CLIMATE CHANGE IMPACTS ON GROWTH OF BLACK SPRUCE IN WESTERN CANADIAN BOREAL FORESTS

by

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ABSTRACT

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This study explored the effects of changes climate on the growth rate of black spruce in western Canadian boreal forests over a 55-year time from 1950 to 2005. A multiple linear regression model was run for tree ring data, mean annual temperature, and precipitation from three sites at different latitudes including the Northwest Territories, norther Yukon, and central Saskatchewan. Correlations between temperature and black spruce in high latitudes were the lowest, while those in middle latitudes were the highest. The effect of precipitation on black spruce was not significant in western Canadian boreal forests. Climate change was found to negatively affect the growth of black spruce, possibly due to its intolerance to drought, resource competition, and temperature stress. In the future, the number and size of black spruce in forests of western Canada are expected to continue to decline if climate change trends continue.

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1.0 INTRODUCTION

Black spruce (*Picea mariana* Mill.) is one of the most abundant and economically important conifers in Canada with a wide distribution across North America from Newfoundland to Alaska (Farrar 1995). The climate for black spruce is characterized by cold, short growing seasons with moisture ranging from humid to dry (Burns et al. 1990). Black spruce grows on a wide variety of sites such as dry sands, gravels, shallow soils over bedrock, mineral soils on uplands, and acidic organic soils in lowlands (Haavisto and Jeglum 1995).

The global climate has been warming since the 1800s, resulting in changes in temperature, precipitation, and moisture availability (Bruch 2021). Temperature, precipitation, soil moisture, and light are the most limiting factors for tree growth, regulating physiological processes such as photosynthesis (Subedi and Sharm 2011).

As a species adapted to cool, moist sites black spruce growth and distribution is likely to be affected by climate change. To determine the effects of climate change on growth of black spruce, this study sought to compare the relationship between the growth rate of black spruce, temperature, and precipitation over a period of climate change.

1.1 Objectives

This study aims to explore the impact of climate change on the growth rate of black spruce in boreal forests of western Canada. Due to the wide range of independent variable conditions of climate change, this study mainly tends to conduct correlation analysis on temperature and precipitation and to discuss the north-south differences in growth rates.

1.2 Hypothesis

Black spruce growth in the boreal forests of western Canada will be negatively affected by climate change at all latitudes, particularly at lower latitudes. Black spruce growth rates at high latitudes will be least affected.

2.0 LITERATURE REVIEW

2.1 Growing Environment of Black Spruce

2.1.1 Site Conditions

Black spruce requires good moisture and light conditions to grow. However, black spruce is an adaptable tree. It can grow in places where humidity, nutrients and heat are limited (Sas-Zmudzinski 1989). Black spruce grows better on nutrient-rich, well-drained mineral soils, and more slowly on poor drainage, nutrient-deficient peats on lowlands. For example, the height and basal area of a 70-year-old black spruce forest on mineral soil far exceed that of a 100–200-year-old black spruce forest on peatland soil (Haavisto and Jeglum 1995).

Black spruce at younger stages can also be shade tolerant and can grow under dense forest canopy or shrub cover. This characteristic makes black spruce better adapted to growth in the understory of a forest. In many northern mixed forests, black spruce tends to gradually dominate the stand without human and natural disturbance (Hopkins 1891). The regeneration of black spruce starts from seed, and seedling development is usually very slow and takes several years. The quality of the seedbed is an important factor affecting black spruce seed germination and seedling establishment. Wet mineral soils generally provide good seedbeds. On upland mineral lands, a seedling reaches heights of 12-15 cm after five years, and the growth rate will increase after that, compared to the growth rate in peatland, which is much slower (Kershaw 1994).

2.1.2 Stand Distribution

Black spruce is found in pure stands on soils with thick organic layers, poor nutrient status, and poor drainage such as peatlands, and sandy outwash soil (Oboite and Comeau 2019). Peatland is a terrestrial wetland ecosystem with high carbon storage capacity and rich organic matter (Dise 2009). Peatlands are the result of the accumulation of organic matter in places with low temperatures and a high water table. Flooding and low temperatures lead to slow decay and decomposition of organic matter, resulting in peat accumulation. Peatlands in Canada cover a large area, about 14% of the total. The area of peatland black spruce in Ontario is estimated at approximately 46 % of the total area of spruce-dominated forest (Ketcheson 1972).

In the north, black spruce range is also covered by permafrost. The shallower rooting habit of black spruce is an adaptation suited to growing on permafrost (Burns et al. 1990). On moist, mineral soils, black spruce is generally found in a mixed forest growing with jack pine (*Pinus banksiana* Lamb.). trembling aspen (*Populus tremuloides* Michx.), and white birch (*Betula papyrifera* Marsh) (Haavisto and Jeglum 1995). In mixed stands with trembling aspen or white birch, the soil is usually well-drained and nutrient-rich. Jack pine is a common associate on dry, rapidly drained, and shallow sites and occurs on fresh moisture mineral soil.

2.2 Climate Change Trends

Climate change refers to the change of the average state of climate over time over a long period, which is usually reflected by the difference in climate elements such as temperature and precipitation in different periods. The length of the change ranges from several billion years to annual change.

2.2.1 Temperature

Since the Industrial Revolution, global temperatures have increased gradually and abnormally comparing with the century before. This phenomenon is related to modern industrial emissions. Greenhouse gases such as carbon dioxide and methane keep the Earth warm. These gases cannot directly reflect the ultraviolet (UVA) radiation from the sun but can absorb and re-emit the longwave radiation reflected by the Earth's surface. Too high a concentration of greenhouse gases can cause temperatures to rise as more energy flows into the earth than flows out (Burch and Harris 2021). From 1906 to 2005, the global average surface temperature rose by 0.6 to 0.9 ° C (Riebeek 2010). Scientists predict that with such high concentrations of carbon dioxide in the earth's atmosphere, the global average temperature is likely to rise between 2.4 and 6.4 ° C by 2100 (Burch and Harris 2021).

2.2.2 Precipitation

The increase and redistribution of precipitation are prominent features of global warming. Rising temperatures speed up the evaporation of water vapor, forming clouds in the lower troposphere (Romps 2011). As for the change of precipitation frequency, studies have shown that heavy precipitation tends to become more frequent and stronger, while weak precipitation becomes less frequent. Global warming has a strong positive effect on precipitation, especially at high latitudes, meaning that precipitation is likely to increase significantly over the next hundred years in the boreal forest (Chou and Lan 2012). But precipitation is not evenly distributed over areas, leading to more extreme weather and natural disasters in many regions, droughts, floods and so on. Global warming is causing glaciers in the north to melt, creating more lakes, and releasing large amounts of carbon dioxide stored in glaciers (Sobek 2014).

2.3 Effects on Black Spruce Stands

2.3.1 Temperature and precipitation

Rising temperatures affect a tree's growth and ability to compete for resources. A common formula relating annual growth in diameter at breast height (DBH) growth relates competition to climate change (Subedi and Sharma 2012). It is based on tree ring data from 25 plantations each of jack pine and black spruce and mixed-effects modelling, combining averages of mean growing season temperature, precipitation during the wettest quarter of the year, and total growing season precipitation. The results showed that temperature increases negatively affected the growth of black spruce. The authors pointed out that due to the drought sensitivity of black spruce, the increasing temperature can lead to increased transpiration, especially in summer, and decrease the effectiveness of water use by competing trees. Precipitation had a negative effect on jack pine and black spruce, but a minor effect on black spruce. Long-term global change, especially warming and drought, will lead to significant carbon loss and may eventually lead to the transfer of some existing peatlands to new ecosystems, such as grasslands or shrubland, which will promote the invasion of black spruce forests by other species (Sniderhan and Baltzer 2016).

2.3.2 Photosynthesis of Black Spruce

Carbon dioxide (CO_2) is the raw material for photosynthesis. Increases in CO_2 concentration and precipitation increase forest productivity. An Increase in CO_2 concentration can also inhibit the photorespiration of plants to a certain extent, thus improving the net photosynthetic efficiency of plants. However, many experiments show that the promotion effect of high CO_2 concentration on the photosynthetic rate of plants will be weaken with the extension of the treatment over time, which is called photosynthetic acclimation (Lin 1998). On the other hand, higher temperatures encourage plants to consume more water and reduce photosynthesis.

The impact of global temperatures on plants varies across species (Sperry et al. 2019). The decline in photosynthetic activity in coniferous forests in the Northern Hemisphere has been largely due to increased drought stress caused by higher evapotranspiration. The decrease in photosynthesis directly resulted in a decrease in carbon storage of black spruce, and carbon starvation inhibited its growth. A comparative study showed that black spruce seedlings were smaller at high temperatures, with 54% less total needle area and 14% higher mortality compared to seedlings at low temperatures (Way and Sage 2007). Plants growing at higher temperatures have lower net CO_2 assimilation rates compared with ambient growth temperatures.

2.3.3 Forest Fire in Boreal Forests

Forest fires usually occur in warm seasons, mainly the dry summer, but can also occur in spring and fall. The time of year when fires are most likely is called the fire season. The boreal fire season in Canada generally runs from April to October, with fire activity peaking from mid-May to August. Global warming is lengthening the annual fire season. Although global warming does not directly affect fires, rising temperatures and droughts are increasing the risk of fires by making forests drier. The increase in the frequency of droughts and the lengthening of the fire season are the two main reasons for the increase in forest fires. The impact of fire on Canadian western boreal forests has been significant. Over the past 25 years, there have been about 7,300 forest fires a year, burning an average of about 2.5 million hectares a year (NRCAN 2022). The shortening of the fire interval accelerates forest succession and changes the pathway of succession (Oris 2014). By the second half of the 21st century, the average area burned in Canada each year will be 74 % to 118 % more than it is now. Fire cycles in black spruce stands may be from 54 to 102 years. However, there are fewer fires in older stands because the soil usually becomes colder and wetter as ages (Aksamit 1983).

Black spruce can also be affected differently by different levels of fire. Heavy burns remove most of the organic layer and usually kill the underground parts of most shrubs. The organic matter in the soil is consumed, leaving the mineral soil. Mineral soil sites are good germination sites for black spruce seeds and seeds of most invading species. A lighter fire merely kills aboveground plant parts and will leave the understory shrubs and many herbs intact. Fires reduce the accumulation of organic matter and avoid the accumulation of peat, thus restoring and sustaining the high-yielding black spruce ecosystem (Viereck 1983). Fire will also consume most of the barren seedbed, reducing competition from grass and other tall shrubs. Although fires provide a good seedbed for the regeneration of black spruce, they also provide a good environment for the regeneration of other species (Sas-Zmudzinski 1989).

2.3.4 Insect Outbreaks in The Boreal Forest

Climate is also a key factor in the distribution and abundance of insects because most insects are poikilotherms. Insects have short reproductive cycles and high reproductive rates, so they are more likely than plants and vertebrates to respond quickly to climate change (Sharma 2014). In boreal forests, temperatures affecting physiological processes tend to be below optimal for most insects for most of the year, and higher temperatures may accelerate the outbreak process (Fleming and Candau 2004). A warmer climate also reduces the risk of extreme cold that kills insect populations in winter, especially at high latitudes. Higher temperatures reduce the frequency of lethal cold temperatures. As the climate changes, the insects' range will expand (Ayres 2000). By summarizing the combination of insect outbreaks and climate change, scientists found the link between climate change and insect outbreaks. Sufficient light and lack of precipitation are ideal living conditions for spruce budworms (Wellington et al. 1950). Graham (1939) analyzed the link between insect outbreaks and climate and pointed out that drought is often the precursor of insect outbreaks.

Forest insects cause more damage to forests each year than forest fires. In northern

Canada, wood loss due to insects maybe 1.3 to 2.0 times the average annual depletion due to fire (Volney and Fleming 2000). Spruce budworms are considered the most serious pest in the fir and spruce forests of eastern North America. They feed on balsam fir, black spruce causing the most damage to mature spruce forests. The insect population cycle is characterized by the epidemic and endemic phases, with outbreaks occurring every 30 to 40 years (NRCAN 2022). Spruce budworms cause a lot of leaf litter. Falling leaves for several years in a row lead to loss of growth, suppression of photosynthesis, and most trees die after four or five years (NRCAN 2022).

2.3.5 Effects of Other Tree Species

Jack pine is one of the most common tree species in Canada's boreal forests. After wildfires, it often establishes in extensive pure stands, or mixed with black spruce. Mineral soils are the best place for jack pine to seed (Rudolf 1965). Seedlings grow highest under sufficient light. Jack pine is not as shade tolerant as black spruce (Rudolph and Laidly 1990). In the study of Longpré and Morris (2012), over 100 years of succession in the western boreal forest, stands dominated by jack pine were gradually replaced by black spruce, mainly in areas with less than 428 mm of rainfall and cooler temperatures.

Trembling aspen invasions often occur on river terraces. A severe fire that clears the organic layer, lack of organic material and river alluvial layers usually provide a good drainage environment, and where it is warm it is a good situation for aspen. Trembling aspen has a positive effect on the productivity of black spruce. Aspen has a higher nutrient cycling rate and inhibition of moss-covered litter can improve the physical and chemical properties of soil. With the increase in the number of aspens, the thickness of organic matter will decrease (Légaré et al. 2005). A high proportion of aspen will have a negative effect on black spruce. The area of aspen basal area accounted for less than 40% of the total base area of the stand, and the height and the base area of black spruce were affected positively, mainly from poplar fibre, and had a negative impact when the proportion was more than 40% (Légaré et al. 2004).

White birch is a boreal tree adapted to cold climates and grows in cool, moist places. It grows best on well-drained sandy loam soil. Birch seeding is best on mineral soils (Safford & Zasada 1990). In black spruce and jack pine stands, as stand age and open space increase, white birch enters the stand and becomes the younger component of the mixed stand.

2.5 Tree Ring Information

Tree rings have proved to be a reliable historical recording tool on many occasions, and tree ring analysis has provided scientists with useful data to better understand the growth cycle of trees in climate change. Tree ring formation is driven by the meristem of the vascular cambium, which lies between the secondary xylem and the secondary phloem, and by cell division, becomes additional xylem and phloem. Tree ring formation is usually confined to the growing seasons and generally lasts from spring to autumn. Outside the growing period, cell formation stops, and the trees cease to grow. The formation of tree rings is driven by both internal (biological and genetic) and external (abiotic) factors: climatic conditions and water and inorganic salts at the time of cambium cell division (Stoffel and Bollschweiler 2008).

3.0 MATERIALS AND METHODS

3.1 Data Description

Tree ring data from three black spruce forests in Canada collected by the National Oceanic and Atmospheric Administration were used as a measure of annual radial growth from the mid-19th century. These stands are located in central Saskatchewan (53.9928°N; 105.1161°W), the Northwest Territories (61.308°N; 121.299°W), and northern Yukon (Latitude: 68.31472°N; 133.4583°W; Sniderhan and Baltzer 2020; **Error! Reference source not found.**).

Figure 1. Locations of black spruce study sites

3.1.1 Tree Ring Data

Tree ring data records the historical growth of trees. The perpendicular distance between each ring represents the DBH growth of trees for the corresponding year. The tree ring data sets of black spruce growth in three study stands in central Saskatchewan, the Northwest Territories and northern Yukon were collected (Appendix 1). The mean tree ring growth data of all trees from 1950 to 2005 was used in this study. The DBH growth rate across black spruce cohorts decreased continuously from 1950 to 2005 in the Northwest Territories, central Saskatchewan, and northern Yukon (Figure 2). The two sites in the central Saskatchewan and northern Yukon had lower rates of change in growth, and the growth rate of black spruce in northern Yukon was always about 10 units (0.01 mm) higher than that in central Saskatchewan. Black spruce in the Northwest Territories grew the fastest before 1970 among these three areas. By 1980, the growth rate of black spruce in this region was lower than that of central Saskatchewan because of its rapid decline.

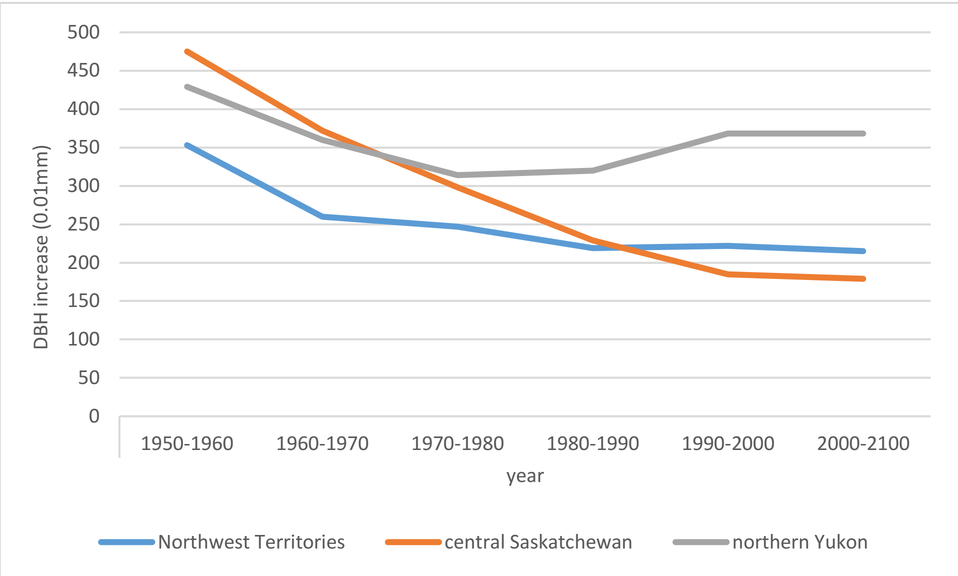

Figure 2. Diameter at breast height (DBH) growth across black spruce cohorts per 10-year interval from 1950-2005 in Northwest Territories, central Saskatchewan, and northern Yukon.

3.1.2 Temperature and Precipitation From 1950 to 2005

The mean temperature data and precipitation in the three study areas from 1950 to 2005 were collected from the Canadian Centre for Climate Services. Precipitation records are in terms of the number of wet days (> 1 mm) per year in three study areas (Appendix 2). Consistent with latitude differences, mean temperatures at the three black spruce sites have a wide range, the northern Yukon being about 10 degrees Celsius warmer than the central Saskatchewan average (Figure 3). All three sites experienced a gradual increase in temperature from 1950 to 2005, in the northern Yukon site by 1.78 °C, in the Northwest Territories site by 0.95 °C, and the central Saskatchewan site by 0.66 °C. Yukon Territory in the northwest has the largest increase in temperatures, while the central Saskatchewan study area had the smallest increase, suggesting climate change is more pronounced in higher latitudes (Figure 3). Consistent with latitude differences, the mean number of wet days (> 1mm) in central Saskatchewan and Northwest Territories is more than in northern Yukon about 10 days all the time. There was no significant difference in precipitation in the three regions from 1950 to 2005 (Figure 4).

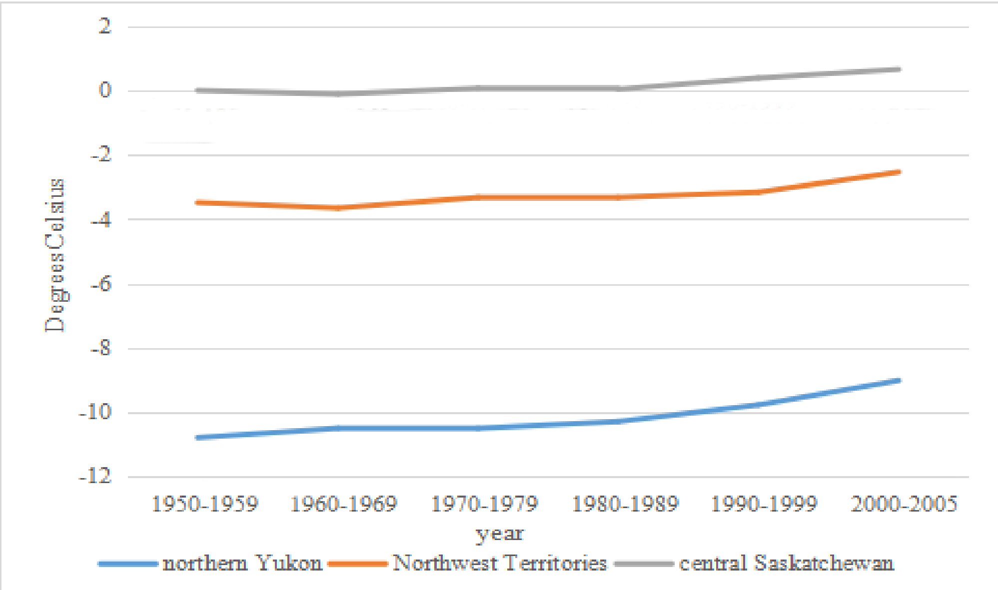

Figure 3. The mean temperature per 10 years from 1950 to 2005 in northern Yukon, Northwest Territories, and central Saskatchewan.

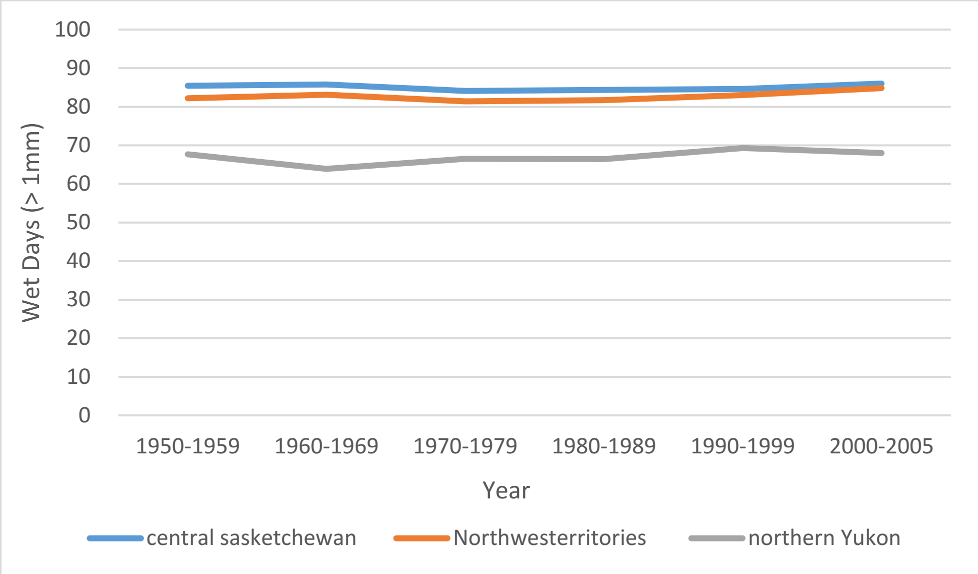

Figure 4. Mean wet days (> 1 mm) per 10 years from 1950 to 2005 in northern Yukon, Northwest Territories, and central Saskatchewan.

3.1.3 Global Average Surface Temperature

The climate model from World Meteorological Organization Climate Explorer produces indices that show the global average surface temperature expectations from 1850 to 2100 (**Error! Reference source not found.**). These were used to project temperature forward in this study.

Blue thin lines are 27 individual climate model runs for representative concentration pathway (RCP) 2.6. Red thin lines are 35 climate model runs for RCP 8.5. A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory. All pathways are possible depending on the volume of greenhouse gases (GHG) emitted in the future. The thick black line is the historical observational annual surface temperature record.

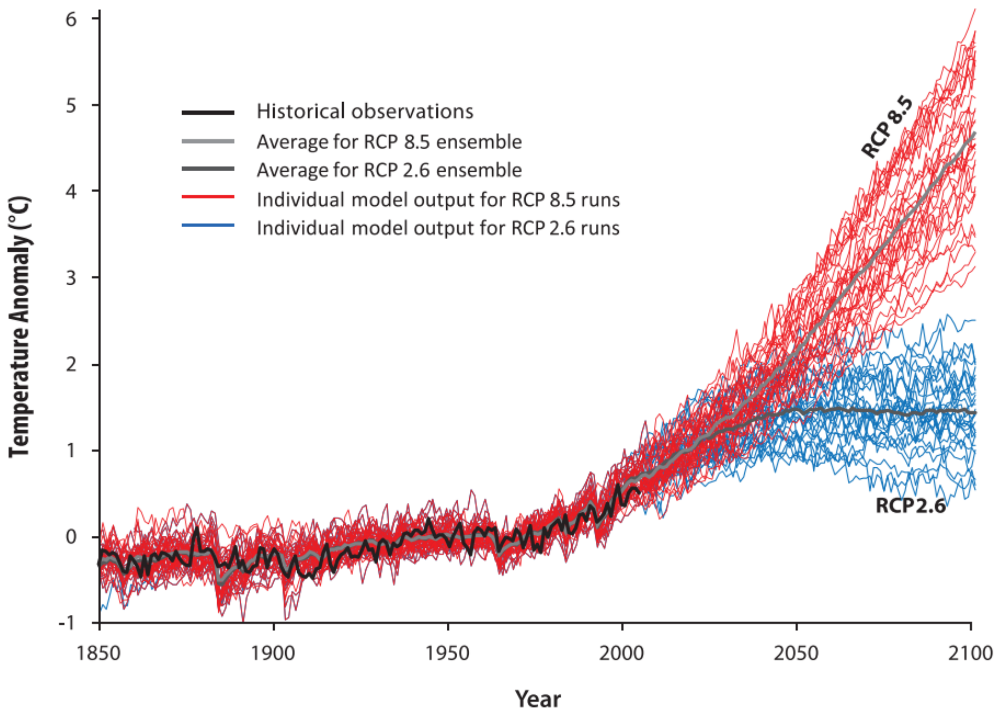

Figure 5. Model of global average surface temperature from 1850-2100 under 2.6 RCP and 8.5 RCP scenarios.

3.2 Data Analysis

Firstly, the one-variable linear regression model was used to analyze the correlations between the time with three variables temperature, wet days (> 1mm) and black spruce growth rate in the three study areas by using SPSS. The multiple linear regression model was established by using Python where the mean temperature, number of wet days (> 1 mm) and tree ring data from 1950 to 2005 were generated for data analysis, in which temperature and precipitation were taken as independent variables and tree ring data as dependent variables. By running the multiple linear regression model, the correlation between temperature, precipitation with tree ring growth was expressed to reflect the fitting degree of the model. Finally, the results of the model are explained in the discussion section by combining them with the literature. The growth and distribution of spruce were discussed by combining the results of influencing factors and future climate change trends of spruce.

4.0 RESULTS

4.1 Change in Black Spruce Growth Over Time

The growth rate of black spruce in central Saskatchewan and the Northwest Territories decreased significantly over time from 1950 to 2005 (Figure 6, Table 1). In the northern Yukon area, the growth rate of black spruce decreased until 1970 and then increased (Figure 6). The fitting degree of black spruce growth and time in the three regions was analyzed by the model summary table. R value in the linear regression analysis of northwest Territory is 0.933 because there is only one predictor, this value represents the simple correlation between time and growth rate. The value of R squared is 0.868, which tells us that time can account for 86.8% of the variation in the black spruce growth rate. Adjusted R squared. There might be many factors that can explain this correlation. This means that 13.2% of the variation in black spruce growth rate cannot be explained by time. Similarly, in the linear regression of time and growth rate for central Saskatchewan, its R value is 0.278 and its R squared value is 0.53. In the northern Yukon fitting model, its R value is 0.263 and its R squared value is only 0.069 (Table 1). The results showed that, in the linear regression analysis of the three areas, the highest fitting degree was found in the Northwest Territory, and the lowest fitting degree was found in the northern Yukon.

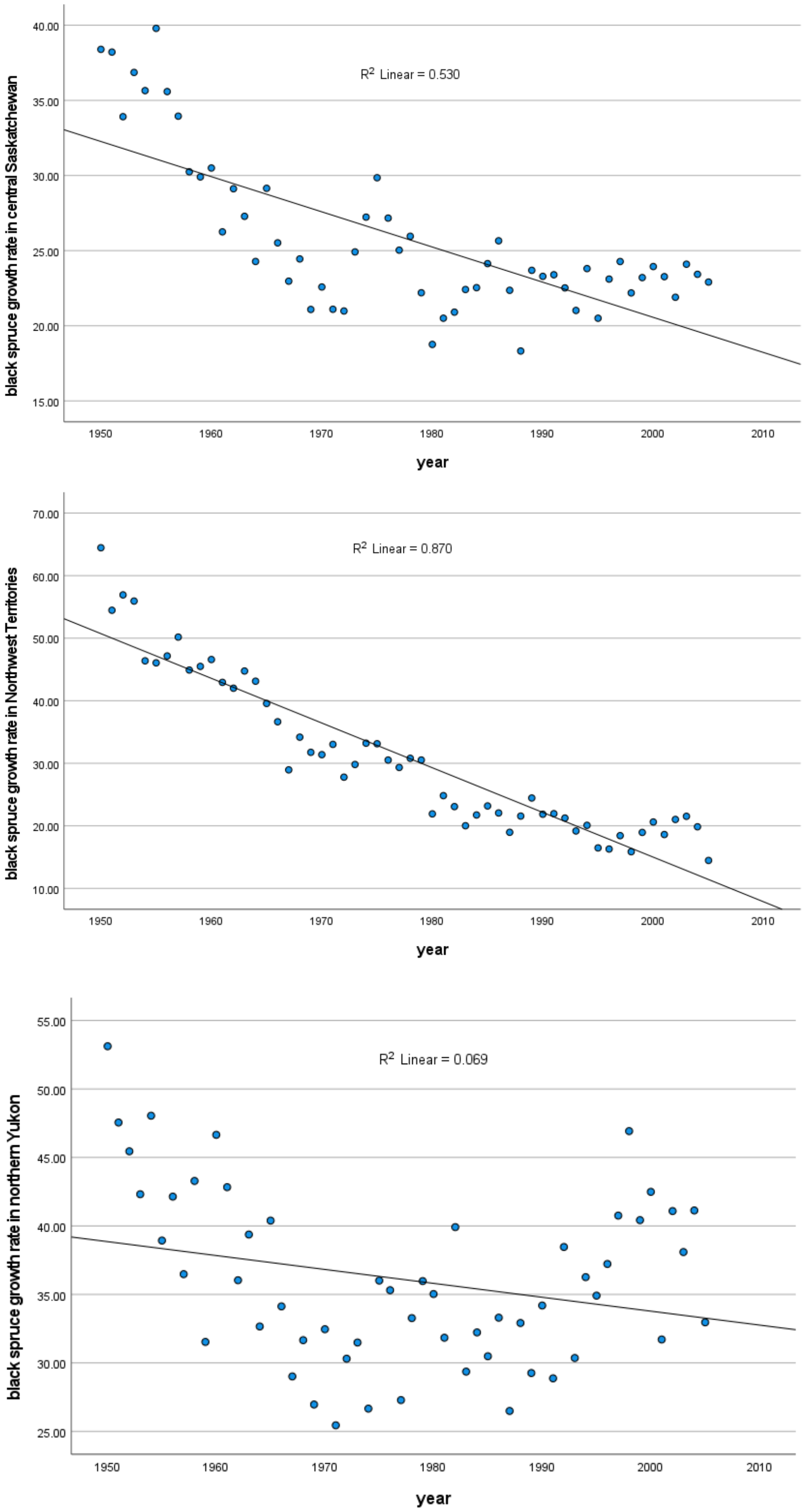

Figure 6. The linear regression analysis between black spruce growth rate and time in three study areas central Saskatchewan, Northwest Territories, and northern Yukon from 1950 to 2005.

Table 1. The model summary of linear regression analysis on black spruce growth rate with time in three study areas central Saskatchewan, Northwest Territories, and northern Yukon.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.728[a]	.530	.522	3.626

a. Predictors: black spruce growth rate in central Saskatchewan
b. Dependent variable: year

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
2	.933[a]	.870	.868	4.538

a. Predictors: black spruce growth rate in Northwest Territories
b. Dependent variable: year

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
3	.263[a]	.069	.052	6.130

a. Predictors: black spruce growth rate in north Yukon
b. Dependent variable: year

4.2 Changes Temperature Over Time

Unitary linear models of temperature and time were run in three study areas central Saskatchewan, the Northwest Territories and northern Yukon from 1950 to 2005. The linear regression scatters plot shows that temperatures in all three areas increased over time from 1950 to 2005 (Figure 7). The fitting degree of temperature and time in the three areas was shown in the model summary Table. The R value represents the simple correlation between time and temperature because there is only one predictor. The value of R squared in the north Yukon area is 0.673 and maximum among these three areas, which tells us that time can account for 67.3% of the variation in the temperature change. Similar, the value of R squared is 0.296 in central Saskatchewan and 0.416 in the

Northwest Territories (Table 2). This statistical analysis shows that the correlation between temperature and time is significant, with the lowest in central Saskatchewan at low latitudes and the highest in northern Yukon at high latitudes. The northern Yukon area had the greatest temperature change between 1950 and 2005, while central Saskatchewan had the smallest temperature change.

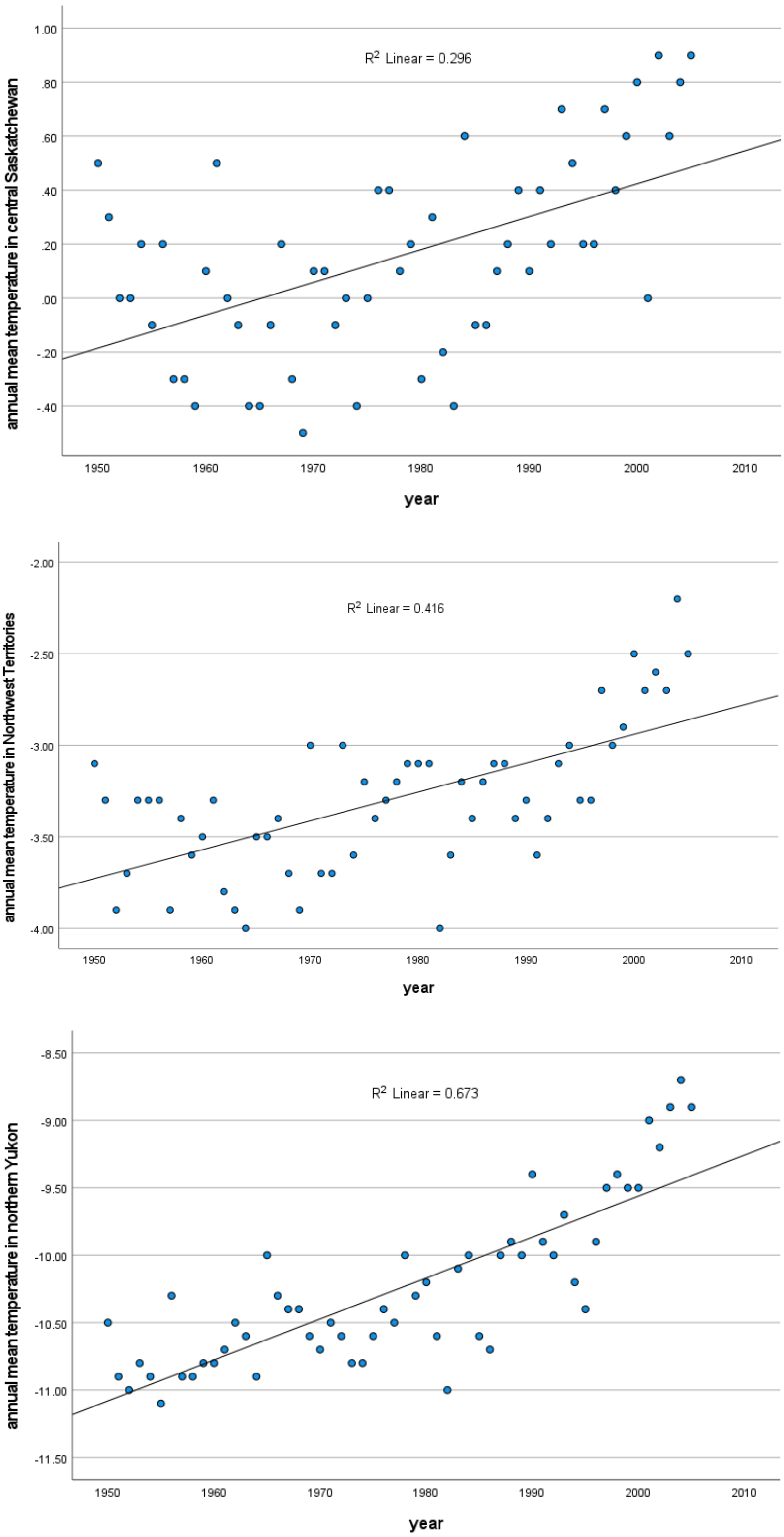

Figure 7. The linear regression analysis graph of temperature and time in three study areas central Saskatchewan, Northwest Territories, and northern Yukon.

Table 2. Model summary of linear regression analysis on temperature with time in three study areas central Saskatchewan, Northwest Territories, and northern Yukon.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.544[a]	.296	.283	.309

c. Predictors: Temperature in central Saskatchewan
d. Dependent variable: year

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.645[a]	.416	.405	.308

a. Predictors: Temperature in Northwest Territories
b. Dependent variable: year

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.820[a]	.673	.667	.349

a. Predictors: Temperature in northern Yukon
b. Dependent variable: year

4.3 Change in Number of Wet Days Over Time

Unitary linear models of wet days (> 1mm) and time were run in three study areas central Saskatchewan, the Northwest Territories and northern Yukon from 1950 to 2005. The value of R squared is 0.008 in central Saskatchewan, 0.037 in the Northwest Territories, and 0.097 in the northern Yukon (Figure 8 and Table3). The results show that the correlation between precipitation change, and time is not significant in the three areas. Precipitation decreased slightly in central Saskatchewan between 1950 and 2005 and increased in the Northwest Territories and northern Yukon. The most significant increase in precipitation occurred in the northern Yukon, where the correlation between precipitation and time was close to 10%.

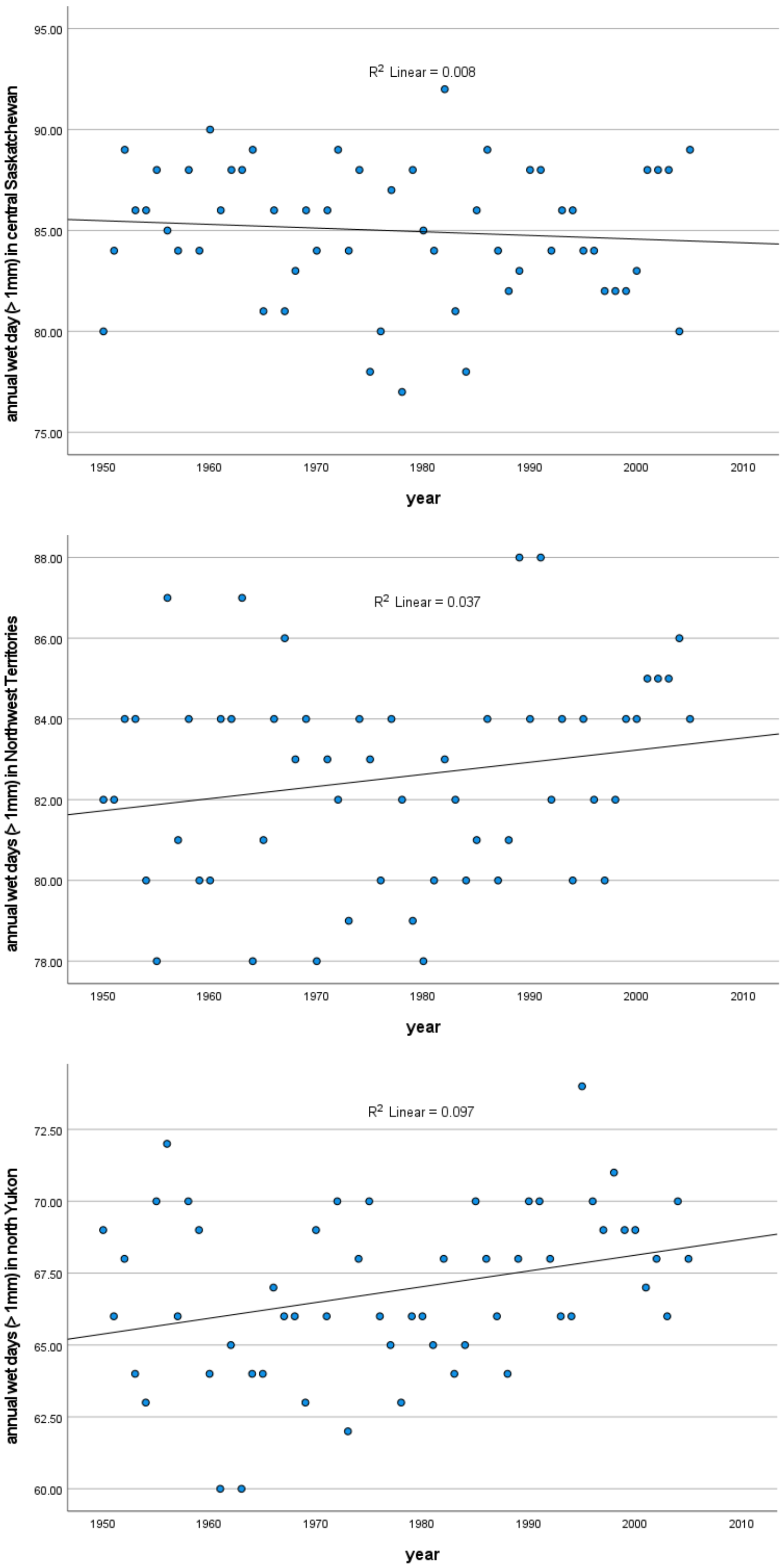

Figure 8. The linear regression analysis graph of wet days (> 1mm) with time in three study areas central Saskatchewan, Northwest Territories, and northern Yukon.

Table 3. The model summary of linear regression analysis on wet days (> 1mm) with time in three study areas central Saskatchewan, Northwest Territories, and northern Yukon.

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.089[a]	.008	-.010	3.345

a. Predictors: wet days (> 1mm) in central Saskatchewan

b. Dependent variable: year

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.193[a]	.037	.019	2.512

a. Predictors: wet days (> 1mm) in Northwest Territories

b. Dependent variable: year

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.311[a]	.097	.080	2.760

a. Predictors: wet days (> 1mm) in in northern Yukon

b. Dependent variable: year

4.4 Multiple Linear Regression

Multiple linear regression model analysis shows that the growth rate of black spruce stands in central Saskatchewan is inversely correlated with temperature, with a slope of -2.289, and with wet days (> 1mm) of only -0.028. The R square value between growth rate with two dependents temperature and wet is 0.025. The growth rate of black spruce forest in the Northwest Territory was inversely correlated with temperature, and its slope value was -15.729. It was also inversely correlated with wet days (> 1mm) only -0.382. The R square value between growth rate with two dependents temperature and wet is 0.259. The growth rate of the black spruce stands in the northern Yukon is inversely correlated with temperature, with a slope of -0.518, and with wet days (> 1mm) of -0.217. The R square value between growth rate with two dependents temperature and wet is 0.010 (Table 4 and Figure 9). Black spruce growth rates in the Northwest Territories showed a large negative correlation with temperature, but not in the northern Yukon. The correlation between black spruce growth rates and wet days is weak.

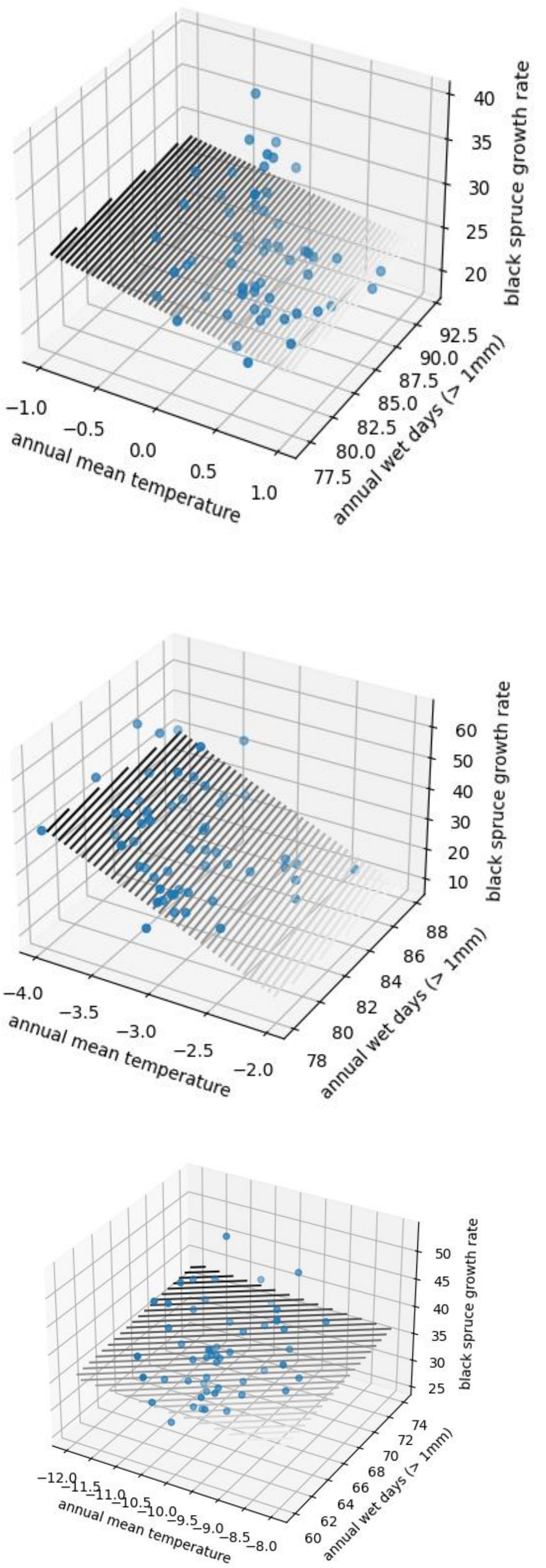

Figure 9. Multiple linear regression model of temperature, wet days (>1 mm), and black spruce growth rate from 1950-2005 in central Saskatchewan, Northwest Territories, and northern Yukon.

Table 4. Model summary of multiple linear regression analysis of temperature, precipitation, and tree rings.

Site	**Central Saskatchewan**	**Northwest Territories**	**Northern Yukon**
Slope (temperature)	-2.289	-15.729	-0.518
Slope (wet days)	-0.028	-0.382	0.217
R square	0.025	0.259	0.010
Standard deviation	5.131	10.661	6.208

5.0 DISCUSSION

5.1 Changes in Black Spruce Growth Rates

The one-variable linear regression analysis showed a high fitting degree between black spruce growth rate and temperature with time, the precipitation change is not significant. The result of multiple linear regression reflects that climate change had played a significant role in the black spruce growth rate, especially the temperature change. And the impact of climate change on black spruce growth in Canada's western boreal forest at all latitudes is negative. The temperature had a more significant negative effect on the black spruce growth rate than precipitation, which was the main reason for the decline of the black spruce growth rate, especially in the Northwest Territories at the middle latitude. From 1950 to 2005, areas at lower latitudes like central Saskatchewan have seen the least increase in temperature, but temperatures have been the highest in the three study areas. Precipitation has been the highest among the three regions, but its change is not obvious. The black spruce growth rate was always lower than those in colder regions at higher latitudes and is more sensitive to heat by comparison through the multiple regression analysis. The reason why black spruce in lower latitudes have lower productivity is that temperature is much higher in lower latitudes than in higher latitudes. Black spruce is a drought-intolerant species and likes the cold environment. Higher temperature and uneven precipitation causing more drought stress are the main factors affecting the growth of black spruce (Subedi and Sharma 2012). In addition, Black spruce is more affected by interspecific competition from other species in the warmer environment because species such as jack pine, and aspen are better adapted to warmer conditions (Subedi and Sharma 2012, Longpré and Morris 2012) In the middle latitudes like Northwest Territories, the most striking feature of black spruce growth rates over the last century was a dramatic decline. The model showed that black spruce trees in the Northwest Territories were most affected by temperature. However, the black spruce in the central region grew better than in the other two regions before 1970. This reflects that black spruce in mid-latitude areas are strongly affected once temperatures rise above a certain level and that temperatures in the northwest have gradually begun to rise above the optimum temperature for black spruce growth in the last century. The loss of peatland also plays an important role, encouraging species that would otherwise not be able to survive on peatland to move into black spruce forests. Rising temperatures and drought can stimulate a decrease in soil organic matter accumulation, more mineral soil will be exposed to the surface (Ketcheson 1972). In high latitudes like the Northern Yukon, the growth rate of black spruce has not changed significantly over the past century, although the rates of temperature increase, and precipitation were most pronounced between 1950 and 2005. The models also show a weak negative correlation between growth rate with climate change. In any case, the black spruce in the Northern Yukon grew at a slower rate than in the Northwest Territories until 1970, reflecting the fact that the temperatures in the high latitudes were always below the optimum for the black spruce, so the temperature increase is positive for the black spruce in the high latitudes in a way. Another reason black spruce trees at high latitudes are least affected by climate change is that increased precipitation at high latitudes, including the melting of permafrost, encourages the formation of thick organic layers on the soil (Sobek 2014). Although black spruce grows more slowly on peatland, the soil conditions limit the survival of other species, allowing the spruce to have enough resources to grow.

5.2 Limitation of Multiple Linear Regression

The multiple regression model was designed to explore the linear relationship between temperature, precipitation, and black spruce growth, but many other factors affect tree growth that causes large standard deviations and small R square value such as fire, forest insect outbreaks, and frost days which are potentially important factors affecting black spruce stands. This suggests that the correlation between the growth rate of black spruce and temperature and wet can be influenced by many other climatic factors. The black spruce forest productivity increases with the rise of carbon dioxide concentration, but whether photosynthetic acclimation will occur still requires more researchers (Lin 1998) In addition, the lack of historical records of climate data and tree ring data makes it impossible to find more data in a longer period, such as, which is also a limitation of this study.

5.2 Climate Change in The Future

Although the trend of global warming is inevitable, countries around the world are also making efforts to mitigate climate change, the intensity of climate change is uncertain and temperature changes are different under different RCP. In predicting the growth of black spruce in the boreal forest, it is very important to determine the standard of change intensity. The intensity of temperature change will lead to different succession results. Under the low emission path RCP2.6, the increase in global average temperature is less than 1 degree Celsius until 2100. Under the high GHG emission path RCP 8.5, temperatures could rise by 4 to 5 degrees over the next 80 years (Figure 2). Emission pathways 2.6 and 8.5 are the more extreme scenarios, while more likely scenarios such as RCP 4.5 are largely determined by emissions from human activities. Countries around the world also began to realize the profound impact of Climate Change. Various international treaties and organizations were born to mitigate The Change, such as The United Nations Framework Convention on Climate Change and Paris Agree. The development of Canada's provincial carbon tax system internalizes the negative externalities of greenhouse gas emissions. These measures in response to climate change will help slow the rate of global warming and the growth of black spruce.

6.0 CONCLUSION

Under global warming, the growth rates of black spruce are expected to decrease at all latitudes, while black spruce at lower latitudes are likely to have larger reductions in growth rates than those at higher latitudes, possibly due to longer growing seasons at higher latitudes somewhat offsetting reduced moisture availability and temperature stress. In the future, climate change is expected to be more significant, and black spruce, as an important cash crop of the boreal forest, is expected to be more seriously affected.

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