.07	354.3	376.83
PRCP 50	424.15	456.84	486.45
PRCP 90	525.01	562.29	620.38

over thirty years and 100 scenarios. The values show a warming of about 4°C and a slight decrease in variability.

The derivative statistics Frost-Free Days and Growing Degree Days are shown for Waskesiu in Table 8. The simulation suggests an increase in frost-free days by a month. The growing degree days show a similar increase. Variability increases in both cases.

Precipitation is anticipated to increase at Waskesiu by an amount smaller than the range of variability at any given time period. The increase is approximately fifteen percent. The change in variability is 25 percent. The values are shown in Table 9.

A summary of the precipitation increase and the temperature increase and how that combination can be used to estimate moisture available to plants. The estimate of the climatic moisture index for Waskesiu is shown in Table 10. The change suggests that Waskesiu will be warmer and wetter. The increase in evapotranspiration because of the increased temperature will overwhelm the increased precipitation. The net result is a increase in moisture deficit for plants.

Interpolated Climate Variables

Interpolating the data between stations was performed with minimal smoothing, to represent the distance between stations, and to minimize smoothing factor search artifacts.

A range of smoothing factors was tested for each factors, and there were obvious problems with the smoothing factors chosen by the smoothing factor search algorithm. This is a frequent problem with smoothing factor searches.

The complete set of interpolated climate surfaces are shown in Appendix .

An example of the surfaces is shown here in Figure 6, the climatic moisture index. What can be seen is the change in the climatic moisture index over the time period. The change in moisture availability is clear. At all points in the study area, there is an anticipated increase in moisture deficit.

Another notable feature of the interpolations can be seen in Figure 7, which shows a warm area around Saskatoon. The warmness of this area is probably an effect of the location of the airport in relation to the city. The airport in Saskatoon is in an exposed location, representing the original reason for placing a weather station there. The Prince Albert weather station is also at the airport, but the airport is quite close to the river, as are many of the small northern community airports used for weather data.

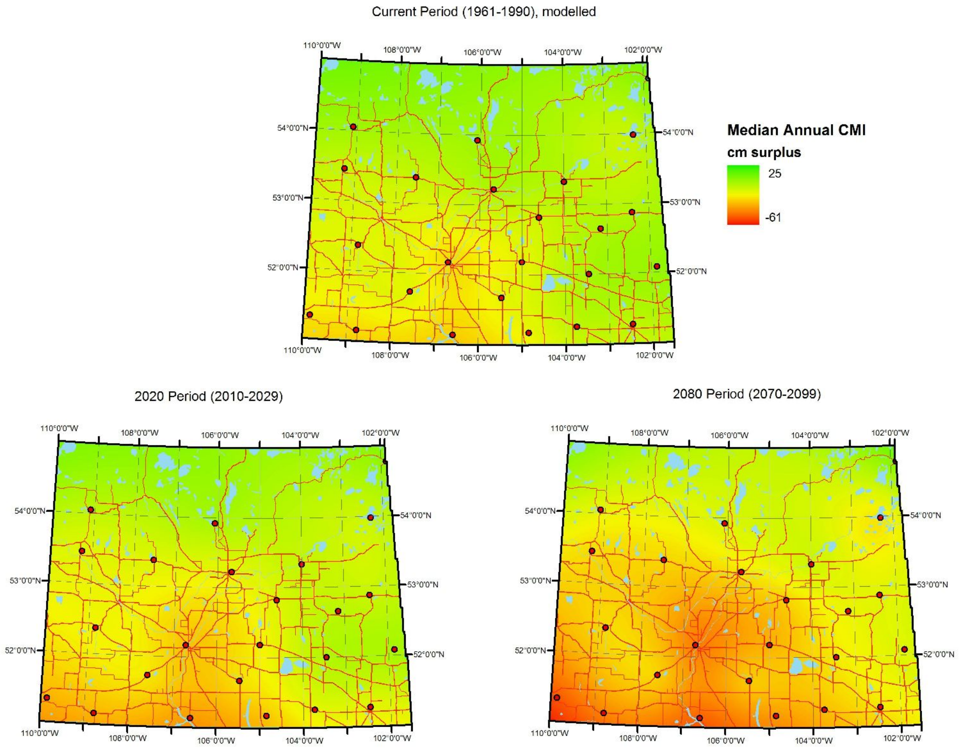
Another notable feature in Figure 3 is the warm area which can be seen at the northern corners of the map. These corners are probably interpolation artifacts, caused by the lack of proximity of weather stations. This is inevitable near the edges of maps with sparse data. There are no weather stations anchoring the data in these two corners.

Range Modelling

The individual tree ranges are derived from the existing range information, the soils data and the climate predictions. Range suggestions for species naturally found in the study area are in Appendix 3. Range suggestions for other species are found in Appendix 4. For each species of tree, there is a decision tree derived from the recursive partitioning process, and a mapped expression of the existing range (for resident species), a prediction of the existing range, and a prediction of the future range in the 2020 period (2010-

Table 10: Values of the annual climatic moisture index (CMI), based on downscaled results for Waskesiu weather station. The 10th percentile, 50th percentile and 90th percentile of the annual values are shown.

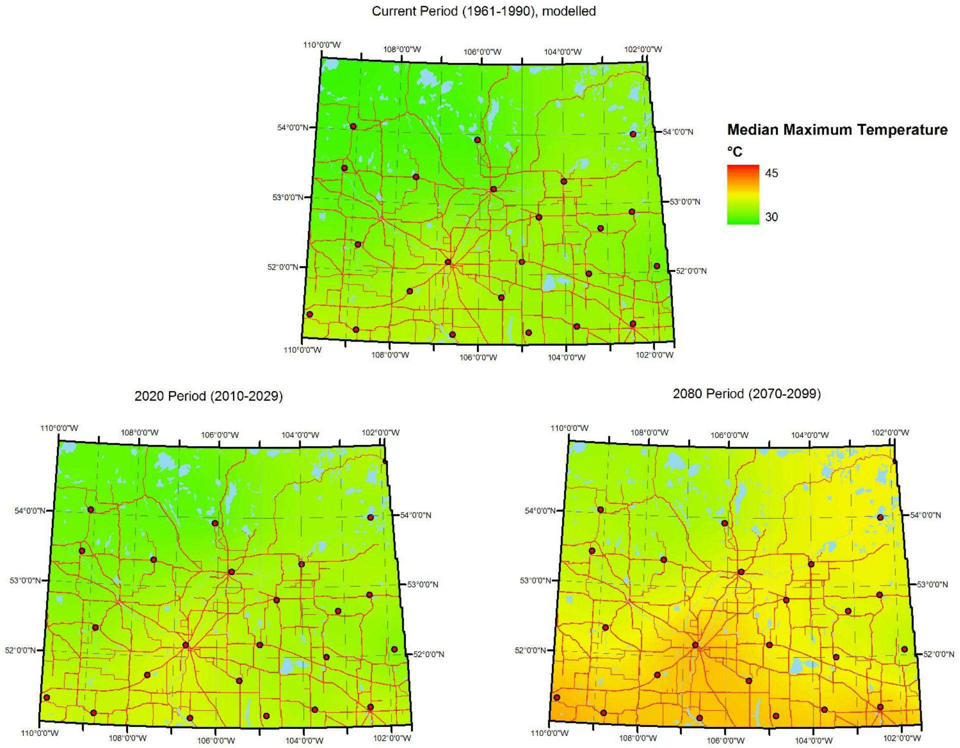
	1970	*2020*	*2080*
CMI 10	-9.93	-11.97	-23.69
CMI 50	0.79	-1.04	-12.3
CMI 90	11.42	9.73	0.39


Current Period (1961-1990), modelled

2020 Period (2010-2029)

2080 Period (2070-2099)

Figure 6: Median Climatic Moisture Index (CMI) interpolated between climate stations. CMI represents moisture deficit as a negative number.


Current Period (1961-1990), modelled

2020 Period (2010-2029)

2080 Period (2070-2099)

Figure 7: Median maximum temperature in the warmest month (TMAX).

2039) and the 2080 period (2070-2099). The range suggestions are collected together in the appendices to facilitate comparison.

Native Species

The statistical model seems to be appropriate for identifying range suggestions. As a whole, the current period range suggestions match the training data, and the future suggestions are in line with expectations. The method is subject to inaccuracy in the training data, and is affected by the limited scope of the study area, but seems generally descriptive and not in particular conflict with other efforts of the type (Natural Resources Canada, 2002). There are species in retreat, species which suggest advance, and a species for which the model's descriptiveness is limited.

Where the existing range of a species cuts across the study area perpendicular to the climate gradient, the model makes clear suggestions. Where the initial range does not act in this way, the range suggestions are less clear.

Range suggestions for species naturally found in the study area are in Appendix 3.

Species in Retreat

What is apparent from examination of the range predictions is that the main coniferous boreal forest species may lose so much of their range that they may re-establish successfully only on the Canadian Shield by the end of this century. This is not a statement of where there will be forest, but rather an expression of where individual trees are most likely to re-establish after disturbance.

Black spruce (*Picea mariana*), white spruce (*Picea glauca*) and jack pine (*Pinus banksiana*), the primary commercial softwood species in Saskatchewan, show substantial range retreat. For *Pinus banksiana*, from the historical period to the 2020 scenario, there is a retreat to the north of as much as 100 km in the western portion of the study area, to a minimal change in the hills of the eastern portion. By 2080, the retreat is complete in the west, and *Pinus banksiana* is restricted to specific areas in the east (page 80).

Both resident *Picea* species show dramatic range retreat. By 2020, the eastern hills are still in *Picea* range, but by 2080, they are no longer suitable, according to the model. In the western part of the study area, by 2020 the range of *Picea* is anticipated to be 100 to 120 km north. By 2080, the range retreat seems complete from the study area. The fringe at the northern edge of the study area is all that is left, and this is the area of least confidence in the model (pages 78 and 79).

Tamarack (*Larix laricina*) is anticiated to retreat more than pine and spruce. It is initially found further south than those trees, but it is suggested that it will retreat as much by 2020 and further by 2080 (page 77). It is not clear why this species shows more retreat than pine and spruce.

White Birch (*Betula papyrifera*) is found further to the south than the boreal conifers. It is suggested to retreat as much as the conifer species, but that leaves it significant range in the study area by 2080 (page 76).

Balsam (*Populus balsamifera*) and aspen (*Populus tremuloides*) poplars both show significant decreases in area suitable for establishment. They are both found throughout much of the study area initially, and show a general decrease in suitable area at both time periods. There is an area of confusion in the southwest in the 2020 period, but by 2080, most of the study area is no longer suitable (pages 81 and 83).

Species in Advance

Species that suggest advance are such species as Manitoba maple (*Acer negundo*), and Plains cottonwood (*Populus deltoides*). These species are well-known plains species, primarily growing in wetter sites throughout the grasslands. The predictions made by these maps are for the range for natural re-establishment. The growth of planted trees may differ, depending on site conditions, tending, irrigation and competition factors.

Acer negundo is found throughout the study area's grassland areas, and extensively through the forest fringe. By 2020, significant range advance is suggested, on the order of 70 km to the north. The 2080 range map shows that practically the entire study area is suitable for these trees (page 75).

Populus deltoides is presently found in the southwestern corner of the study area. By 2020, it may have advanced as far as Prince Albert, and by 2080, as far as the northern limit of the study area (page 82). This species may be the most adaptable to the suggested climate regime. It is known to grow successfully north of the range expressed by Little (1971) under cultivation.

Species of Confusion

There is one species for which the model was not clear. American Elm (*Ulmus americana*) is found in the southeast corner of the study area. The area in which it is presently found exhibits a gradient of climatic conditions which seems to confuse the modelling approach. Some attempt was made to adjust the model to make this species' decision tree work, but was fruitless. An examination of the proposed present and future range suggestions shows the confused model (page 84).

Non-Local Resident Species

The non-local resident species we examined are species that are candidates for growth here in the study area. These species are not found naturally in the study area at this time, so we are forced to make estimates of the suggested range. Information concerning the requirements of individual species was used to develop decision trees. Where possible, decision trees were built using similar native species. Some species were too different from native species to use that approach. In those cases, an estimate must be developed just from species requirements.

Range suggestions for other species are found in Appendix 4.

Pinus resinosa

This tree shows range possibilities along the present fringe and somewhat south of the range of *P. banksiana*. The decision tree used to identify this tree was derived from *P. banksiana*, with a higher tolerance for low moisture. As the climate changes, *P. resinosa* shows range movement to the north, but always to the south of the range of *P. banksiana* (page 96).

Picea pungens

This species is presently reported to be able to grow in the southern portion of the study area. By 2020, it is anticipated to grow throughout the western portion of the study area, but not in the eastern portion. By 2080, it’s range suggestion is throughout the study area. The decision tree used for this tree was a simple one developed from scratch, as no native species seemed appropriate to build from. It was assumed that the minimum temperature line of -40°C was the lowest survivable temperature. It seemed that this tree should be able to grow in the range of moisture and soil conditions found in the study area (page 88). It shows relatively large change in range because the minimum temperature is the climate measurement with the highest anticipated change.

Pinus ponderosa and Pseudotsuga menzienssii

These two species were treated together, as they show similar characteristics in so many ways, and share range quite closely in their native areas. The primary split was that the tree would not do well where the minimum temperature was less than -37°C. In these warmer sites, the split was that these species do not grow in wet sites, so we asserted that an annual climatic moisture index value of -5 or less would allow these trees to grow. The range suggestion is that these species will grow successfully in much of the area (page 94).

Pinus contorta

Pinus contorta was assumed to have a profile similar to *P. banksiana*, with the exception that the fringe sites where CMI was limiting for *P. banksiana* were not necessarily as limiting for *P. contorta* (page 90). The range retreat shows a pattern similar to *P. banksiana*, only further to the south.

Non-Resident Species

Larix sibirica

Larix sibirica was assumed to be similar in growth habit to *L. laricina*. It is known to more drought tolerant than *L. laricina*, so we changed the initial split to a value of ACMI greater than -28. This indicated that the entire study area would be appropriate range initially for *L. sibirica*. By 2020, and more so by 2080, there is an area in the southwest of the study area that would not support these trees (page 86).

Pinus nigra

Pinus nigra is known to be frost-hardy to -30°C in its natural range., It grows in areas which are quite dry, so we assumed it can tolerate drought at a level of CMI greater than -10. The product range is in the south to start, moving north over time (page 92).

Pinus sylvestris

This tree is known to grow throughout the study area. It is quite widely grown in the south, and can be grown in the north of the study area. We estimated that the values of CMI that it would tolerate are above -30. We also estimated that there was no expectation of a minimum temperature. *Pinus sylvestris* shows some range retreat at the southern end of the study area by the end of the period examined (page 98).

Discussion

The results suggest that the major tree species currently present in the boreal forest fringe will retreat to the north if the CGCM1 GHG+A1 scenario is valid. This retreat will be in the form of establishment failure for new trees while existing mature stands of trees are removed by fire, infestation and harvesting. This change represents some risks to the forest and the people who depend on it. Some new opportunities may also occur, especially for species and people who are associated with drier ecosystems.

Risks, Opportunities and Responses

The changes that may come represent risks to existing interests in the forest fringe area and opportunities for interests from people and animals from plains ecosystems. There is a suggestion that softwood species will retreat to the Canadian Shield, at the north of the study area. If this does occur, people and other organisms in the southern boreal fringe will experience loss of economy or habitat. Opportunities are available to the organisms and people which move in to fill the vacuum.

Loss of Forest Cover

As boreal species find it harder to establish new individuals, it is anticipated that their range will retreat. Other species may be better able to exploit the environment recently vacated, but these species are not typically found in contiguous, closed stands. There is a significant risk that there will be a loss of closed forest cover.

The typical forest found in the forest fringe today includes pure jack pine and trembling aspen and mixtures of white spruce-trembling aspen with some mixtures of jack pine-black spruce. Where a stand-replacing event occurs, it might be anticipated that the reduced viability of the softwood seedlings would lead to a change in forest composition. In some cases, this change will favour the hardwoods present on the site. In others, the change is expected to result in loss of forest cover.

The change in forest composition, and possible loss of cover will not happen overnight, and indeed not on every site. It will be affected by temporally and spatially local conditions. A site might be disturbed at a time of year when establishment potential is high, and where sufficient moisture is available for the growth of any boreal species. This is very site-specific and subject to the randomness of weather events.

The retreat of the boreal forest may be a punctuated steady state retreat. Nothing happens until a disturbance occurs. With disturbance, the micro climate that has been established by the standing forest is lost. The specifics of the site may lead it to becoming a closed forest site, an open forest site, or an open non-forest site. At a gross scale, the changes in climate predicted by the climate modelling will push sites away from closed boreal forest to open aspen parkland and into grassland.

One looming possibility that has been identified with respect to the forest at risk is the possibility of Mountain Pine Beetle (*Dendroctonus ponderosae*) infesting *Pinus banksiana*. It has been observed that the beetle is capable of surviving on *P. banksiana*. It has also been observed that the beetle is killed by temperatures below -37°C (Gedalof, 2004; Leatherman, 2004). The temperature must be significantly below -37° C in order to overcome the insulative effect of the wood surrounding the larva. An examination of the minimum temperature maps in this study suggests that *Pinus* in the study area are at specific risk from this beetle in the time period of this study. This may significantly affect the distribution of the tree by being the disturbing agent which precipitates stand replacement. A suggestion of the speculative Mountain Pine Beetle range can be seen in the range suggestion for *Picea pungens*, which we have also speculated is controlled primarily by the minimum temperature.

As a management choice to maintain forest cover, trees in the forest areas at risk may be supplemented by new plantings by people. The adaptation to climate change is a change in how the trees might be chosen. Informing the forest manager what their options are for achieving their objectives, adaptation becomes a part of wise planning, not an objective unto itself.

There is a strong policy regarding the management actions that may be taken in order to maintain forest cover. The forested portions of the fringe that are Crown lands are managed largely to produce wood products. On these lands, there is a commitment from the forest company and the government to maintain a forest. The composition of that forest is defined in management objectives. The use of non-resident tree species may not be allowed, or may be allowed under specific conditions. New paradigms may need to be designed to ensure that appropriate adaptation strategies are incorporated into sustainable management practices in the future.

Loss of Forest Industry

The forest industry's existing stake in the forest fringe is as a source of softwood and hardwood fibre for pulp and lumber production. The dramatic reduction in area suitable for softwood species suggests that the forest industry may be facing a change in availability of softwood fibre. Although the utilization of hardwoods has increased dramatically in recent years, the industry still requires a significant input of softwood to make the present product mix.

The change in range that has been suggested by the results of this analysis for the softwood species represents the area presently under active forest management for fibre production. There is a significant risk that much of the softwood-dependent forest industry will be extirpated from the present forest fringe.

The pattern of change for the industry may start as an increase in costs, as regeneration costs increase because of plantation failures. As mature softwood is not expected to be at risk directly, the immediate wood supply is not directly at risk. The risk is to the future wood supply as area under softwood is disturbed and not regenerated.

A risk to the forest industry not under consideration in this study is the impact on wood supply following a presumed change in the fire regime under a climate-change scenario. Work is progressing on this issue and some information is to be expected from the forest and climate change research community.

An immediate response by the forest industry is possible. The industry might choose to increase efforts at regeneration support, or might choose to change planting practices to use species presently not found on specific sites. These responses will both increase costs, with no anticipated return until a full tree generation has passed.

Another response from the forest industry might be to advance the degree of harvest in fire-prone areas, in order to harvest mature wood before it is burned by fire. After disturbance, the area might be regenerated to a species that will do well under significantly drier conditions, such as *Pinus sylvestris*. In order to counter the increased risk of fire, the manager might arrange plantings with deciduous native species (high cost) or permit them to regenerate naturally in areas where they grow in mixes with conifers (no cost). This approach is quite interventionist, but recognizes that fire has enormous disruptive potential, far in advance of our abilities to control it. This approach has significant policy challenges, and moderate cost challenges.

Another response from the forest industry might be to make no effort to adapt, accept the change in the forest, and depend on technological advances to adapt to reduced softwood fibre, increased hardwood fibre, and possibly an increase in alternative fibre sources, such as hemp.

Economic Change for Non-Timber Products

Economic impacts outside the timber-based forest industry are expected. Boreal forest products include tourism opportunities and non-timber products such as mushrooms and medicinal plants.

Tourism opportunities might be anticipated to change as tree cover is reduced. The change to a sparse aspen parkland environment might reduce appeal to some tourists, while increasing other opportunities. A tourist seeking the classic boreal forest lake with spruce trees overhanging a dark forest pond will need to seek further north after some time. A tourist seeking snowmobiling or deer hunting may find the open forest environment acceptable. Hunting may stay the same, but with different species, as boreal animals move north with the closed boreal forest.

Non-timber forest products such as mushrooms, wreathes, and medicinal plants are not specifically threatened in the short term. Morels may increase in the short term if there is an increase in fire. As the area of closed boreal forest is reduced, the area available for such products will also reduce. If a morel is dependent on *Pinus spp.* being present on the site (Mohammed, 1999), then an introduction of alternative *Pinus* species may promote the continued presence of morels on a site.

Wreathes depend on the production of young, flexible branches, particularly on coniferous trees. As tree species change, wreath species would presumably change, too. There may be an economic consequence to this change – either a change in cost or a change in product price. Search costs for the raw materials could change, or the selling price may change with species choice. These are unknowns at this point.

Similarly, many native medicinal plants are extremely site-specific, and even modest changes in site conditions will affect their viability.

Fast-Growing Species Area Increase

The area where fast-growing species are likely to grow is anticipated to increase, although not as broadly as the large swathes suggested by the maps in Appendices 3 and 4. For example, *Populus deltoides* is anticipated to grow throughout the plains component of the study area. That broad range estimate should be tempered by the knowledge that it mainly grows naturally today in riverine ecosystems, not out on the bald prairie. It can be established in appropriate sites outside the riverine area, and seems to be limited in its northern advance by cold hardiness limits. As a species appropriate for afforestation, it may show great promise on sites with sufficiently rich soil and suitable soil water holding capacity.

The species which grow on the plains successfully can be anticipated to thrive in sites similar to those where they grow today.

Boreal Forest Management Approaches

Although we have only begun to quantify the risk to human and ecological values in the forest fringe, we can begin to describe possible responses and adaptations to these risks. Each of the suggestions we have developed is a mindset, and describes in general terms what we, as a society, can do to counter risks to values we care most about.

For each of these management mindset suggestions, objectives for the scenario are described, as are specific responses that might meet those objectives. None of these are quantified suggestions, but they represent where we might like to go. The names and general character of the first three options are taken from Henderson *et al.* (2002).

The management approaches suggested here are presented as starkly different options. This does not preclude a blending of the approaches.

Unmanaged Change

Objectives: Minimize cost of response, maximize certainty of risk before action, minimize arrogance expressed by management activities.

The Unmanaged Change scenario is an expression of a “Business as Usual” attitude. It can be characterized by specific small-scale reactions to a larger pattern. Whenever an event happens, we have confirmation of the event, and can respond to it. This approach allows a pattern of events to unfold, and when change is observed, response to change is also observed.

This scenario allows us to make sure that something really is happening before we take corrective action, but limits our ability to effectively and efficiently respond. For example, after *Pinus banksiana* no longer grows in the Nisbet forest, near the middle of our study area, it will likely take significant effort to re-establish it. A likely response is to plant another *Pinus* species, but establishment may be more diffiuclt in 2080 than in 2010.

A concern with any management response is the assumption that we are sufficiently knowledgable to effectively manage change. This charge may be leveled at any intervention strategy. An unmanaged retreat scenario is a possible response to this concern. We may accept that we have caused a problem by warming up the climate. We do not necessarily need to manipulate the ecosystem further, as we still do not know the complete ramifications of our actions.

Managed Retreat

Objectives: Maintain some type of forest on key sites we care about, act in advance of the trend of change, minimize long-term cost by early action.

The Managed Retreat scenario represents the option of accepting that change is happening, and that we want to maintain our environment in a way that maximizes some set of values, likely human values. As a rule, the high-value sites could be maintained with forest cover, and lower priority sites can be left to their own devices.

If we decide that it is important to maintain closed forest cover for tourism, the forest industry, or other human values, we have the opportunity to adapt our forest management policies towards a focus on forest maintenance in the face of a changing environment. We would need to develop a wood supply modelling strategy which includes climate change into yield estimates and fire modelling. We would need to identify key forest areas for forest maintenance intervention.

Intervention into the existing forest landscape might include specific planting activities, or irrigation activities, or moisture capture activities. Planting activities might include choosing non-resident species tolerant of the anticipated climate to complement existing species.

For example, the range prediction for *Pinus resinosa* suggests that it will be able to grow south of where *Pinus banksiana* grows, although it will be in a band that moves north as the climate changes. In open stands where *P. banksiana* is at risk now, we may be able to establish *P. resinosa* underneath, and have a forest once the existing trees die. This is a particularly attractive approach in areas with significant mistletoe problems.

By acting early in the process, we keep the costs to a minimum, when measured over the long term. Unfortunately, we also have to assume we know what to do and how to respond. If we take a longer time to respond, then there are that many more sites which need a strong response to match our objectives.

Frozen Landscape

Objectives: Maintain existing cover, under any future circumstances.

This management scenario represents the option to keep the landscape as it is today. In order to achieve this, we would need to aggressively re-plant after any disturbance, and take any action necessary to maintain those seedlings. For example, by the later part of the study term, irrigation might be necessary but impractical, in order to maintain closed boreal forest.

We do not know everything about the forest now. It is unreasonable to assume we can keep the forest exactly as it is. Boreal forest environments are continuously subject to change at a variety of scales. .

It could be possible to describe the forest in sufficient detail to make a good attempt at maintaining it in its current state. It may not be possible to fund the maintenance functions required over such a large area.

Accelerate Capture Before Loss

Objectives: Maximize economic returns in the short to medium terms, embrace climate change as inevitable.

This scenario suggests that we embrace the climate change model as valid, and act to maximize harvest activities as long as the forest is there. Once re-establishment of the boreal forest is no longer a viable option on a site, then we may as well use the wood present to produce wood products. Conversion to a different land use such as agriculture may be appropriate.

As areas in southern Saskatchewan and Alberta become too arid for maintenance of herds of animals, it may be possible to open up new agricultural areas north of Prince Albert. These areas are too cold now, but as the length of the growing season increases, perhaps the present boreal plain can be made the new breadbasket of the country.

This scenario maximizes economic returns at the risk of over-achievement of forest removal. We might initially overestimate the area no longer viable for forest renewal, resulting in a reduction of forest without cause.

This option can also be attacked for the inherent arrogance of assuming we know best, and that the inherent values of the landscape might not be represented. Instead, only a specific set of human values are in consideration.

Another argument about this management approach is the over-representation of short-term forest exploitation objectives over other human values for the forest area. It is clear that this management approach denies the interests of people who would like to see the fading boreal forest in as natural a state as possible, given the circumstances. The choice of which human values to support is likely to be a difficult political issue.

Agroforestry Management Approaches

Agroforestry is the incorporation of trees into regular farming operations, resulting in economic, social and environmental benefits. Benefits include maintenance of forested areas, and re-establishment of forest on previously cleared land (afforestation).

The results of this study suggest that a greater area will be suitable for agroforestry and afforestation using fast-growing species such as hybrid poplars. This may be observed in the range suggestion for Plains cottonwood (*Populus deltoides*), a close relative of the many hybrid poplar cultivars.

Hybrid poplar range is constrained by frost limitations and moisture. These trees can be planted to maintain forest cover, increase economic viability of marginal land, and provide carbon sequestration. By the end of the study period, the entire boreal plain area is anticipated to be a viable area for hybrid poplars.Our results do not suggest a reduction in the range of Plains cottonwood at the southern end of the study area. There may be a good outlook for agroforestry activities using hybrid poplars throughout existing agricultural lands.

Limitations of the Modelling Approach

There are some caveats to the modelling approach used in this report. The climate portion can be criticized on the basis of the number of GCM's and scenarios used and on the use of uncorrected station data. The range predictions can be criticized for using overly broad training data.

Climate model uses a single GCM

This study uses a single GCM (CGCM1), and a single scenario (GHG+A1) to predict a set of impacts. This is not sufficient to give the range of impacts under the range of scenarios being examined by the global climate change community. This particular scenario is not an extreme case, but represents a scenario in the middle of the pack. It would be ideal to include a range of scenarios in order to develop a range of equally likely model outputs, as is done in the GCMs.

The reason that this study follows a single scenario is driven by data availability. The plan for this project was to use the data available at the CICS scenarios website. At the beginning of the modelling effort, the CGCM1 data was the only one available in a suitable format. A variety of scenarios could be made available in SDSM format in the future.

The impact on the results of the choice to use a single scenario can be mitigated by critical evaluation of model outputs. We have presented maps with a moderate prediction of the range change. For scenarios where the GCM suggests a higher level of change, we might expect a greater degree of range change, and vice versa. The amount of range change suggested by this study is a single estimate, not a bounded range with probabilities assigned.

The issues caused by using a single GCM scenario are somewhat mitigated by understanding where the GCM scenario falls in relation to the constellation of scenarios outlined by the IPCC and implemented by the various modelling groups who implement GCMs. The CGCM1 GHG+A1 experiment suggests a scenario where the global temperature increase is warmer than many of the other GCM experiments. It is generally in the middle of the group for precipitation increase suggestions.

From the placement of the experiment in relation to other experiments, we could suggest that the range change indicated by this study is near the 70th percentile of severity among the various GCM experiments. The temperature change is close to the 70th , while the precipitation increase is around the middle.

Range may not represent growing areas well

The range of the species found on the prairie, like Plains cottonwood (*Populus deltoides*) is probably an overestimate of the conditions in which these species grow naturally. These trees are known to grow primarily in riverine ecosystems, with rich alluvial soils and occasional flood events. However, they do not necessarily establish from seed in open plains conditions.

The training ranges for these species recognize that specific conditions must be available for the growth of the organisms. Not all of the area is appropriate for the tree, but when conditions are acceptable the species grows. This assumption must be carried forward into the range suggestions. Plains cottonwood will probably grow best in rich sites wherever it is. When we use the tree as a crop, we should expect to have to adjust or choose its environment appropriately. Success to date with related hybrid poplars on agricultural land suggests that the broader range scenario is appropriate, as long as we either plant the cuttings, or the site is a riverine ecosystem.

There is some discussion in the literature concerning the utility of models like the one used in this study for predicting species range (Pearson and Dawson, 2003). The limitations of this model include lack of considerations of factors such as biotic interactions, evolutionary change, and dispersal ability. Overall, we know that we are still incapable of fully understanding complex natural systems.

The major defense of this study in the face of these potential shortcomings and limitations is that we are considering the species' ability to grow once placed on site, which implies either natural or human dispersal. If we consider human dispersal, then we must assume that appropriate provenances will be chosen for a particular species, and that we will do our best for the plant when we place it in the ground. Our actions may include reduction of competition, irrigation, and other forest management choices. These actions are dependent on our choice of management approach.

Uncorrected station data

Several stations in this study seem to be “a little warm” or “a little wet”. This can be observed on the climate model outputs as an apparent “hill” in the temperature surface. Saskatoon, for example, is consistently warmer by at least a degree, when it is compared to adjacent stations(Appendix 1).

The reasons for the deviation from the surrounding stations is probably derived from inconsistent location of the weather stations. Typically, the weather station is at the airport. In most small communities on a river, it is near the river. In Saskatoon, it is not near the river. This may be the cause of the deviation. Another possibility is mis-calibrated instruments.

An algorithm could be developed to manage corrections to the weather predictions, which would facilitate comparisons between stations, and therefore interpolations between stations. One way to develop this would be to find a community with multiple stations and investigate the relationships between the stations’ data. This is a complex approach to an issue that may defy easy resolution, and deviates from using the station data to add information to GCM predictions.

Modelling Lessons Learned

In preparing this model and developing these results, two major lessons were learned. The level of manual direction of the computer was substantial, and we found some difficulties in presenting clear results.

Batch Mode Analysis

The first lesson we learned was that downsampling using the Statistical Down Sampling Model (SDSM) was a slow and difficult process to complete. It was a substantial effort to apply downsampling to even a single station. This was acceptable, as we had to go through the process to develop procedures and understanding. Once we had developed a procedure and started to downsample the other 26 stations, it was tedious and error-prone. We developed coping mechanisms to prevent errors creeping in, but the fact remains that a human makes a very poor batch control operator. It took between 30 and 45 minutes per station to perform the procedure.

The net result is that for multiple station downsampling, a batch mode would be very useful. SDSM as it stands does not have this. There is a model, developed by Benestad (2002) which provides a command-line tool for performing the downsampling. He was able to downsample 115 locations under 48 scenarios each to provide an ensemble of extrapolations. If this work had been performed with SDSM, it would have taken well over a year of operator time to complete.

Batch mode downsampling is required to perform substantially multi-station, multi-scenario analysis of this type.

Geographic Extents Limitation

The study area is specifically limited to an approximate rectangle 4° of latitude by 8° longitude. This area contains a range of densities of weather stations. In the traditionally agricultural area in the south, there are good historical weather records, with few gaps in the record. In the northern parts of the study area, there are few stations, often with substantial gaps in the record. Because of this lack of good weather data in the north, interpolation artifacts creep into the predictions. The northeast and northwest corners of the climate predictions seem warmer than the centre of the northern study area due to this uneven coverage and associated interpolation artifacts.

To achieve better interpolations, more weather stations outside the study area should be used. Some were used for this study, but more were obviously needed. There is already a lack of weather data in the area surrounding our study area, so etting more historical data may be an unrealistic option.

Conclusion

This work suggests that there is good reason for concern about the possible retreat of the boreal forest. The suggestion from this climate model is that natural regeneration of the boreal forest is unlikely to occur in the bulk of the study area by 2080. That is, the model suggests a retreat to the north of the primary economically valuable tree species.

The corollary of this retreat is the reduction of opportunity for forest industries, and a change in tourism and other industry environments. If we are to adapt to the situation, we will have to account for the risks associated with climate change: Environmental change leading to economic change leading to social change.

Our approach to adaptation could be a change in behavior, in which case we will be challenged to represent human values in an inclusive way. The choices we make about the particular values to represent in meeting the challenges of a changing environment will shape the environment for which we are increasingly responsible.

References

Agriculture Canada, 2000. Soil Landscapes of Canada. Version 2.2 http://sis.agr.gc.ca/cansis/nsdb/slc/intro.html.

Benestad, R.E. 2002. Empirically downscaled temperature scenarios for northern europe based on a multi-model ensemble. Clim. Res. 21: 105-125.

CICS, 2003a. CICS - Canadian institute for climate studies. http://www.cics.uvic.ca/.

CICS, 2003b. SDSM Background. http://www.cics.uvic.ca/scenarios/index.cgi?More_Info-SDSM_Background

Environment Canada. 2001. 2001 CDCD West CD. Environment Canada. http://ftp.cmc.ec.gc.ca/cd2001west.zip.

ESRI, 2003. ArcGIS, version 8.2. ESRI, Inc., http://www.esri.com.

Gedalof, Z., 2004. Incorporating climate information into management strategies for the mountain pine beetle in central british columbia, Canada. http://www.cses.washington.edu/cig/outreach/classes/585/files/ZG_whitepaper.pdf

Henderson, N., E. Hogg, E. Barrow, B. Dolter. 2002. Climate Change Impacts on the Island Forests of the Great Plains and the Implications for Nature Conservation Policy: The Outlook for Sweet Grass Hills (Montana), Cypress Hills (Alberta-Saskatchewan), Moose Mountain (Saskatchewan), Spruce Woods (Manitoba) and Turtle Mountain (Manitoba-North Dakota). Prairie Adaptation Research Collborative: Regina. Available at http://ims.parc.uregina.ca/publications/norman.pdf.

Hengeveld, H. G. 2000. Projections for Canada's climate future. Minister of Public Works and Government Services, Canada. http://www.cccma.bc.ec.gc.ca/data/cgcm1/cgcm1_ghga.shtml

Hogg, E.H. 1994. Climate and the southern limit of the western Canadian boreal forest. Canadian Journal of Forest Research 24: 1835-1845.

Hogg, E.H. 1997. Temporal scaling of moisture and the forest-grassland boundary in western Canada. Agricultural and Forest Meteorology 84: 115-122.

Hogg, E.H., and Hurdle, P.A.1995. The aspen parkland in western Canada: A dry-climate analogue for the future boreal forest? Water, Air, and Soil Pollution 82: 391-400.

Hogg, E.H., Brandt, J.P, and Kochtubajda, B. 2002. Growth and dieback of aspen forests in northwestern Alberta, Canada, in relation to climate and insects. Can. J. For. Res. 32: 823-832.

Hutchinson, M.F. 2002. ANUSPLIN, version 4.2. Software package available at http://cres.anu.edu.au/outputs/anusplin.html. Checked Jan 31, 2003.

Ihaka, R., and R. Gentleman. 1996. R: a language for data analysis and graphics. Journal of Computational and Graphical Statistics, 5, pp 299-314. Information available from http://www.r-project.org.

Leatherman, D.A., 2004. Mountain pine beetle. Colorado State University Cooperative Externsion fact sheet no. 5.528. http://www.ext.colostate.edu/pubs/insect/05528.html

Mohammed, 1999. Non-timber forest products in Ontario: An Overview. Queen's Printer for Ontario: Sault Ste Marie. Forest Research Information Paper No. 145.

Natural Resources Canada, 2002. Plant Hardiness Data. http://g4.glfc.cfs.nrcan.gc.ca/ph_main.pl.

Pearson, R.G. and Dawson, T.P., 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography 12, 361-371.

Prasad, A. M. and L. R. Iverson. 1999. A Climate Change Atlas for 80 Forest Tree Species of the Eastern United States [database]. http://www.fs.fed.us/ne/delaware/atlas/index.html, Northeastern Research Station, USDA Forest Service, Delaware, Ohio.

Wilby, R.L., Dawson, C.W. and Barrow, E.M. (2002): SDSM - a decision support tool for the assessment of regional climate change impacts. Environmental Modelling Software, 17, 145-157.

Appendix 1 - Climate Station Model Output

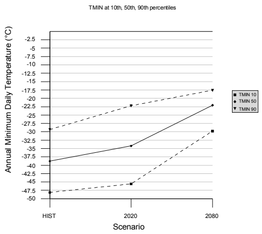
This appendix contains the diagrams of individual station output. Each station occupies an individual page, and is considered entirely independently from each other. For the interpolations of these results to the full study area, please see the maps in Appendix 2.

Data presented for each weather station represents the modelled results for the historical period (HIST), modelled results for the 2020 period, and modelled results for the 2080 persiod. These are the results shown in the interpolations, and are the source for the climate component of the range suggestions.

Alsask

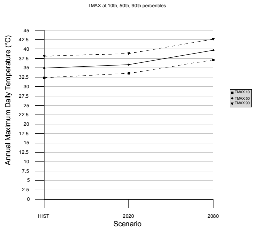
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-48.13	-45.57	-29.8
TMIN 50	-38.79	-34.23	-22.06
TMIN 90	-29.35	-22.22	-17.59



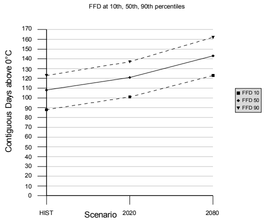
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	32.37	33.53	37.15
TMAX 50	34.96	35.84	39.71
TMAX 90	38.09	38.79	42.61



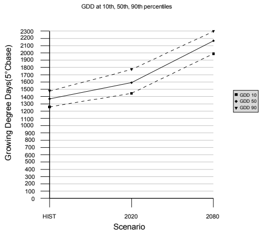
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	88	101	123
FFD 50	108	121	143
FFD 90	123	137	162



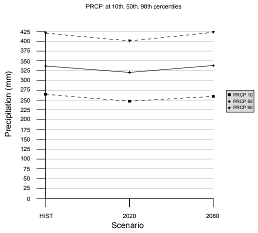
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1258.19	1444.72	1988.96
GDD 50	1369.71	1590.8	2166.75
GDD 90	1475.07	1771.63	2296.37



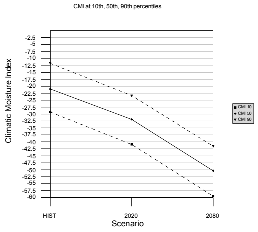
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	264.65	247.1	259.51
PRCP 50	336.74	320.42	337.78
PRCP 90	420.38	400.58	422.45



CMI at 10th, 50th, and 90th percentiles

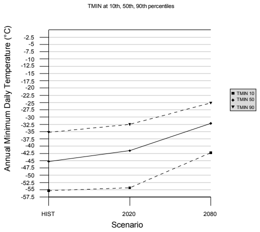
	HIST	2020	2080
CMI 10	-29.26	-40.93	-59.52
CMI 50	-21	-31.9	-50.37
CMI 90	-11.76	-23.36	-41.58



Butte St. Pierre

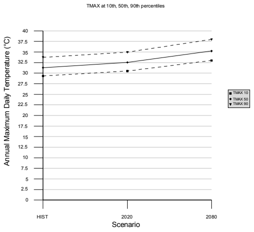
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-55.32	-54.34	-42.27
TMIN 50	-45.24	-41.57	-32.18
TMIN 90	-35.25	-32.52	-25.16



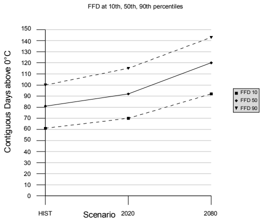
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	29.33	30.5	33
TMAX 50	31.31	32.55	35.23
TMAX 90	33.72	34.96	37.98



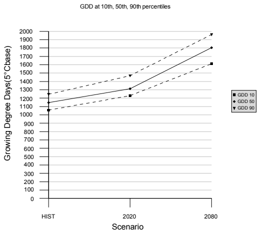
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	61	70	92
FFD 50	81	92	120
FFD 90	100	115	143



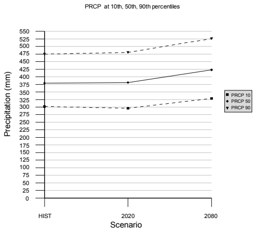
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1056.56	1229.06	1612.99
GDD 50	1146.72	1312.97	1804.43
GDD 90	1245.51	1468.64	1961.12



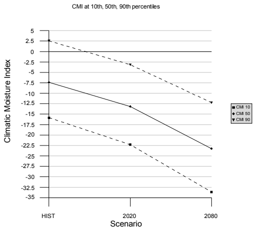
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	302	296.06	328.61
PRCP 50	378.79	381.13	423.02
PRCP 90	474.49	480.15	525.99



CMI at 10th, 50th, and 90th percentiles

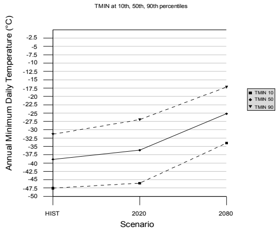
	HIST	2020	2080
CMI 10	-15.86	-22.3	-33.64
CMI 50	-7.38	-13.15	-23.25
CMI 90	2.54	-3.16	-12.23



Cold Lake

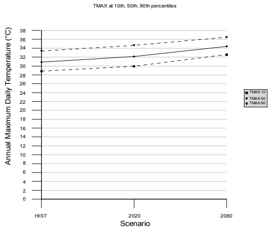
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-47.52	-46.05	-34.02
TMIN 50	-38.88	-36.17	-25.21
TMIN 90	-31.37	-26.98	-17.2



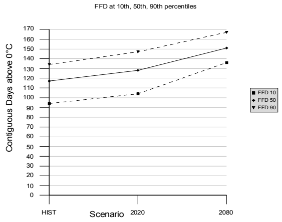
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	28.82	29.93	32.57
TMAX 50	30.87	32.12	34.44
TMAX 90	33.36	34.64	36.47



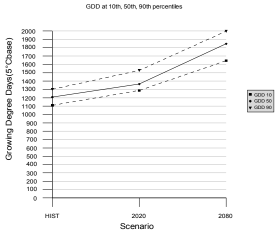
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	94	104	136
FFD 50	117	128	151
FFD 90	134	147	167



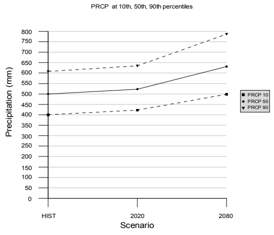
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1109.57	1288.22	1644.35
GDD 50	1209.21	1364.45	1846.57
GDD 90	1302.38	1527.96	1998.23



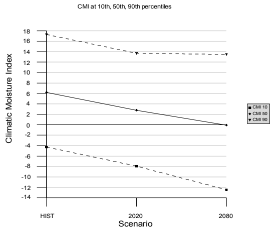
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	400.24	422.46	497.96
PRCP 50	500.05	523.05	631.49
PRCP 90	607.91	634.51	786.42



CMI at 10th, 50th, and 90th percentiles

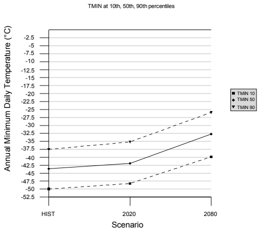
	HIST	2020	2080
CMI 10	-4.28	-7.95	-12.46
CMI 50	6.21	2.78	-0.08
CMI 90	17.29	13.69	13.48



Cumberland House

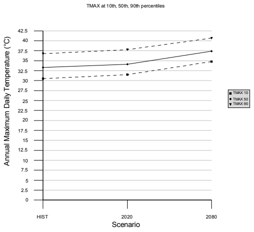
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-50.01	-48.26	-39.9
TMIN 50	-43.65	-41.92	-32.72
TMIN 90	-37.54	-35.2	-25.94



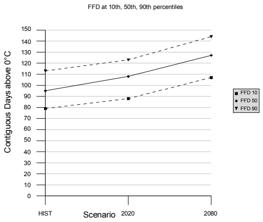
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	30.49	31.47	34.79
TMAX 50	33.28	34.08	37.38
TMAX 90	36.76	37.77	40.68



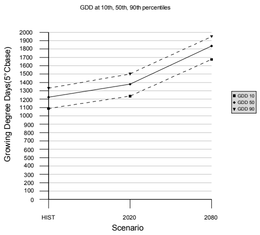
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	79	88	107
FFD 50	95	108	127
FFD 90	113	123	144



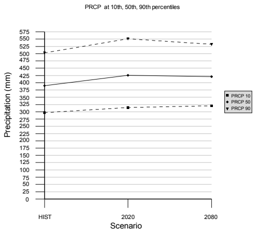
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1087.99	1236.02	1675.46
GDD 50	1224.49	1378.17	1836.23
GDD 90	1330.34	1501.72	1949.19



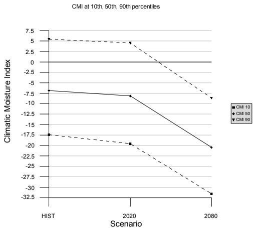
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	297.05	314.69	320.55
PRCP 50	389.77	425.77	420.84
PRCP 90	502.73	551.33	532.1



CMI at 10th, 50th, and 90th percentiles

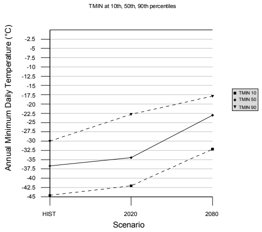
	HIST	2020	2080
CMI 10	-17.4	-19.59	-31.56
CMI 50	-6.87	-8.17	-20.47
CMI 90	5.44	4.55	-8.65



Duval

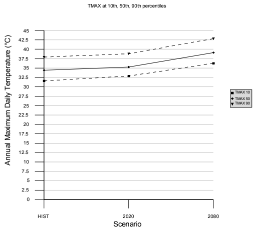
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-44.61	-42.05	-32.17
TMIN 50	-36.7	-34.45	-23.03
TMIN 90	-30.01	-22.79	-17.89



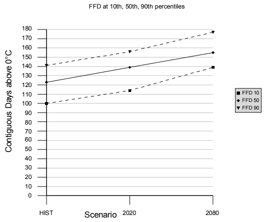
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	31.58	32.88	36.29
TMAX 50	34.44	35.31	39.14
TMAX 90	37.93	38.81	42.84



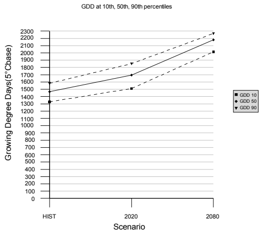
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	100	114	139
FFD 50	123	139	155
FFD 90	141	156	177



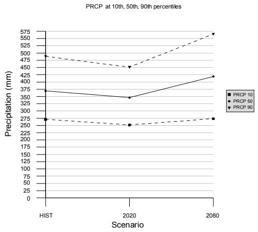
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1327.66	1510.82	2014.83
GDD 50	1466.45	1695.67	2179.59
GDD 90	1581.95	1852.5	2266.95



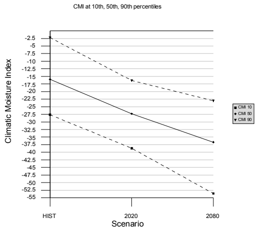
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	271.06	251.54	273.31
PRCP 50	369.32	345.73	419.19
PRCP 90	488.24	450.95	565.63



CMI at 10th, 50th, and 90th percentiles

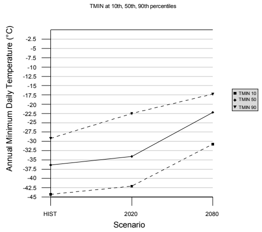
	HIST	2020	2080
CMI 10	-27.64	-38.69	-53.6
CMI 50	-15.99	-27.32	-36.69
CMI 90	-2.23	-16.36	-23.06



Elbow

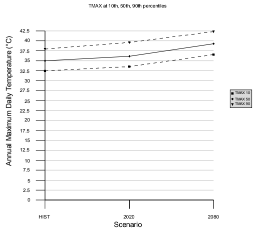
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-44.3	-42.1	-30.77
TMIN 50	-36.38	-34.09	-22.2
TMIN 90	-29.2	-22.51	-17.29



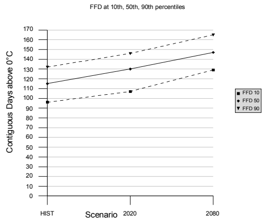
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	32.45	33.51	36.54
TMAX 50	34.96	36.1	39.24
TMAX 90	37.95	39.59	42.32



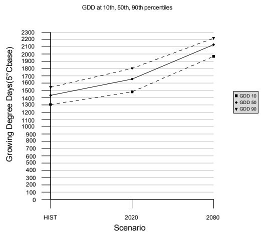
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	96	107	129
FFD 50	115	130	147
FFD 90	132	146	165



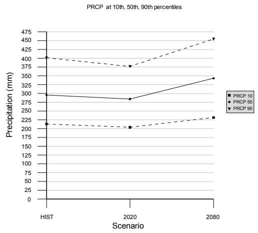
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1305.66	1480.02	1968.9
GDD 50	1432.87	1656.75	2129.26
GDD 90	1544.11	1802.67	2219.38



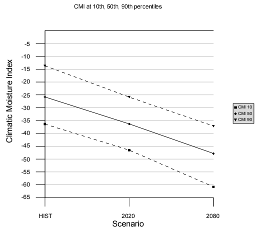
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	213.02	203.73	231.61
PRCP 50	295.33	284.27	342.89
PRCP 90	401.51	376.69	454.86



CMI at 10th, 50th, and 90th percentiles

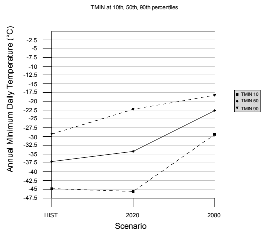
	HIST	2020	2080
CMI 10	-36.38	-46.49	-60.78
CMI 50	-25.82	-36.32	-47.86
CMI 90	-13.71	-25.89	-37.14



Eston

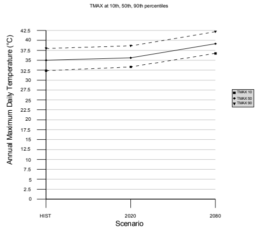
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-44.85	-45.63	-29.43
TMIN 50	-37.1	-34.24	-22.61
TMIN 90	-29.32	-22.27	-18.27



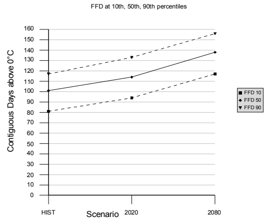
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	32.36	33.3	36.72
TMAX 50	34.98	35.61	39.19
TMAX 90	37.94	38.63	42.15



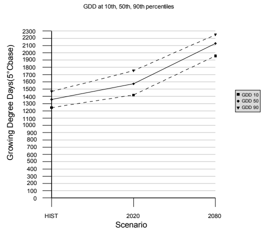
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	81	94	117
FFD 50	101	114	138
FFD 90	117	133	156



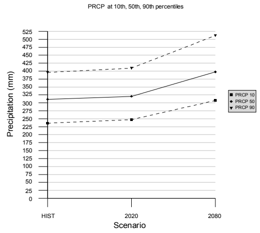
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1245.57	1418.71	1957.02
GDD 50	1358.58	1572.33	2128.36
GDD 90	1466.77	1752.8	2248.46



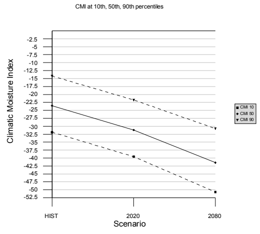
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	236.11	247.21	307.64
PRCP 50	311.46	320.7	397.72
PRCP 90	395.74	409.1	511.96



CMI at 10th, 50th, and 90th percentiles

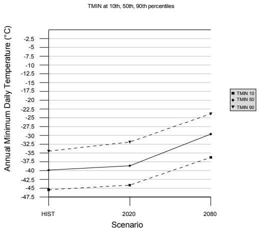
	HIST	2020	2080
CMI 10	-31.88	-39.58	-50.71
CMI 50	-23.52	-31.18	-41.45
CMI 90	-14.23	-21.74	-30.74



Flin Flon

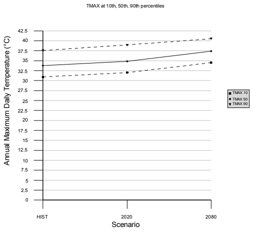
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-45.45	-44.14	-36.25
TMIN 50	-39.87	-38.6	-29.6
TMIN 90	-34.45	-31.88	-23.85



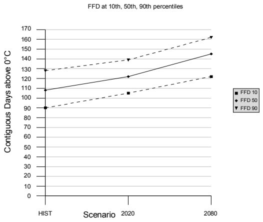
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	30.91	32	34.51
TMAX 50	33.76	34.85	37.41
TMAX 90	37.57	38.97	40.51



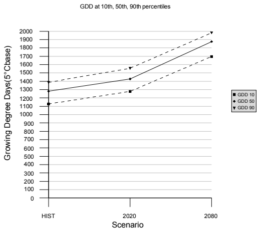
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	90	105	122
FFD 50	108	122	145
FFD 90	128	139	162



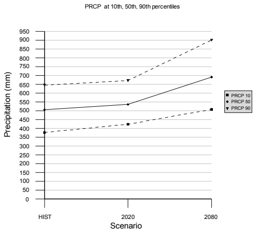
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1127.8	1278.21	1696.43
GDD 50	1281.2	1428.17	1875.51
GDD 90	1386.84	1555.86	1981.58



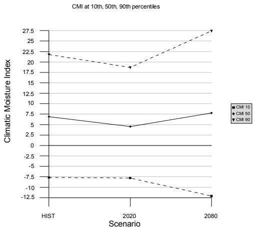
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	376.57	423.26	507.58
PRCP 50	506.11	535.71	691.36
PRCP 90	645.11	671.35	901.21



CMI at 10th, 50th, and 90th percentiles

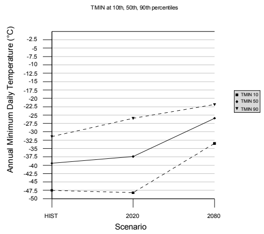
	HIST	2020	2080
CMI 10	-7.67	-7.81	-12.1
CMI 50	6.88	4.54	7.78
CMI 90	21.75	18.7	27.42



Harris

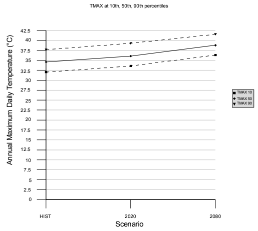
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-47.52	-48.2	-33.47
TMIN 50	-39.43	-37.39	-25.96
TMIN 90	-31.44	-25.99	-21.84



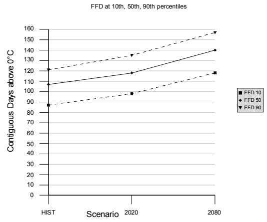
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	32.04	33.57	36.33
TMAX 50	34.58	36.1	38.79
TMAX 90	37.67	39.28	41.56



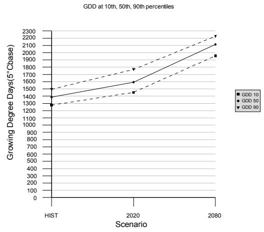
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	87	98	118
FFD 50	107	118	140
FFD 90	121	135	157



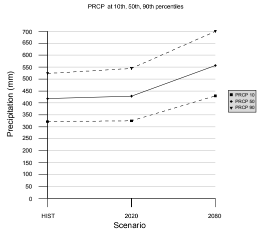
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1275.76	1452.15	1956.03
GDD 50	1387.63	1592.77	2113.81
GDD 90	1495.33	1768.05	2226.04



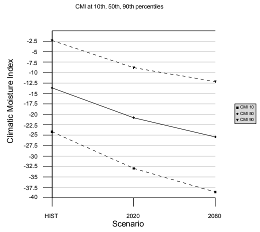
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	321.6	324.88	429.49
PRCP 50	417.81	428.45	557.01
PRCP 90	523.18	544.35	699.8



CMI at 10th, 50th, and 90th percentiles

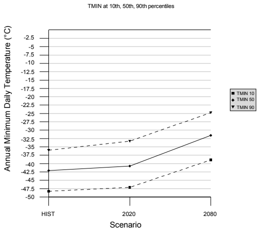
	HIST	2020	2080
CMI 10	-24.18	-32.98	-38.63
CMI 50	-13.68	-20.82	-25.41
CMI 90	-2.31	-8.83	-12.16



Hudson Bay

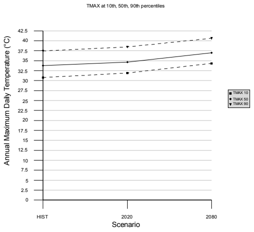
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-48.3	-47.13	-38.91
TMIN 50	-42.06	-40.76	-31.55
TMIN 90	-36.01	-33.29	-24.76



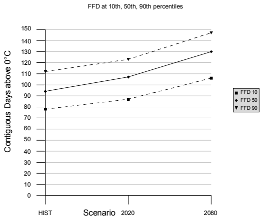
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	30.78	31.89	34.32
TMAX 50	33.78	34.67	37
TMAX 90	37.45	38.45	40.64



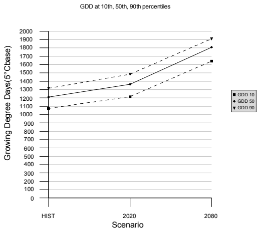
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	78	87	106
FFD 50	94	107	130
FFD 90	112	123	147



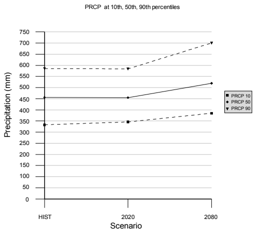
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1073.58	1215.49	1641.38
GDD 50	1211.01	1363.5	1808.89
GDD 90	1315.97	1483.96	1910.04



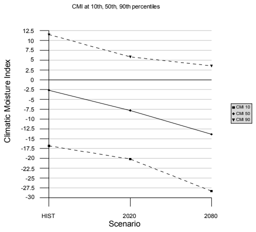
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	332.72	345.57	384.8
PRCP 50	455.43	455.01	519.49
PRCP 90	585.46	583.64	700.03



CMI at 10th, 50th, and 90th percentiles

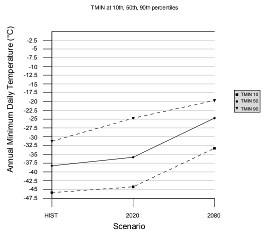
	HIST	2020	2080
CMI 10	-16.84	-20.19	-28.33
CMI 50	-2.64	-7.81	-13.89
CMI 90	11.48	5.81	3.53



Kelliher

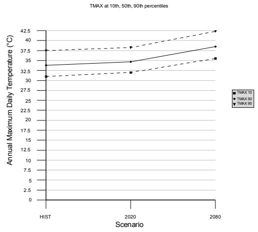
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-45.9	-44.27	-33.29
TMIN 50	-38.24	-35.85	-24.67
TMIN 90	-31.29	-24.74	-19.67



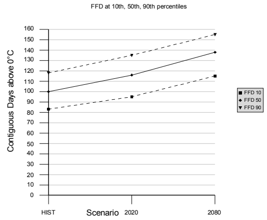
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	30.96	32.01	35.5
TMAX 50	33.82	34.69	38.52
TMAX 90	37.49	38.25	42.31



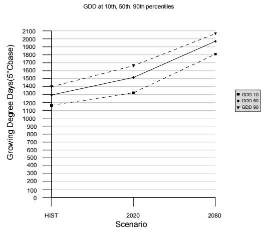
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	83	95	115
FFD 50	100	116	138
FFD 90	118	135	155



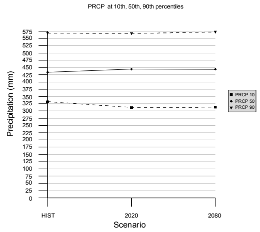
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1162.07	1320.28	1808.58
GDD 50	1294.74	1514.94	1968.71
GDD 90	1397.94	1661.26	2065.84



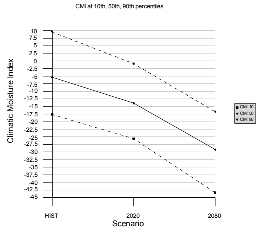
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	332.19	311.86	312.78
PRCP 50	433.73	444.21	444.17
PRCP 90	568.39	567.44	572.37



CMI at 10th, 50th, and 90th percentiles

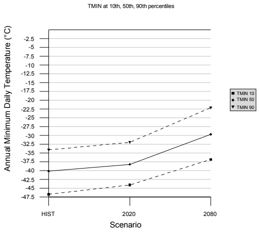
	HIST	2020	2080
CMI 10	-17.66	-25.62	-43.39
CMI 50	-5.35	-13.91	-29.22
CMI 90	9.52	-0.89	-16.76



Kuroki

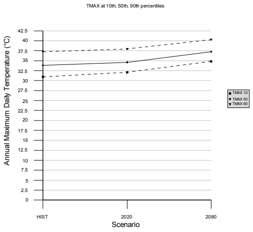
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-46.74	-44.1	-36.84
TMIN 50	-40.15	-38.22	-29.67
TMIN 90	-34.1	-31.97	-22.14



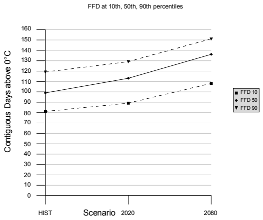
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	30.94	32.1	34.85
TMAX 50	33.84	34.61	37.25
TMAX 90	37.24	37.94	40.3



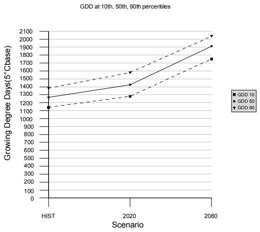
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	81	89	108
FFD 50	99	113	136
FFD 90	119	129	151



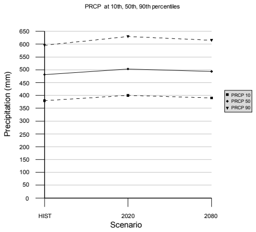
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1141.47	1280.4	1749.44
GDD 50	1267.66	1426.61	1912.31
GDD 90	1382.73	1578.01	2036.78



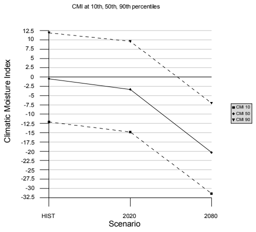
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	379.1	400.31	390.3
PRCP 50	481.63	503.39	493.72
PRCP 90	595.31	629.54	615.09



CMI at 10th, 50th, and 90th percentiles

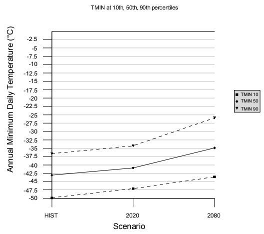
	HIST	2020	2080
CMI 10	-12.12	-14.84	-31.4
CMI 50	-0.48	-3.33	-20.34
CMI 90	11.89	9.63	-7.01



La Ronge

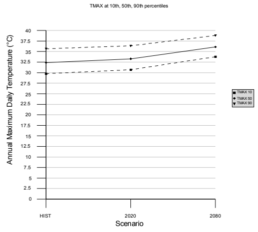
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-49.89	-47.11	-43.61
TMIN 50	-43.08	-40.92	-34.9
TMIN 90	-36.66	-34.31	-25.93



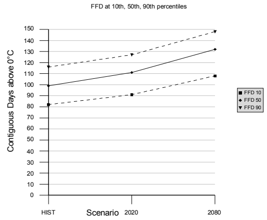
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	29.73	30.69	33.78
TMAX 50	32.36	33.28	36.1
TMAX 90	35.64	36.36	38.81



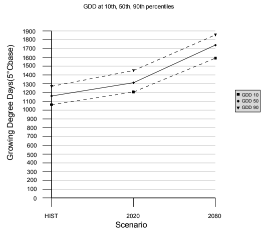
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	82	91	108
FFD 50	99	111	132
FFD 90	116	127	148



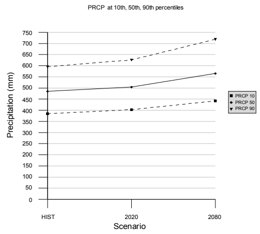
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1061.36	1206.33	1591.3
GDD 50	1161.45	1311.65	1739.34
GDD 90	1270.53	1449.82	1855.81



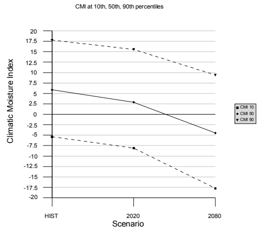
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	384.3	402.51	442.12
PRCP 50	484.63	503.74	565.21
PRCP 90	595.75	625.98	718.89



CMI at 10th, 50th, and 90th percentiles

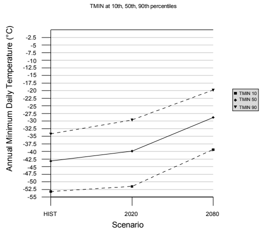
	HIST	2020	2080
CMI 10	-5.39	-8.11	-17.76
CMI 50	5.87	2.89	-4.5
CMI 90	17.77	15.55	9.42



Loon Lake

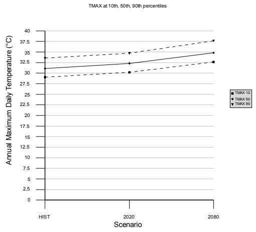
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-53.2	-51.52	-39.4
TMIN 50	-43.17	-39.9	-28.8
TMIN 90	-34.25	-29.63	-19.79



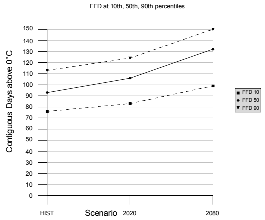
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	29.05	30.19	32.65
TMAX 50	31.1	32.32	34.84
TMAX 90	33.53	34.72	37.63



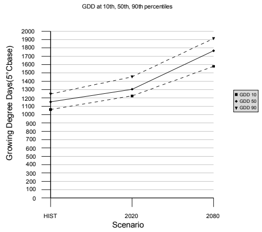
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	76	83	99
FFD 50	93	106	132
FFD 90	113	124	150



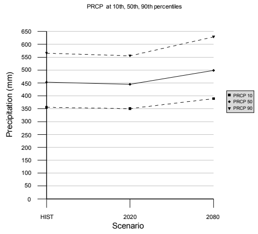
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1061.22	1224.56	1579.5
GDD 50	1152.14	1304.89	1765.8
GDD 90	1247	1452.6	1913.33



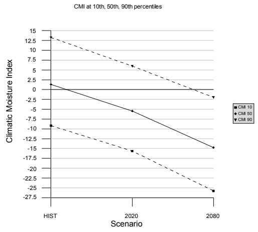
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	355.52	350.15	389.24
PRCP 50	453.26	444.71	498.91
PRCP 90	565.78	555.13	628.88



CMI at 10th, 50th, and 90th percentiles

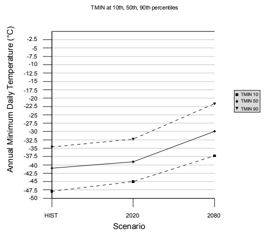
	HIST	2020	2080
CMI 10	-9.17	-15.64	-25.77
CMI 50	1.32	-5.44	-14.74
CMI 90	13.26	5.96	-1.97



Melfort

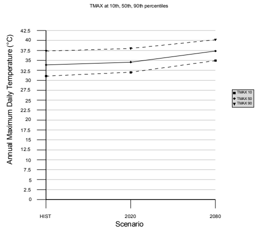
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-47.92	-45	-37.3
TMIN 50	-40.95	-39.1	-29.93
TMIN 90	-34.64	-32.31	-21.7



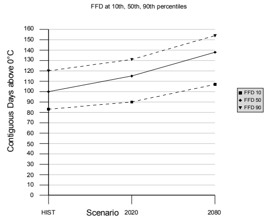
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	31.03	32.01	34.93
TMAX 50	33.83	34.56	37.35
TMAX 90	37.32	37.98	40.18



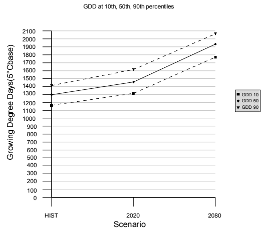
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	83	90	107
FFD 50	100	115	138
FFD 90	120	131	154



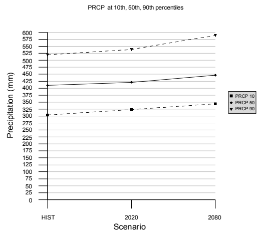
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1162.81	1313.22	1770.03
GDD 50	1296.89	1456.11	1934.65
GDD 90	1411.96	1613.71	2063.89



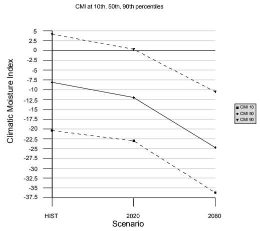
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	303.64	322.94	344.04
PRCP 50	409.95	421.16	446.76
PRCP 90	519.73	538.48	589.2



CMI at 10th, 50th, and 90th percentiles

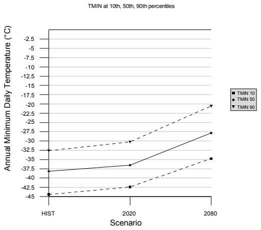
	HIST	2020	2080
CMI 10	-20.4	-23.02	-36.22
CMI 50	-8.11	-12	-24.71
CMI 90	4.13	0.3	-10.52



Muenster

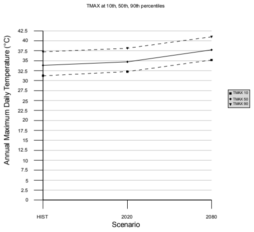
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-44.44	-42.41	-34.76
TMIN 50	-38.14	-36.53	-27.86
TMIN 90	-32.63	-30.25	-20.57



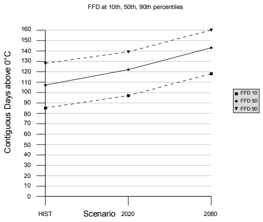
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	31.21	32.24	35.17
TMAX 50	33.84	34.73	37.71
TMAX 90	37.23	38.13	41.01



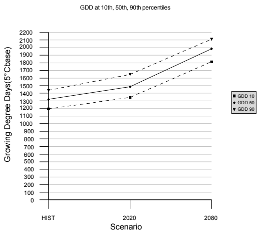
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	85	97	118
FFD 50	107	122	143
FFD 90	128	139	160



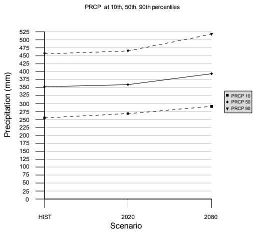
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1194.44	1344.8	1814.97
GDD 50	1319.92	1486.49	1984.87
GDD 90	1439.39	1647.16	2111.76



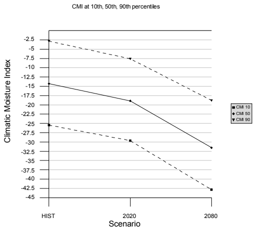
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	254.73	268.21	290.71
PRCP 50	352.65	359.31	393.65
PRCP 90	455.8	465.18	517.72



CMI at 10th, 50th, and 90th percentiles

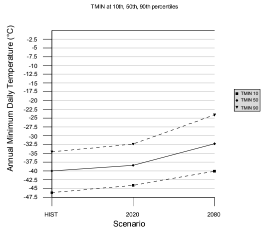
	HIST	2020	2080
CMI 10	-25.48	-29.64	-42.84
CMI 50	-14.31	-18.92	-31.56
CMI 90	-2.85	-7.59	-18.79



Nipawin

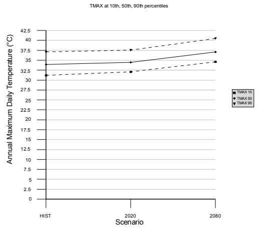
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-46.18	-44.09	-40.1
TMIN 50	-40.02	-38.4	-32.28
TMIN 90	-34.58	-32.37	-24.06



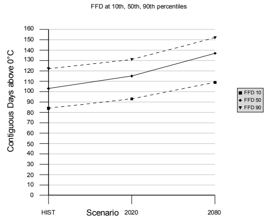
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	31.19	32.06	34.59
TMAX 50	33.93	34.49	37.09
TMAX 90	37.09	37.55	40.48



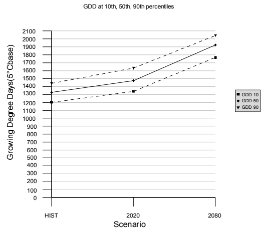
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	84	93	109
FFD 50	103	115	137
FFD 90	122	131	152



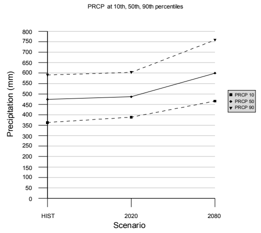
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1200.94	1338.55	1766.06
GDD 50	1325.95	1474.06	1924.47
GDD 90	1439.67	1632.1	2042.35



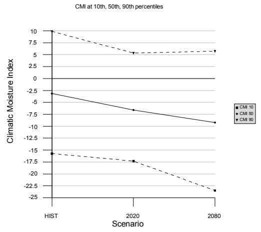
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	363.2	388.55	465.92
PRCP 50	473.75	486.56	599.84
PRCP 90	590.54	603.05	758.6



CMI at 10th, 50th, and 90th percentiles

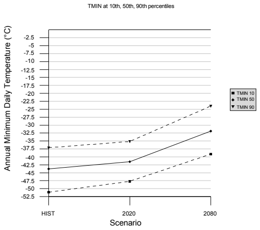
	HIST	2020	2080
CMI 10	-15.73	-17.32	-23.48
CMI 50	-3.15	-6.6	-9.23
CMI 90	9.87	5.34	5.73



Prince Albert

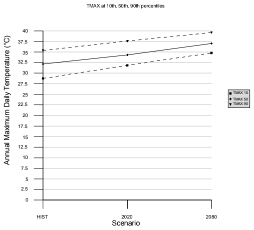
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-51.12	-47.7	-39.15
TMIN 50	-43.77	-41.54	-31.9
TMIN 90	-37.11	-35.16	-24.03



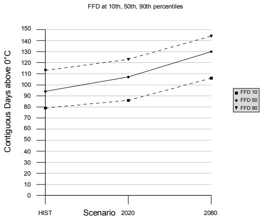
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	28.74	31.86	34.78
TMAX 50	32.18	34.29	37.03
TMAX 90	35.36	37.58	39.6



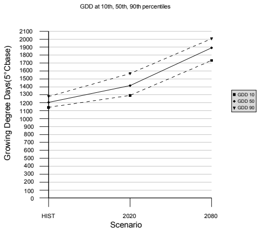
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	79	86	106
FFD 50	94	107	130
FFD 90	113	123	144



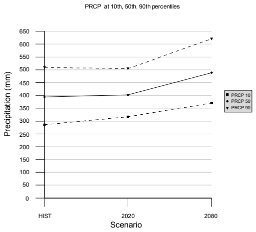
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1141.46	1291.66	1732.21
GDD 50	1204.74	1415.54	1890.95
GDD 90	1277.36	1566.7	2006.18



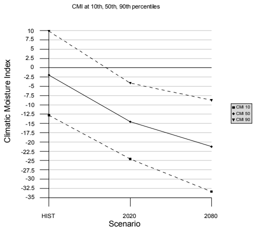
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	285.48	316.78	370.59
PRCP 50	394.23	401.92	488.89
PRCP 90	508.92	504.41	620.83



CMI at 10th, 50th, and 90th percentiles

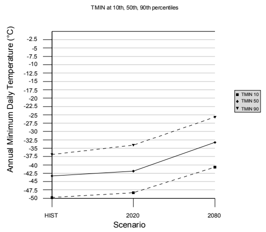
	HIST	2020	2080
CMI 10	-12.81	-24.59	-33.38
CMI 50	-1.96	-14.56	-21.27
CMI 90	9.85	-4.16	-8.77



Pelly

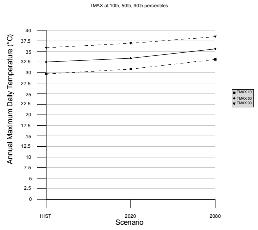
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-49.76	-48.35	-40.69
TMIN 50	-43.3	-41.87	-33.27
TMIN 90	-36.91	-34.09	-25.7



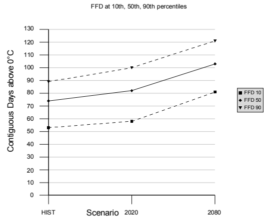
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	29.67	30.81	33.1
TMAX 50	32.47	33.38	35.61
TMAX 90	35.86	36.91	38.47



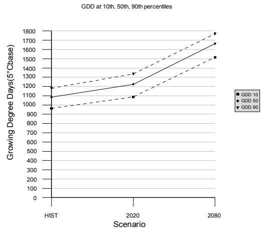
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	53	58	81
FFD 50	74	82	103
FFD 90	89	100	121



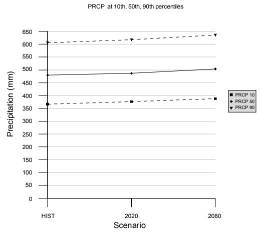
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	963.02	1087.46	1515.45
GDD 50	1084.07	1224.34	1662.99
GDD 90	1180.91	1335.43	1769.49



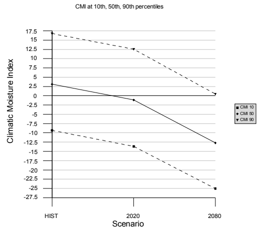
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	366.34	376.07	387.99
PRCP 50	479.31	486.58	503.92
PRCP 90	605.31	617.34	635.66



CMI at 10th, 50th, and 90th percentiles

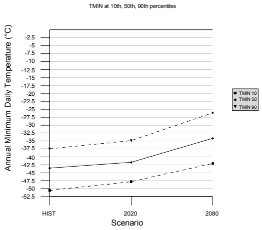
	HIST	2020	2080
CMI 10	-9.34	-13.66	-25.04
CMI 50	3.1	-1.14	-12.71
CMI 90	16.76	12.53	0.46



Porcupine Plain

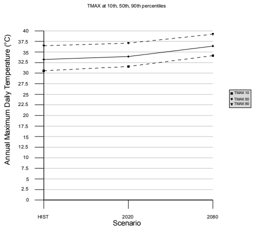
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-50.58	-47.8	-42.06
TMIN 50	-43.56	-41.71	-34.17
TMIN 90	-37.47	-34.89	-26.15



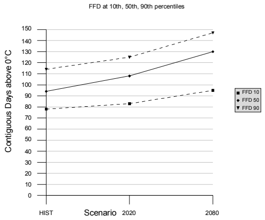
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	30.56	31.57	34.14
TMAX 50	33.22	33.92	36.42
TMAX 90	36.47	37.08	39.19



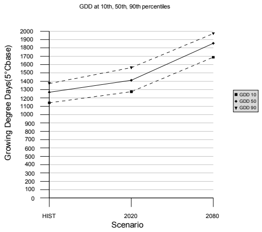
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	78	83	95
FFD 50	94	108	130
FFD 90	114	125	147



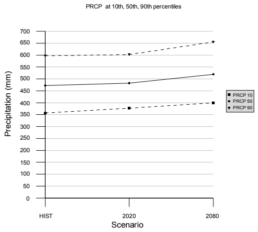
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1141.32	1274.18	1687.63
GDD 50	1269.31	1411.46	1855.57
GDD 90	1372.65	1562.41	1971.83



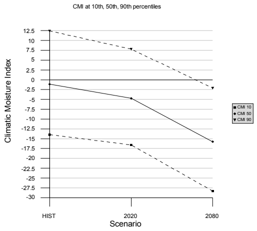
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	356.8	377.02	399.46
PRCP 50	472.18	482.35	519.87
PRCP 90	597.06	602.27	655.31



CMI at 10th, 50th, and 90th percentiles

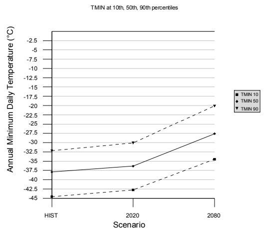
	HIST	2020	2080
CMI 10	-13.98	-16.59	-28.34
CMI 50	-1.15	-4.74	-15.75
CMI 90	12.42	7.79	-2.12



Saskatoon

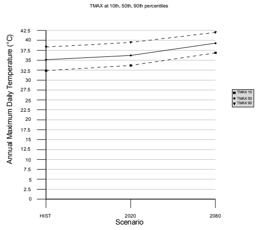
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-44.57	-42.74	-34.49
TMIN 50	-37.92	-36.34	-27.59
TMIN 90	-32.2	-30.08	-20.1



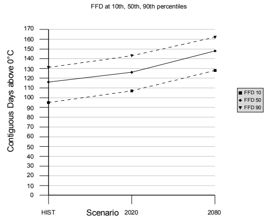
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	32.39	33.68	36.86
TMAX 50	35.12	36.21	39.3
TMAX 90	38.31	39.48	42



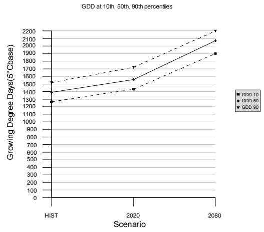
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	95	107	128
FFD 50	116	126	148
FFD 90	131	143	162



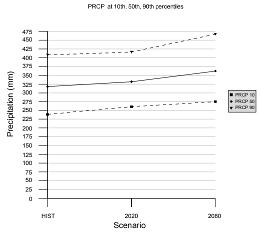
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1263.19	1430.06	1901.32
GDD 50	1388.37	1557.86	2071.83
GDD 90	1516.85	1719.57	2199.57



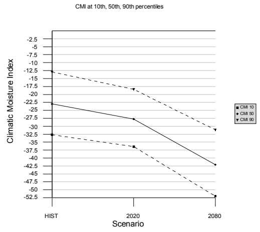
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	238.68	260.59	274.89
PRCP 50	317.91	331.74	362.28
PRCP 90	407.85	416.07	467.04



CMI at 10th, 50th, and 90th percentiles

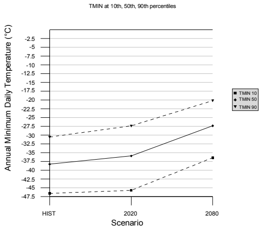
	HIST	2020	2080
CMI 10	-32.7	-36.43	-52
CMI 50	-23.01	-27.77	-42.1
CMI 90	-12.93	-18.4	-31.15



Scott

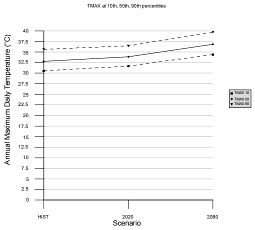
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-46.6	-45.72	-36.42
TMIN 50	-38.29	-35.93	-27.35
TMIN 90	-30.55	-27.36	-20.17



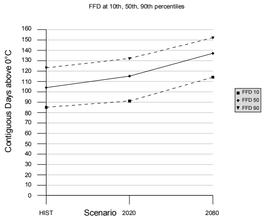
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	30.54	31.67	34.4
TMAX 50	32.8	33.88	36.82
TMAX 90	35.62	36.46	39.7



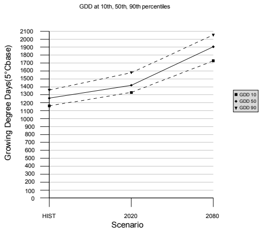
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	85	91	114
FFD 50	104	115	137
FFD 90	123	132	152



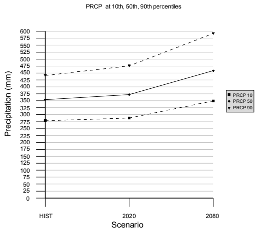
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1160.7	1328.87	1726.76
GDD 50	1256.76	1420.23	1904.58
GDD 90	1358.72	1577.7	2052.89



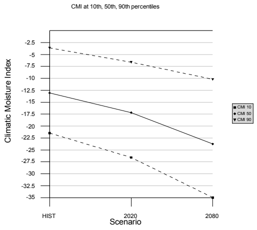
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	278.15	287.77	349.41
PRCP 50	353.63	372.2	458.1
PRCP 90	440.89	475.48	592.16



CMI at 10th, 50th, and 90th percentiles

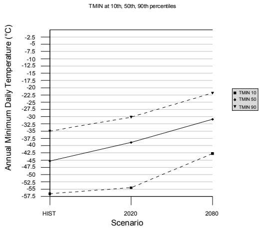
	HIST	2020	2080
CMI 10	-21.47	-26.58	-34.98
CMI 50	-13.06	-17.19	-23.75
CMI 90	-3.61	-6.62	-10.22



Spiritwood

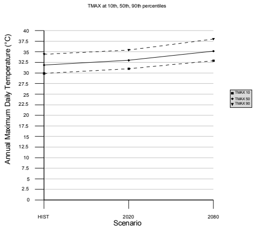
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-56.59	-54.53	-42.74
TMIN 50	-45.31	-38.92	-30.93
TMIN 90	-35	-30.15	-21.84



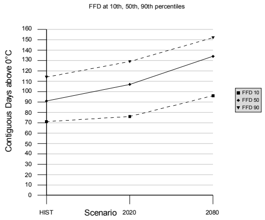
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	29.87	31	32.88
TMAX 50	31.88	32.97	35.13
TMAX 90	34.41	35.4	37.99



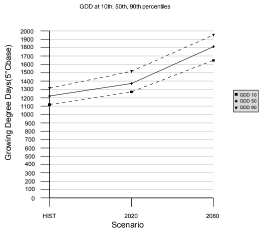
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	71	76	96
FFD 50	91	107	134
FFD 90	114	129	152



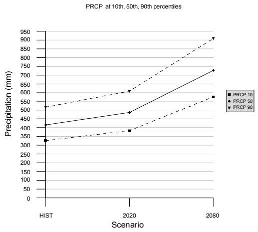
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1118.77	1271.05	1648.88
GDD 50	1222.16	1371.1	1812.77
GDD 90	1315.67	1517.08	1952.41



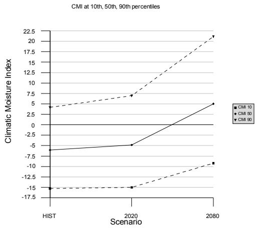
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	325.99	383.4	575.59
PRCP 50	416.04	487.24	726.75
PRCP 90	516.79	608.24	909.05



CMI at 10th, 50th, and 90th percentiles

	HIST	2020	2080
CMI 10	-15.28	-15.01	-9.23
CMI 50	-6.05	-4.84	5.01
CMI 90	4.15	6.95	21.12



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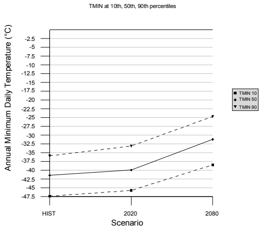
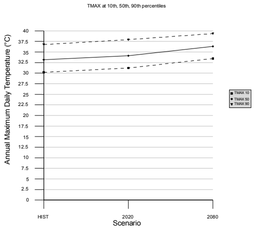
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-47.37	-45.77	-38.46
TMIN 50	-41.46	-39.95	-31.2
TMIN 90	-35.9	-33.11	-24.69



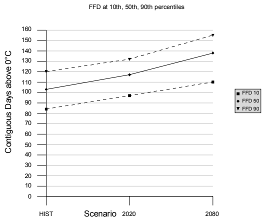
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	30.2	31.22	33.45
TMAX 50	33.17	34.1	36.31
TMAX 90	36.76	37.92	39.35



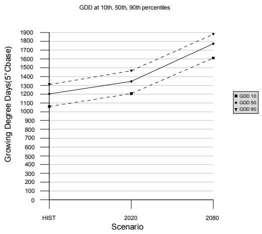
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	84	97	110
FFD 50	103	117	138
FFD 90	120	132	155



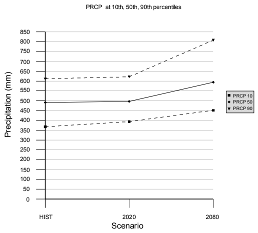
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1059.85	1204.72	1610.27
GDD 50	1201.57	1343.79	1772.69
GDD 90	1307.83	1463.17	1878.69



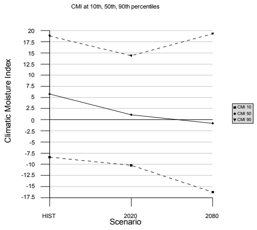
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	367.2	393.27	450.87
PRCP 50	491.08	495.7	593.47
PRCP 90	611.05	621.55	808.14



CMI at 10th, 50th, and 90th percentiles

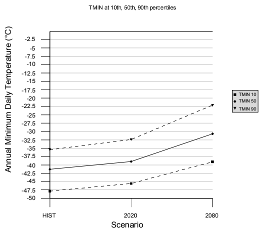
	HIST	2020	2080
CMI 10	-8.44	-10.23	-16.25
CMI 50	5.77	1.11	-0.8
CMI 90	18.78	14.36	19.3



Waskesiu

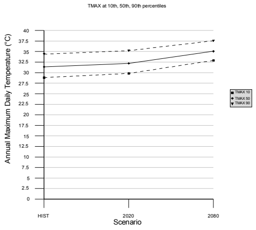
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-47.87	-45.58	-39.07
TMIN 50	-41.32	-38.99	-30.68
TMIN 90	-35.46	-32.42	-22.1



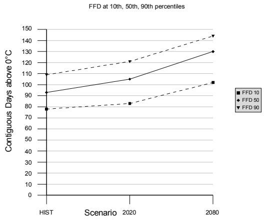
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	28.81	29.8	32.89
TMAX 50	31.36	32.19	35.06
TMAX 90	34.37	35.21	37.56



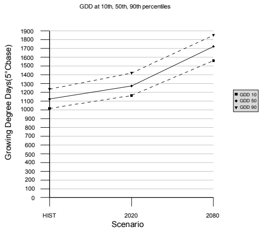
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	78	83	102
FFD 50	93	105	130
FFD 90	109	121	144



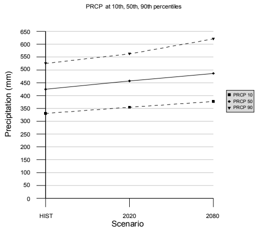
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1016.57	1163.09	1561.37
GDD 50	1123.2	1272.41	1723.84
GDD 90	1235.91	1419.3	1851.25



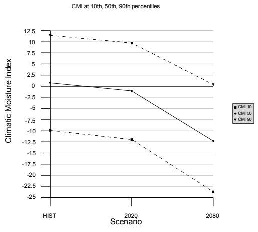
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	330.07	354.3	376.83
PRCP 50	424.15	456.84	486.45
PRCP 90	525.01	562.29	620.38



CMI at 10th, 50th, and 90th percentiles

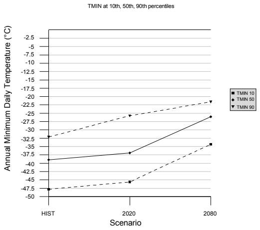
	HIST	2020	2080
CMI 10	-9.93	-11.97	-23.69
CMI 50	0.79	-1.04	-12.3
CMI 90	11.42	9.73	0.39



Watrous

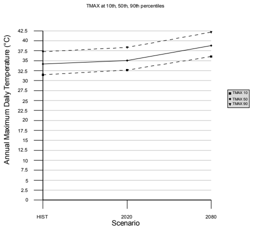
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-47.82	-45.62	-34.32
TMIN 50	-38.96	-36.92	-26.07
TMIN 90	-32.13	-25.76	-21.61



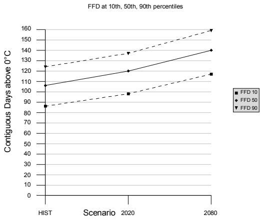
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	31.46	32.64	36.04
TMAX 50	34.18	35.07	38.82
TMAX 90	37.26	38.34	42.17



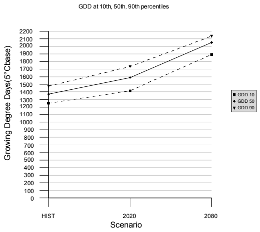
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	86	98	117
FFD 50	106	120	140
FFD 90	124	137	159



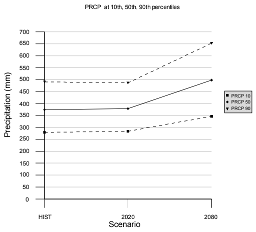
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1249.24	1414.28	1892.78
GDD 50	1369.41	1589.45	2051.65
GDD 90	1474.89	1733.53	2135.07



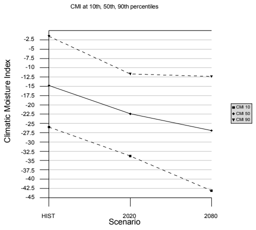
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	278.74	283.72	346.25
PRCP 50	373.72	378.6	497.96
PRCP 90	490.63	486.25	652.45



CMI at 10th, 50th, and 90th percentiles

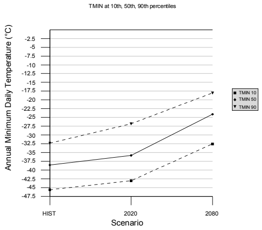
	HIST	2020	2080
CMI 10	-25.97	-33.8	-43.13
CMI 50	-14.78	-22.43	-26.91
CMI 90	-1.53	-11.68	-12.36



Yorkton

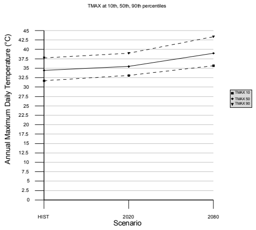
TMIN at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMIN 10	-45.61	-43.04	-32.55
TMIN 50	-38.56	-35.83	-24.1
TMIN 90	-32.35	-26.81	-18.01



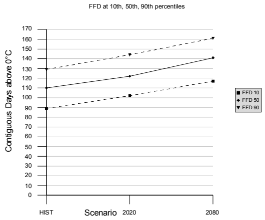
TMAX at 10th, 50th, and 90th percentiles

	HIST	2020	2080
TMAX 10	31.67	33.09	35.67
TMAX 50	34.43	35.46	38.97
TMAX 90	37.73	38.98	43.37



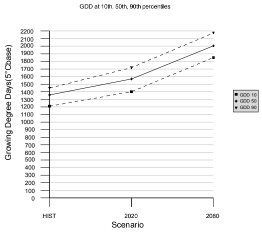
FFD at 10th, 50th, 90th percentiles

	HIST	2020	2080
FFD 10	89	102	117
FFD 50	110	122	141
FFD 90	129	144	161



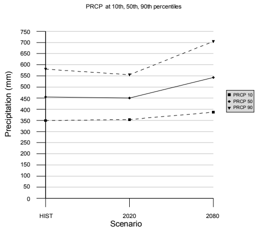
GDD at 10th, 50th, and 90th percentiles

	HIST	2020	2080
GDD 10	1209.83	1400.31	1850.36
GDD 50	1358.66	1569.36	2004.74
GDD 90	1447.7	1717.46	2174.68



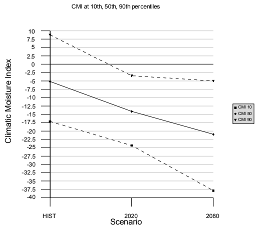
PRCP at 10th, 50th, 90th percentiles

	HIST	2020	2080
PRCP 10	349.1	353.72	386.74
PRCP 50	455.42	450.55	542.97
PRCP 90	580.16	554.73	704.87



CMI at 10th, 50th, and 90th percentiles

	HIST	2020	2080
CMI 10	-17.15	-24.33	-37.87
CMI 50	-5.18	-14.14	-21
CMI 90	8.79	-3.45	-5.01



Appendix 2 - Climate Model Interpolations to Study Area

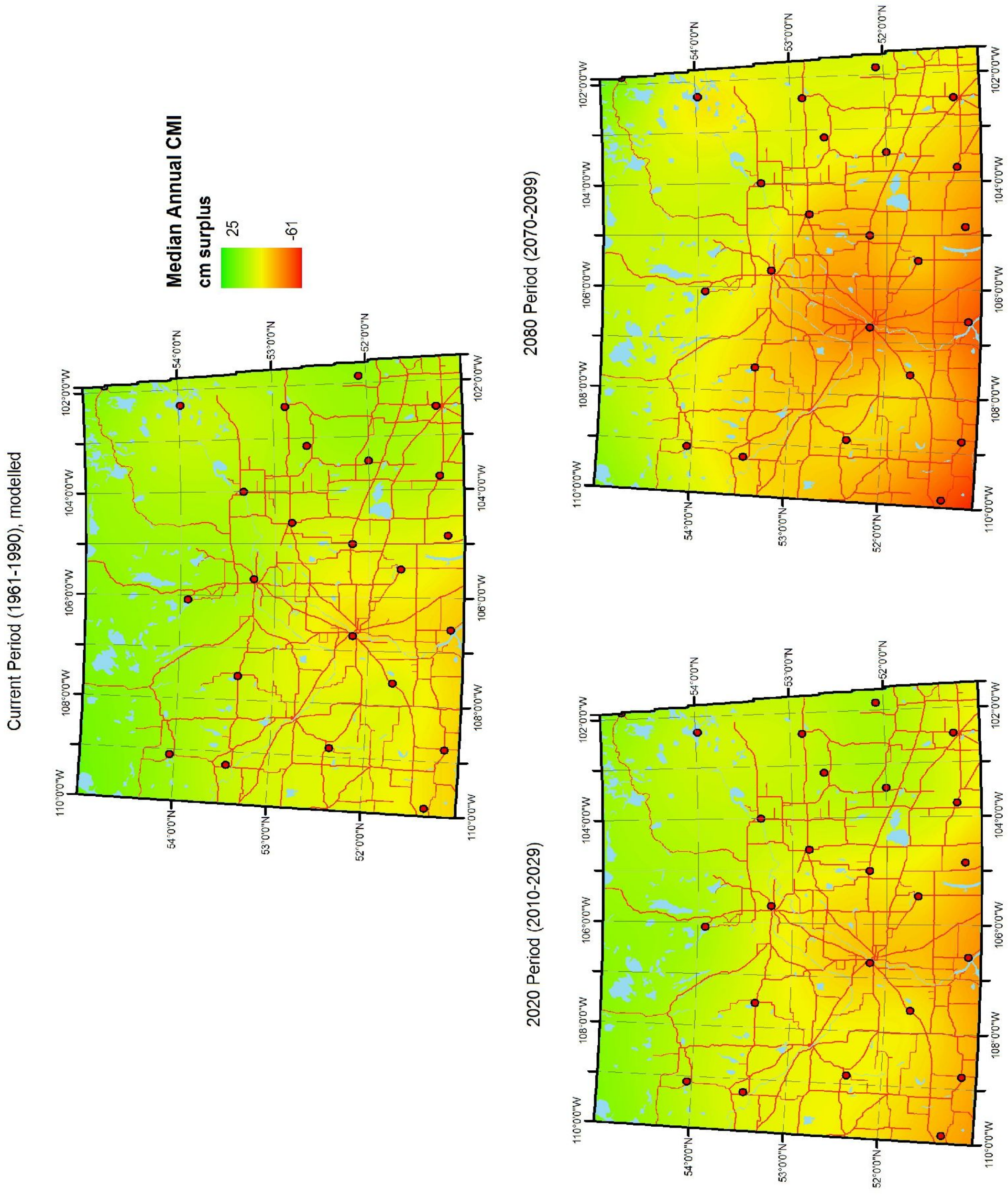


Figure 8: Climatic Moisture Index (CMI) interpolation over the study area. CMI was accumulated by year and scenario. The map is derived from the median at each station among 30 years and 100 scenarios.

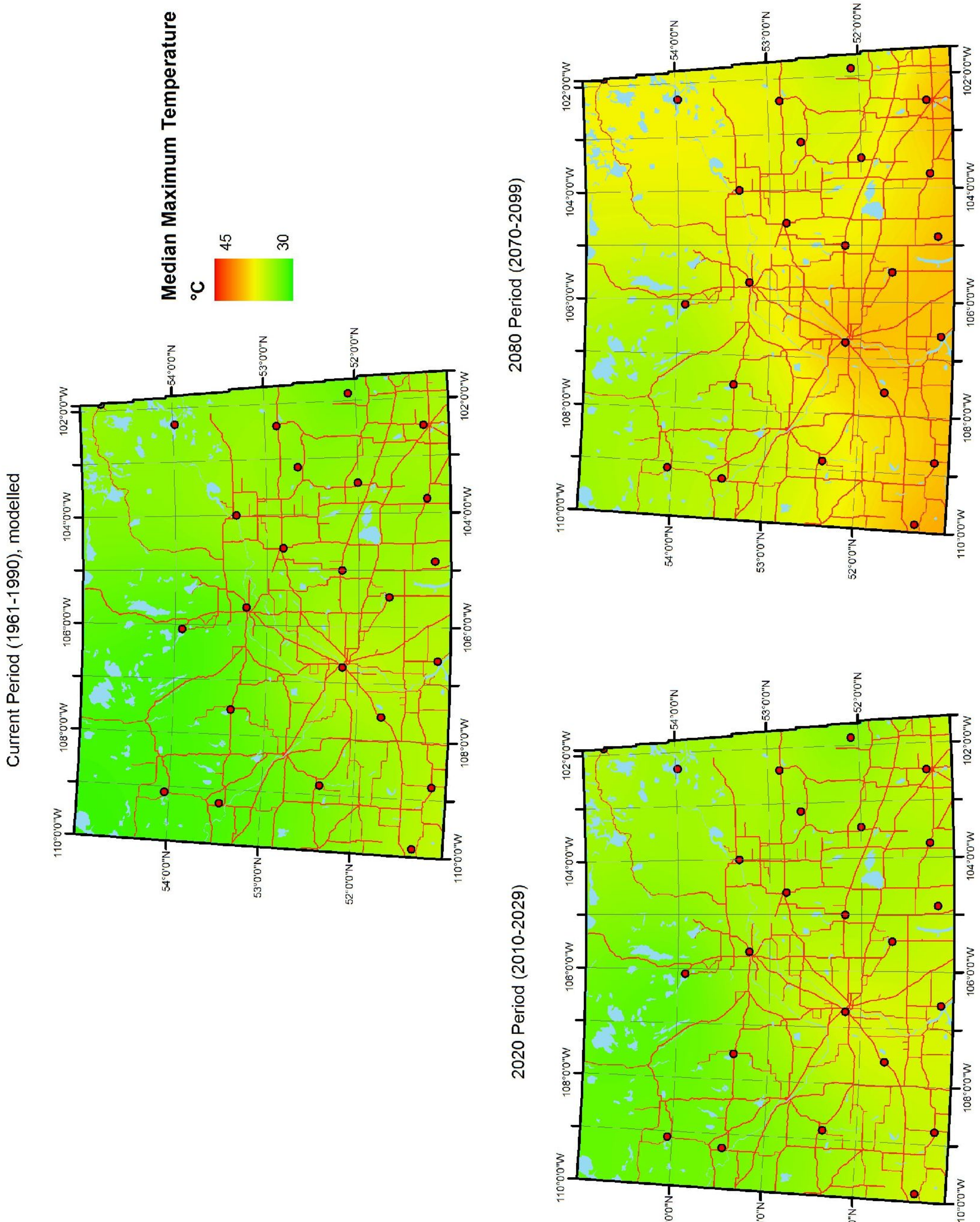


Figure 9: Maximum daily temperature (TMAX) interpolation over the study area. TMAX was determined by year and scenario. The map is derived from the median at each station among 30 years and 100 scenarios.

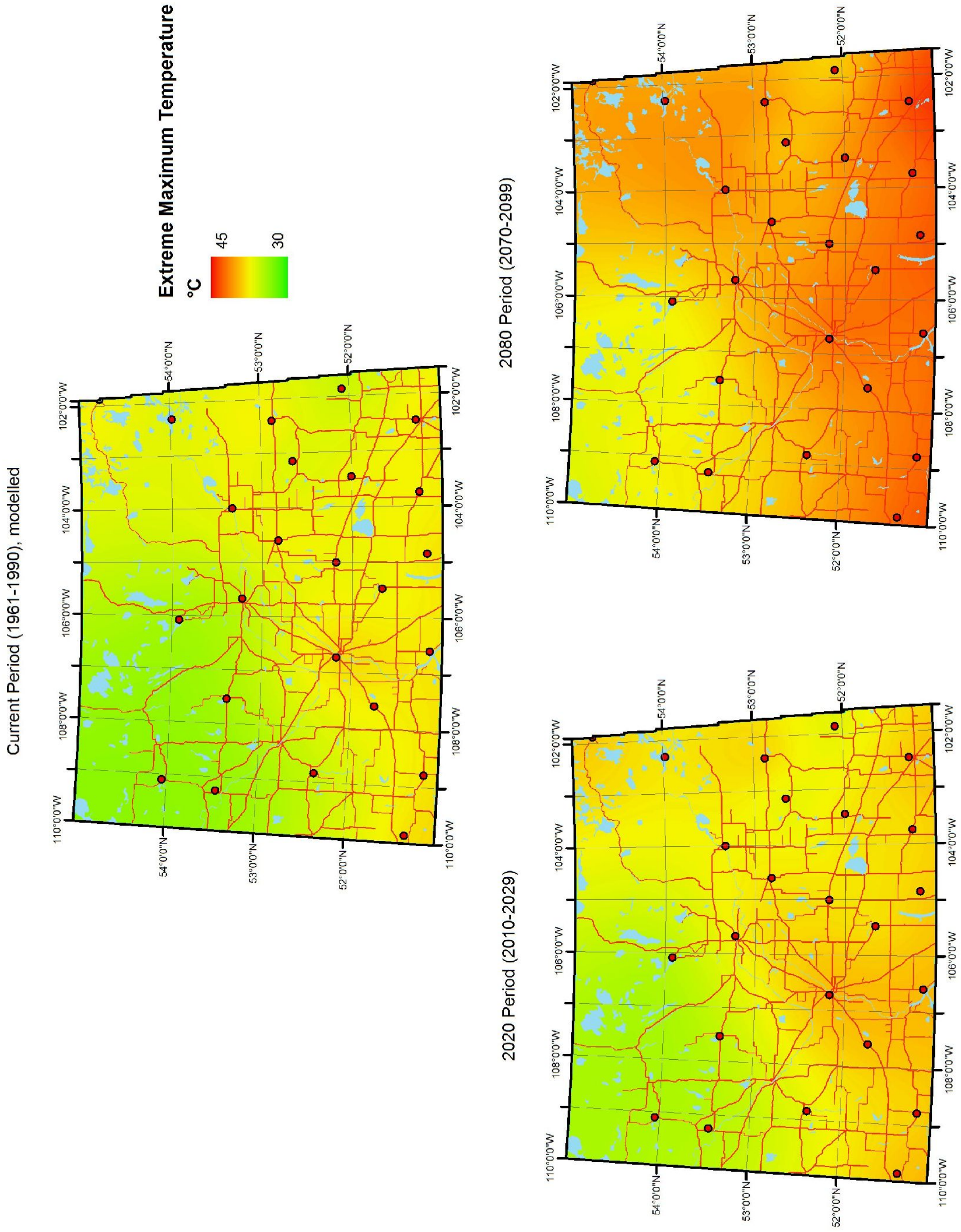


Figure 10: Extreme maximum daily temperature (TMAX) interpolation over the study area. TMAX was determined by year and scenario. The map is derived from the 90th percentile at each station among 30 years and 100 scenarios.

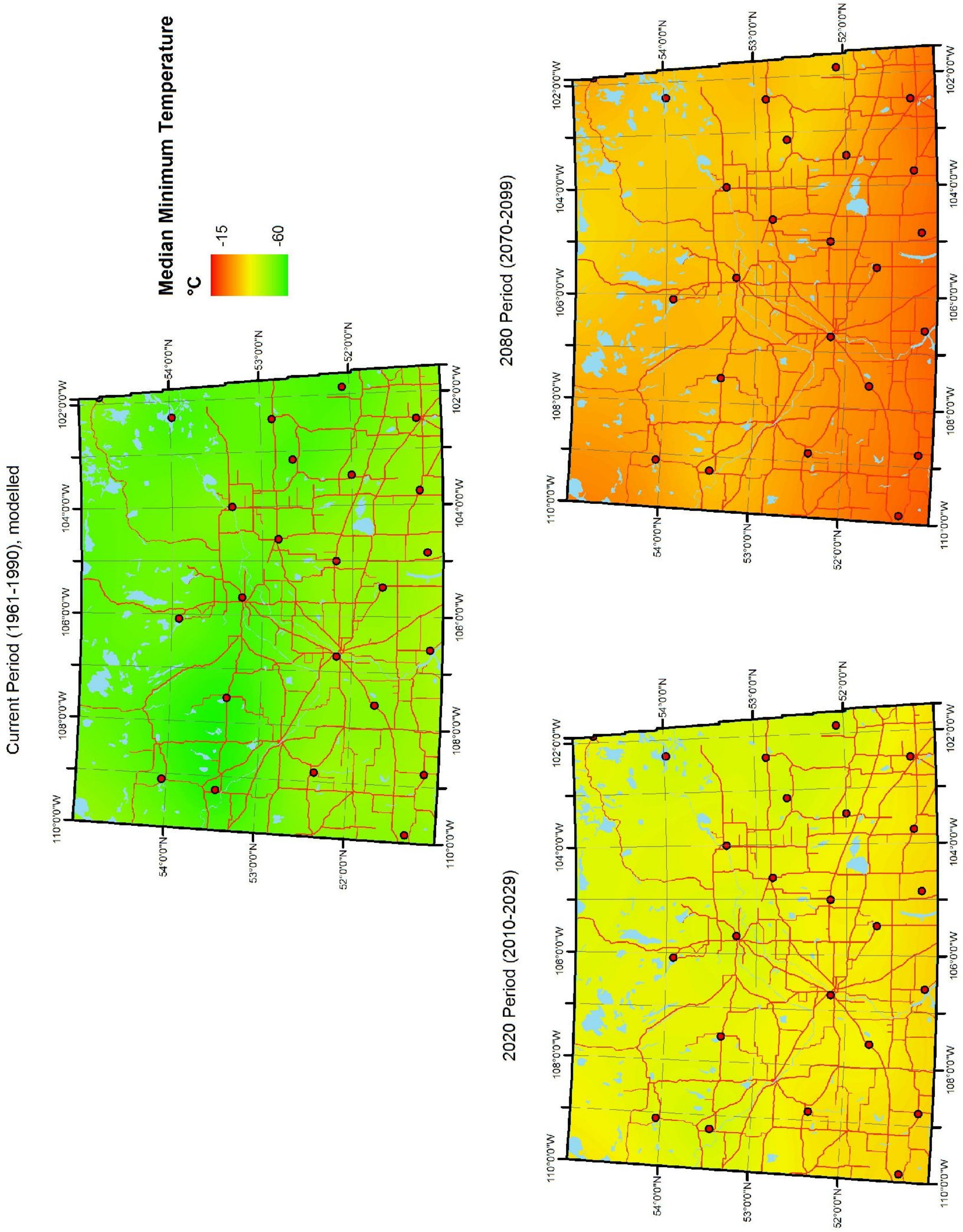


Figure 11: Minimum daily temperature (TMIN) interpolation over the study area. TMIN was determined by year and scenario. The map is derived from the median at each station among 30 years and 100 scenarios.

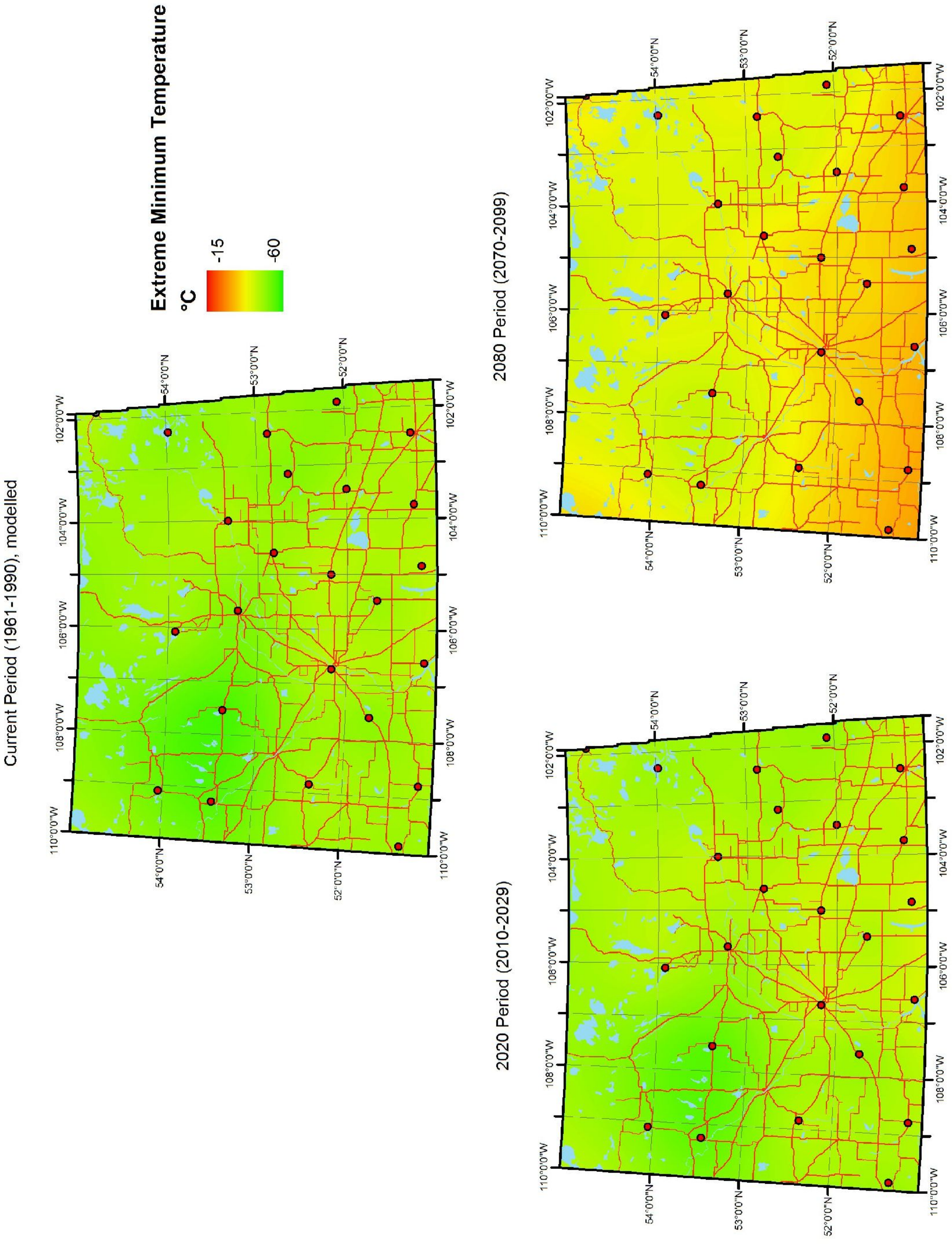


Figure 12: Extreme minimum daily temperature (TMIN) interpolation over the study area. TMIN was determined by year and scenario. The map is derived from the 10th percentile at each station among 30 years and 100 scenarios.

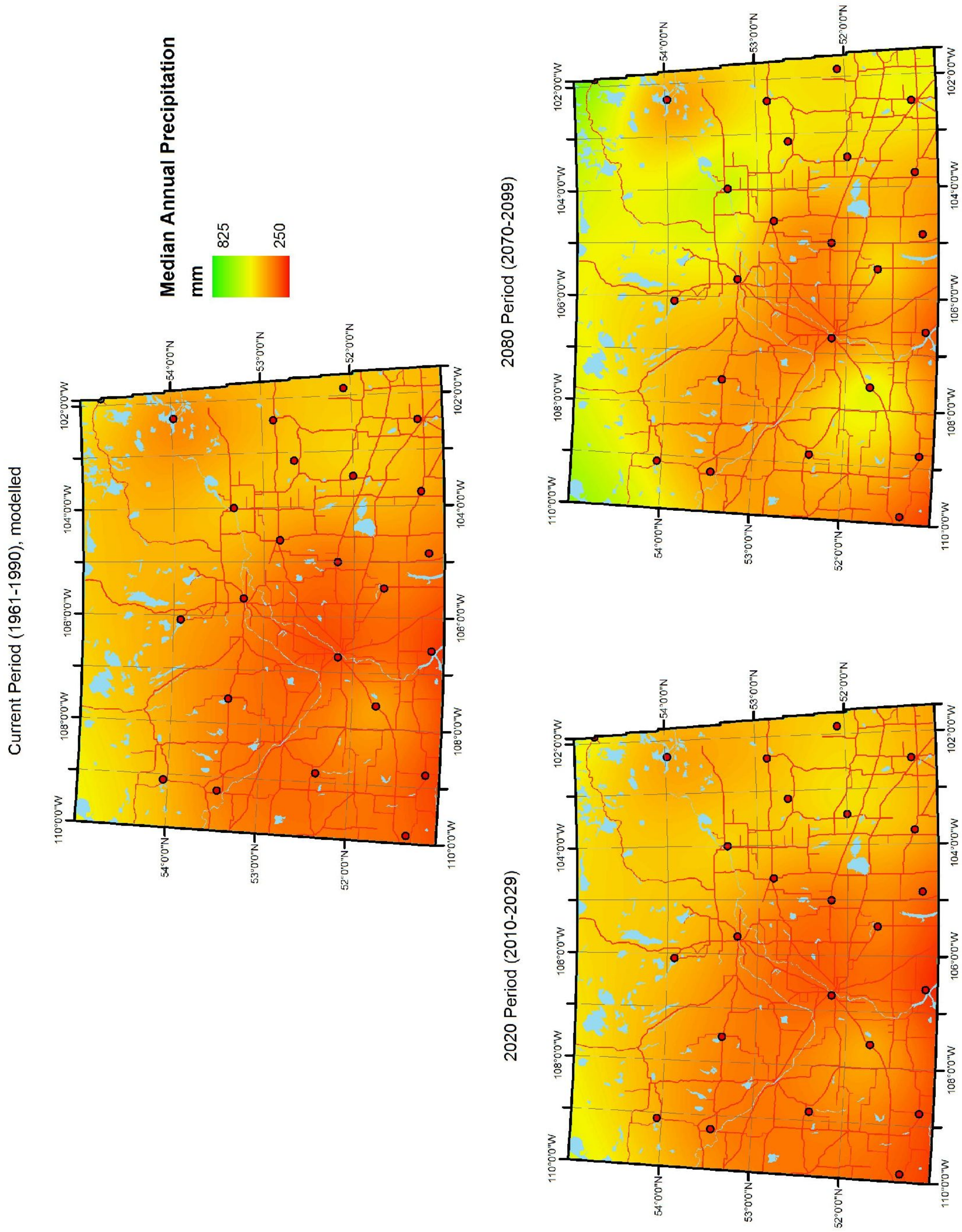


Figure 13: Precipitation (PRCP) interpolation over the study area. PRCP was accumulated by year and scenario. The map is derived from the median at each station among 30 years and 100 scenarios.

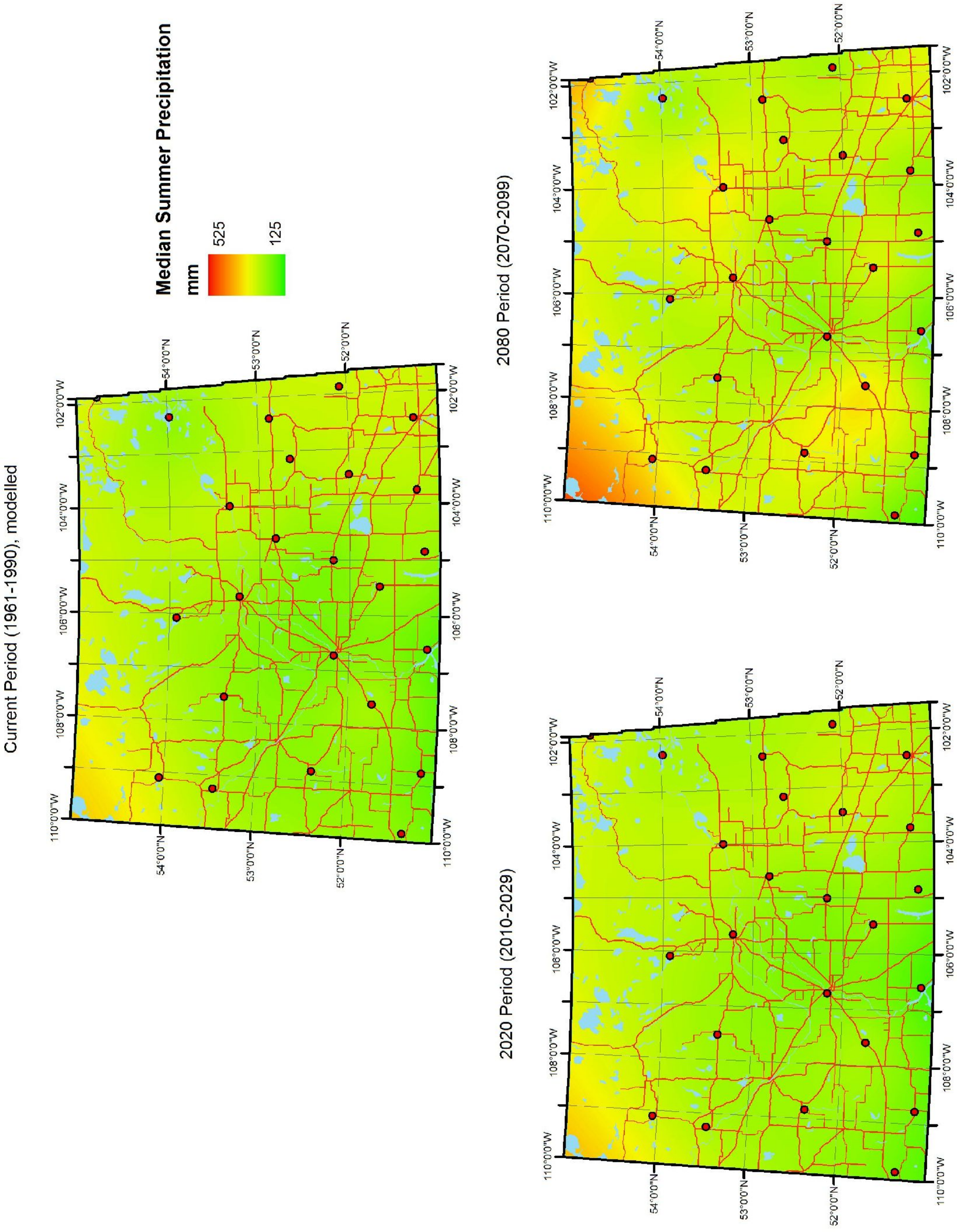


Figure 14: Summer precipitation (PRCP) interpolation over the study area. PRCP was accumulated by year and scenario, restricted to the months from May to September. The map is derived from the median at each station among 30 years and 100 scenarios.

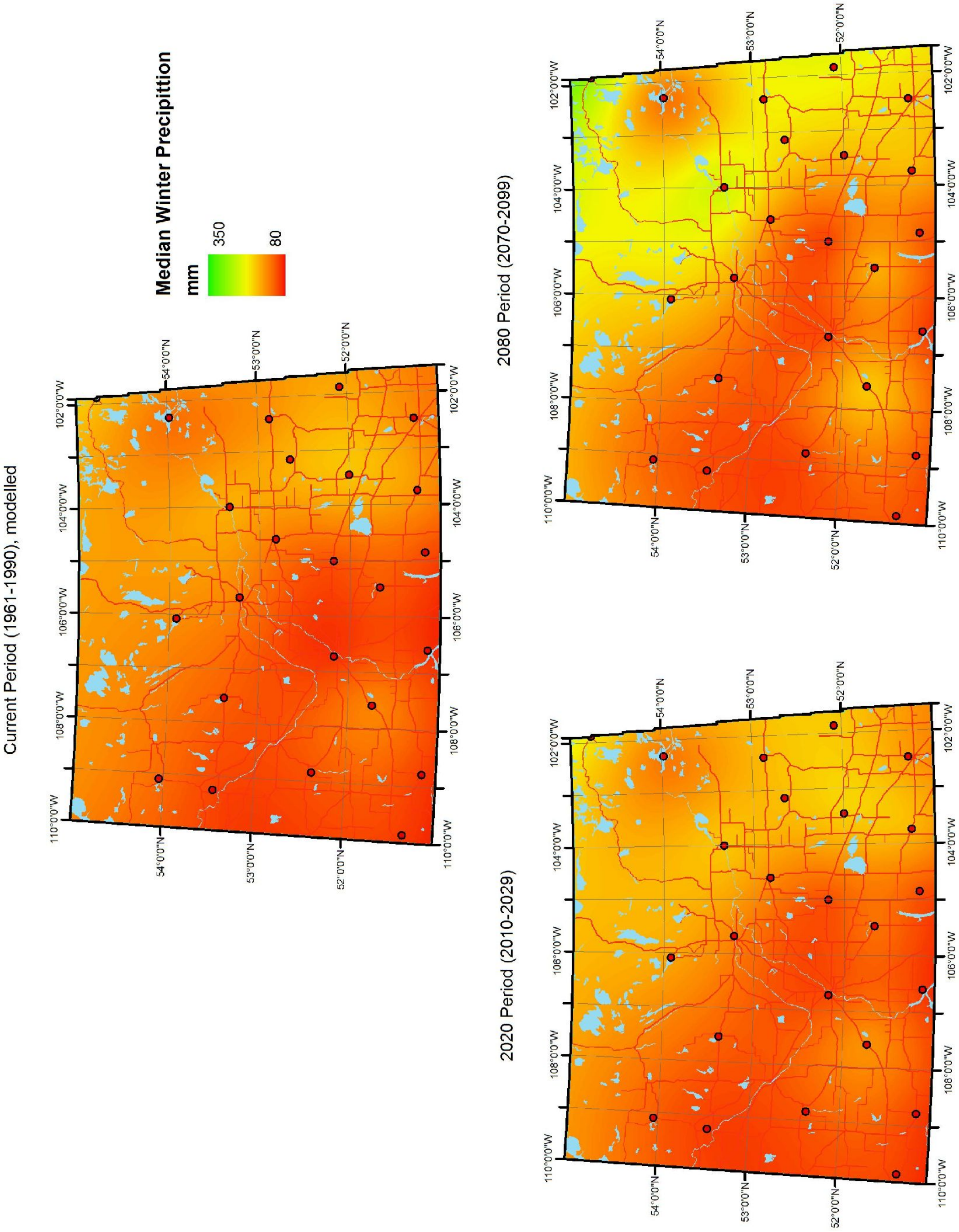


Figure 15: Winter precipitation (PRCP) interpolation over the study area. PRCP was accumulated by year and scenario, restricted to the months from January to April and October to December. The map is derived from the median at each station among 30 years and 100 scenarios.

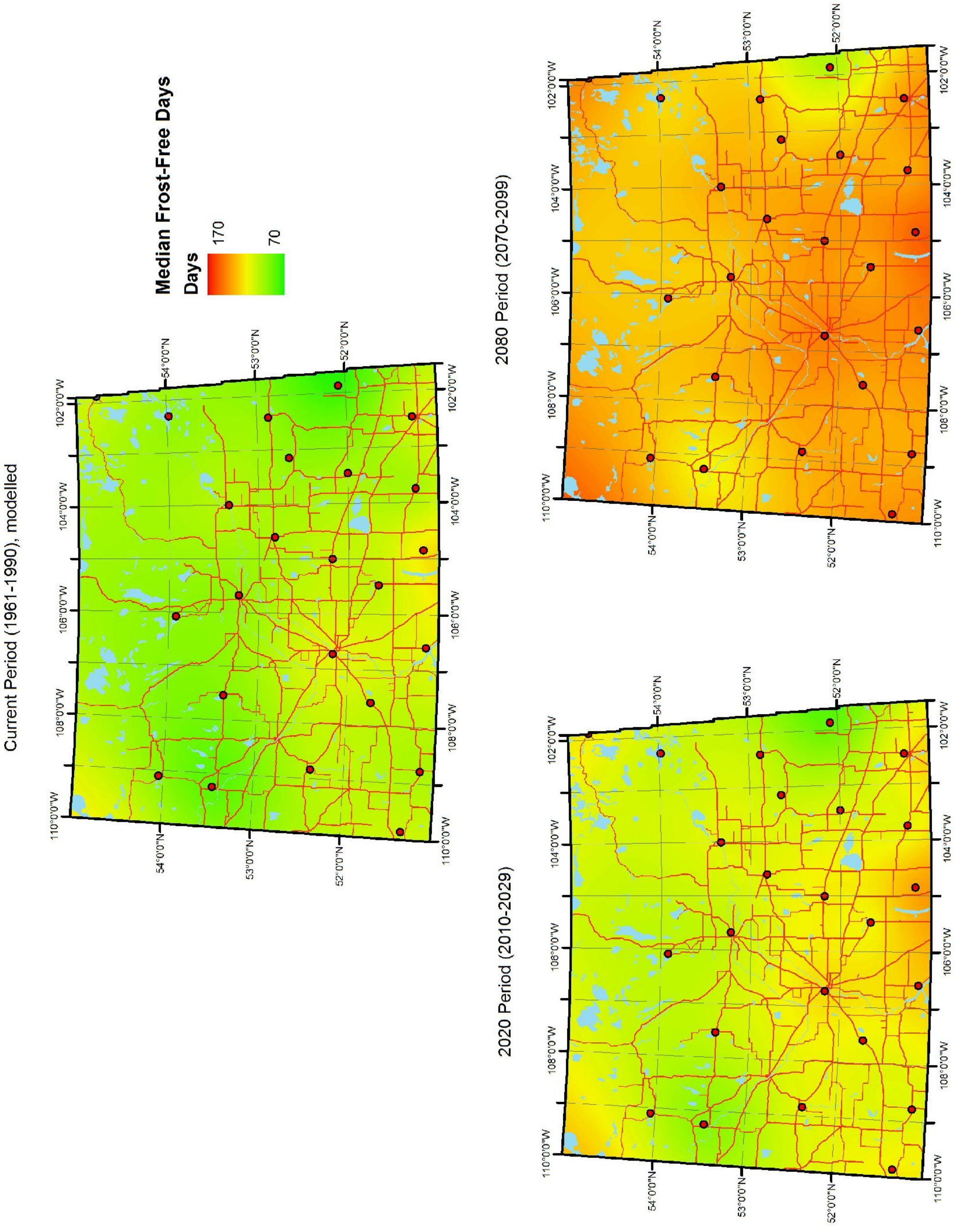


Figure 16: Frost-free days (FFD) interpolation over the study area. The longest individual period of days between days with a minimum temperature below 0°C was the value for the year and scenario. The map is derived from the median at each station among 30 years and 100 scenarios.

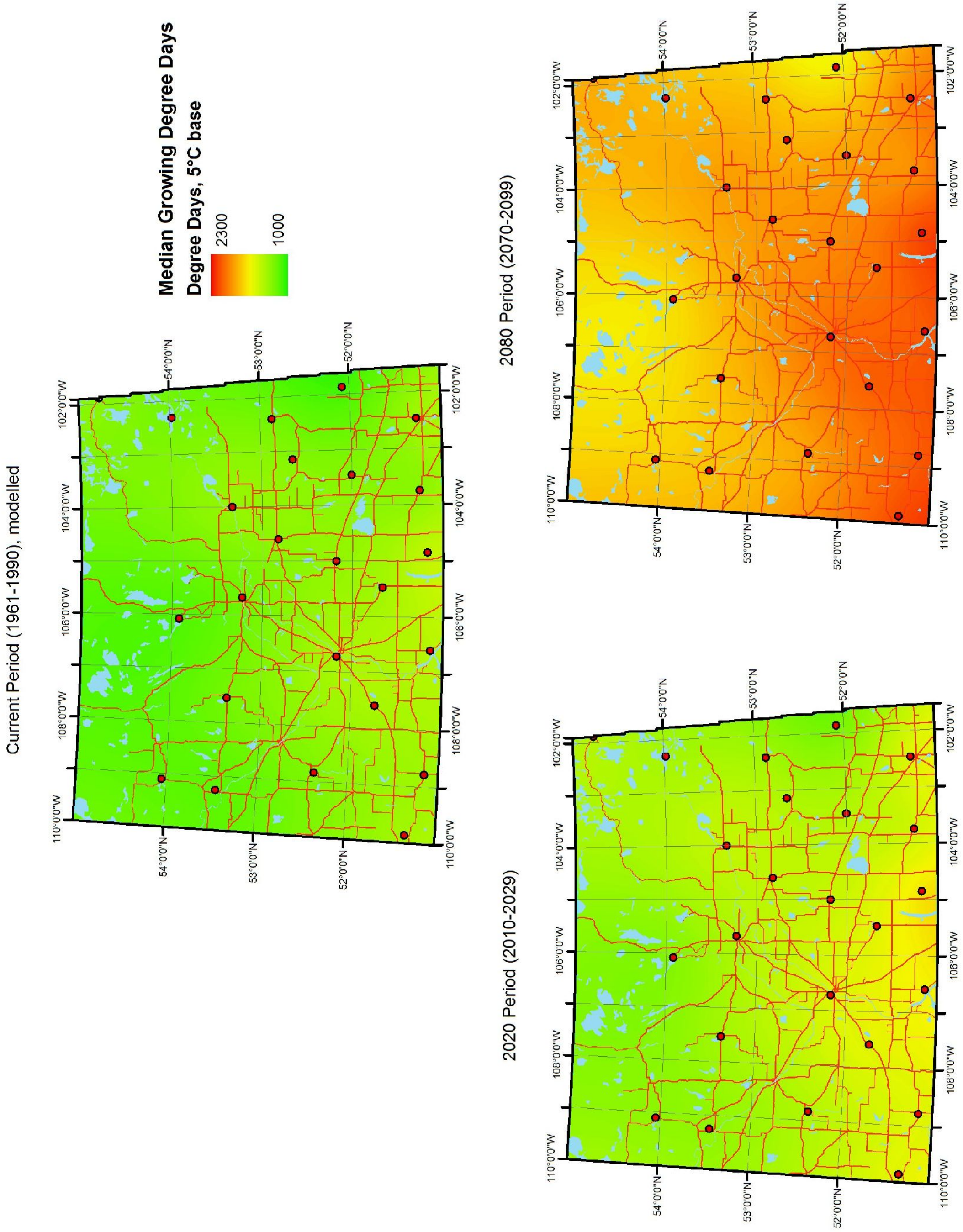


Figure 17: Growing degree days (GDD) interpolation over the study area. Growing degree days are counted by subtracting 5 from the daily mean temperature. If the result is positive then it is accumulated by year and scenario. The map is derived from the median at each station among 30 years and 100 scenarios.

Appendix 3 - Analysis of Tree Species Presently found in Study Area

This appendix shows the individual species' range predictions and the decision tree which drives those predictions.

The decision tree shows the recursive partitioning scheme. The ovals are parent nodes, while the rectangles are terminal nodes. The line drawn between the parent node and a child node is labelled with the decision that takes a pixel down toward that node. Every node has a mean value and a number of pixels.

The mean represents the mean value of pixels at that node. 1 represents pixels in the training data that are inside the range polygon. A 0 represents a pixel not in the training range polygon.

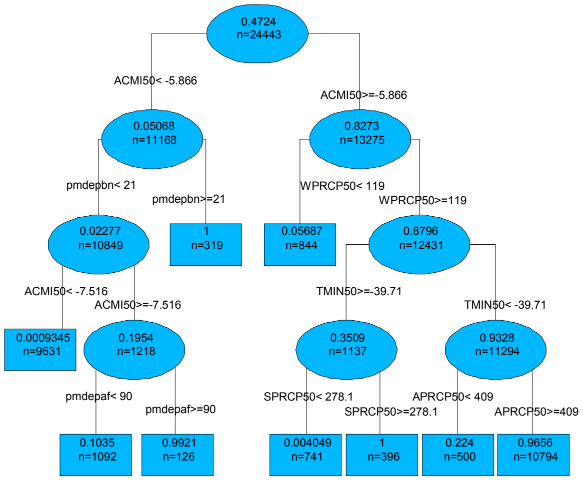
Where an area is grey, it is an area where the mean value of the terminal node of the decision tree is between zero and one. It is an area of mild confusion, in that the areas that were originally analysed to produce the decision tree were not uniformly range or not range, even though they are uniform for the predictor variables. The darker the grey, the higher likelihood the area is "range".

The statistics were originally run on a 10% sample of potential habitat cells, specifically a 24443-element sample.

The set of range prediction figures show four representations of tree range. In the top left is the training data. This data is derived from Little, 1971. The recursive partitioning trees were developed from these data, the soils data and the climatic data. The top right shows a prediction based on that same input data, using predicted climate data for the historic period. The other two representations of range (2020 and 2080) are developed from the same source data, except using the appropriate projected climate data.

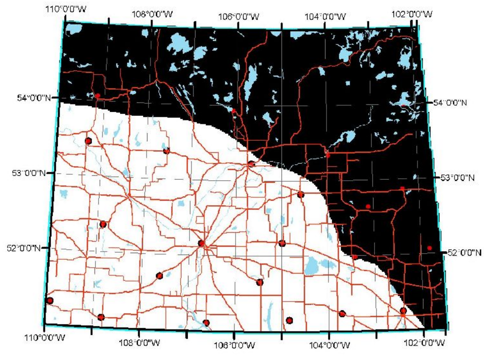
Abies balsamea

RPart Decision Tree

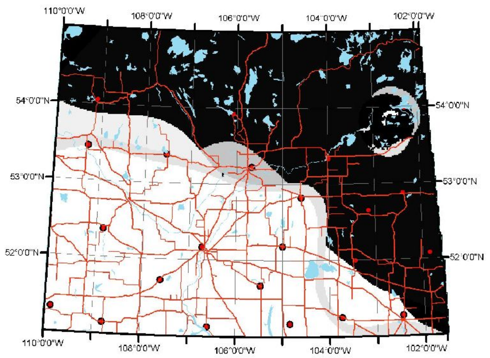


Range

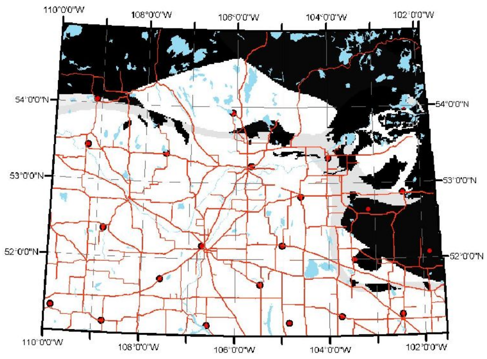
Training Data



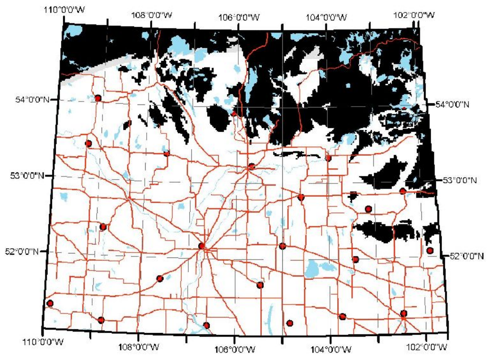
Current Period (1961-1990), modelled



2020 Period (2010-2029)

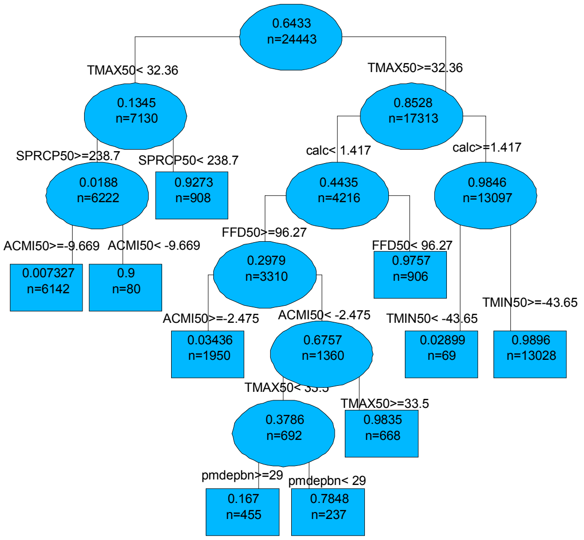


2080 Period (2070-2099)



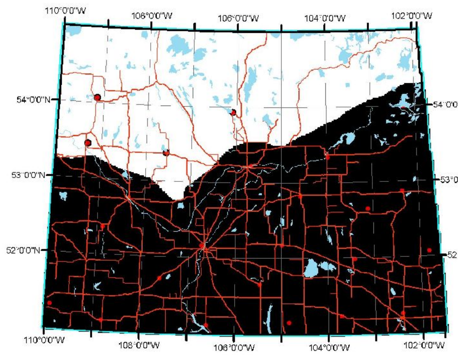
Acer negundo

RPart Decision Tree

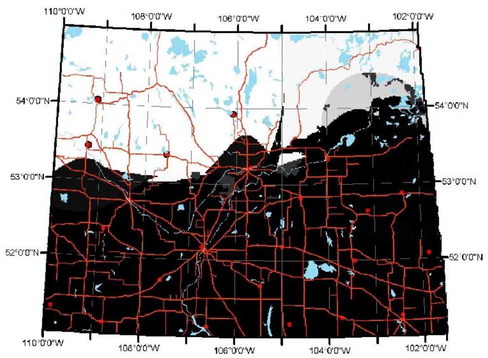


Range

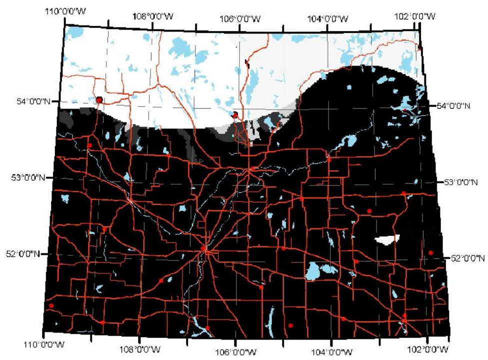
Training Data



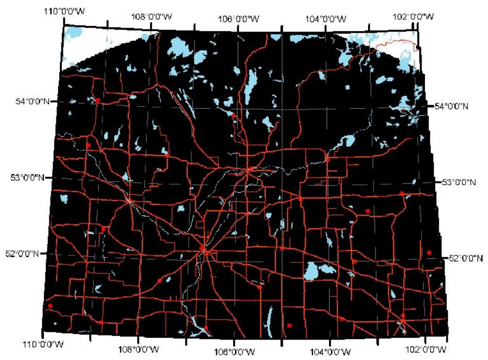
Current Period (1961-1990), modelled



2020 Period (2010-2029)

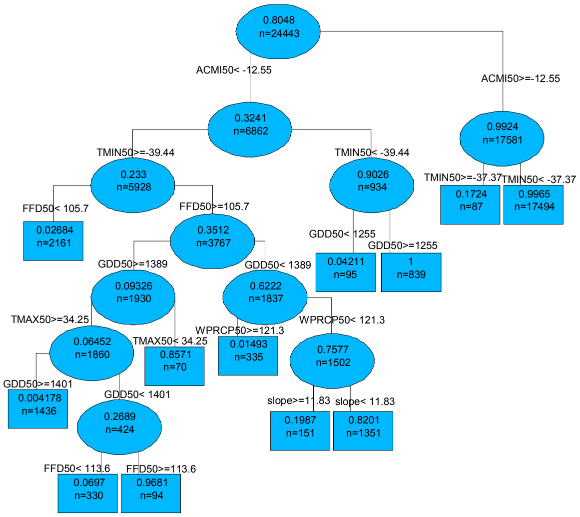


2080 Period (2070-2099)



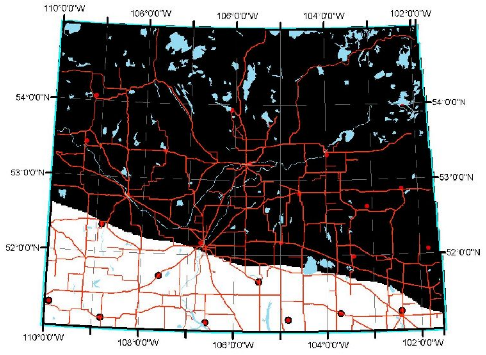
Betula papyrifera

RPart Decision Tree

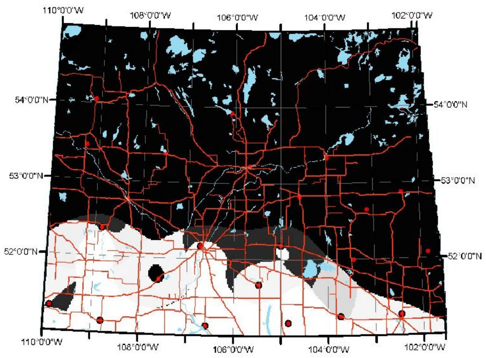


Range

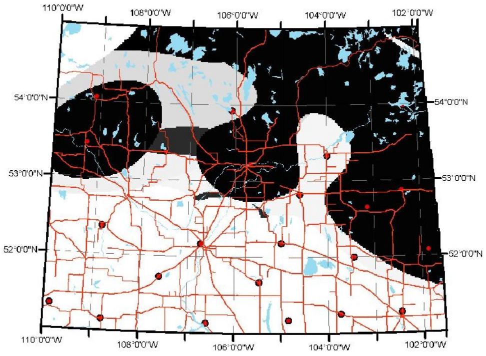
Training Data



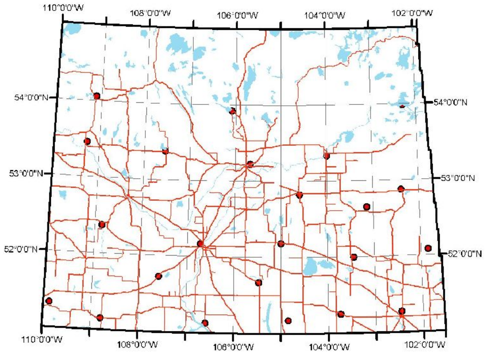
Current Period (1961-1990), modelled



2020 Period (2010-2029)



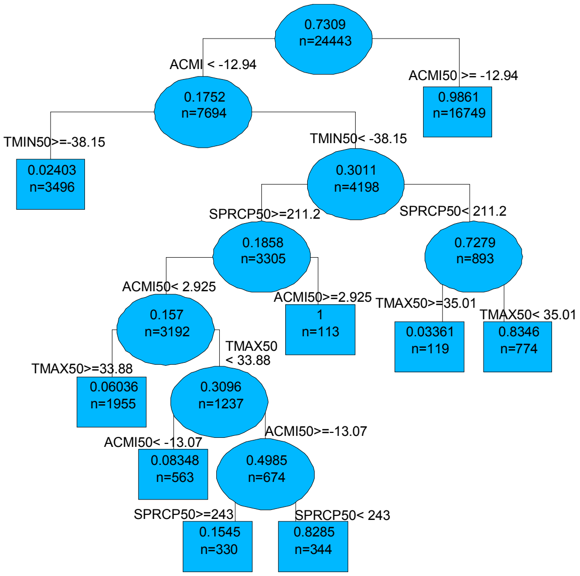
2080 Period (2070-2099)



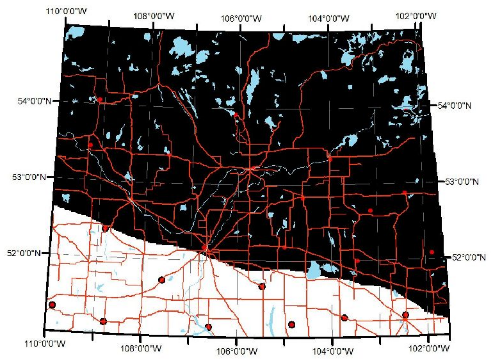
Larix laricina

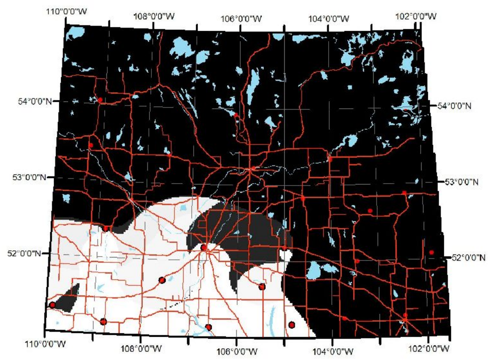
This species showed substantial range retreat (complete) for 2080. This did not seem reasonable, as we were expecting *Larix* to be found further south than *Picea*. The key factor in this seemed to be winter minimum temperature, which rises fairly uniformly across the study area. Switching to a closely related split using climatic moisture index brought the estimates in line with our expectations.

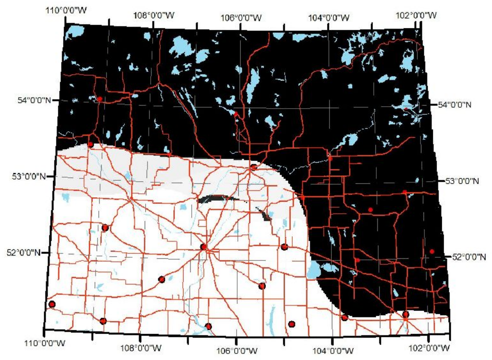
RPart Decision Tree

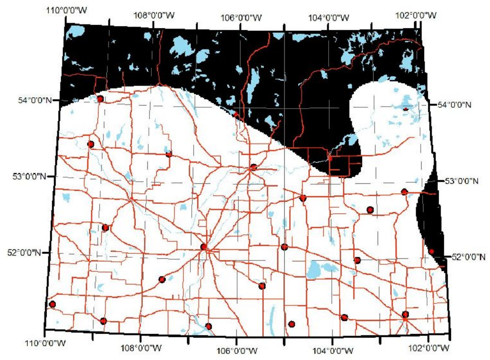


Range


Training Data


Current Period (1961-1990), modelled


2020 Period (2010-2029)


2080 Period (2070-2099)

Picea glauca

This species seems alright at first glance, but the 2080 time period predicted substantial range advance. That was tracked down to a very small subset of the training data fitting a very large subset of the 2080 climate data. Substitutions to improve consistency between data sets:

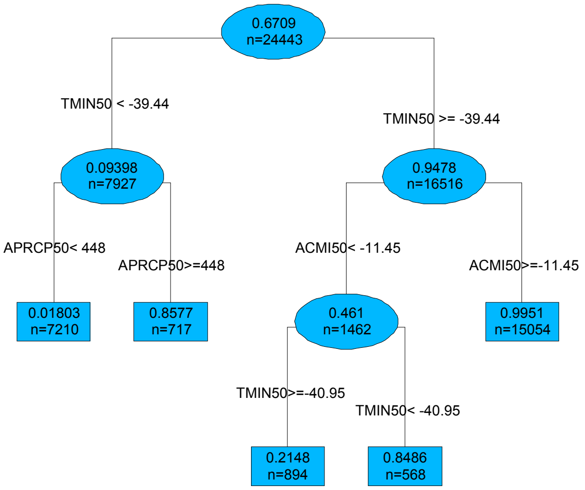
Node 2:

ACMI50 < -5.420353 to the left

APRCP50 < 447.9965 to the left

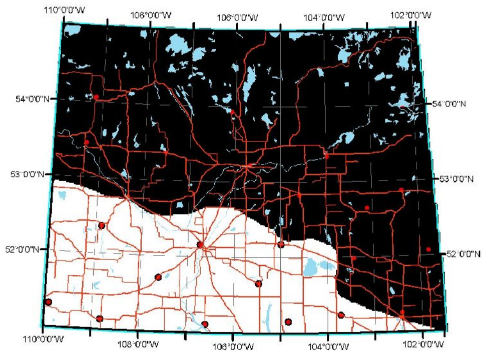
Node 2 effectively collapses, which affects 3% of the pixels in the training data set. The substitution of ACMI < -5 (drier to the left) for APRCP < 448 (drier to the left) should be

RPart Decision Tree

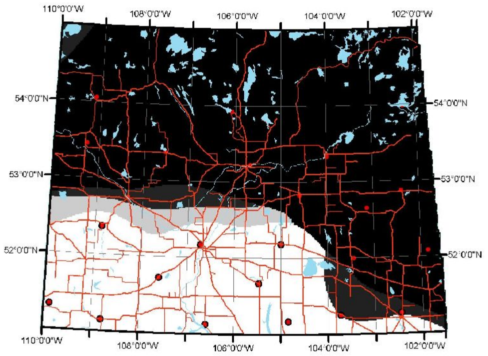


Range

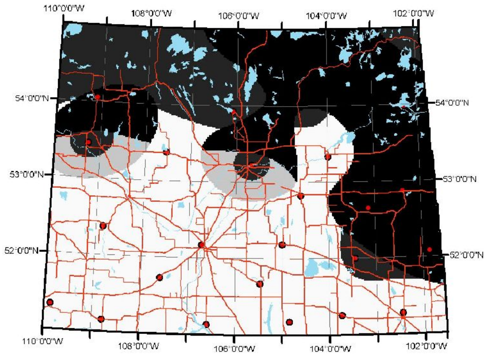
Training Data



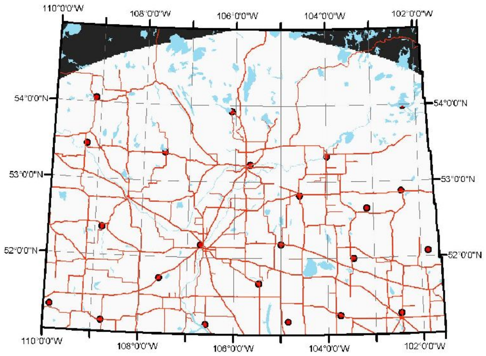
Current Period (1961-1990), modelled



2020 Period (2010-2029)



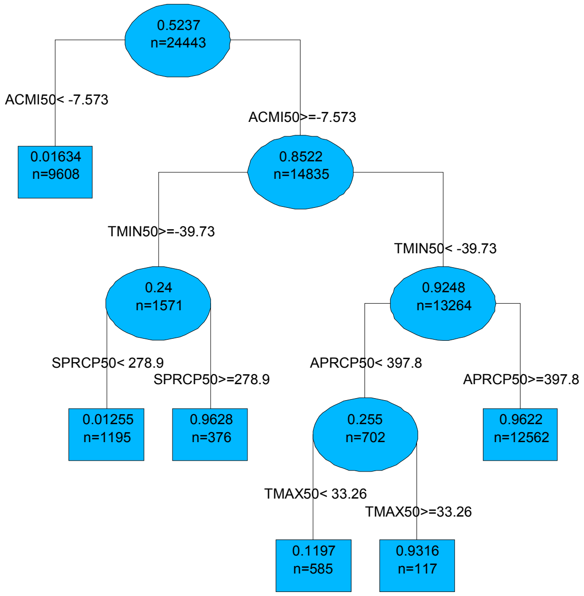
2080 Period (2070-2099)



Picea mariana

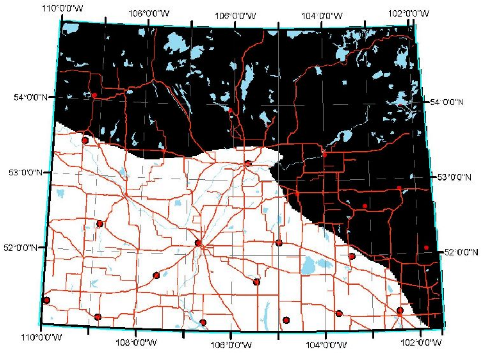
In general, this species' map seems to work. It shows retreat slightly less than *P. glauca*, but only marginally. The rather odd pattern in the 2020 period suggests that there are some smoothing artifacts in the data. The areas that show a "swirl" should probably be interpreted as a moderate probability area, rather than a nil probability.

RPart Decision Tree

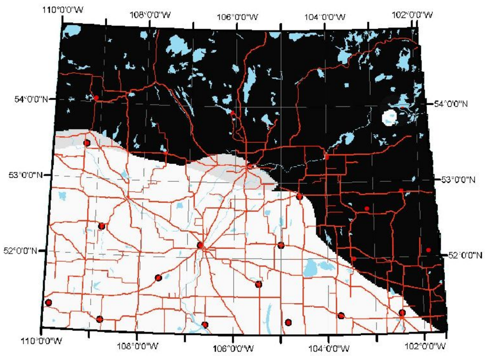


Range

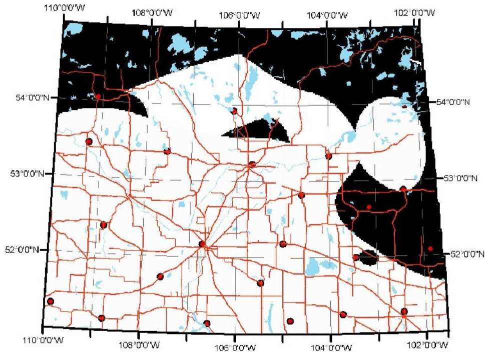
Training Data



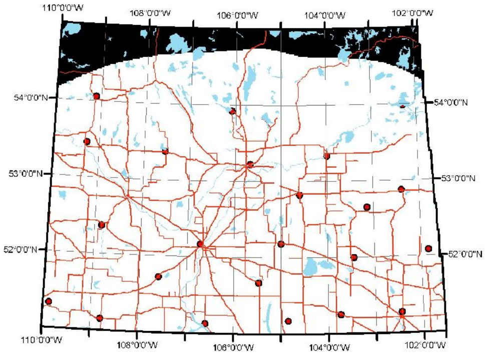
Current Period (1961-1990), modelled



2020 Period (2010-2029)

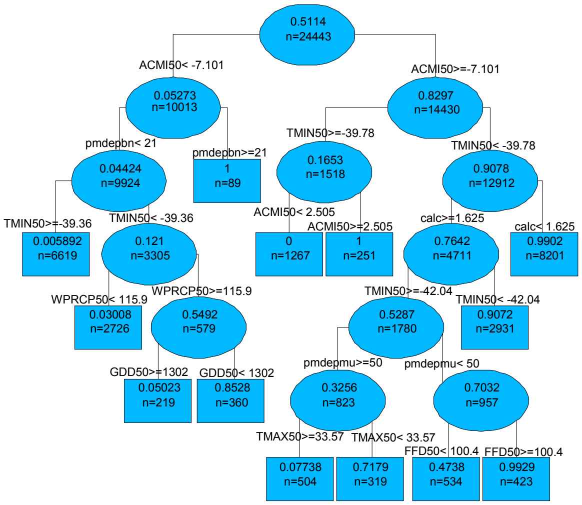


2080 Period (2070-2099)



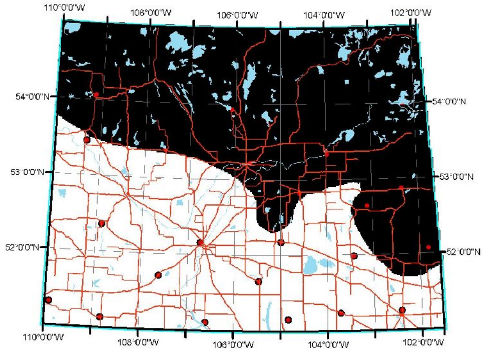
Pinus banksiana

RPart Decision Tree

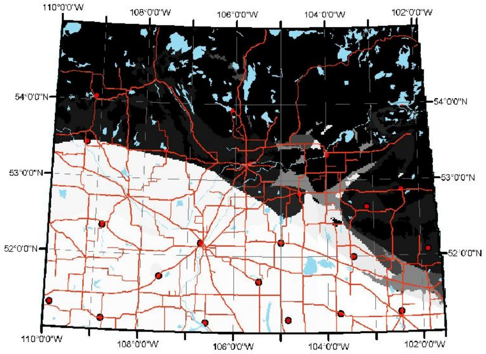


Range

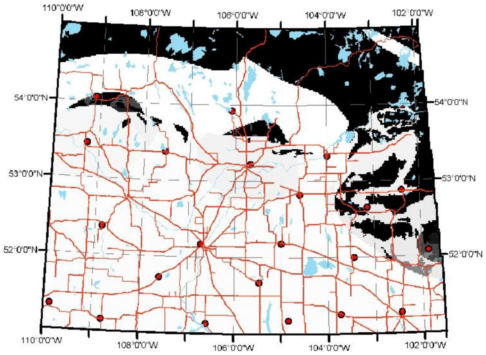
Training Data



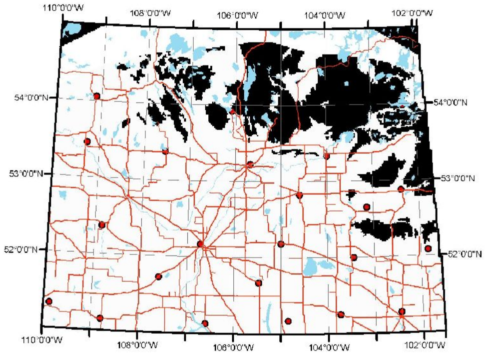
Current Period (1961-1990), modelled



2020 Period (2010-2029)

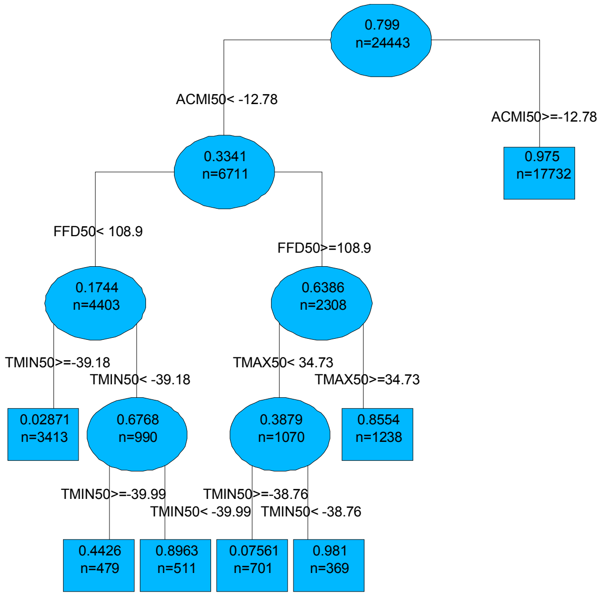


2080 Period (2070-2099)

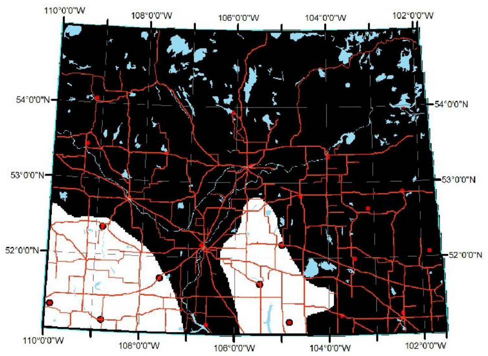


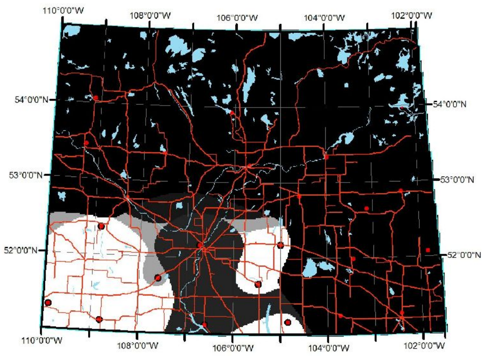
Populus balsamifera

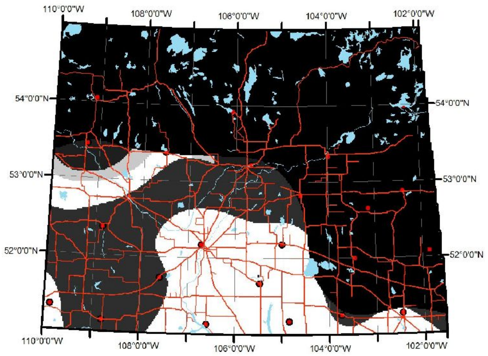
RPart Decision Tree

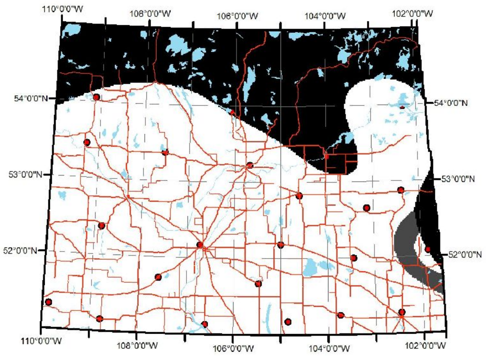


Range


Training Data

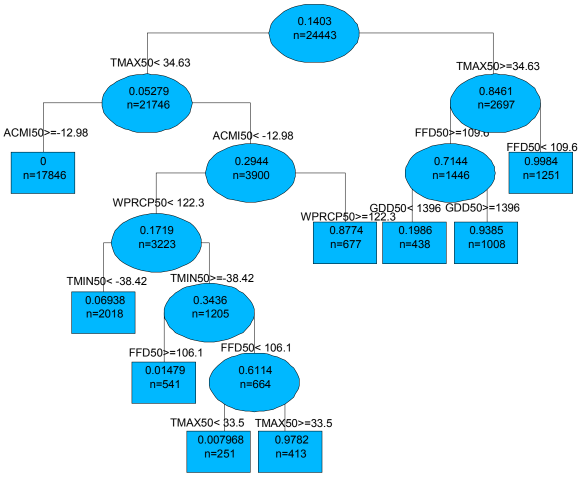

Current Period (1961-1990), modelled


2020 Period (2010-2029)


2080 Period (2070-2099)

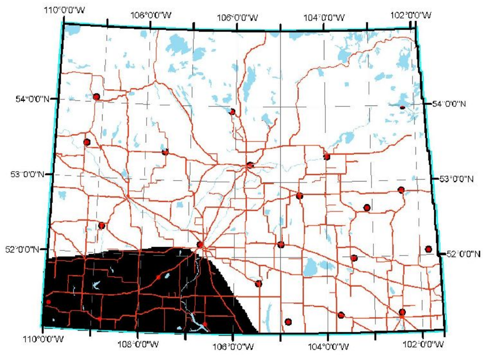
Populus deltoides

RPart Decision Tree

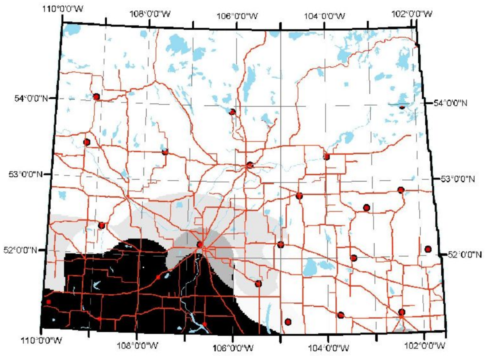


Range

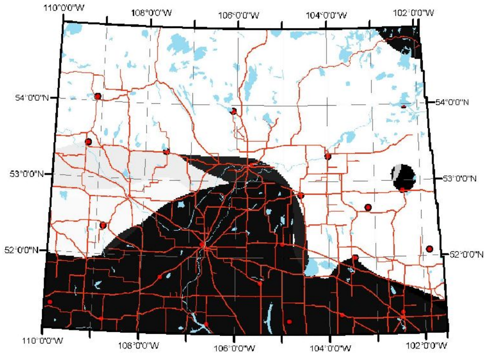
Training Data



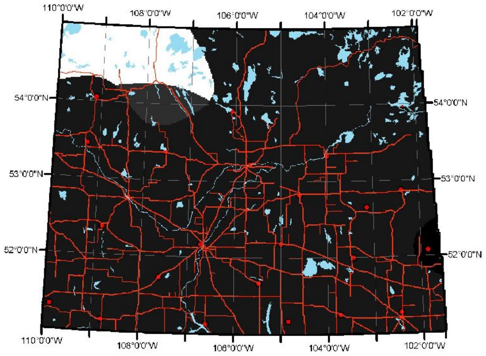
Current Period (1961-1990), modelled



2020 Period (2010-2029)

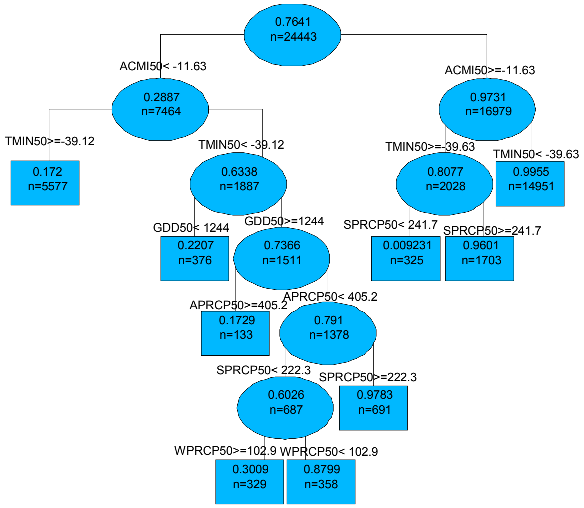


2080 Period (2070-2099)

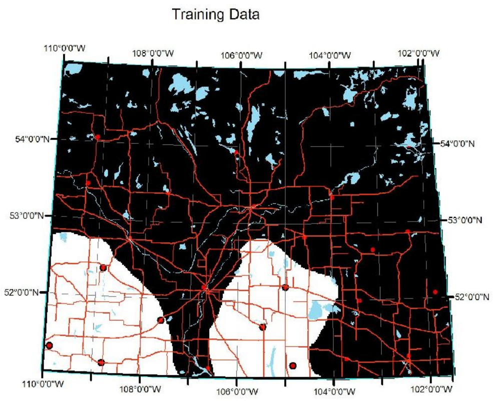


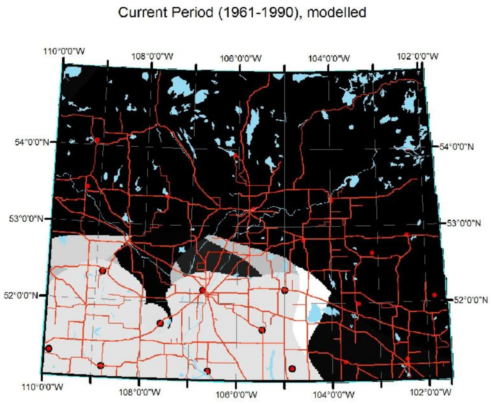
Populus tremuloides

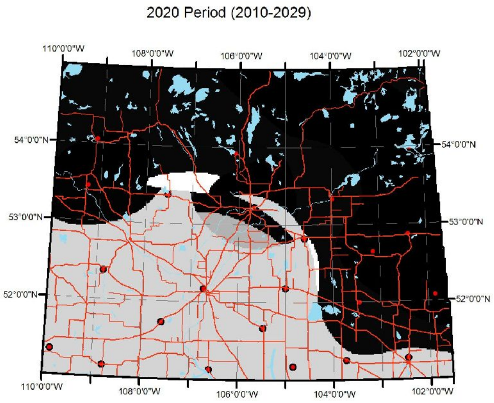
RPart Decision Tree

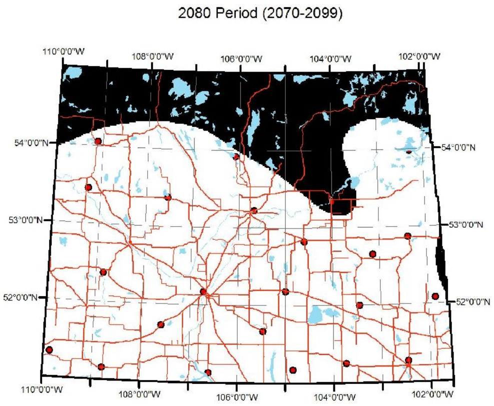


Range


Training Data

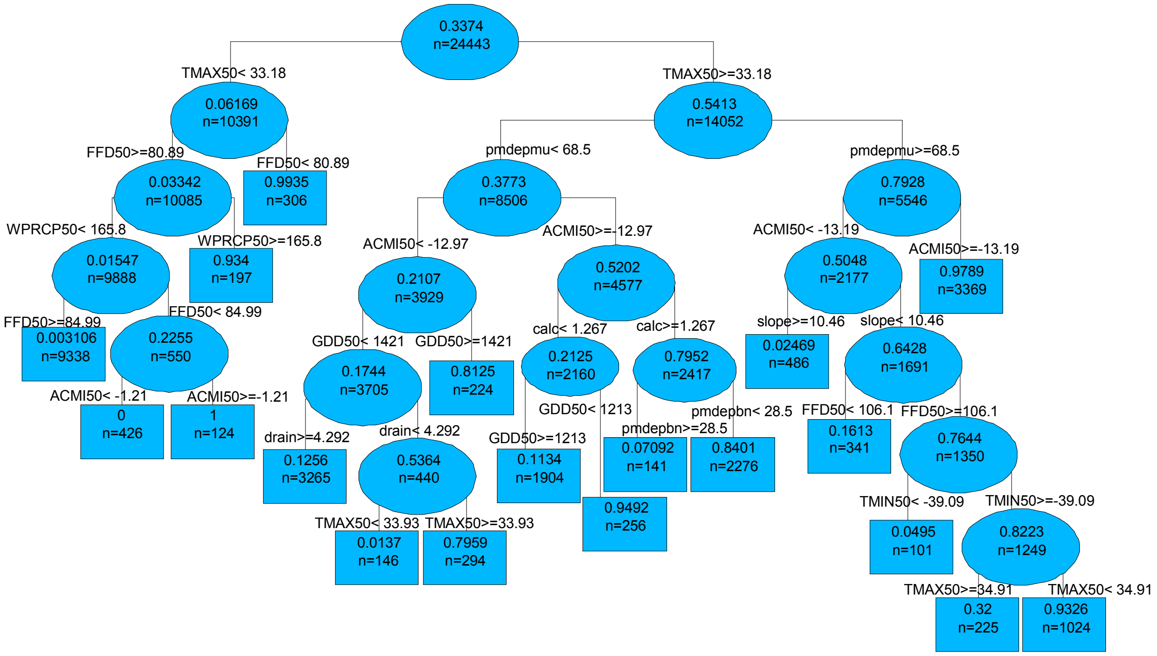

Current Period (1961-1990), modelled


2020 Period (2010-2029)


2080 Period (2070-2099)

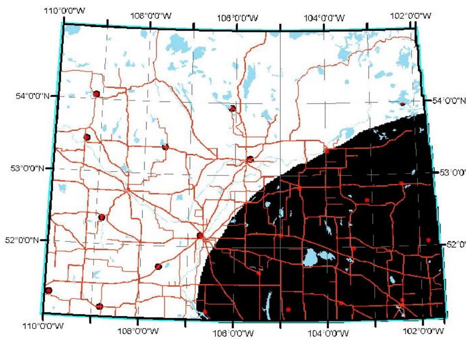
Ulmus americana

RPart Decision Tree

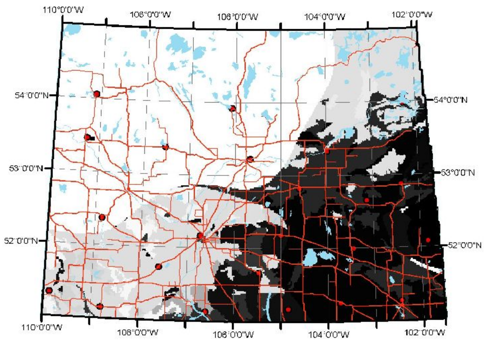


Range

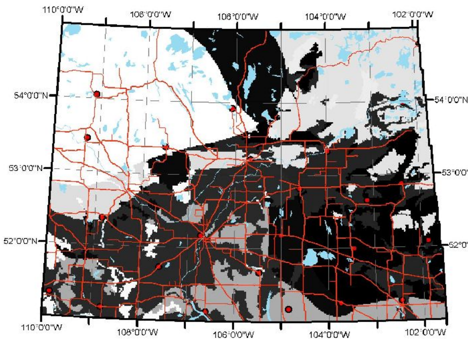
Training Data



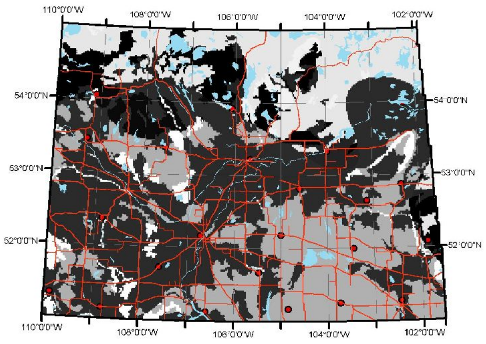
Current Period (1961-1990), modelled



2020 Period (2010-2029)



2080 Period (2070-2099)



Appendix 4 - Analysis of Tree Species not Presently Found in Study Area

This appendix shows the individual non-resident species' range predictions and the decision tree which drives those predictions.

The decision tree shows the recursive partitioning scheme. The ovals are parent nodes, while the rectangles are terminal nodes. The line drawn between the parent node and a child node is labelled with the decision that takes a pixel down toward that node.

The mean represents the mean value of pixels at that node. A “1” (black on the map) represents pixels in the training data that are inside the range polygon. A “0” (white on the map) represents a pixel not in the training range polygon.

The set of range prediction figures show three representations of tree range. The top right shows a prediction based on the decision tree, using predicted climate data for the historic period. The other two representations of range (2020 and 2080) are developed from the same source data, except using the appropriate projected climate data.

These range suggestions are based on opinion, silvics information and a judgement based on knowledge found in the literature, and from knowledge of plantings known to the project team. These decision trees are either based on similar species, or are derived purely from the literature. These range suggestions are only suggestions – they are not based on real range data within the study area.

The species represented in this appendix are not presently naturally found in the study area although some may be found in the study area as plantings.

Larix sibirica

The natural range of *Larix sibirica* in Eurasia is from between 60 ° E and 85 ° E at its northern extent (70 ° N) and between 85 ° E and 117 ° E at its southern extent (48 N) (Abaimov *et al.* 1998). It was introduced to Saskatchewan in 1906 at Indian Head. Originally introduced as a woodlot tree, it recently has received greater interest as a field shelterbelt tree (Prairie Farm Rehabilitation Administration 2002). The latitudinal range completely encompasses Saskatchewan and our study area. As a result, the rpart decision tree for Siberian larch is based on *L. Laricina*, but modified according to Siberian larch's greater percieved drought tolerance as evidenced from its past and current use in shelterbelts in southern Saskatchewan and North Dakota.

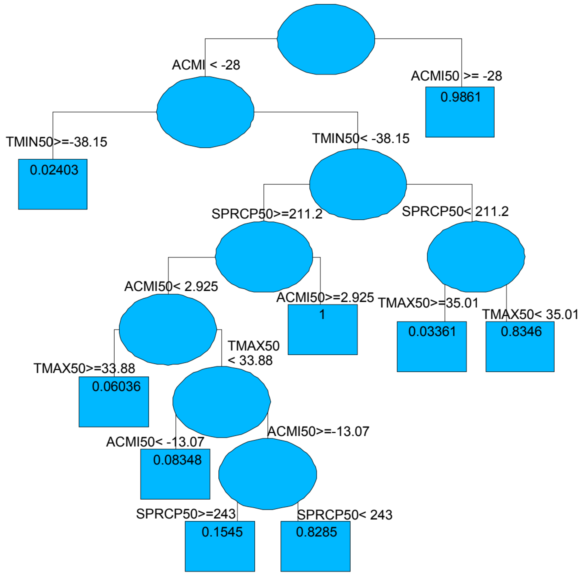
Abaimov, A.P., J.A. Lesinski, O. Martinsson and L.I. Milyutin.

1998. Variability and ecology of Siberian larch species. Swedish

University of Agricultural Sciences, Department of Silviculture, Umea. Rep. No. 43.

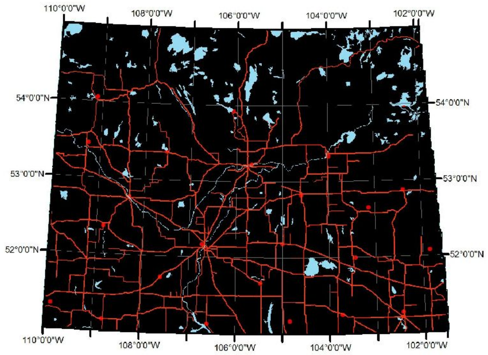
Prairie Farm Rehabilitation Administration. 2002. Siberian Larch (*Larix sibirica*). Retrieved June 4 2004 from http://www.agr.gc.ca/pfra/shelterbelt/shbpub27.htm

RPart Decision Tree

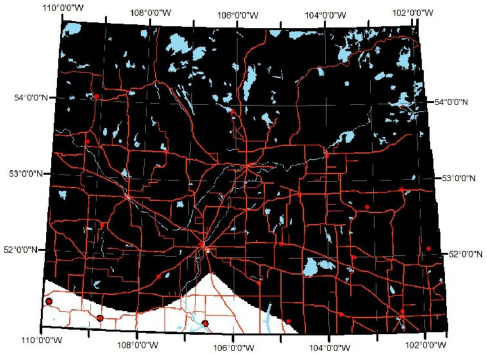


Range

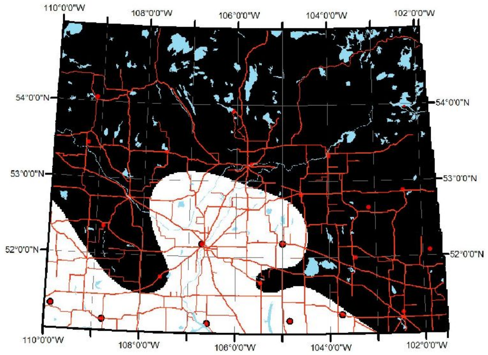
Current Period (1961-1990), modelled



2020 Period (2010-2029)



2080 Period (2070-2099)



Picea pungens

Although the natural range of blue spruce is limited to the central and southern Rocky Mountains of the western United States (Fechner 1990) and an outlier population in north-central Montana near the Alberta border (Strong 1978), it has been established successfully as an ornamental in cities throughout Canada and has shown a tolerance for environmental conditions not common in its natural range.

Goor and Barney (1976) state that the ability of blue spruce to withstand drought is superior to any other spruce so it is unlikely that moisture in itself is a factor limiting blue spruce's range. Temperature does not seem to be a sole factor limiting the survival of blue spruce beyond its natural range either. Blue spruce is known to survive as a planted ornamental at the 54th parallel in Saskatchewan where the extreme minimum January temperature is approximately -47 C and the January average daily minimum temperature is -23.3; roughly 10 degrees C lower than lowest mean Janurary minimum temperature of -11.1 C reported for Colorado (Fechner 1990). It is reported that blue spruce can weather extremely low temperaures (-40 C) and withstand high insolation and frost damage better than other species it grows with (Fechner 1990). Cram (1966) reported that although growth was inferior, survival of blue spruce was better than white spruce in 1908 and 1910 plantations at Indian Head, SK. Seedling progenies grown from seed collected from twenty-one vigorous trees selected from these 1908 to 1910 plantings and three Sutherland Nursery collections was sown in 1949 at Indian Head in a bareroot seedbed and transplanted in 1952 to adjacent beds. Randomly selected individuals from each of the 24 families was field planted in 1954. The upper-25th-percentile average height (by family) of the 13-year-old trees in this field planting was 148 centimetres (Cram 1983), not bad considering they had been transplanted twice.

Seed production in blue spruce begins at about 20 years (Vines 1960) and is considered to be good to prolific, with a consistent full crop every 2 to 3 years (Safford 1974). Fecundity, therefore, does not appear to be a limitation to movement of this species. In fact, blue spruce appears to have a greater capacity for sustained seed production than the white spruce native to the study area. Blue spruce seed does not require cold stratification and can germinate under a wide range of tempereatures, with or without light (Heit 1961). An exposed mineral soil seedbed with side shade appears to be one of the most important requirements for natural regeneration of this species (Sudworth 1916) which is also dependent on adequate precipitation (Jones 1974).

The use of TMIN50>-40 as the benchmark identifying a suitable environment for blue spruce is supported by the survival of several individuals approximately 30-years-old in Candle Lake, Saskatchewan near the 54th parallel. However, the current line of survivability is obviously farther north sugggesting that a data collection effort to determine presence in northern towns and structured test plantings of suitable provenance sources could be of value in determining the true hardiness of this species.

Cram, W.H. 1966. Performance of coniferous plantings at Indian Head. Rept. Ornamentals Comm., Proc. West. Can. Soc. Hort. Pp.83-85

Cram, W.H. 1983. Performance of seedling progenies of *Picea pungens* in southern Saskatchewan. For. Chron. 59(3):146-147.

Fechner, G.H. 1990. Blue spruce, *in* Burns, R.M. and B.H. Honkala (tech. coords.), Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654.
U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p

Goor, A.Y. and C.W. Barney. 1976. Forest tree planting in and zones. Ronald Press, New York. 504 p.

Heit, C. E. 1961. Laboratory germination and recommended testing methods for 16 spruce *(Picea)* species. Proceedings of the Association of Official Seed Analysts 51:165-171.

Jones, John R. 1974. A spot seeding trial with southwestern white pine and blue spruce. USDA Forest Service, Research Note RM-265. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 7 p.

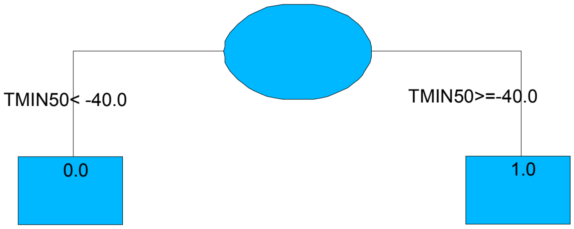
Safford, L. 0. 1974. Picea A. Dietr. Spruce. In Seeds of woody plants in the United States. p. 587-597. C. S. Schopmeyer, tech. coord. U.S. Department of Agriculture, Agriculture Handbook 450. Washington, DC.

Strong, W. L. 1978. Evidence of Picea pungens in north-central Montana and its significance. Canadian Journal of Botany 56(9):1118-1121.

Sudworth, George B. 1916. The spruce and balsam fir trees of the Rocky Mountain region. U.S. Department of Agriculture, Bulletin 327. Washington, DC. 43 p.

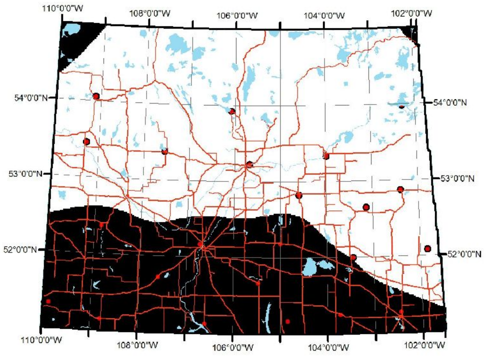
Vines, Robert A. 1960. Trees, shrubs and woody vines of the Southwest. University of Texas Press, Austin. 1104 p.

RPart Decision Tree

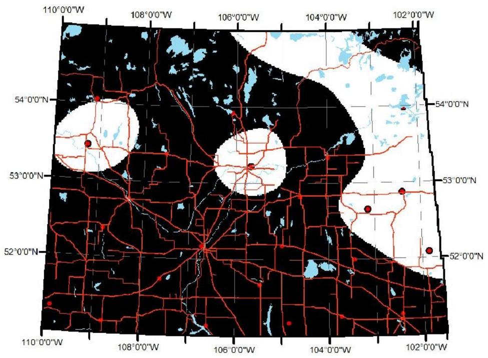


Range

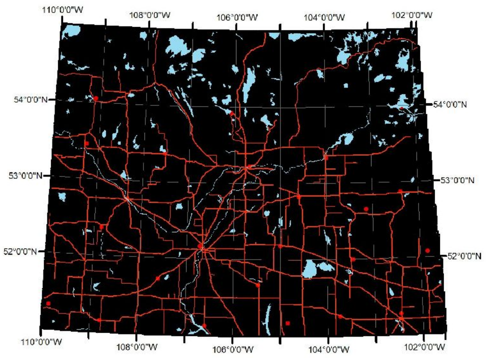
Current Period (1961-1990), modelled



2020 Period (2010-2029)



2080 Period (2070-2099)



Pinus contorta

The decision tree for *Pinus contorta* is based on the decision tree of *Pinus banksiana*.

Lodgepole pine has a wide ecological amplitude. Lodgepole pine is found in areas where minimum temperatures range from 7 C to -57 C and where maximum temperatures range from 27 C to over 38 C (Lotan and Critchfield 1990). Lodgepole pine seedlings are somewhat immune to frost injury (Lotan and Perry 1983). Snowfall provides most of the soil moisture for rapid growth of new germinants in spring and early summer. Lodgepole pine prefers moist soils but not drier calcareous soils. When it is the only species capable of growing in a given environment, such as on cool, dry, poor sites, it is a self-perpetuating climax species (Lotan and Critchfield 1990).

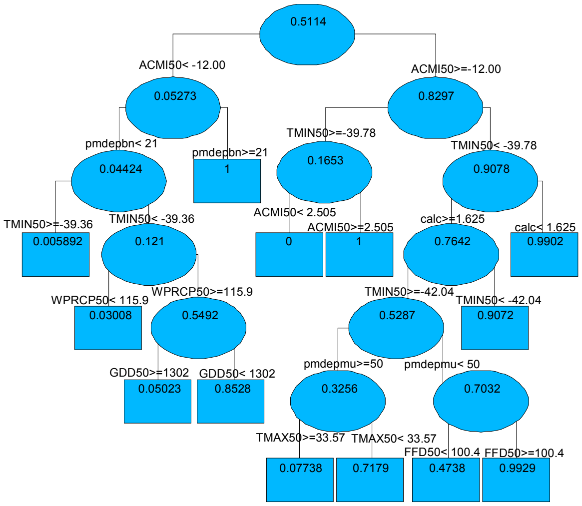
Seed production generally starts at between 5-10 years in persistent and serotinous cones that accumulate for decades until the next stand replacing fire. Mortality among first-year seedlings is primarily due to drought but is greatest on soils with duff and litter and those with low water holding capacity (Lotan and Critchfield 1990). The huge number of seed produced and stored in persistent serotinous cones provides a larger chance that some seeds will fall and germinate on safe sites to and persist. Soil surface temperatures higher than 60 C can be tolerated by first year germinants that are at least 2 to 4 weeks old (Cochran 1969).

Although not a natural resident of the study area, lodgepole pine occurs naturally in the Cypress Hills in southwestern Saskatchewan. In the study area, it has survived and grown relatively well in block plantings in the Nisbet (1930’s) and Fort la Corne (1940’s and 50’s) forests west and east of Prince Albert, respectively.

Cochran, P. H. 1969. Thermal properties and surface temperatures of seedbeds: a guide for foresters. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR. 19 p.

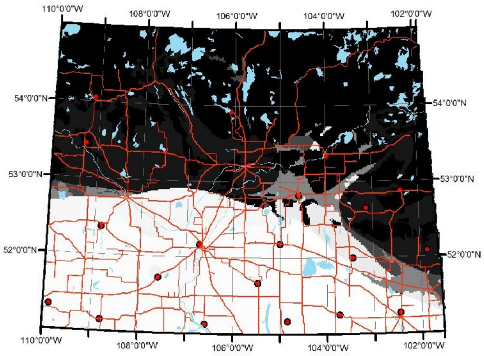
Lotan, J.E. and W.B. Critchfield. 1990. Lodgepole pine, *in* Burns, R.M. and B.H. Honkala (tech. coords.), Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 pp.

RPart Decision Tree

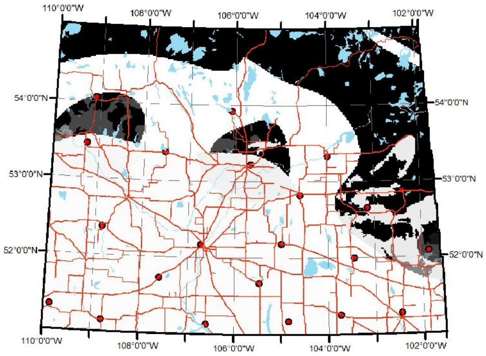


Range

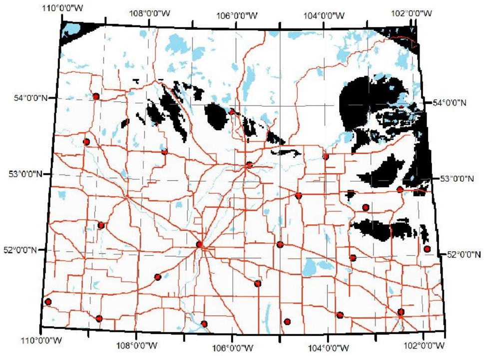
Current Period (1961-1990), modelled



2020 Period (2010-2029)



2080 Period (2070-2099)



Pinus nigra

European black pine is native to Europe but has been planted in the United States either as an ornamental or shelterbelt tree since 1759 (Rehder 1940). Currently, black pine is hardy in southern Ontario and New England, the north central United states, and in parts of the west, and is reported to have becom naturalised in parts of New England and the Lake States (York and Littlefield 1942).

Northern European varieties of the species are very frost-hardy, withstanding temperature minima of -30 C (Van Haverbeke 1990). Provenance trials in cold regions of the United States have regularly found that eastern European sources (primarily from Austria) are much more cold-tolerant than western sources (Lee 1968, Wheeler *et al*. 1976).

Saskatchewan soils do not appear to be a barrier to suitability of European black pine. Good growth is realised on sandy loams, silty clays, and calcareous soils. In the Great Plains of the United States it is planted on soils of the orders Aridisols, Entisols, Mollisols, and Vertisols. European black pine has the ability to withstand drought and as a result has been planted in cold, semi-arid, exposed areas and on light, dry sandy soils of low productivity. It is similar to pondersoa pine in its adaptability to windbreak and shelterbelt sites on the Great Plains. Regardless of soil type, deep, permeable and well-drained soils result in better survival, height, vigor and crown development in the Great Plains (Van Haverbeke 1990).

European black pine is not adapted to frequent crown fires because it lacks cone serotiny. Rather, successful regeneration of European black pine following fire is similar to red pine and results from the ability of thick-barked individuals to withstand low-intensity ground fires (Tapias *et al.* 2001; Tapias *et al.* 2004) and subsequently act as a seed source.

Lee, C. H. 1968. Geographic variation in European black pines. Silvae Genetica 17:165-172.

Rehder, A. 1940. Manual of cultivated trees and shrubs in North America. 2d ed. Macmillan, New York. 996 pp.

Tapias, R., L. Gil, P. Fuentes-Utrilla and J. A. Pardos. 2001. Canopy seed banks in Mediterranean pines of southeastern Spain: a comparison between Pinus halepensis Mill., P. pinaster Ait., P. nigra Arn. and P. pinea L. J. Ecol. 89: 629–638.

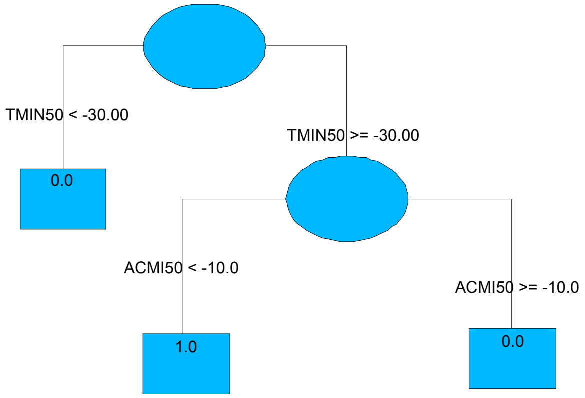
Tapias, R., J. Climent, J. A. Pardos and Luis Gil. 2004. Life histories of Mediterranean pines. Plant Ecol. 171: 53-68.

Van Haverbeke, D.F. 1990. European black pine, in Burns, R.M. and B.H. Honkala (tech. coords.), Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 pp.

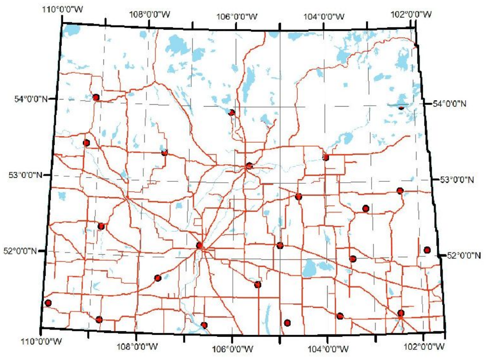
Wheeler, N. C., H. B. Kriebel, C. H. Lee. 1976. 15-year performance of European black pine in provenance tests in North Central United States. Silvae Genetica 25:1-6.

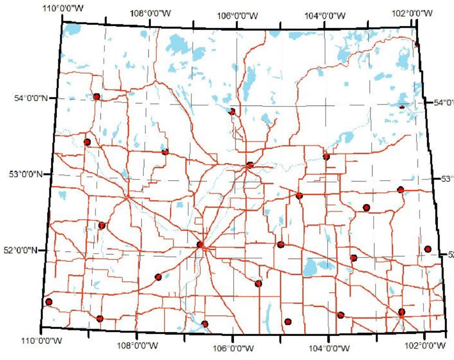
York, H. H. and E. W. Littlefield. 1942. The naturalization of Scotch pine, northeastern Oneida County. Journal of Forestry 40:552-559.

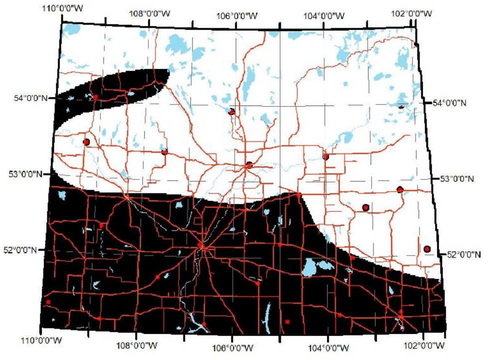
RPart Decision Tree



Range


Current Period (1961-1990), modelled


2020 Period (2010-2029)


2080 Period (2070-2099)

Pinus ponderosa

Ponderosa pine is absent from substantial pockets within its range including southwestern Montana, western Wyoming, southern Idaho, and part of the Great Basin (Critchfield *et al.* 1966). Steele *et al.* (1981) suggested that its establishment in these areas is prevented by poor timing of summer rainfall except at higher elevations where the shorter growing season becomes a limiting factor. Annual extreme temperatures in ponderosa pine's range are from -40 to 43 C (Oliver and Ryker 1990).

A provenance test in Michigan and one in northern Idaho show ponderosa pine's wide range of resistance to cold. In the Michigan study, two-year-old seedlings from California progenies experienced substantial damage from cold, while British Columbia, Washington, eastern Oregon, Arisona, and southern New Mexico provenances had minimal damage. Progenies from the rest of ponderosa pine's range experienced no damage (Wells 1964). The northern Idaho study reported similar results in 10- to 15-year-old trees (Wang 1977). In Saskatchewan, a ponderosa pine provenance test (Saskatchewan Environment internal report 1984) was established in 1977 at 3 locations; Crean River, MacDowall, and the South Branch Nursery. This test used provenances from North Dakota, South Dakota, Nebraska, Colorado, Montana, and Wyoming. Total annual precipitation at these locations ranged from 32 to 60 cm with growing season precipitation ranging from 24 to 41 cm. Growing season days ranged from 108 to 149. The elevation range of these provenances was between 701 m and 2438 m. The majority of the trees in the South Branch Nursery site suffered from winter dessication in 1982 and 1983. Currently, only two trees still survive at the this site and only one can be considered to have a tree form. The trees at the other two sites were below snow cover in both 1982 and 1983 and were unaffected by dessication. Information on their current status is unavailable. This information indicates that the harsh winter conditions that currently exist at the forest fringe in Saskatchewan are probably the limiting factor for this species' establishment in the study area. The combination of limited snow cover exposed the living cell tissue of pondersosa pine to the relatively strong dry winter winds and the extremely low winter temperatures of the study area. This result is supported by Oliver and Ryker (1990) who noted that older seedlings are usually hardy in severe winter temperatures but can be affected by winter desiccation under conditions of low temperature, drying winds and frozen ground. The short length of growing season at the provenance sites may also have been a factor limiting ponderosa pine ability to adequately prepare itself for the winter extremes at the test locations.

Since winter exposure appeared to have the greatest impact on the current performance of the ponderosa pine provenance test in Saskatchewan it made sense to use Tmin as a key factor in the Rpart decision tree.

Critchfield, W.B., and E.L. Little, Jr. 1966. Geographic distribution of the pines of the world. U.S. Department of Agriculture, Miscellaneous Publication 991. Washington, DC. 97 p.

Oliver, W.W. and R.A. Ryker. 1990. Ponderosa pine, *in* Burns, R.M. and B.H. Honkala (tech. coords.), Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p

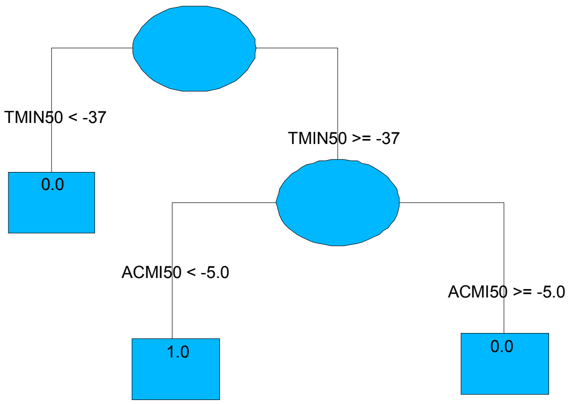
Saskatchwan Environment (internal report). 1984. Ponderosa pine provenance test at 3 Saskatchwan locations.

Steele, R, R.D. Pfister, R.A. Ryker and J.A. Kittams. 1981. Forest habitat types of central Idaho. USDA Forest Service, General Technical Report INT-114. Intermountain Forest and Range Experiment Station, Ogden, UT. 137 p.

Wang, Chi-Wu. 1977. Genetics of ponderosa pine. USDA Forest Service, Research Paper WO-34. Washington, DC. 24 p.

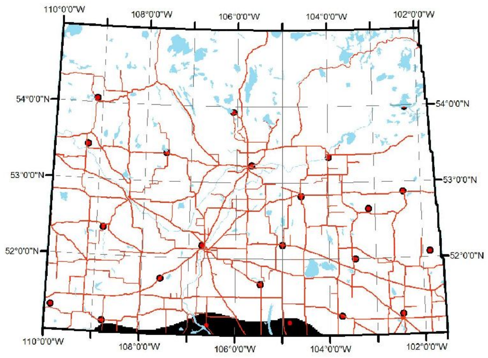
Wells, 0. 0. 1964. Geographical variation in ponderosa pine. 1. The ecotypes and their distribution. Silvae Genetics 13:89-103.

RPart Decision Tree

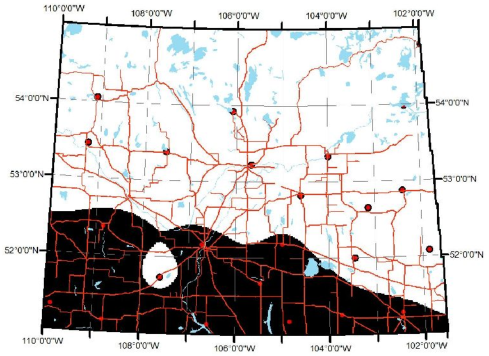


Range

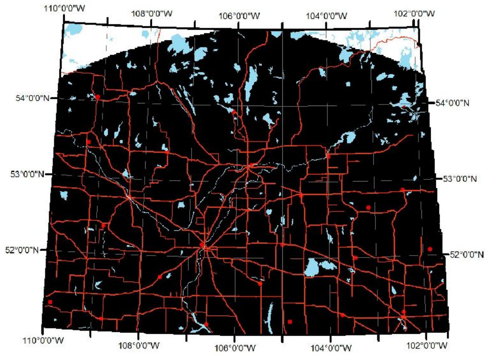
Current Period (1961-1990), modelled



2020 Period (2010-2029)



2080 Period (2070-2099)



Pinus resinosa

A review of literature by Sutton *et al.* (2002) suggested that a list of interelated factors such as climatic conditions, habitat availability, competition, fire regime, and random extinctions limit the range of Red Pine. In addition, the physical barrier of Lake Winnipeg and the rise in elevation west of the lake may have contributed to limiting natural range expansion to the northwest.

Natural stands of red pine are typically found on sandy, dry soils of low fertility and an acidic upper layer (25 cm). In its natural range it is commonly associated with jack pine on these sites (Rudolf 1990). Due to its close association with jack pine where their ranges overlap, the rpart decision tree is based on jack pine (*P. banksiana*).

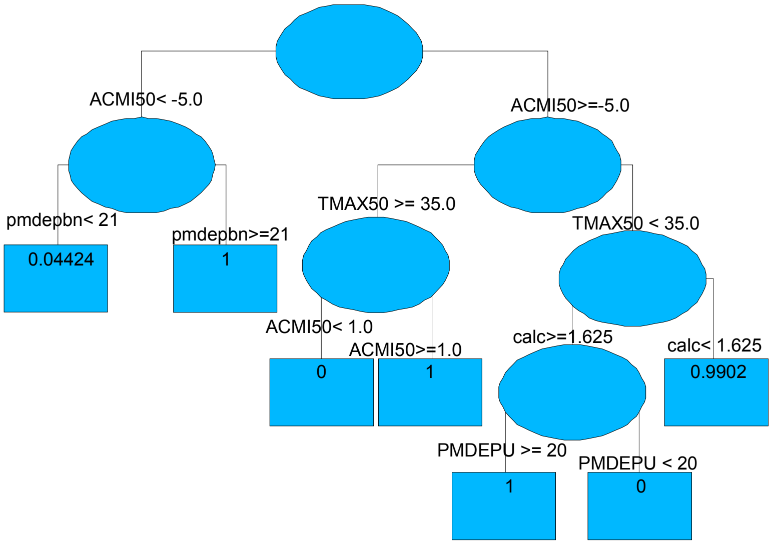
The northern limit of red pine is near the 2 C isotherm for mean annual temperature. The range of average January temperature in red pine's natural range is -18 to -4 C and the range of average July temperatures is 16 to 21 C. Average annual maximum temperatures range from 32 to 38 C and average annual minimum temperatures range from -23 to -40 C. The average growing season precipitation ranges from 380 to 640 mm (Rudolf 1990).

Summer surface fires that provide a suitable mineral soil seedbed free of excessive litter and competing vegetation are required for successful establishment of seedlings. Freedom from surface fires until the bark thickens is required to permit perpetuity of this species on a given site. In droughty or rainfall deficient conditions, seeds can remain in the soil seedbank for 1 to 3 years before germinating (Rudolf 1990), a condition that potentially can permit a longer window for establishment success on poorer sites.

Rudolf, P.O. 1990. Red pine, *in* Burns, R.M. and B.H. Honkala (tech. coords.), Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 pp.

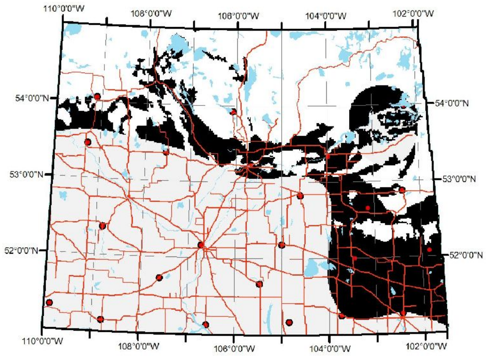
Sutton, R.J., R.J. Staniforth and J. Tardif. 2002. Reproductive ecology and allometry of red pine (*Pinus resinosa*) at the northwestern limit of its distribution range in Manitoba, Canada. Can. J. Bot. 80: 482-493.

RPart Decision Tree

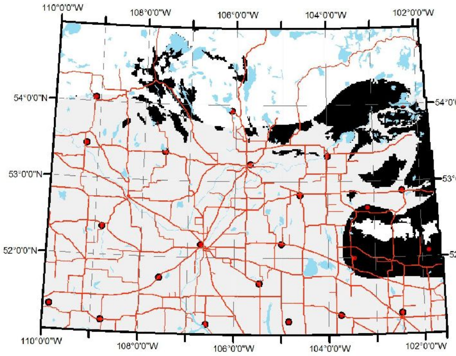


Range

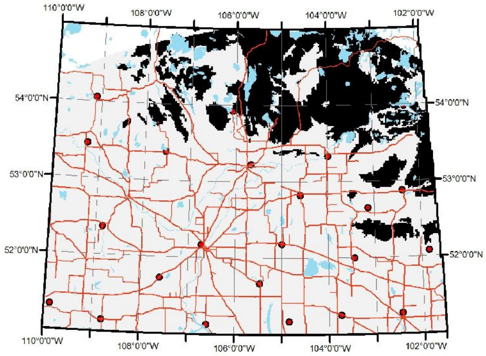
Current Period (1961-1990), modelled



2020 Period (2010-2029)



2080 Period (2070-2099)



Pinus sylvestris

Although not a natural resident of the study area, Scots pine has survived and grown relatively well farm shelterbelts and in block plantings in the Nisbet (1930's and 60's) and Fort la Corne (1940's and 50's) forests west and east of Prince Albert, respectively.

Among pines, Scots pine is the most widely distributed on earth. It has the capacity to grow on a wide variety of soils and due to its adaptation to a wide range of climate, in a latitudinal range from above the Arctic Circle to the Mediterranean. However, it is primarily a tree of continental climates. It grows in locations with annual precipitation down to 200mm and in areas with winter temperatures as low as -64 C (Skilling 1990). Scots pine grows on acidic soils with a pH of 4.0 to 7.0 (Skilling 1990). Consequently, it appears to perform well on sites in Saskatchewan that support jack pine.

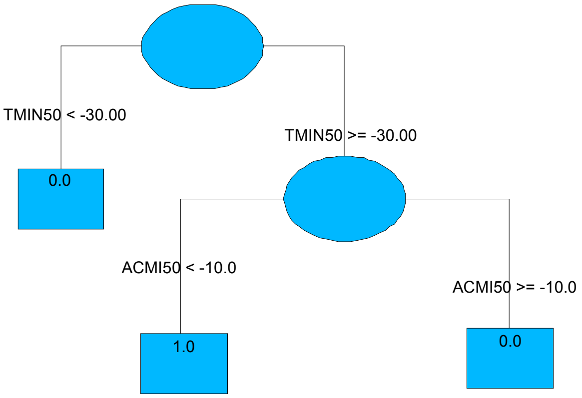
The ability of Scots pine to survive and grow to tree size in the more arid areas of Saskatchewan south of the study area and of the current forest fringe suggests an tolerance for drier conditions greater than that of jack pine. As a result, the rpart decision tree for this species was based on jack pine but with a lower ACMI50 value.

The ability of Scots pine to regenerate using a seed-tree or shelterwood silviculture system lends itself to the sandy sites typical of the forest fringe in the study area. This ability is expressed as a result of prolific seeding when the tree canopy is open, with a minimal ground vegetation layer, exposed mineral soil and a lack of a humus layer (Steven and Carlisle 1959).

Skilling, D.D. 1990. Scotch pine, in Burns, R.M. and B.H. Honkala (tech. coords.), Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 pp.

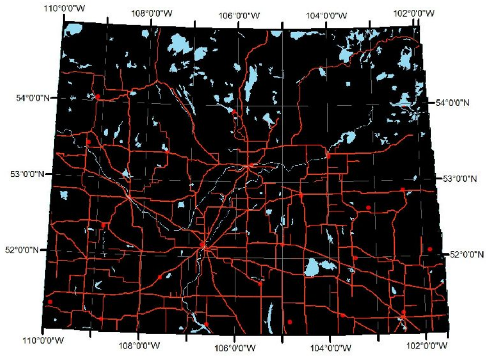
Steven, H.M. and A. Carlisle. 1959. The native pinewoods of Scotland. Oliver and Boyd Publications, Edinburgh. 368 pp.

RPart Decision Tree

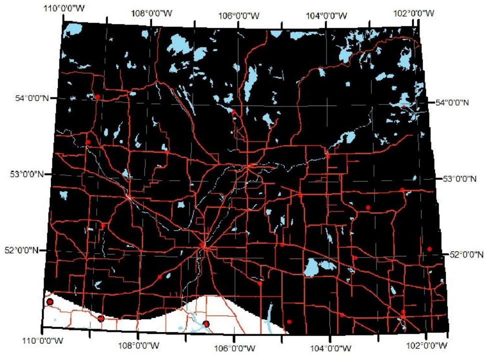


Range

Current Period (1961-1990), modelled



2020 Period (2010-2029)



2080 Period (2070-2099)