Identifying historical climate-growth limitations of white spruce (*Picea glauca)* populations across North America

by

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Abstract

Climate change may cause reduced forest productivity and higher tree mortality due to water deficits that result from increased evapotranspiration. Such limitations may occur in some areas of the North American boreal forest, where precipitation is low and warming trends are high. This thesis analyzes climatic factors that limit the growth of a commercially important and widespread boreal tree species, white spruce (*Picea glauca* (Moench) Voss), based on a range-wide dendroclimatological analysis of 9795 trees from 227 sample sites across the North American boreal forest. A bootstrapped response function analysis was conducted for monthly temperature and precipitation variables, and a multivariate regression tree analysis was used to group white spruce populations with similar response coefficients, where climatic factors explained 46% of the total variance in response coefficients. The results of this study shows that white spruce populations in the west-central boreal forest of North America are the most precipitation-limited group and therefore likely to be most susceptible to climate change. Populations both to the north and south of this group appear less vulnerable, and eastern populations generally do not experience growth-limiting moisture deficits. Given regional climate change projections, it is possible that declines of white spruce in the southwest and west-central boreal forest may be inevitable.

Preface

A version of this thesis has been published as "Hynes, A., Hamann, A. 2020. Moisture deficits limit growth of white spruce in the west-central boreal forest of North America. *Forest Ecology and Management* **461**: 117944. *https://doi.org/10.1016/j.foreco.2020.117944*". The study was conceived and designed by myself and AH. I assembled the database and conducted the analysis with input from AH. I wrote the first draft of the paper and AH contributed to editing the manuscript.

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1. Introduction

Northern forest ecosystems play a vital role in carbon sequestration and are a globally important carbon sink (Reinmann *et al.*, 2019). The ability of northern forests to regulate other natural cycles such as water cycles and climatic feedback loops makes them a crucial terrestrial ecosystem for preserving the ecological functions that leave way for many of the forest products and services we rely on in society. An increasingly important concern in particular is that northern forests will continue to experience hotter, drier conditions as climate change is anticipated to bring with it more frequent and intense climatic events. Studying and quantifying genetic adaptation to current and projected climatic conditions is imperative in order for forest managers to understand how species might respond to environmental stress (Hornoy *et al.*, 2015). Recent IPCC reports have indicated that regions in northern latitudes are experiencing more rapid warming than their southern counterparts, creating the impetus to study how climatic changes might affect northern tree species throughout their entire range (IPCC, 2014).

In the simplest of terms, in order for sustained and successful primary productivity to occur, plants require access to three biological factors: sunlight, water, and carbon dioxide (Landsberg and Sands, 2010). Though this seems easy enough to achieve, even with these three basic components satisfied, many additional nuanced and dynamic influences are at play that dictate how quickly a forest stand grows, which tree species thrive in certain areas, and how they respond to ongoing environmental changes. These additional parameters range from smaller site-specific conditions such as soil fertility, medium-scale stand dynamics such as inter-and-intraspecies competition, and larger-scaled regional influences such as gene flow and genetic adaptations to climate (Boisvenue and Running, 2006).

As this study focuses on how global climate change could affect the boreal forest across North America, a vast continental-scale forest that spans many ecological biomes, it is important to acknowledge that impacts on forest growth will inevitably include both regional and site-specific influences (Wiken, 1986). Specifically, growth-limiting climatic variables that directly influence annual tree growth will vary considerably over large spatial scales where climate change patterns are also anticipated to vary (Boisvenue and Running, 2006). A report conducted by Price *et al.* (2013) suggests that Aspen Parkland and Boreal Plains biomes could expect up to a 4.5°C increase in mean daily temperature during the growing season while northern biomes such as the Boreal Shield and the Hudson Plains could experience up to a 5.0°C increase during the summer. Given that over 600 million tree seedlings were planted across Canada in 2016 alone, having a deeper knowledge of which tree populations are already experiencing limited growth as a result of climate change can better guide our reforestation programs moving forward (Natural Resources Canada, 2018).

One way of analyzing how forest growth has been limited by climate over time is through the study of tree-rings, more formally known as dendrochronology. This non-destructive technique uses a sharp borer to extract a small wooden sample from the core of a tree for further analysis without the need of cutting down the tree (Natural Resources Canada, 2017). Wooden core samples reveal a great deal of paleoecological information regarding a tree's history, including the age of the tree, the climatic conditions it grew under through time, and the quality of the wood fibres. Fascinatingly, the scientific discovery that annual tree ring widths and climate are correlated with each other traces back to the early 20th century (Douglass, 1919). These correlations led to the study of dendroclimatology, where tree rings are studied to estimate climatic conditions of the past (Sheppard, 2010). This quantification of climatic influences on tree growth is a particularly important tool for forest managers as climate change projections consistently predict increased water stress through rising temperatures and lower annual precipitation over much of North America (IPCC, 2014). In boreal ecoregions today, where precipitation is already a limiting climatic variable on forest productivity, this could lead to increased tree mortality and a loss of suitable habitat for certain maladapted species.

1. Literature Review

2.1. The development of dendroclimatological analyses

Now that the general process of using dendrochronological records to estimate past climatic conditions and subsequent radial growth limitations has been introduced, it is time to explore the conditions that allow this type of analysis to take place. Dendrochronology is possible because tree-ring formation occurs with four distinct phases: cell division and expansion, the formation of multilayered cell walls, lignification, and cell death (Rossi *et al.*, 2006; Piermattei *et al.*, 2015; Savidge, 1996). At the beginning of a growing season, initial and undifferentiated cambial cells start to divide, producing large-diameter but thin-walled xylem cells called earlywood (Fritts, 1966). As the growing season progresses, thick-walled xylem cells that are smaller in diameter but darker in color are produced, hereby referred to as latewood (Fritts, 1966). These visual growth rings occur primarily in colder, temperate climates such as the boreal where distinct seasons give rise to clearly defined growth ring boundaries (Schweingruber, 1988). The delineation between earlywood and latewood is what is then used to analyze annual growth increments where many concentric rings are stacked together (Fritts, 1966). Through a process referred to as crossdating, these radial growth rings are compared, matching the variations in the wide and narrow rings to specific years in time where growing conditions limited or promoted growth (Speer, 2010).

An essential component of dendroclimatology is determining the signal-to-noise ratio where only the most relevant information is included in the analysis (Speer, 2010). As described by Speer (2010), changes in radial growth that resulted from random variation at the tree level, such as a neighboring tree dying and freeing up resources needed for increased growth, could obscure necessary stand-level information. In order to reduce the error probability that the rings of a single tree are not representative of the broader limited growing conditions of an entire site, replication is necessary, where variations in growth are supported by enough samples in a given area to produce statistical significance. Long-term biological factors such as age also affect the ring-width sizes, where radial growth naturally reduces as a tree matures. This additional variation, or noise, that is not specific to climatic influences needs to be reduced through a process of detrending and standardization to build stand-level tree ring chronologies (Fritts, 1966). With a large enough sample size, master chronologies can accurately produce growth “signatures” that encapsulate historical growth periods with a fine enough temporal resolution to describe the conditions of a particular growing season (Ambers, 2005).

These two processes apply a curve-fitting or smoothing function that removes short-term variations without losing important inter-annual and long-term signals (Schweingruber, 1988). This creates a detrended, dimensionless ring width indices with a mean of 1.0 that can be cross-dated with trees from the same site to then build master chronologies (Fritts, 1966). From here, the remaining patterns observed in the varying ring-widths of a stand indicate varying historical levels of temperature and water availability, allowing dendroclimatologists to then compare these growth patterns with historical climate data to make inferences on how productivity in that area has been limited by climate.

Applications of this technique across North America has revealed distinct patterns of precipitation and temperature-limited tree populations. For example, tree populations in the northeast likely receive annual precipitation levels high enough to outweigh the negative impacts of climatic warming under future climate change projections (D’Orangeville *et al.*, 2016). The mean annual precipitation (MAP) received in this part of the continent is more than double the amount that is normally received in central and western areas of North America, creating a strong east-west gradient for water availability (D’Orangeville *et al.*, 2016). Contrarily, various climate change studies have concluded that much of the western regions of North America are projected to see up to 5% in tree mortality per year as a result of regional warming and water stress (van Mantgem *et al.*, 2009; Birdsey & Pan, 2011; Peng *et al.*, 2011). Forests in the western Canadian interior are particularly vulnerable to drought when compared to their eastern and western coastal counterparts as dry, prairie-like conditions expand northward (Hogg and Bernier, 2005).

Based on these consistent findings, tree populations in areas that already experience more frequent periods of drought could be more at risk than populations where annual precipitation levels remain high. Therefore, the logical next step is to investigate whether these findings are consistent with historical growth data from a widespread and commercially valuable tree species: white spruce.

2.2. *White spruce as a dendroclimatological candidate*

White spruce (*Picea glauca* (Moench) Voss) is a shade-tolerant, late successional species that can currently be found throughout much of Canada. This common species also extends into Alaska, as well as north-central and northeastern parts of the United States (Canadian Forestry Service, 1971; Natural Resources Canada, 2015a). White spruce often thrives in later stand development stages as the overstory canopy is reduced from disturbance events or natural self-thinning processes (Gärtner *et al.*, 2011). It is formally known as a monoecious tree species, where both male and female flowers are borne on the same individual tree (Sutton, 1969). Standing at a height of up to 25 meters tall, this coniferous species has a dense, obtusely-rounded crown form with horizontal branches that gradually slope downward towards the base of the tree (Sutton, 1969). White spruce grows primarily in mesic to subhygric sites in a mixture of other boreal tree species such as trembling aspen, balsam fir, and white birch (Gärtner *et al.*, 2011; Natural Resources Canada, 2015b).

Ecologically, this tree species provides ideal habitat and food for a variety of terrestrial species. According to the Canadian Wildlife Federation, white spruce is a food source for many terrestrial avian and mammal species (CWF, 2019). Birds such as pine siskins, crossbills, nuthatches, and chickadees feed on the seeds. Game birds such as native grouse and small mammals such as red squirrels consume the early buds. Young shoots are often eaten by corvid and lagomorph species, while large predators such as black bears sometimes consume the bark. Climate change associated reductions in the geographical range of this tree species would inevitably affect all the animal species that rely on it also.

White spruce seeds are classified as “conditionally dormant”, where seeds remain ungerminated until ideal growing conditions are achieved (Nienstaedt and Zasada, 1990; Baskin and Baskin, 2004; Gärtner *et al.*, 2011). As exemplified by Kabzems *et al.*, (2016), natural white spruce regeneration is the most successful when grown under the moderated environment of an overstory tree species where an ideal microclimate is created to protect seedlings from prevailing winds and moisture-deficits. However, in the context of harvesting white spruce for wood products, this species often relies on artificial regeneration with the replanting of seedlings to ensure success (Sutton, 1969). I would like to emphasize this fact, because as we increasingly rely on planted forests to provide sustainable wood products, it is imperative to understand which climatic variables are limiting tree growth in particular regions to inform reforestation guidelines (Chang *et al.*, 2019). In general, a decrease in natural regeneration resulting from unfavorable environmental conditions has been observed westwards across its range due to higher chances of drought (Candy, 1951; Sutton, 1969; CCFM, 2009; D’Orangeville *et al.*, 2016). If seedlings are planted by the millions in the wrong areas, this could have devastating economic impacts.

Collectively, the forestry sector directly employs approximately 211,075 people across Canada, with many of these jobs occurring in rural areas (Natural Resources Canada, 2018). Within these rural areas, forestry is often the sole industry for many communities and Indigenous groups (Natural Resources Canada, 2018). In 2016, the forestry sector contributed approximately $23 billion to the national Gross Domestic Product, and to date, no other country in the world derives more net benefit from trading forest products than Canada (Natural Resources Canada, 2018). These economic statistics are important because white spruce is one of the most valuable boreal tree species and a key lumber export for the Canadian forestry sector. Accounting for approximately 26% of Canada's softwood growing stock, this species is sought after softwood lumber product due to its relatively low mass and high wood stiffness (Beaulieu *et al.*, 2006; Forintek Canada Corp, 2006; Sattler and Stewart, 2016). Products derived from white spruce are wide ranging and include structural materials for building construction, interior finishes, furniture, and pulp for packing boxes and cases (Beaulieu *et al.*, 2006). The versatility of this timber species, along with the socioeconomic implications of reductions in species distribution and productivity, fosters the need for further research on how to best mitigate the effects of climate change.

2.3. *Dendrochronological applications and limitations*

Though this species can tolerate a relatively wide spectrum of climatic conditions, white spruce is often limited by drought in the southern portion of its range (Gärtner *et al.*, 2011). In fact, recent growth reductions have already been linked to late-20th century warming (Jacoby and D'Arrigo, 1995; Porter and Pisaric, 2011). Highly vulnerable areas such as those in ecological transition zones are perceived to be most at risk to future climate change because white spruce growing in these regions are often at the limit of their environmental tolerance (CCFM, 2009). Using species distribution modelling, Hamann and Wang (2006) discovered that white spruce could potentially lose a significant portion of its suitable habitat and current frequency in British Columbia by applying a classical CGCM1gax general circulation model. This model was based on a moderate prediction of climate change variables when compared to the range of other IS92a scenarios, making the implications of these findings potentially significant.

Chhin *et al.* (2004) associated reduced radial growth to historical drought events in the prairies of Canada and the Great Plains of the United States. Similarly, dendroclimatic analyses of spruce in the western Canadian interior concluded that climatic drying and drought conditions over the last 20 years have significantly impacted the growth of white spruce in this region (Chen *et al.*, 2017; Hogg *et al.*, 2017; Hogg and Wein, 2005). Further north, white spruce populations in the interior of Alaska exhibited precipitation-limited growth (Lloyd *et al.*, 2013). Sang *et al.* (2019) found that western white spruce populations planted in a common garden experiment suffered substantial growth reductions, with similar behavior of all populations throughout the species range under severe drought conditions in this experiment.

Other considerations in addition to species distribution is how the rate of growth might affect adaptation over time. Previous studies studying the physiological responses of white spruce to heat exposure and drought conditions showed that families with superior growth performance were the most sensitive to these effects, implying that slower-growing white spruce families are the best adapted to drought (Bigras 2000; 2005). Other undesirable implications of fast-growing spruce genotypes is an increase in herbivory where carbon allocated to growth reduces defensive compounds (Olnes *et al.*, 2018). These differences among families and regions could provide a valuable insight on how variability between local white spruce populations could respond to multiple negative impacts associated with future climate change.

Therefore, it is imperative to determine which variables have been limiting the growth of white spruce over the last 100 years throughout its North American range in order to better prepare for the future. Because climate change projections predict an increase in evaporative demand driven by rising mean annual temperatures, this method could help predict which populations are particularly vulnerable in areas that are already experiencing a moisture deficit. Furthermore, these results could be informative to forest managers by creating a regional-scale understanding which climate variables are primarily controlling inter-annual variations in radial growth among white spruce populations.

This study will contribute a continental-scale analysis of white spruce response to climate by reanalyzing a comprehensive dataset from the International Tree Ring Data Bank (Grissino-Mayer and Fritts, 1997; Zhao *et al.*, 2018), a sample plot network of the Canadian Forest Service (Hogg *et al.*, 2017), and additional data from scientists who previously published regional dendrochronological studies with white spruce (Girardin *et al.*, 2016; Hogg *et al.*, 2017; Roy *et al.*, 2017; Lemus-Lauzon *et al.*, 2018). The research approach is a dendroclimatological response function analysis, where monthly historical climate data are correlated with interannual variation in radial growth. I will use a constrained cluster analysis to group individual chronologies according to similar response coefficients, with the groups being delineated by long-term climate conditions of the sample sites. The objective is to compare the climatic limitations of white spruce populations across broad macroclimatic regions of the North American boreal forest, and to identify populations that are most vulnerable to growth reductions or mortality under climate change.

2. Methods

3.1. Climate data

Climate data for North America were generated using the ClimateNA v5.10 software package based on the methodology described by Wang *et al.* (2016). These climate data were generated by interpolating historical weather station data using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) methodology (Daly *et al.*, 2008). This software was used to extract climate data for all white spruce chronology locations used in this study, including historical monthly data from 1901 to present to analyze interannual growth response to climate variation. In addition, 30-year (1961-1990) climate normal data were extracted to characterize the general climate conditions of sample sites. Also, future climate projections were generated based on 15 atmospheric-ocean general circulation models (AOGCMs) from the CMIP5 multimodel dataset. The AOGCMs CanESM2, ACCESS1.0, IPSL-CM5A-MR, MIROC5, MPI-ESM-LR, CCSM4, HadGEM2-ES, CNRM-CM5, CSIRO Mk 3.6, GFDL-CM3, INM-CM4, MRI-CGCM3, MIROC-ESM, CESM1-CAM5, GISS-E2R were chosen to represent all major clusters of similar AOGCMs by Knutti *et al.* (2013). All extractions of data for historical and future climate at chronology sites were carried out with the ClimateNA software package (Wang *et al.* 2016), available on-line at *http://tinyurl.com/ClimateNA*.

The following climate variables were used to characterize long term climate conditions: Mean Annual Temperature in units of °C (MAT); Mean Warmest Month Temperature in °C (MWMT); Mean Coldest Month Temperature in °C (MCMT); Mean Annual Precipitation in mm (MAP); Total Difference between MCMT and MWMT in °C (TD); May to September Precipitation in mm (MSP); Annual Heat-Moisture Index (AHM) calculated as (MAT+10)/(MAP/1000);

Summer Heat-Moisture Index (SHM) calculated as MWMT/(MSP/1000); Hargreaves Climatic Moisture Deficit (CMD) calculated as E_{ref}-PPT, representing the sum of the monthly difference between reference evaporation (E_{ref}) and precipitation (PPT) according to Wang *et al.* (2012); Degree Days below 0°C (DD<0); Degree Days above 5°C (DD>5); Frost-Free Period (FFP); Beginning of the Frost-Free Period (bFFP); End of the Frost-Free Period (eFFP); Extreme Minimum Temperature (EMT); Precipitation as Snow (PAS); and Number of Frost-Free Days (NFFD). For further details on the estimation of these climate variables, see Wang *et al.* (2016).

3.2. Tree-ring data

Tree-ring data for white spruce across North America were obtained from the International Tree-Ring Data Bank (ITRDB) (Grissino-Mayer and Fritts, 1997). I used a version of the database prepared by Zhao *et al.* (2018), where raw tree-ring data were collected and formatting issues were corrected. Additional raw tree-ring data were collected from researchers who previously published dendrochronological research with white spruce (Girardin *et al.*, 2016; Hogg *et al.*, 2017; Roy *et al.*, 2017; Lemus-Lauzon *et al.*, 2018). An additional source used to cross-reference master chronologies was Dendrobox, an interactive and exploratory tool to visualize tree-ring data available from the ITRDB (Zang, 2015). In total, white spruce chronology data were compiled for 9795 trees from 227 sample locations across the North American boreal forest (for details, refer to Table 1 in the Appendix).

Trees that experience drought or defoliation from insect pests can produce false or missing tree-rings (Keen, 1937; Evenden, 1940; O'Neil, 1963; Swetnam *et al.*, 1985). Therefore, individual chronologies from the same sample sites were cross-dated to identify and correct for missing and false rings. I then detrended the chronologies by fitting a smoothing spline to each ring-width series using a frequency response of 0.5 and a wavelength of 0.67 for all chronologies, dividing the actual ring-width by each yearly value of the fitted growth curve (Fritts, 1966). Detrending was implemented with the *dplR* package (Bunn, 2008) for the R programming environment (R Core Team, 2018). The resulting dimensionless ring-width indices were then averaged with other trees from the same sample location to build a master chronology for each white spruce site (Cook & Peters, 1997), also implemented with the *dplR* package. This resulted in a total of 227 master chronologies with an average expressed population signal of 0.88 and a mean of 43 trees per chronology that were used for further dendroclimatological analysis (for detailed statistics on inter-series correlations and expressed population signal for each chronology, see Table 1 in the Appendix).

3.3. Analysis of climate-growth associations

I tested mean monthly temperature and precipitation variables from June of the previous year to September of the current year as predictor variables for standardized annual growth increments from 1901 to 2001. Climate variables from the previous growing season and winter months can be important to incorporate into the model because legacy growing conditions can influence tree growth the following year (Fritts, 1966; Swetnam, 1985). For the response function analysis, indirect regression techniques aim to mitigate predictor multicollinearity by regressing the annual growth measurements against the principal components of the climate data, where the principal components with the smallest variances are discarded (Bondi and Waikul, 2004, Zang and Bondi, 2013). Statistical significance of growth-climate relationships was tested through bootstrapping, generating a distribution of response coefficients through subsampling the chronology data with 1000 iterations. Coefficients that did not include zero within the 95% confidence interval of the distribution were regarded as statistically significant. All the above analysis was implemented with the *treeclim* package (Zang, 2015) for the R Programming Environment (R Core Team, 2018).

3.4. Constrained clustering of chronologies

I used a multivariate regression tree (MRT) analysis in order to group chronologies based on the similarity in their response coefficients to monthly climate, but using long-term average climate conditions of the chronology sites as partitioning criteria to arrive at groups that are interpretable as macroclimatic regions. MRT minimizes the variance in multiple response variables (here, coefficients from the response function analysis described above), using multiple predictor variables as grouping criteria (here, 30-year normal climate variables) in a recursive binary partitioning algorithm (Ouellette *et al.*, 2012). MRT is a constrained clustering method where splitting the data at the initial node explains most of the variance and maximizes homogeneity of the response variables within groups (De'Ath, 2002).

For the groups of chronologies resulting from the MRT, average monthly climate data for the 1961-1990 normal period were used to generate Walter and Lieth climate diagrams (Walter and Lieth, 1969) with the R package *climatol* (Guijarro, 2018). The diagrams were created for each group of chronologies generated by the multivariate regression tree analysis to interpret monthly response coefficients in light of long-term average climate conditions, i.e. the environment to which tree populations are putatively adapted.

3. Results

4.1. Grouping of chronology sites

The multivariate regression tree analysis produced six groups that explained 46% of the variance in monthly response function coefficients among chronologies (Fig. 1). According to their approximate geographic location, I will hereby label these groups Northwest, North-central, Northeast, Southwest, West-central, and East-central (Fig. 2). The first split (Node #1), explaining 13% of the variance in response coefficients, created a roughly diagonal separation of the species range into samples comprising the southwest and west-central populations versus all other groups (Table 1).

Table 1. Alternative auto-correlated climate variables that could be used in the multivariate regression tree analysis in Fig. 2 to delineate regional chronology groups.

Alternative climate variables	Value (right side)
Node #1	
Degree days above 5˚C	≥ 894
Mean annual temperature (˚C)	≥ –2.3
Annual heat moisture index	≥ 15
Node #2	
Beginning of frost-free period (day)	< 154
Frost-free period (days)	≥ 103
Node #3	
End of frost-free period (day)	< 245
Node #4	
No alternative variable	
Node #5	
Degree days below 0˚C	≥ 2241

This split was based on the number of frost-free days, or alternatively could also be made using growing degree days, mean annual temperature, or the annual heat moisture index. Thus, the primary split describes groups with response functions unique to warmer and drier environments with a longer growing season in the southwestern portion of the species range. The second split explained 10.7% of the variance in response coefficients and created the north-central group based on the mean coldest monthly temperature being below -27.1˚C or alternatively variables that indicate a short frost-free period (Table 1), i.e., this group is characterized by winter length and severity.

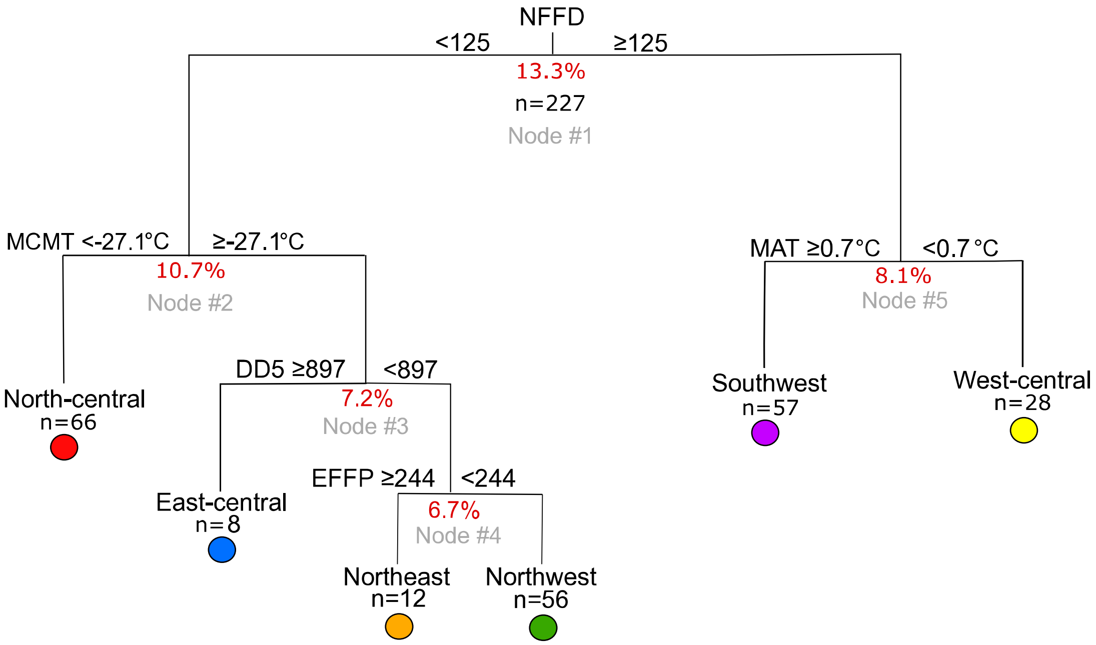

Figure 1. Multivariate regression tree analysis of 277 chronology sites, where six groups with similar dendrochronological response functions are delineated based on climate normal conditions at each site. The climate variables chosen by the MRT algorithm include: NFFD (number of frost-free days); MCMT (mean coldest month temperature); DD>5 (degree days above 5°C); EFFP (end of the frost-free period); and MAT (mean annual temperature). Each node shows the percentage of variance in response coefficients explained in red.

The third and fourth split resulted in east-central, northwest, and northeastern groups based on growing degree days and growing season length. Split 5 further partitions the warm and dry portion of the species range created by the first split accounting for 8.1% of the variance, where the southwest group is distinguished from the west-central group by the warmest mean annual temperatures or the highest growing degree days (Fig 3, Table 1). Overall, the regression tree clustering partitioned groups primarily by variables that describe temperature and growing season length conditions. Variables describing drought conditions only occur once as alternative auto-correlated climate variable for the first split (Table 1), which would create the same or near identical groups as number of frost-free days (Fig 2, Node 1).

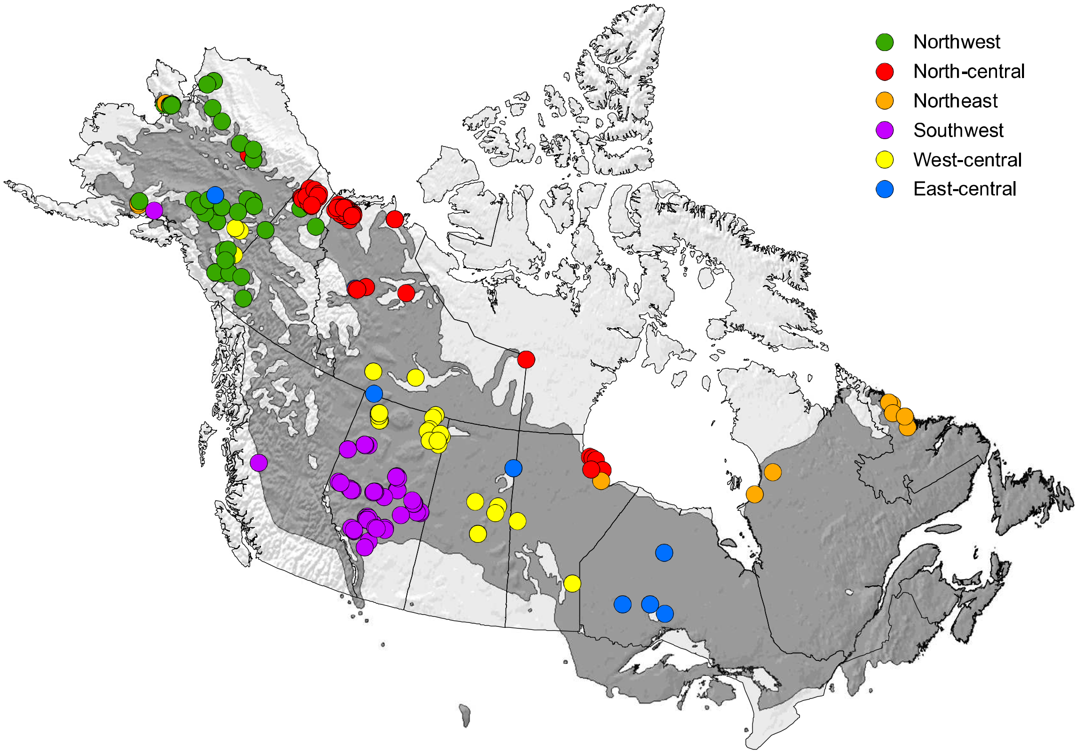

Figure 2. The location of each white spruce chronology used in this study grouped into regions with similar climate and growth response coefficients by a multivariate regression tree analysis (Fig 1). The dark grey area represents the species range of white spruce.

4.2. Climate of chronology groups

Walter and Leith climate diagrams (Fig. 3) and additional climate variables (Table 2) for the six groups produced by the multivariate regression tree analysis provide a more comprehensive characterization of seasonal and annual climatic conditions. Overall, average annual temperatures between the six groups varied by approximately 10°C (Table 2). The lowest temperatures occurred in the north-central group, and the highest average annual temperature was in the southwest group, making this region the only one to have mean annual temperature above freezing (Table 2).

Table 2. Climate normals (1961-1990) for biologically relevant climate variables for six chronology groups. Climate variables include: MAT, mean annual temperature; MWMT, mean warmest month temperature; MCMT, mean coldest month temperature; MAP, mean annual precipitation; MSP, May to September precipitation; AHM, annual heat moisture index; SHM, summer heat moisture index; CMD, climate moisture deficit; DD>0, degree-days above 0˚C; DD>5, degree-days above 5˚C; and FFP, frost-free period.

Group	MAT (˚C)	MWMT (˚C)	MCMT (˚C)	MAP (mm)	MSP (mm)	CMD (mm)	AHM (˚C/m)	SHM (˚C/m)	DD>0	DD>5	FFP (days)
Northwest	-4.8	12.4	-20.3	536	333	87	11.7	44.8	3032	6445	83
North-central	-8.9	12.9	-28.8	257	152	133	3.7	90.2	4380	609	71
Northeast	-3.7	10.9	-19.3	747	353	29	8.6	31.6	2524	525	70
Southwest	1.4	14.9	-23.0	551	366	125	21.3	42.2	1572	1158	101
West-central	-1.9	16.3	-23.4	408	254	184	20.2	66.8	2682	1167	99
East-central	-2.6	15.5	-23.3	581	347	108	13.8	47.8	2818	991	88

The Walter and Lieth climate diagrams show that the southwest and the west-central groups have the longest and warmest growing seasons for white spruce populations with 5 months above 0°C

(Fig. 3), about 100 days of continuous frost-free period, and more than 1000 growing degree days (Table 2), far exceeding the remaining groups. White spruce growing in the northwest and north-central groups have only 3 months above 0°C (Fig 3) and only about 70 days of continuous frost-free periods (Table 2). The remaining east-central groups are characterized by relatively high mean annual temperature and precipitation levels, and frost-free periods of 80-90 days (Fig. 3).

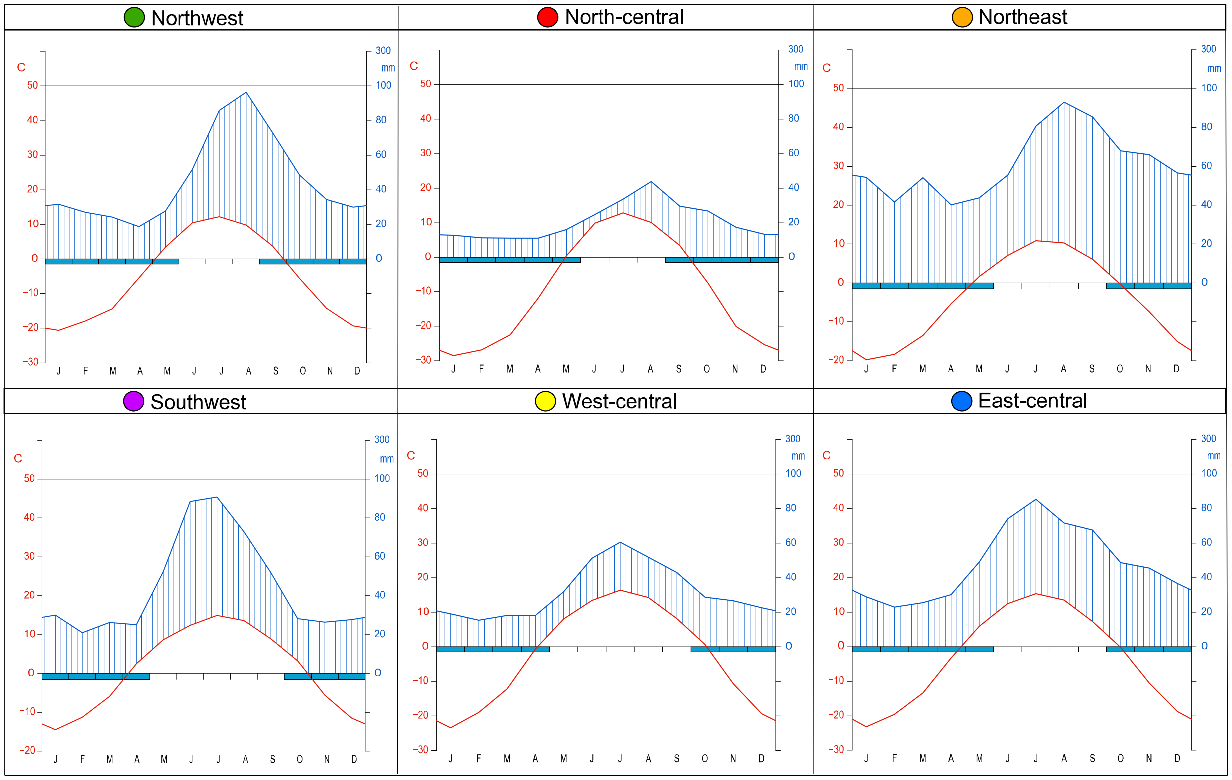

Figure 3. Walter and Lieth climate diagrams for each of the six chronology groups. The blue y-axis and related lines represent average precipitation (mm) received in that region from 1901-2001. The red y-axis represents the average temperature (°C) recorded over the same 100-year time series. The dark blue horizontal bars indicate months with freezing temperatures.

Drought conditions arise in areas where the interplay between temperature and precipitation result in moisture deficits. A useful metric to assess drought risk in addition to temperature and precipitation levels is Hargreave’s climate moisture deficit (CMD). Here, evapotranspirative demand relative to precipitation is expressed in mm, where higher CMD values indicate a larger moisture deficit. These results show the highest moisture deficits were present in the west-central group (Table 2). Moisture deficits were substantially smaller for populations both north and south of the west-central group. Although the north-central group received the least precipitation, temperatures in this region are also low, reducing evapotranspirative demand. The north-central group does have the strongest summer drought condition as indicated by the summer heat moisture index (Table 2, SHM) and also visible in Fig 3. The highest amount of total annual precipitation was received in the northeast group, around 750 mm per year (Fig. 3), likely making this group the least susceptible to drought conditions with a SHM of 31.6 and a CMD of 30 mm.

4.3. Drought limited populations

Dendrochronological response coefficients also indicate that white spruce in the west-central group is the most sensitive to drought conditions, as indicated by their response to variations in monthly precipitation and temperature (Fig. 4). Radial tree growth was consistently negatively affected by years with high temperature or low precipitation across most months with the exception of July of the current year. Temperature increases during the previous growing season in particular caused a negative growth response. The west-central group also showed the highest number of statistically significant relationships between monthly precipitation variables and growth in individual chronologies (Table 3). Response coefficients for temperature were less consistently significant for this group, however.

In addition to the west-central group, the southwest chronology group also appears to be potentially vulnerable to drought. Response coefficients generally show similar magnitude and direction as the west-central group, although to a lesser degree and with fewer percentages of significant response coefficients. This group also deviates from the west-central group by generally preferring warmer temperatures during the current growing season, whereas the west-central group predominately showed a negative response to higher temperatures.

Table 3. The percent of significant growth-climate response coefficients in each chronology group. Significance for an individual chronology implies that the 95% confidence interval of the coefficient does not include zero. The gray scale highlights high percentages of significant coefficients in the group.

	Month of previous year							Month of current year								
Group	j	j	a	s	o	n	d	J	F	M	A	M	J	J	A	S
Precipitation																
Northwest	-	11	7.1	5.4	3.6	3.6	5.4	1.8	1.8	-	3.6	1.8	-	1.8	3.6	7.1
North-central	-	4.5	-	-	-	7.6	1.5	-	-	1.5	-	-	-	1.5	-	-
Northeast	8.3	-	-	-	-	8.3	8.3	8.3	-	-	-	-	-	-	-	-
Southwest	11	3.5	12	1.8	5.3	7	1.8	7	1.8	1.8	7	8.8	16	8.8	1.8	-
West-central	11	11	32	11	-	3.5	7.1	7.1	-	-	7.1	3.6	14	11	-	-
East-central	-	-	13	13	-	-	-	-	-	13	-	13	-	-	-	-
Temperature																
Northwest	14	38	-	-	8.9	29	5.4	3.6	3.6	-	8.9	13	66	5.4	-	-
North-central	3	58	-	-	9.1	1.5	-	7.6	1.5	1.5	7.6	4.5	33	6.1	-	-
Northeast	8.3	17	8.3	-	8.3	-	8.3	-	-	17	-	-	33	42	-	-
Southwest	7	-	5.3	-	11	1.8	-	3.5	1.8	1.8	1.8	1.8	3.5	11	1.8	7
West-central	3.4	-	3.4	14	3.4	3.4	-	3.4	-	3.4	3.4	3.4	6.9	10	-	-
East-central	13	-	13	-	-	-	-	-	-	-	13	13	-	-	13	-

The remaining populations do not generally appear to be drought limited. Coefficients between growth and precipitation for the northwest and east-central groups are variable, and for the north-central and northeast groups low precipitation values are generally associated with better growth. This is partially consistent with the climate for these regions. They either receive relatively large amounts of precipitation, or in the case of north-central group, the conditions are presumably too cold and growing seasons are too brief to respond negatively to increases in temperature (Fig 3, Table 2).

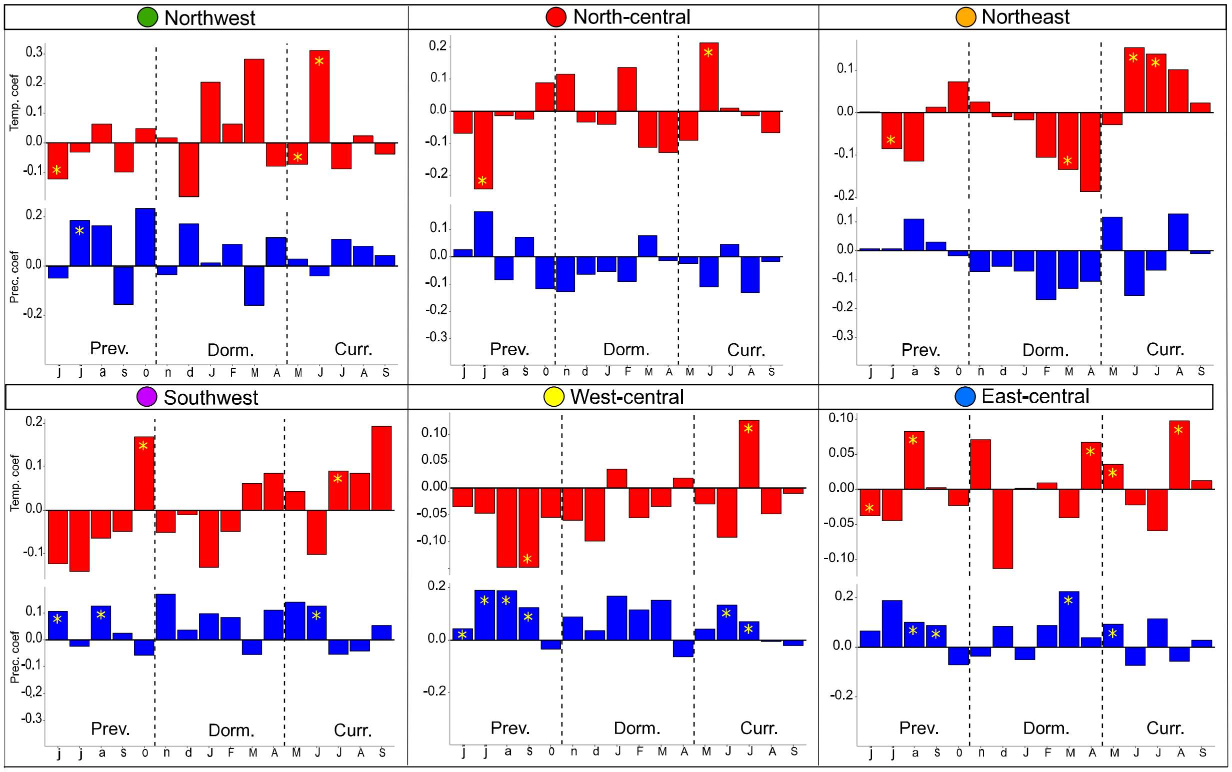

Figure 4. Average response coefficients for each chronology group, where negative or positive responses to precipitation and temperature are displayed for the previous, dormant, and current growing period. An asterisk denotes where more than 10% of individual chronologies showed a statistically significant growth response. Note that the y-axis scales differ among regions.

4.4. Temperature limited populations

All three northern populations (northwest, north-central and northeast), show a consistent positive response to temperature in June of the current growing season (Fig. 4). This is also the first month with temperatures above freezing for these three populations, indicating that an early start to the growing season due to warm temperatures is an essential condition to above average radial growth. Temperature response of these three northern populations to the previous dormancy period is variable. In the northwest, response to warm winter temperature was generally positive, in the north-central region neutral, and in the northeast negative. Given that the northeastern group received the most annual precipitation, more precipitation as snow in cold years may prevent an early spring thaw which could benefit growth. The northern populations generally had a large proportion of significant individual response coefficients for temperature variables, with some of the highest proportions of significant within-population responses found in some months (Table 3).

4. Discussion

5.1. Populations vulnerable to climate change

One important finding was that white spruce populations in the southwest and west-central boreal regions are precipitation-limited, where significant positive growth responses to increased precipitation occurred during the previous and current growing season (Fig. 4). Given the longer growing season length, higher temperatures, and low precipitation levels, a moisture-deficit has already limited the radial growth of white spruce over the past century. Regional tree-ring studies have reported reduced productivity under drought conditions in these regions (Hogg and Wein, 2005; Chhin *et al.*, 2004; Sang *et al.*, 2019). Our study suggests that the west-central group, north of the southwest group, is actually the most precipitation-limited group and therefore likely to be most susceptible to climate change. Although further north and colder than the southwest group, overall climate moisture deficits are highest here due to low precipitation.

In the last several decades, the west central group has experienced substantial warming, leading to one of the highest increases in climate moisture deficits across the study area (Table 4). Future projections from general circulation models for the 2050s show that the west-central region is also predicted to have the strongest warming, leading to the highest moisture deficit of any region: a CMD value of 212 mm (Table 4 difference added to Table 1 value). This would make the moisture deficit of the west-central group 25% higher than the second driest group in the southwest by the 2050s. The second highest moisture deficits are expected for the southwest group with CMD values of 155 mm by the 2050s. The southwest group has also experienced the highest increase in climate moisture deficits based on observed climate trends (Table 4).

Table 4. Observed climate change expressed as the difference between the 1961-1990 climate normal period and a recent 15-year climate average (2001-2015), and projected climate change for the 2050s relative to the 1961-1990 normal (mean and range). The future predictions are based on 15 models of the CMIP5 multi-model dataset for the RCP 4.5 scenarios that were chosen for high validation statistics and for representing all major clusters of similar AOGCMs (Knutti *et al.*, 2013). Variables include: MAT, change mean annual temperature (˚C); MAP, change in mean annual precipitation (mm); and CMD, change in climate moisture deficit (mm).

	Observed trend			Predicted 2050s mean			Predicted 2050s range		
Groups	MAT	MAP	CMD	MAT	MAP	CMD	MAT	MAP	CMD
Northwest	+1.2	+20	+8.6	+3.6	+89	+6.6	+2.2 to +5.9	+54 to +164	–12 to +29
North-central	+1.2	–9.2	+11	+4.1	+40	+17	+2.0 to +6.6	+15 to +81	–22 to +71
Northeast	+0.8	+14	+5.3	+3.5	+72	+16	+1.7 to +6.3	+21 to +122	–14 to +40
Southwest	+0.7	–12	+3.5	+2.8	+34	+30	+1.5 to +4.5	–24 to +170	–60 to +87
West-central	+1.1	+/-0	+7.7	+3.2	+38	+28	+1.8 to +4.6	+1.3 to 101	–38 to +87
East-central	+0.9	+29	–3	+3.3	+51	+21	+1.8 to +4.7	+16 to +117	–22 to +65

It remains important to highlight the fact that I report 2050s projections for a relatively optimistic future climate change scenario RCP 4.5, where global carbon emissions would peak and subsequently reduce over the next 20 years. The projections from 15 general circulation models are fairly consistent for temperature, but show wide variance in precipitation projections. As a consequence, the range of projected changes to moisture deficits are also quite variable, and reductions in climate moisture deficits remain a possibility in all regions (Table 4, CMD range). That said, observed trends over the last decades indicate that all except one region in the east have experienced trends towards higher moisture deficits.

5.2. Positive growth effects from climate warming

While the southern white spruce groups were often precipitation-limited, radial growth at the northern sites were instead primarily limited by cold temperatures and short growing seasons. Extended growing seasons under climate change would likely have beneficial effects on growth. This study has shown a consistent positive growth response to warmer spring temperatures for northern populations. Other studies have also shown that populations in the most northern reach of the boreal forest possess the earliest budbreak as a key adaptation to fully utilize the short growing season (Liepe *et al.*, 2016). Since the northern regions are expected to have the lowest moisture deficits, with CMD values below 100 by the 2050s, an extended growing season should be conducive to increased growth without moisture limitations. For the east-central region, moisture deficits by the 2050s are still moderate as well, with a CMD value of 129 (Table 1 and 4), and climate warming may have positive growth effects. It is important to note, however, that this study lacks samples from the southeast of the species range, where moisture limitations may occur under climate change.

Out of the three northern regions, the north-central group appears to be the most susceptible to drought. Though this group historically received the least mean annual precipitation overall, the response coefficients did not exhibit the same temperature-induced drought risk when compared to the southern groups (Fig. 4). This is likely because the north-central group currently experiences relatively cooler annual temperatures and much a shorter growing season (Table 2). However, future increases in temperature could likely intensify the current evapotranspirative demand for this region where warmer, longer growing seasons could prove to be undesirable in the long-term.

5.3. Applications and limitations

The chronologies we analyzed were originally taken for diverse purposes, but most of them were collected by dendroclimatologists who selected trees and sites they expect to be sensitive to the climate variable of interest. Therefore, there is likely a partial sampling bias toward sites exposed to warm and dry conditions, such as south facing slopes, ridges or rocky microsites. However, it is unlikely that prior sampling objectives are confounded with geographic regions (i.e. differences in sampling objectives for different regions) to produce bias relative to the main objective: detecting broad regional differences in climatic factors that limit growth, and inferring regional vulnerability to climate change.

Because of this partial sampling bias, and because I analyzed growth response to high frequency climate variability in detrended chronology data, this research does not provide evidence for long-term growth response to directional climate trends. Furthermore, standardized radial increments are not necessarily representative of whole tree growth. For example, moisture-limited trees may shift resource allocation to favor root growth.

Lastly, I note that the statistical power to detect climate-growth relationships was limited by the choice of statistical technique, which accounts for multicollinearity, as well as time series length of 80-100 years. Nevertheless, climatic factors in the MRT analysis explained 46% of the total variance in response coefficients, with the remainder attributable to other site factors such as soil fertility and ground water access. Biotic factors may also play a role. For example, at forest edges, exposed vegetation is more sensitive to climate fluctuations than under continuous canopy coverage (Helama *et al.*, 2005). Canopy density and early successional competition can also influence growth at a particular site where climatic conditions are otherwise identical (Juday *et al.*, 2003). The sampling used in this study reflects growth on mature stands, and highlights differences among broad macroclimatic regions while smaller scale variation remains unaccounted for in the methodology, but nevertheless accounts for more than half the variation.

5. Conclusion

From the evolution of dendroclimatological analysis techniques, forest managers now have increasingly reliable and cost-effective means to understand the relationship between a changing climate and tree growth. Scaled up, publicly accessible databases such as the International Tree-Ring Data Bank provide free data on countless tree species across the world and prove to be an invaluable tool for assessing global forest changes. By using historical tree-ring and climate data, this thesis project offered a dendroclimatological analysis to highlight the specific climatic variables which have been limiting the growth of white spruce across broad macroclimatic regions of the North American boreal forest.

Regional climate warming trends throughout the western interior boreal forest have raised the alarm for forest managers, particularly when trying to anticipate the impacts to current reforestation programs. The literature review component of this thesis project revealed that similar tree-ring studies expect precipitation-limited populations of boreal tree species to the most likely to be at risk of ongoing drought conditions and tree mortality in the future. Research gaps surrounding climatic influences on white spruce growth, combined with the ecological and economic importance of this boreal tree species, spurred a close evaluation of how and where the evidence shows past radial growth limitations across North America. Results of this study contribute findings consistent with previous dendrochronological research, indicating that white spruce populations in the west-central boreal forest have already experienced growth limitations from moisture deficits over the last 100 years. This contrasts the eastern white spruce populations, where climate change projections anticipate the lowest annual climate-moisture deficit values.

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Appendix

Table 1. Supplemental data table showing the location of each master chronology, the originator(s), chronology statistics, and the final macroclimatic group to which each chronology has been assigned.

ID	Lat	Long	Elev	Sample Depth	rbar.bt	EPS	Time Series	Originator(s)	Literature	Region
ak031	67.93333	-161.7	126	34	0.288	0.899	1901-1990	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		Northwest
ak034	64.81667	-162.3	61	29	0.314	0.911	1901-1997	Andrea Lloyd		Northwest
ak035	63.25	-146.217	884	35	0.228	0.841	1901-1997	Andrea Lloyd		Northwest
ak036	65.5	-144.667	945	17	0.318	0.83	1901-1997	Andrea Lloyd		Northwest
ak037	65.5	-144.667	945	8	0.037	0.183	1901-1996	Andrea Lloyd		Northwest
ak038	64.91667	-162.333	150	24	0.448	0.937	1901-1999	Andrea Lloyd		Northeast
ak039	63.26667	-146.083	884	51	0.331	0.923	1901-1998	Andrea Lloyd		Northwest
ak041	65.36667	-145.383	884	32	0.252	0.89	1901-1997	Andrea Lloyd		Northwest
ak042	65.36667	-144.067	945	12	0.411	0.854	1901-1996	Andrea Lloyd		Northwest
ak043	65.36667	-144.067	945	12	0.209	0.676	1901-1997	Andrea Lloyd		Northwest
ak044	63.9	-147.333	762	15	0.175	0.719	1901-1996	Andrea Lloyd		Northwest
ak045	63.9	-147.333	762	15	0.023	0.227	1901-1996	Andrea Lloyd		Northwest
ak046	67.06667	-158.383	100	106	0.264	0.966	1901-1992	John C. King, Lisa J. Graumlich	Graumlich & King (1997)	Northwest
ak048	67.11667	-149.917	100	75	0.156	0.879	1901-2001	Martin Wilmking		North-Central
ak049	67.15	-149.917	100	99	0.201	0.918	1901-2001	Martin Wilmking		North-Central
ak050	67.15	-148.867	100	154	0.225	0.951	1901-2000	Martin Wilmking		Northwest
ak051	67.15	-148.867	100	39	0.367	0.941	1901-2001	Martin Wilmking		Northwest
ak052	67.13333	-151.933	100	186	0.234	0.962	1901-2001	Martin Wilmking		Northwest
ak054	63.1	-150	100	106	0.156	0.898	1901-2000	Martin Wilmking, Glenn Juday		Northwest
ak055	63.08333	-147.867	100	91	0.142	0.847	1901-2001	Martin Wilmking		Northwest
ak056	63.11667	-149	100	106	0.156	0.898	1901-2000	Martin Wilmking, Glenn Juday, Jens Ibendorf		Northwest
ak057	65.18333	-161.8	168	37	0.248	0.886	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest

ak058	65.18333	-161.783	213	58	0.244	0.904	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak059	65.11667	-161.817	282	94	0.326	0.962	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak060	65.21667	-161.75	259	24	0.331	0.888	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak061	65.08333	-161.817	282	33	0.362	0.92	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak062	65.2	-161.733	239	49	0.3	0.917	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak063	65.1	-161.85	229	36	0.33	0.917	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak064	65.08333	-161.85	229	47	0.385	0.941	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak065	65.2	-161.8	168	20	0.245	0.743	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak066	65.21667	-161.783	213	48	0.306	0.924	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak067	65.21667	-161.783	229	66	0.311	0.935	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak068	65.08333	-161.817	229	53	0.365	0.93	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak069	65.06667	-161.767	244	34	0.333	0.912	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak070	65.18333	-161.783	251	48	0.307	0.923	1901-2001	R. D'Arrigo, E. Mashig, D. Frank, R. Wilson, G. Jacoby		Northwest
ak071	62.56667	-141.667	1030	16	0.287	0.8	1901-1957	Gordon Jacoby, Nicole Davi, Greg Wiles		West-Central
ak073	61.36667	-141.317	995	16	0.201	0.642	1901-1997	Gordon Jacoby, Nicole Davi, Greg Wiles		Northwest
ak074	62.36667	-142.95	1167	37	0.313	0.9	1901-1997	Gordon Jacoby, Nicole Davi, Greg Wiles		Northwest
ak075	61.15	-141.917	1030	29	0.335	0.908	1901-1998	Gordon Jacoby, Nicole Davi, Greg Wiles		Northwest
ak076	62.08333	-141.983	1006	8	0.419	0.782	1901-1994	Gordon Jacoby, Nicole Davi, Greg Wiles		Northwest
ak077	62.55	-142.717	994	24	0.199	0.763	1901-1996	Gordon Jacoby, Nicole Davi, Greg Wiles		Northwest
ak078	61.33333	-141.283	1040	20	0.264	0.815	1901-1997	Gordon Jacoby, Nicole Davi, Greg Wiles		Northwest
ak086	60.48333	-153.667	550	41	0.32	0.922	1901-2001	Greg Wiles, Will Driscoll, Rosanne D'Arrigo		Northeast
ak087	60.5	-153.88	580	50	0.37	0.944	1901-2001	Greg Wiles, Will Driscoll, Rosanne D'Arrigo		Northeast
ak088	60.96667	-152.083	400	20	0.293	0.865	1901-2001	Greg Wiles, Will Driscoll, Rosanne D'Arrigo		Southwest
ak089	60.65	-153.983	580	33	0.27	0.887	1901-2001	Greg Wiles, Will Driscoll, Rosanne D'Arrigo		Northwest
ak097	61.13333	-141.933	876	25	0.302	0.883	1901-1998	Gordon Jacoby, Greg Wiles,		Northwest

								Nicole Davi		
ak103	63.73333	-148.817	930	31	0.305	0.888	1901-1990	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		Northwest
ak105	61.61667	-140.633	1000	19	0.287	0.834	1901-1999	Gordon Jacoby, Nicole Davi, Greg Wiles		Northwest
ak109	67.91667	-161.7	750	25	0.367	0.893	1901-1990	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		Northwest
ak110	67.08333	-156.083	0	41	0.317	0.886	1901-1990	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		Northwest
ak111	64	-147	0	46	0.256	0.902	1901-1990	Rosanne D'Arrigo, Rob Wilson, Gordon Jacoby	D'Arrigo et al. (2006)	Northwest
ak113	67.5	-150	0	248	0.199	0.955	1901-2000	Rosanne D'Arrigo, Rob Wilson, Gordon Jacoby	D'Arrigo et al. (2006)	Northwest
ak115	65.16667	-161.75	0	46	0.346	0.9	1901-2001	Rosanne D'Arrigo, Rob Wilson, Gordon Jacoby	D'Arrigo et al. (2006)	Northwest
ak116	62	-142	0	141	0.171	0.938	1901-1999	Rosanne D'Arrigo, Rob Wilson, Gordon Jacoby	D'Arrigo et al. (2006)	Northwest
ak122	63.81667	-143.2	420	29	0.308	0.903	1901-2001	Andrea Lloyd, Daniel Mann, Paul Duffy		West-Central
ak123	63.71667	-143.85	437	20	0.479	0.917	1901-2001	Andrea Lloyd, Daniel Mann, Paul Duffy		West-Central
ak124	64.16667	-148.7	339	29	0.515	0.952	1901-2001	Andrea Lloyd, Daniel Mann, Paul Duffy		East-Central
ak125	64.48333	-145.033	245	20	0.625	0.956	1901-2001	Andrea Lloyd, Daniel Mann, Paul Duffy		Northwest
ak126	64.8	-140.8	341	30	0.49	0.951	1901-2001	Andrea Lloyd, Daniel Mann, Paul Duffy		Northwest
ak148	67.48333	-161.783	125	25	0.27	0.847	1901-2001	Patrick Sullivan	Sullivan et al. (2015)	Northwest
ak149	67.48333	-161.783	120	25	0.309	0.896	1901-2001	Patrick Sullivan	Sullivan et al. (2015)	Northwest
bre_ws09	53.13808	-114.609	814	5	0.653	0.897	1953-2001	Ted Hogg	Hogg et al. (2017)	Southwest
bre_ws10	53.12209	-114.614	807	5	0.535	0.8	1953-2001	Ted Hogg	Hogg et al. (2017)	Southwest
bre_ws11	53.12209	-114.614	807	5	0.392	0.76	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cal_ws01	55.34101	-113.441	637	5	0.574	0.871	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cal_ws02	55.34571	-113.374	632	5	0.623	0.884	1930-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cal_ws03	55.34365	-113.322	663	5	0.748	0.926	1934-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cana038	51.62	-95.83	1000	23	0.331	0.9	1901-1988	Fritz Schweingruber		West-Central
cana041	50.4	-91.45	1300	22	0.319	0.898	1901-1988	Fritz Schweingruber		East-Central

cana043	50.3	-89.05	1120	24	0.277	0.862	1901-1988	Fritz Schweingruber		East-Central
cana079	53.07	-87.33	645	24	0.163	0.78	1901-1988	Fritz Schweingruber		East-Central
cana117	65.35	-125.3	820	54	0.135	0.827	1901-1991	J. M. Szeicz, G. M. MacDonald		North-Central
cana119	64.96667	-126.517	680	49	0.153	0.8	1901-1989	J. M. Szeicz, G. M. MacDonald		East-Central
cana121	66.71667	-135.717	800	108	0.236	0.934	1901-1992	J. M. Szeicz, G. M. MacDonald, J. Lundberg		Northwest
cana123	64.98333	-126.433	950	76	0.178	0.909	1901-1989	J. M. Szeicz, G. M. MacDonald, M. Hutton		North-Central
cana129	59.98333	-111.65	200	34	0.359	0.942	1901-1989	C. Larsen, J. Szeicz, M. Hutton		West-Central
cana130	59.8	-111.833	240	30	0.403	0.928	1901-1989	C. Larsen, J. Szeicz, M. Hutton		West-Central
cana131	59.11667	-111.817	220	21	0.629	0.967	1901-1989	C. Larsen, J. Szeicz, M. Hutton		West-Central
cana145	53.95	-104.85	590	32	0.44	0.951	1901-1994	D. M. Lawrence, I. D. Campbell, T. M. L. Varem-Sanders		West-Central
cana154	65.33333	-125.317	725	39	0.225	0.884	1901-1983	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		North-Central
cana155	64.03333	-102.133	160	42	0.314	0.935	1901-1984	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		North-Central
cana156	65	-126.167	1375	53	0.363	0.947	1901-1984	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		North-Central
cana158	58.72	-94.07	50	19	0.196	0.788	1901-1982	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		North-Central
cana159	56.16667	-75.45	50	35	0.396	0.949	1901-1982	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley		Northeast
cana197	57.86667	-102.2	425	27	0.402	0.925	1901-2001	A. Beriault, D. Sauchyn, J. Stroich		East-Central
cana198	54.93333	-101.217	315	55	0.324	0.938	1901-2001	A. Beriault, D. Sauchyn, J. Stroich		West-Central
cana202	55.7	-105.567	390	53	0.467	0.974	1901-2001	A. Beriault, D. Sauchyn, J. Stroich		West-Central
cana205	55.63333	-103.267	360	33	0.424	0.954	1901-2001	A. Beriault, D. Sauchyn, J. Stroich		West-Central
cana206	55.21667	-103.467	370	47	0.383	0.953	1901-2001	A. Beriault, D. Sauchyn, J. Stroich		West-Central
cana210	56.92	-61.5	25	38	0.353	0.922	1901-1997	Brendan Buckley, Rosanne D'Arrigo		Northeast
cana211	61.9	-139.283	731	21	0.358	0.897	1901-1999	Gordon Jacoby, Nicole Davi, Greg Wiles		Northwest
cana212	59	-112	209	45	0.539	0.963	1901-2000	David Meko, Charles Stockton, Hal Fritts, Tony Knowles		West-Central
cana213	58.8	-110.5	209	54	0.503	0.967	1901-2000	David Meko, Charles Stockton,		West-Central

								Hal Fritts		
cana214	58.9	-110.4	209	30	0.585	0.969	1901-2000	David Meko		West-Central
cana215	58.9	-110.6	209	57	0.424	0.956	1901-2000	David Meko, Charles Stockton, Hal Fritts, Tony Knowles		West-Central
cana216	59	-110.6	209	53	0.482	0.963	1901-2000	David Meko, Charles Stockton, Hal Fritts, Tony Knowles		West-Central
cana217	58.4	-110.5	209	41	0.38	0.943	1901-2000	David Meko, Charles Stockton, Hal Fritts, Tony Knowles		West-Central
cana218	58.5	-111.5	209	27	0.536	0.948	1901-2000	David Meko		West-Central
cana219	58.6	-110.7	209	25	0.47	0.93	1901-2000	David Meko		West-Central
cana270	58.62	-93.8	50	154	0.298	0.955	1901-2001	Steven D. Mamet, G. Peter Kershaw		North-Central
cana274	58.53	-93.47	17	142	0.274	0.945	1901-2001	Steven D. Mamet, G. Peter Kershaw		North-Central
cana277	57.95	-92.7833	27	55	0.137	0.773	1901-2001	Steven D. Mamet, G. Peter Kershaw		North-Central
cana279	57.31667	-92.9667	56	31	0.212	0.825	1901-2001	Steven D. Mamet, G. Peter Kershaw		Northeast
cana282	53.95	-104.85	575	31	0.452	0.957	1901-1994	D. M. Lawrence, I. D. Campbell, T. M. L. Varem-Sanders		West-Central
cana295	61.7	-115.05	0	18	0.368	0.887	1901-2001	Andy Bunn, Andrea Lloyd, Logan Berner		West-Central
cana296	61.2	-120	270	16	0.299	0.842	1901-2001	Andy Bunn, Andrea Lloyd, Logan Berner		West-Central
cana298	60.03333	-118.95	0	41	0.515	0.966	1901-2001	Andy Bunn, Andrea Lloyd, Logan Berner		East-Central
cana309	56	-61	50	15	0.16	0.543	1901-1988	Rosanne D'Arrigo, Brendan Buckley, Gordon Jacoby		Northeast
cana310	57.15	-61.7	50	53	0.253	0.918	1901-1996	Rosanne D'Arrigo, Brendan Buckley, Gordon Jacoby		Northeast
cana311	56.5167	-61.9167	150	25	0.362	0.883	1901-1998	Rosanne D'Arrigo, Brendan Buckley, Gordon Jacoby		Northeast
cana312	55.4167	-61.3167	50	50	0.314	0.893	1901-1997	Rosanne D'Arrigo, Brendan Buckley, Gordon Jacoby		Northeast
cana313	56	-61	50	35	0.328	0.924	1901-1998	Rosanne D'Arrigo, Brendan Buckley, Gordon Jacoby		Northeast
cana318	64.03333	-102.133	160	283	0.24	0.979	1901-2001	Gordon Jacoby, Rosanne D'Arrigo		North-Central
cana319	69.5	-126.167	0	105	0.35	0.955	1901-1994	Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley, Greg Wiles		North-Central
cana320	69.5	-126.167	0	67	0.342	0.943	1901-1994	Rosanne D'Arrigo, Brendan Buckley, Greg Wiles		North-Central
cana321	69.5	-126.167	0	22	0.401	0.862	1901-1993	Gordon Jacoby, Rosanne D'Arrigo, Greg Wiles		North-Central
cana322	66	-120	0	447	0.215	0.977	1901-2001	Rosanne D'Arrigo, Rob Wilson, Gordon Jacoby	D'Arrigo et al. (2006)	North-Central

cana324	58	-94	0	45	0.163	0.875	1901-1982	Rosanne D'Arrigo, Rob Wilson, Gordon Jacoby	D'Arrigo et al. (2006)	North-Central
cana326	67	-139	0	129	0.201	0.939	1901-2001	Rosanne D'Arrigo, Rob Wilson, Gordon Jacoby	D'Arrigo et al. (2006)	Northwest
cana348	54.75	-114.383	0	11	0.258	0.769	1901-2001	David Sauchyn	St. George et al. (2009)	Southwest
cana354	61.03333	-137.5	800	86	0.366	0.951	1901-2001	Brian Luckman, Richard van Dorp, Don Youngblut		Northwest
cana388	53.76667	-126.717	1220	60	0.31	0.916	1901-2001	J. C. Aravena, D. Morimoto, E. Watson, D. Youngblut, B. Luckman		Southwest
cana502	68.25	-133.267	2	75	0.303	0.958	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana503	68.28333	-133.217	2	24	0.38	0.919	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana504	68.61667	-133.617	2	74	0.251	0.917	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana505	68.26667	-132.6	130	57	0.213	0.822	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana506	68.15	-132.233	25	61	0.19	0.857	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana507	68.13333	-133.233	2	95	0.223	0.948	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana508	68.36667	-133.033	2	75	0.266	0.945	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana509	68.51667	-134.933	2	78	0.259	0.928	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana510	68.11667	-133.833	2	85	0.239	0.925	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana511	68.26667	-133.85	2	67	0.228	0.933	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana512	68.43333	-133.417	2	69	0.236	0.933	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana513	68.4	-133.733	2	77	0.237	0.945	1901-2001	University of Toronto, Trevor Porter, Michael	Porter et al. (2013)	North-Central

								Pisaric		
cana514	68.58333	-132.317	98	88	0.333	0.964	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana515	68.53333	-133.367	2	112	0.27	0.955	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana516	68.15	-134.85	2	77	0.276	0.948	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana517	68.36667	-133.333	2	92	0.28	0.959	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana518	68.45	-134.483	2	79	0.288	0.952	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana519	68.31667	-134.8	2	81	0.369	0.96	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana520	68.45	-132.15	2	105	0.261	0.959	1901-2001	University of Toronto, Trevor Porter, Michael Pisaric	Porter et al. (2013)	North-Central
cana521	68.43333	-132.183	2	55	0.313	0.941	1901-2001	Brock University, Michael Pisaric, Steve Kokelj	Porter et al. (2013)	North-Central
cana522	68.51667	-132.133	2	43	0.291	0.9	1901-2001	Brock University, Michael Pisaric, Steve Kokelj	Porter et al. (2013)	North-Central
cana523	68.58333	-133.9	2	45	0.386	0.956	1901-2001	Brock University, Michael Pisaric, Steve Kokelj	Porter et al. (2013)	North-Central
cana524	68.46667	-132.15	2	40	0.3	0.886	1901-2001	Brock University, Michael Pisaric, Steve Kokelj	Porter et al. (2013)	North-Central
cana525	68.46667	-132.133	2	83	0.252	0.941	1901-2001	Brock University, Michael Pisaric, Steve Kokelj	Porter et al. (2013)	North-Central
cana526	68.51667	-134	2	73	0.346	0.962	1901-2001	Brock University, Michael Pisaric, Steve Kokelj	Porter et al. (2013)	North-Central
cana527	68.4	-132.2	2	67	0.399	0.954	1901-2001	Brock University, Michael Pisaric, Steve Kokelj	Porter et al. (2013)	North-Central
cana531	67.5	-138.033	249	42	0.363	0.95	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana532	67.51667	-138.033	249	41	0.194	0.885	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana533	67.51667	-138.017	251	42	0.266	0.911	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana534	67.51667	-140	243	35	0.274	0.907	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric	North-Central

									(2011)	
cana535	67.5	-139.95	243	55	0.358	0.922	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana536	67.48333	-139.683	244	61	0.254	0.929	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana537	67.8	-139.567	245	67	0.239	0.939	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana538	67.95	-138.867	286	73	0.269	0.941	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana539	67.58333	-138.25	258	67	0.264	0.919	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana540	67.7	-138.183	267	54	0.263	0.938	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana541	67.71667	-138.183	259	56	0.231	0.877	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana542	68.13333	-138.067	282	45	0.247	0.889	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana543	68.06667	-138.217	272	75	0.247	0.94	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana544	68.05	-138.417	269	52	0.231	0.915	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana545	67.85	-138.2	265	74	0.19	0.909	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana546	68.21667	-139.917	292	30	0.25	0.827	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana547	67.55	-138.583	251	94	0.29	0.968	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana548	67.53333	-138.683	251	60	0.17	0.886	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana549	67.75	-139.483	647	38	0.239	0.881	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana550	68.33333	-139.25	339	89	0.248	0.953	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana551	68.33333	-138.283	315	94	0.252	0.95	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana552	68.16667	-138.217	305	60	0.2	0.896	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
cana553	67.53333	-138.067	251	67	0.27	0.934	1901-2001	Trevor Porter, Michael Pisaric	Porter & Pisaric (2011)	North-Central
car_ws12	52.1328	-114.536	1018	5	0.564	0.815	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest

col_ws04	54.43311	-110.609	556	5	0.543	0.821	1948-2001	Ted Hogg	Hogg et al. (2017)	Southwest
col_ws06	54.50666	-110.66	564	5	0.576	0.86	1956-2001	Ted Hogg	Hogg et al. (2017)	Southwest
col_ws08	54.41536	-110.951	567	5	0.422	0.76	1953-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cyn_ws01	53.44195	-115.329	877	5	0.694	0.914	1956-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cyn_ws02	53.33976	-115.432	959	5	0.694	0.914	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cyn_ws03	53.23969	-115.388	946	5	0.633	0.888	1933-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cyn_ws04	53.36514	-115.18	908	5	0.553	0.854	1944-2001	Ted Hogg	Hogg et al. (2017)	Southwest
cyn_ws05	53.26229	-115.27	911	5	0.602	0.874	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
fox_ws01	54.51292	-117.5	875	5	0.396	0.764	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
fox_ws02	54.55511	-117.845	884	5	0.231	0.567	1957-2001	Ted Hogg	Hogg et al. (2017)	Southwest
fox_ws03	54.55559	-117.725	838	5	0.443	0.78	1964-2001	Ted Hogg	Hogg et al. (2017)	Southwest
fox_ws04	54.51832	-117.602	852	5	0.475	0.819	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
gra_ws01	54.67969	-118.976	976	5	0.493	0.825	1903-2001	Ted Hogg	Hogg et al. (2017)	Southwest
gra_ws02	54.68794	-119.067	1045	5	0.55	0.843	1953-2001	Ted Hogg	Hogg et al. (2017)	Southwest
gra_ws03	54.67656	-118.801	909	5	0.494	0.814	1957-2001	Ted Hogg	Hogg et al. (2017)	Southwest
hig_ws01	58.75412	-117.335	354	5	0.738	0.933	1901-2001	Ted Hogg	Hogg et al. (2017)	West-Central
hig_ws02	58.72607	-117.387	405	5	0.611	0.877	1901-2001	Ted Hogg	Hogg et al. (2017)	West-Central
hig_ws03	58.95748	-117.61	361	5	0.676	0.912	1901-2001	Ted Hogg	Hogg et al. (2017)	West-Central
hig_ws04	59.09101	-117.696	336	5	0.584	0.874	1901-2001	Ted Hogg	Hogg et al. (2017)	West-Central
hig_ws05	59.1078	-117.661	353	5	0.713	0.919	1901-2001	Ted Hogg	Hogg et al. (2017)	West-Central
kuuj	55.27457	-77.7638	14	5	N/A	N/A	1901-1983	Ann Delwaide		Northeast
lac_ws01	54.89474	-111.407	699	5	0.469	0.811	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
lac_ws02	54.8634	-111.419	643	5	0.471	0.776	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
lac_ws03	54.86345	-111.485	724	5	0.519	0.833	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
lac_ws04	55.00812	-111.668	670	5	0.73	0.924	1953-2001	Ted Hogg	Hogg et al. (2017)	Southwest
mac	49.68	-87.9	0	48	0.292	0.936	1901-2000	Martin Girardin		East-Central
man_ws01	57.19733	-117.555	547	5	0.531	0.844	1907-2001	Ted Hogg	Hogg et al. (2017)	Southwest
man_ws02	57.15273	-117.847	650	5	0.471	0.776	1917-2001	Ted Hogg	Hogg et al. (2017)	Southwest
man_ws03	57.16552	-117.955	663	5	0.587	0.859	1928-2001	Ted Hogg	Hogg et al. (2017)	Southwest
man_ws04	57.17353	-117.983	689	5	0.55	0.851	1908-2001	Ted Hogg	Hogg et al. (2017)	Southwest

mil_ws14	53.1014	-113.493	767	5	0.476	0.801	1931-2001	Ted Hogg	Hogg et al. (2017)	Southwest
mil_ws15	53.10031	-113.49	761	5	0.335	0.701	1921-2001	Ted Hogg	Hogg et al. (2017)	Southwest
mil_ws16	53.01142	-113.46	803	5	0.302	0.664	1945-2001	Ted Hogg	Hogg et al. (2017)	Southwest
nor_ws01	52.41125	-116.097	1378	5	0.77	0.944	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
nor_ws02	52.42579	-116.104	1449	5	0.698	0.916	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
nor_ws03	52.46087	-116.103	1422	5	0.594	0.874	1902-2001	Ted Hogg	Hogg et al. (2017)	Southwest
nor_ws04	52.52692	-116.416	1663	5	0.423	0.763	1913-2001	Ted Hogg	Hogg et al. (2017)	Southwest
nor_ws05	52.46888	-116.131	1379	5	0.505	0.836	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
smo_ws02	54.03964	-112.357	605	5	0.447	0.752	1936-2001	Ted Hogg	Hogg et al. (2017)	Southwest
sun_ws13	51.76469	-114.709	1128	5	0.483	0.824	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
swa_ws01	54.89035	-115.364	901	5	0.517	0.843	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
swa_ws02	54.83554	-115.387	962	5	0.38	0.75	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
swa_ws03	54.83145	-115.382	893	5	0.17	0.507	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
swa_ws04	54.8083	-115.538	1102	5	0.571	0.87	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
swa_ws05	54.84791	-115.479	1038	5	0.192	0.543	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
wab_ws04	56.03066	-113.734	610	5	0.437	0.795	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
wab_ws05	56.07079	-113.769	615	5	0.375	0.748	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
wab_ws07	55.98518	-113.628	595	5	0.63	0.895	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
wab_ws08	56.02949	-113.864	614	5	0.304	0.655	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
win_ws17	52.96239	-114.3	919	5	0.31	0.669	1929-2001	Ted Hogg	Hogg et al. (2017)	Southwest
win_ws18	52.95372	-114.194	932	5	0.602	0.879	1914-2001	Ted Hogg	Hogg et al. (2017)	Southwest
wor_ws02	56.55927	-119.392	730	5	0.513	0.84	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
wor_ws03	56.59526	-119.37	889	5	0.633	0.896	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest
wor_ws04	56.58466	-119.347	810	5	0.525	0.847	1901-2001	Ted Hogg	Hogg et al. (2017)	Southwest

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