OPTIMAL BLACK SPRUCE SEED SOURCES FOR ANTICIPATED FUTURE CLIMATES

by

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ABSTRACT

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Key Words: black spruce (*Picea mariana)*, climate shift, precipitation, provenance test, regeneration, seed source, temperature,

Climate change is occurring at an increasingly rapid pace. Many tree species, even those with wide seed dispersal and high genetic variability, are long-lived and unable to “keep pace” with these shifting climates. The combination of the longevity of trees and human-caused fragmentation of habitat makes it unlikely that these species will adapt on their own. Therefore, local seed sources, though once adapted to local conditions, will no longer be the optimal seed source and will decline in health and rate of growth. Instead, seeds adapted to areas with temperature and precipitation conditions typically seen in more southern sources and lower latitudes will be the best solution. This thesis explores the importance of considering climate shift when selecting seed sources for regeneration. A study of data from provenance tests with various Ontario seed sources was conducted to identify the optimal growing conditions for each seed source. It was found that, in most cases, optimal growth occurred for sources originating from lower latitude. This growth implies to replant harvested forests that are ideally suited for climatic variables present at that site, seeds should be sourced from these “more suitable” locations.

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INTRODUCTION

Global climate has fluctuated gradually throughout the earth's history. Alongside these gradual shifts in climate, vegetation has evolved to adapt and change genetically with traits best adapted for these climates (Williams and Dumroese 2013). Thus, climate has historically played a significant role in shaping vegetative growth, composition, and genetic variation (Williams and Dumroese 2013). While vegetation has so far adapted to these changes, global mean temperatures are increasing at unprecedented rates. Human interference and a resulting surge in greenhouse gasses have accelerated these changes at a rate unequaled in the geological time scale (Overpeck 1991, IPCC 2007, Hoegh-Guldberg et al. 2008). This global warming has resulted in a "shift" of these warmer climates towards the poles and to higher elevations (Williams and Dumroese 2013). As the Earth's atmosphere slowly heats up, these changes in climate are predicted to have significant effects on the habitat of tree species and will have a considerable impact on global vegetation as a whole (Overpeck 1991, Bartlein et al. 1997). A combination of adaptation and migration is vital to vegetation reacting to a changing climate; however, modern climatic changes have been so drastic that assistance in this migration may become necessary (Davis and Shaw 2001).

While vegetation was once able to respond to gradual changes through natural selection, the unprecedented rate of climate change has caused a significant lag in adaptation (Williams and Dumroese 2013). In addition, vegetation faces barriers that may further inhibit adaptation. The first major barrier is the rate at which this change is occurring when compared to, for example, the longevity of black spruce and other tree species. Significant climate change can occur over the length of a single generation, causing the next generation to be ill-adapted (Bartlein at al. 1997, Davis 1989, Lenoir 2008). The second major barrier is that human habitat fragmentation can prevent seed sources from reaching optimal climates (Crowe and parker 2008, Vitt et al. 2010). These combined factors can lead to the eventual extinction or extirpation of a species from their natural habitat.

This problem can be addressed through assisted migration. Assisted migration is the process of moving a species from a gene pool adapted to certain environmental factors to an area that has those same specific factors (Crowe and parker 2008, Vitt et al. 2010). In order to determine the best-adapted seed source, provenance tests can be conducted. These tests allow for a wide variety of seed sources across a specific geographic range to be planted in sites (across this range) so that growth across different climatic conditions can be compared. Seasonal temperature minimums, maximums, and averages, as well as precipitation rates, can be analyzed through response and transfer functions so that ideal seed sources may be determined for a certain climatic range. Furthermore, through the use of anticipated future climate data, seed sources can be matched to an ideal future climate.

The objective of this thesis is to improve seed source selection for harvested sites within Ontario. Through the use of existing provenance data for black spruce, this thesis will attempt to create response and transfer functions to determine optimal seed sources for planting sites across Ontario, and the likely future climates of these sites. I predict that transfer functions will indicate that seed sources from southern climates and lower elevations will outperform local seed sources under climate change.

LITERATURE REVIEW

BLACK SPRUCE

Black spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenburg: Pinaceae) ranges across Canada and, to a limited extent, the northern US (Farrar 1995). It can tolerate a wide variety of habitats. Swamps characterize its southern range while the northern range is characterized by northern facing slopes where permafrost affects drainage (Farrar 1995, Wirth et al. 2008). Climate change will have a significant effect on the habitat of this species as increases in temperature will cause permafrost to melt and lakes to shrink, which will severely impact drainage. Black spruce is semi-serotinous and often regenerates after fire events. Seeds are stored in aerial seed banks and can survive for up to 30 years (Greene et al. 1999). Dispersal of seeds typically happens directly around black spruce due to their short stature (Wirth et al. 2008). This short dispersal distance will have a significant effect on the survival of this species as migration is extremely limited and cannot keep pace with a shifting climate. The combined effects of black spruce's limited dispersal range, as well as the susceptibility of its natural range to increasing temperatures, will make local seed sources ill-adapted to anticipated future climatic conditions.

POTENTIAL TREE RESPONSES TO CLIMATE CHANGE

There is a significant relationship between plant species and climate, which can be used to identify potential future habitat (Keith 2008). This association is based on the idea that plant species more easily establish in new regions in which their climate regime is met than evolve to new pressures. Modern studies of vegetation and their current climates in the face of climate change have predicted significant displacement and widespread extinctions (Dawson et al. 2007). Global warming will cause shifts in habitat towards the poles (Hickling et al. 2006, IPCC 2007, parmesan 2008) and areas of higher elevation (Hickling et al. 2006, Lenoir et al. 2008). A study of 134 plant species modelled under various climate change scenarios found that a shift of up to 800-1000 km towards the poles can be predicted under the hottest climate change scenarios (Overpeck 1991, Iverson et al. 2008). Between 7-11% of North American tree species may be entirely displaced from their local climate (Morse et al. 1993). Many species will likely shift alongside these changes; however, dispersal ability or specialized habitat requirements will significantly reduce the success of this movement (Morse et al. 1993). In order to meet this rapid shift of habitat, plant species would need to migrate 3000-5000 metres annually (Williams and Dumroese 2013).

Intrinsic factors such as biology and genetic diversity, and evolutionary processes, including reproduction capacity and dispersal, will predict the success of a plant species adaptation to a changing range (Davis and Shaw 2001, Keith et al. 2008, Morgenstern 2011, Parmesan 2008). Additionally, extrinsic factors such as the magnitude and rate of climate change will act as a further influence (Dawson et al. 2011). The success of adaption to a new habitat is dependent on the interaction between selection and gene flow (Davis and

Shaw 2001). Trees have high phenotypic plasticity and, in most cases, have high levels of genetic variation (Crowe and Parker 2008). High levels of genetic variation allow for evolution under climate change pressures; therefore, preservation of this variation is essential (Crowe and Parker 2008).

HABITAT FRAGMENTATION

Humans and their influence on the modern landscape over centuries have caused significant habitat fragmentation throughout Ontario. Colonization by plants is limited by considerable geographic barriers (Davis, 1989). Rates of response by plants are influenced by their evolutionary ability to persist and are dependent on the spatial arrangement of suitable habitat and the rate of habitat appearance (Keith et al. 2008). Habitats are highly fragmented and dominated by humans, which will have a detrimental impact on plant dispersal (Dawson et al. 2011). If a potential habitat is not available so that seed dispersal can occur and follow climatic shifts, plant species will be unable to keep up with the rate of climate change as these spatial barriers arise.

EFFECTS OF LONGEVITY AND MIGRATION LAG ON BLACK SPRUCE

Trees are particularly long-lived species. Though trees have so far adapted alongside natural variation, current climate change is occurring at such an unprecedented rate that this adaptation is no longer feasible primarily due to their longevity (Davis 1989). Though black spruce has high phenotypic plasticity, the rate at which climate change is occurring will result in significant changes over a single generation of black spruce growth. This lifespan and long reproductive cycle will likely result in changes that lag by decades and therefore leaving the next generation poorly adapted (Bartlein at al. 1997, Davis 1989, Lenoir 2008). As tree migration lags further and further behind changes in climate, the shift in forest composition will be severely impacted, and survival may be threatened (Crowe and parker 2008, Williams and Dumroese 2013).

Habitat fragmentation and migration lag are of particular importance for black spruce. A study conducted by Yang et al. (2005) determined that most black spruce within southern and central Ontario grow in sub-optimal conditions and, on average, will begin to decline in the coming decades. These central Ontario seed sources typically grow at temperatures close to their optimum. Therefore, any increase in temperatures from climate change will likely result in reduced growth (Thomson et al. 2009). Sources in southern Ontario climates have typically already surpassed their optimal growing temperatures and will likely continue to decline in growth (Thomson et al. 2009).

ASSISTED MIGRATION

Black spruce will not be able to naturally adapt to shifting climates nor shift alongside their ideal climates towards northern ranges. These adaptations and the need for natural range expansion can be emulated through assisted migration, specifically, forestry assisted migration (Davis 1989, Vitt et al. 2010). Assisted migration of trees is done through planting species adapted to certain temperature and precipitation regimes, in new environments that have similar climates. Through this process, tree migration may be able to keep pace with climate change (Crowe and parker 2008, Vitt et al. 2010). While assisted migration may seem like a radical or potentially dangerous solution, there is a long history of assisted migration to reintroduce extirpated species, respond to disturbances, escape disease, or introduce ornamental species (Vitt et al. 2010). This movement is not without risk as assisted migration can introduce invasive species or maladapted genotypes (Vitt et al. 2010).

RESPONSE MODELS

Response models can be used to determine the climatic factors that are the most significant in their effect on the growth of trees. Spring and summer temperatures can be used as a measure of the growing season (Overpeck 1991), which is measured as the frost-free period in a growth cycle (Walsh et al. 2014). The growing season's warmth and length have a significant effect on vegetation as growth is controlled by temperature, precipitation, and light (Overpeck 1991). Fluctuations in the growing season period have a significant impact on plant fitness and competition (Menzel et al. 2003). Tree growth is typically synchronized with seasonal cycles and changes brought about by climate change. As a result of this, climate change may cause tree species to become maladapted (Walsh et al. 2014, Williams and Dumroese. 2013).

The length of the growing season has increased along with summer photosynthetic activity in recent years. The recent increase in mean temperature has increased the foliation period (Menzel et al. 2003). This foliation period is critical as plants are susceptible to extreme cold events and frost killing in the first days of foliation (Menzel et al. 2003). In North America, spring has been advancing at a rate of 1.2-2.0 days per decade showing a significant increase (Menzel et al. 2003). Additionally, the longer growing season provides an increased opportunity for fire as elevated levels of evaporation and transpiration dries leaves, and the extended warmth dries soil (Walsh et al. 2014)

Precipitation also has a significant effect on local vegetation as precipitation often determines water availability. Precipitation has increased by 5% a year across the U.S. since 1990 (Walsh et al. 2014). Due to climate change, these trends will be magnified; areas that regularly experience high precipitation will receive more, and places with lower rates will receive less. Without human assistance, plant species will quickly become maladapted to their new climate (Williams and Dumroese 2013). For replanting, it is vital that appropriate sources are selected. Even within plant species, geographic variation is so vast that ignorance of this topic can lead to failures in replanting (Morgenstern 2011). The wide dispersal of black spruce has led to natural selection adapted to particular sites (Morgenstern 2011).

MATERIALS AND METHODS

PROVENANCE TRIAL MEASUREMENTS

Black spruce is an economically important species within Canada, and in 1963 the Canadian Forestry Service began studies of this species within the central parts of its range (Morgenstern 1978). This study allowed for the effects of natural selection to be studied, as growing sites and their individual climates would select for seed sources best adapted for these conditions (Morgenstern 1978). Six agencies across the United States and Canada assisted in the collection of seeds across 202 stands, with seeds from approximately 15 trees collected from within each seed source (Morgenstern 1978). The Canadian provenance results used within this study come from Lakehead University students in 2003, while results from Minnesota were collected by Carrie Pike from the Minnesota Tree Improvement Cooperative. Height and diameter data were collected from each surviving tree (Thomson and Parker 2008). The volumes for each tree species were calculated using the black spruce volume equation provided by Luckai (1999), where black spruce constants determine that A=361.8 and B = 23150.3.

$$VT\ (dm^3) = \left(\frac{Dbhob^2}{\left(A + \left(\frac{B}{Ht}\right)\right)}\right)1000$$

Average means for each plot within each provenance were calculated. These averages were then used to calculate the average volume for each provenance within each of the six test locations.

STUDY AREA

Seed source data was obtained from across the research area. Of the 192 seed sources that data was received for, six sources were present across all six provenances, 22 sources were present across five provenances, 22 sources were present across four sources, 14 sources were present across three provenances, 13 sources were present across two provenances, 73 sources were present in only one provenance, and 41 were not present in any provenances. This study focused exclusively on the sources present in four or more provenances and within central and northwestern Ontario. Of these sources, 14 provenances were present in four sites, 21 were present in five sites, and three were present in all six sites. These provenances are displayed below in Table 1.

Test sites include Chapleau, Dryden, Longlac, St Cloud (MN), Petawa, and Raith as displayed in Table 2.

Table 1. Site data for provenance locations

provenance	n sites present in	Jurisdiction	Latitude	Longitude	Elevation (m)
6906	5	ON	48.20	-82.38	340
6907	5	ON	48.53	-81.42	300
6908	4	ON	48.98	-80.63	300
6909	6	ON	49.75	-85.08	210
6910	5	ON	49.67	-87.83	300
6911	5	ON	46.33	-82.83	240

6912	5	ON	46.77	-83.43	370
6913	5	ON	46.72	-84.38	210
6914	6	ON	48.63	-85.33	370
6915	4	ON	49.13	-85.78	310
6917	5	ON	49.00	-90.45	470
6918	4	ON	49.42	-91.52	460
6919	5	ON	50.32	-90.68	400
6920	5	ON	50.73	-90.57	380
6921	4	ON	51.47	-90.18	400
6922	5	ON	50.22	-91.67	400
6923	5	ON	50.40	-93.33	350
6924	5	ON	50.88	-93.73	350
6925	4	ON	49.83	-93.50	380
6927	5	ON	50.83	-94.28	340
6928	4	ON	49.33	-93.92	340
6930	6	ON	48.80	-93.67	370
6931	5	ON	48.73	-91.67	380
6932	5	ON	48.07	-90.18	450
6936	4	ON	51.27	-80.77	60
6937	4	ON	51.10	-80.87	61
6941	5	MI	44.63	-84.33	320
6942	4	MI	44.20	-85.58	180
6943	5	MI	46.05	-84.78	210
6944	4	MI	45.98	-86.85	180
6945	4	MI	46.40	-89.70	470
6947	5	WI	45.28	-88.45	400
6948	5	WI	45.73	-88.98	460
6949	4	WI	45.73	-89.05	460
6953	5	MN	47.62	-90.87	680
6954	5	MN	47.70	-91.30	400
6957	4	MN	47.53	-93.72	470
6975	4	MB	50.07	-95.45	340

Table 2. Test location data

Test abbreviation	Town	State/ province	Latitude	Longitude	Elevation
Chap	Chapleau	Ontario	47.96	-83.43	472
Dry	Dryden	Ontario	49.92	-92.48	383
Long	Longlac	Ontario	49.75	-86.16	312
Min	St. Cloud	Minnesota	47.19	-93.41	400
Pet	Petawawa	Ontario	45.97	-77.40	525
Rait	Raith	Ontario	48.94	-89.88	495

CLIMATE DATA

Climate data were obtained from the ClimateNA software developed by Wang et al. (2016). This software has created a small-scale climate database using baseline climate data from 1961-1990 as defined by the World Meteorological Organization so that current and future data can be predicted across regions of North America. Through the use of monthly temperature and precipitation data from General Circulation Models (GCMs) of the Climate Model Intercomparison Project 5 (CMIP5) climate change and the associated change in climate variables can be predicted. For future data, two greenhouse gas concentration trajectories were used to represent the impacts on future climate so that prospective variables could be predicted.

As temperature and precipitation have a statistically significant impact on growth and, therefore, the volume of vegetation, 16 climate variables were tested through regressions so that the most significant variable on black spruce volume could be determined. Temperature and precipitation were tested under four variables (minimum temperature, average temperature, maximum temperature, and precipitation) across winter, spring, summer, and autumn. These climate variables and the abbreviations for each are described in table 3.

Table 3. Climate variables

Climate Variable Abbreviation	Climate Variable
Tmax_wt	maximum winter temperature
Tmax_sp	maximum spring temperature
Tmax_sm	maximum summer temperature
Tmax_at	maximum autumn temperature

Tmin_wt	minimum winter temperature
Tmin_sp	minimum spring temperature
Tmin_sm	minimum summer temperature
Tmin_at	minimum autumn temperature
Tave_wt	average winter temperature
Tave_sp	average spring temperature
Tave_sm	average summer temperature
Tave_at	average autumn temperature
PPT_wt	winter precipitation
PPT_sp	spring precipitation
PPT_sm	summer precipitation
PPT_at	autumn precipitation

RESPONSE AND TRANSFER FUNCTIONS

Response functions model the regressions of growth and success of provenances within a defined test range according to an individual climate variable. Response and transfer functions were first introduced to compare tree growth to climatic variables in 1971 by Fritss et al. (Blasing 1984). Until this point, humans and computers were unable to process the variables required to conduct this research (Fritts et al. 1971). Here, 16 climate variables were screened using quadratic regressions, calculated in Excel, to determine the strongest climate predictor of black spruce growth. To determine Cauchy functions, the regression wizard function of Sigmaplot software was used. The peak, Lorentzian 3-parameter formula (line position, maximum height and half-width) as seen below, was used to calculate these parameters.

$$y = \frac{a}{1 + \left(\frac{x - x_o}{b}\right)^2}$$

RESULTS

The coefficients of determination for quadratic regressions ranged from 0.0527 to 0.1933 within Chapleau, 0.036 to 0.3412 in Dryden, 0.0292 to 0.3415 in Longlac, 0.0319 to 0.3490 in Minnesota, 0.0204 to 0.2332 in Petawa, and 0.0062 to 0.0785 in Raith (Figures 1 to 16, Table 3). The values determined for Raith are particularly small and so were not used to calculate averages. Across average coefficients of determination, the highest values come from maximum autumn temperature (0.235).

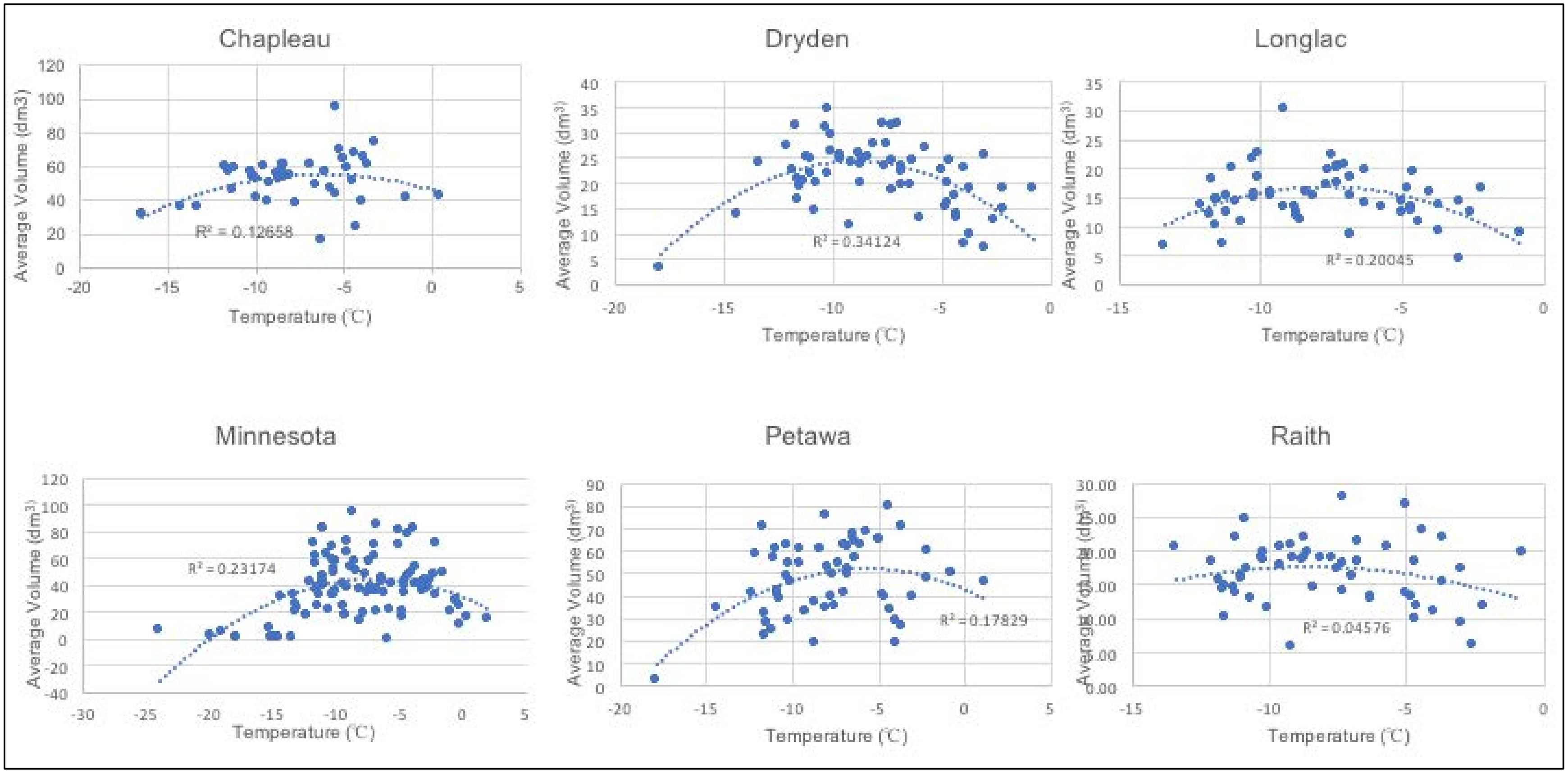

Figure 1. Maximum Temperature - Winter

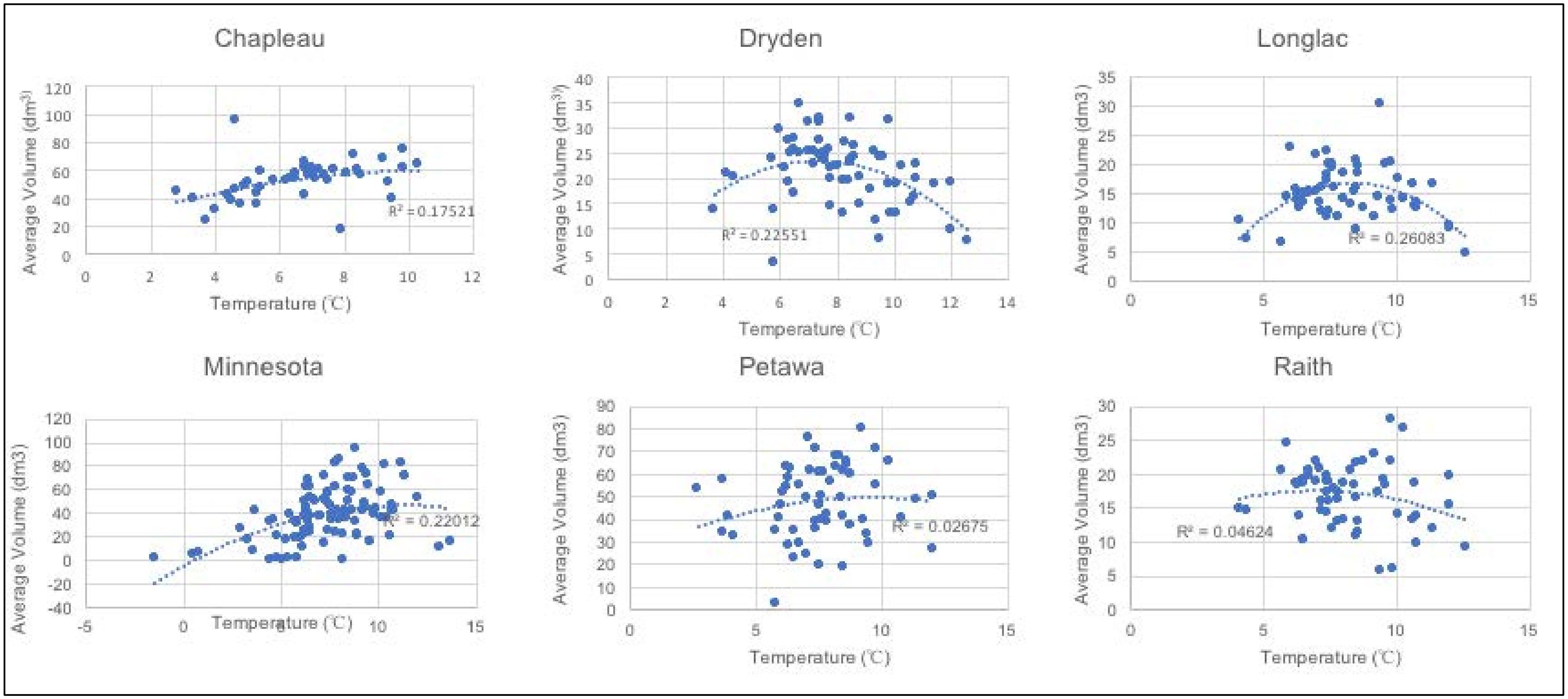

Figure 2. Maximum Temperature – Spring

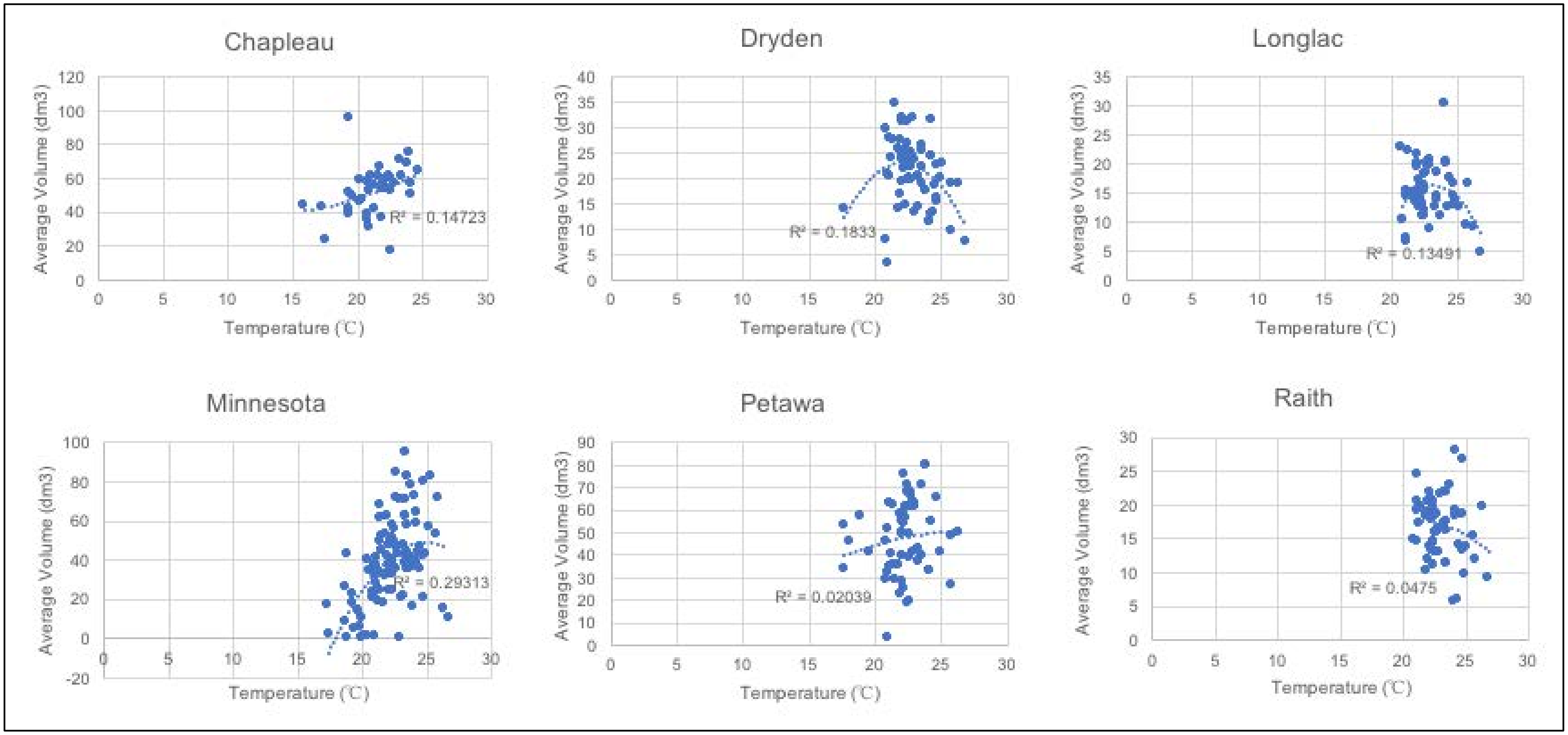

Figure 3. Maximum Temperature - Summer

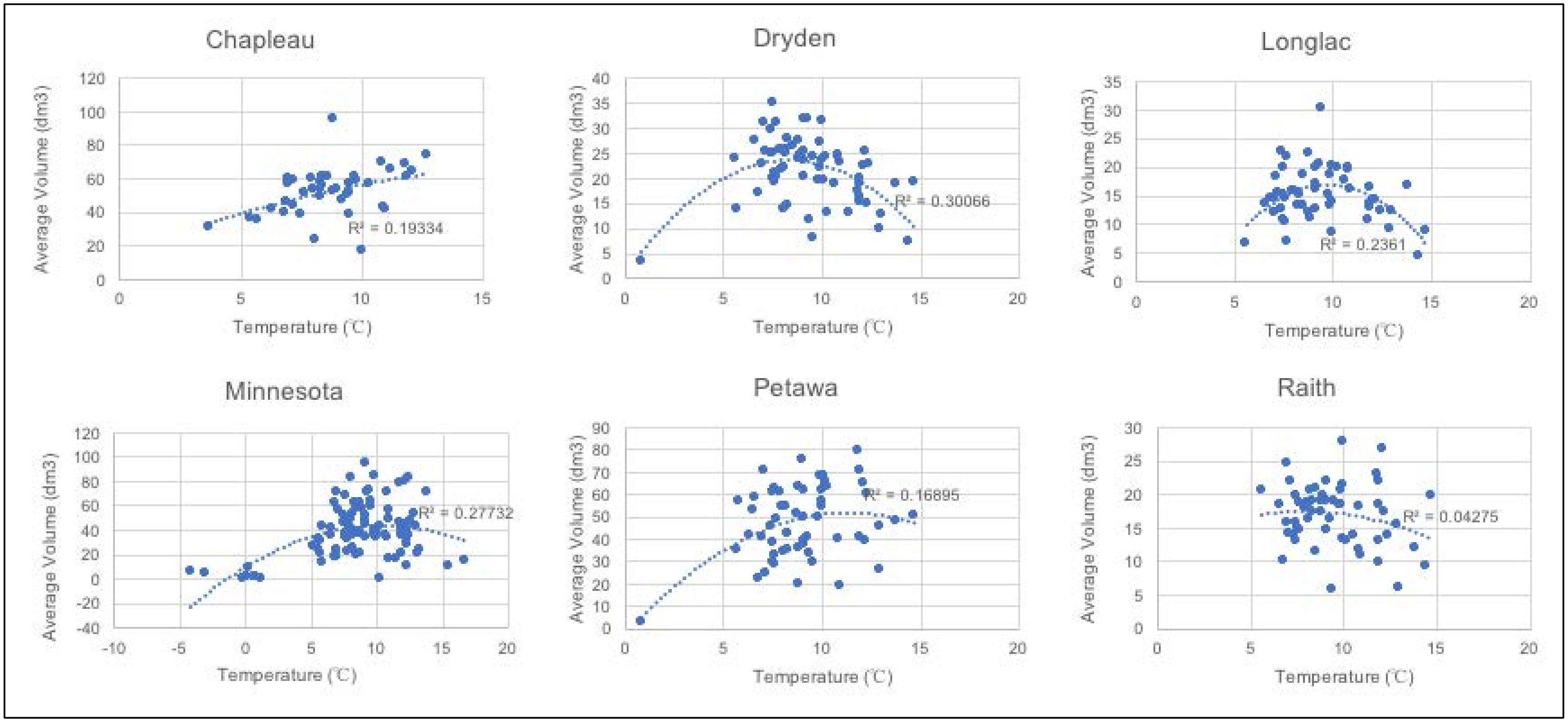

Figure 4. Maximum Temperature - Autumn

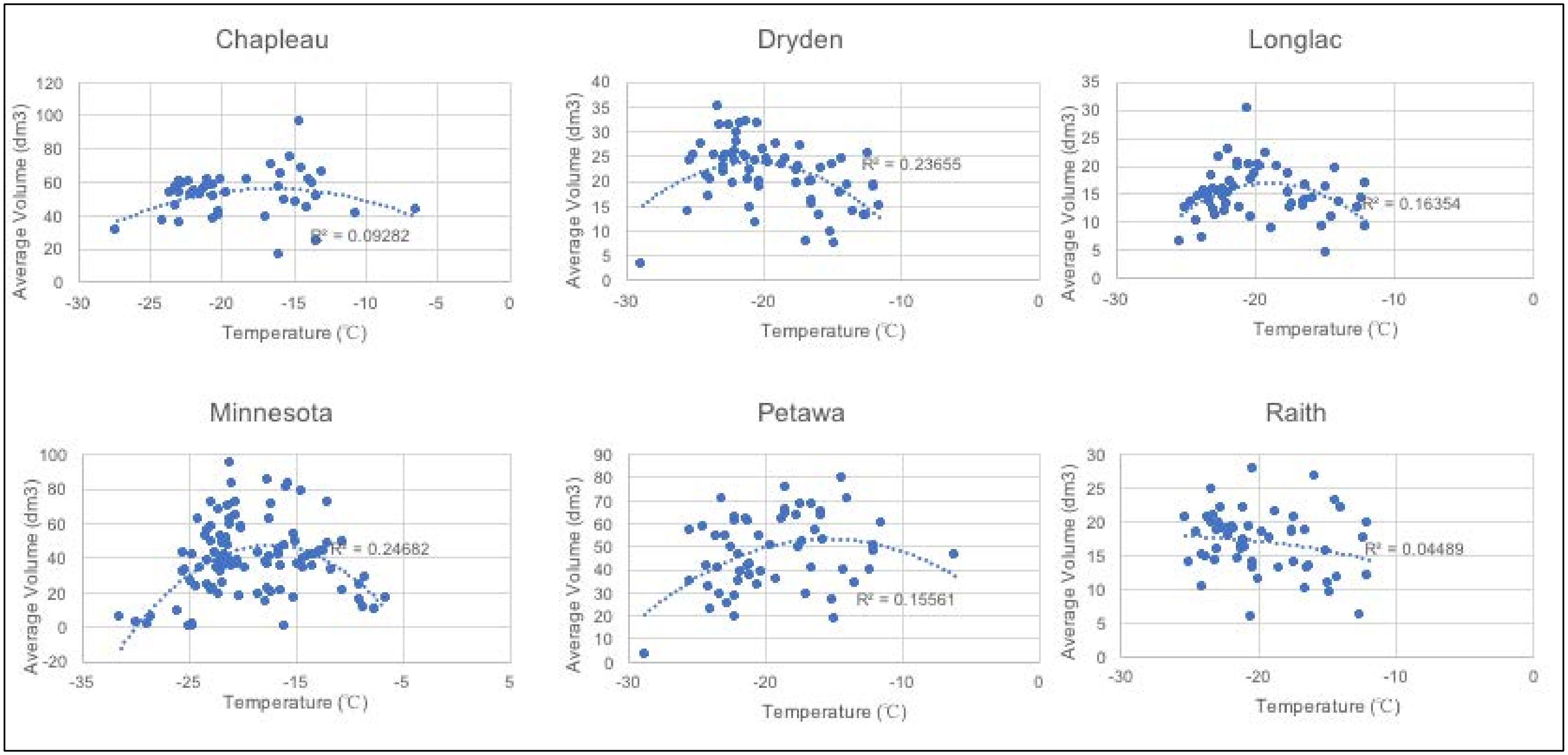

Figure 5. Minimum Temperature - Winter

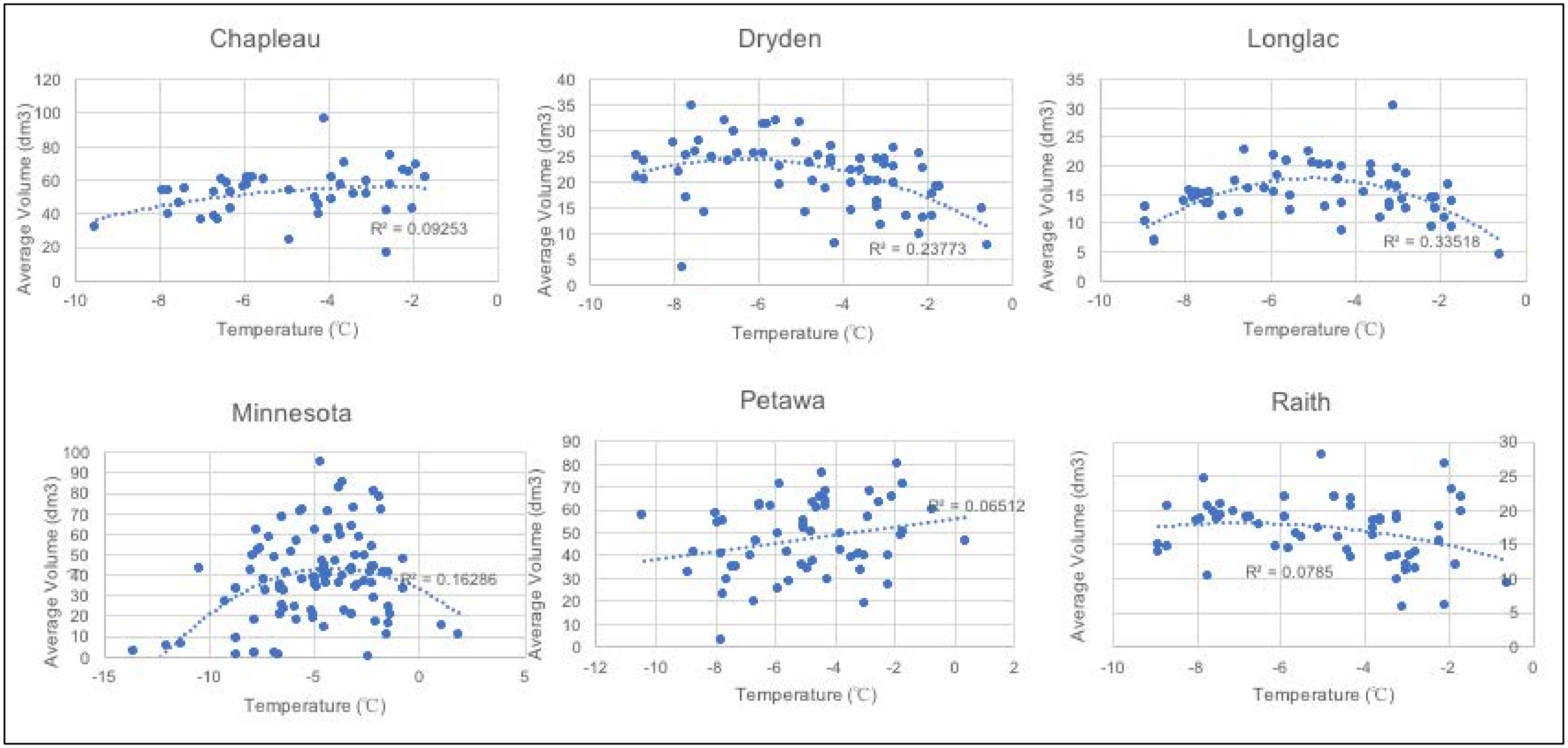

Figure 6. Minimum Temperature - Spring

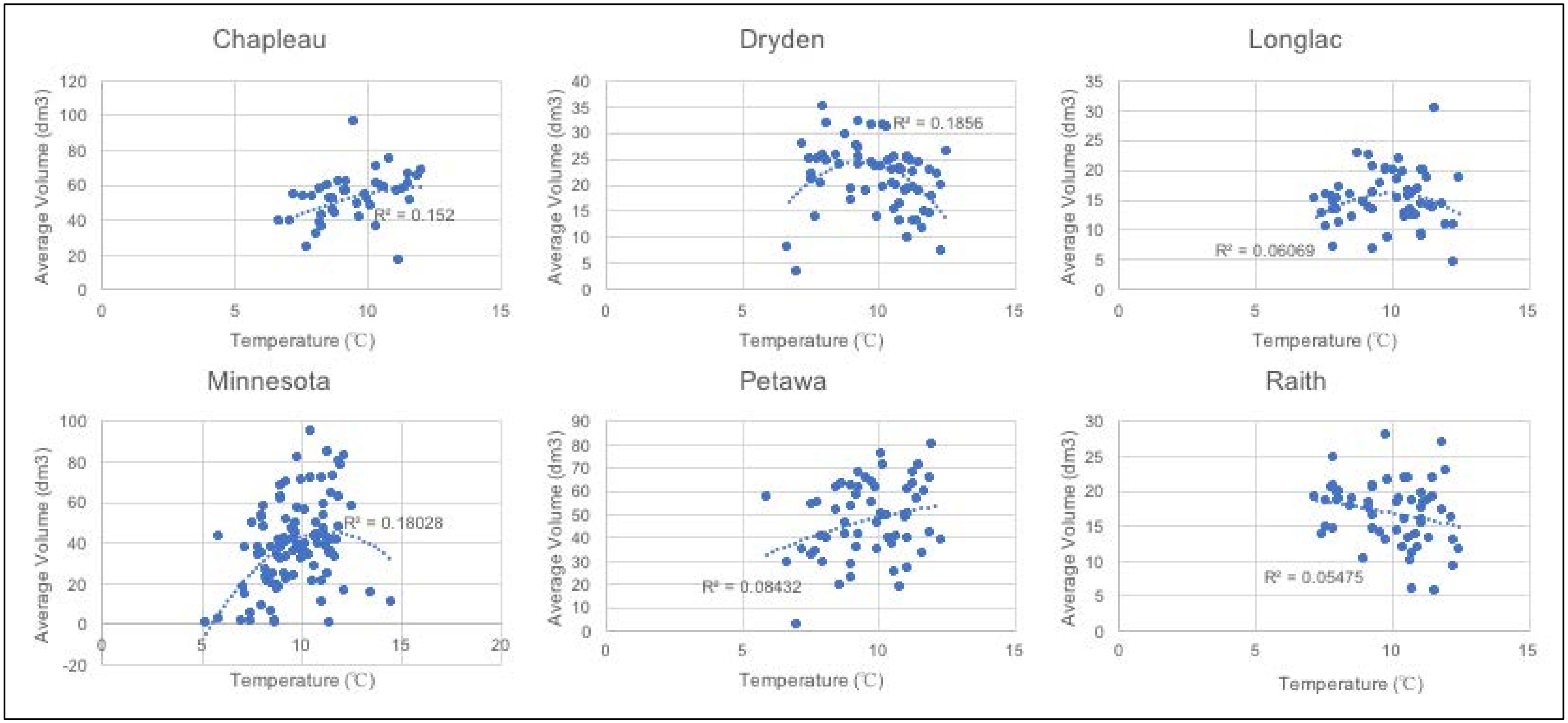

Figure 7. Minimum Temperature - Summer

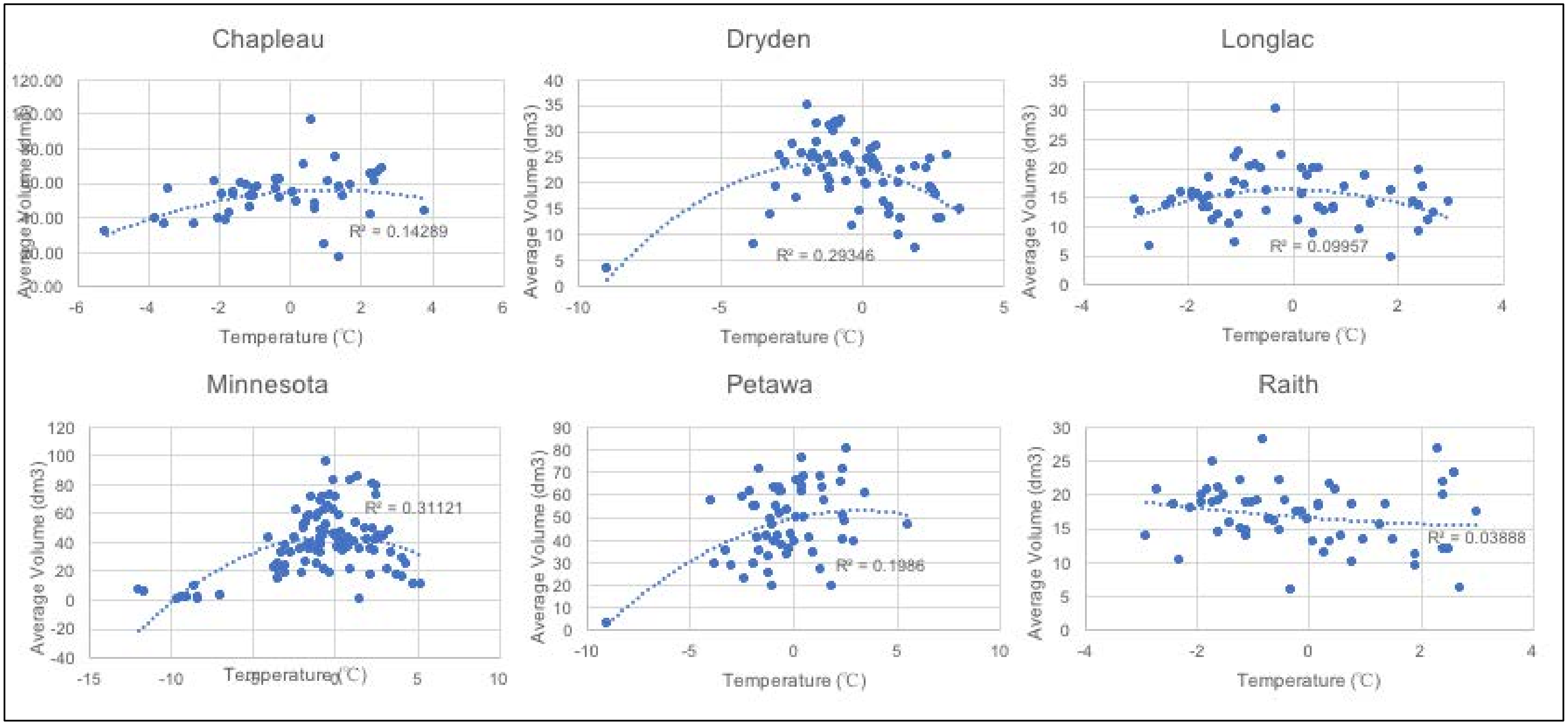

Figure 8. Minimum Temperature - Autumn

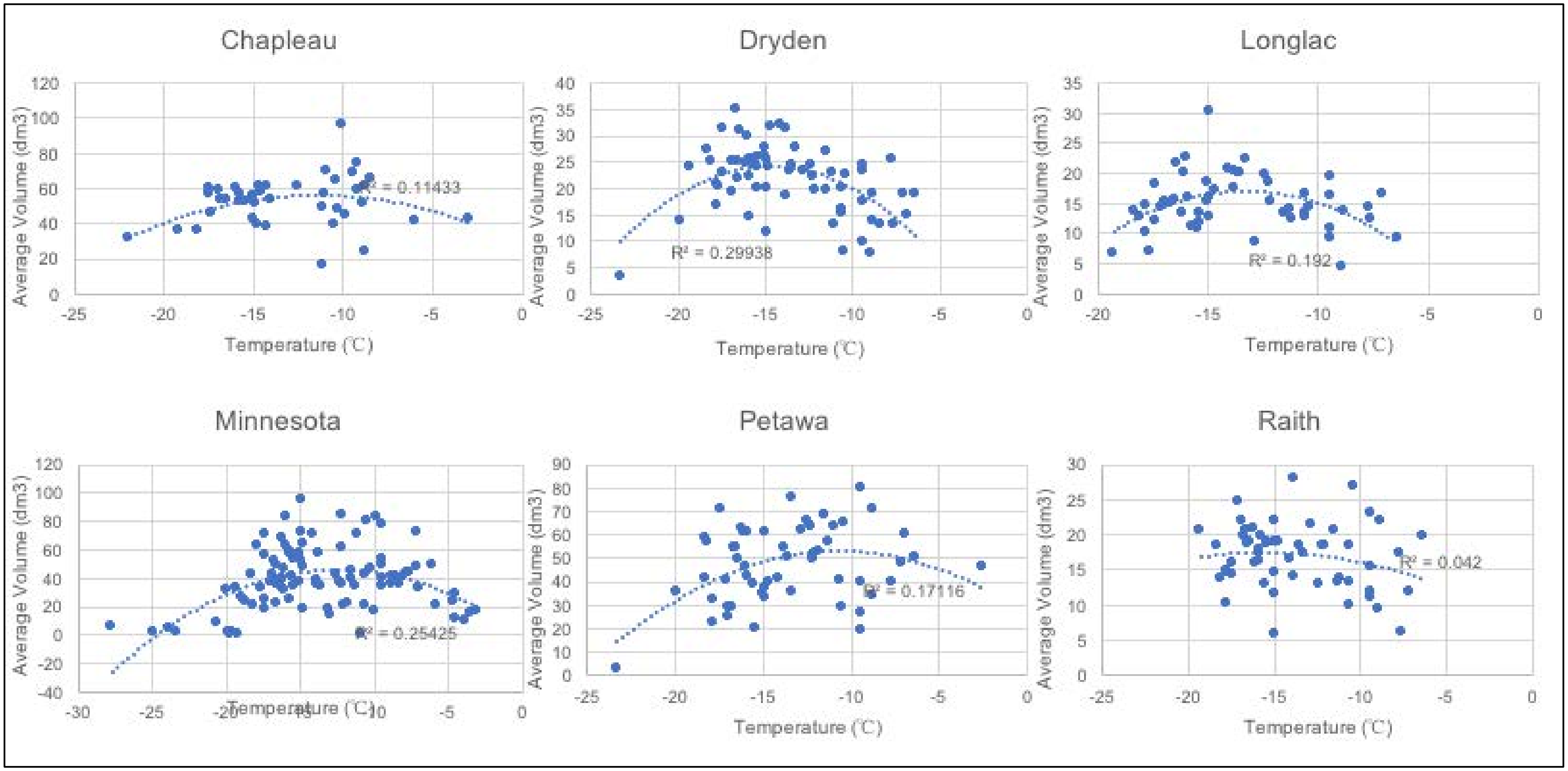

Figure 9. Average Temperature - Winter

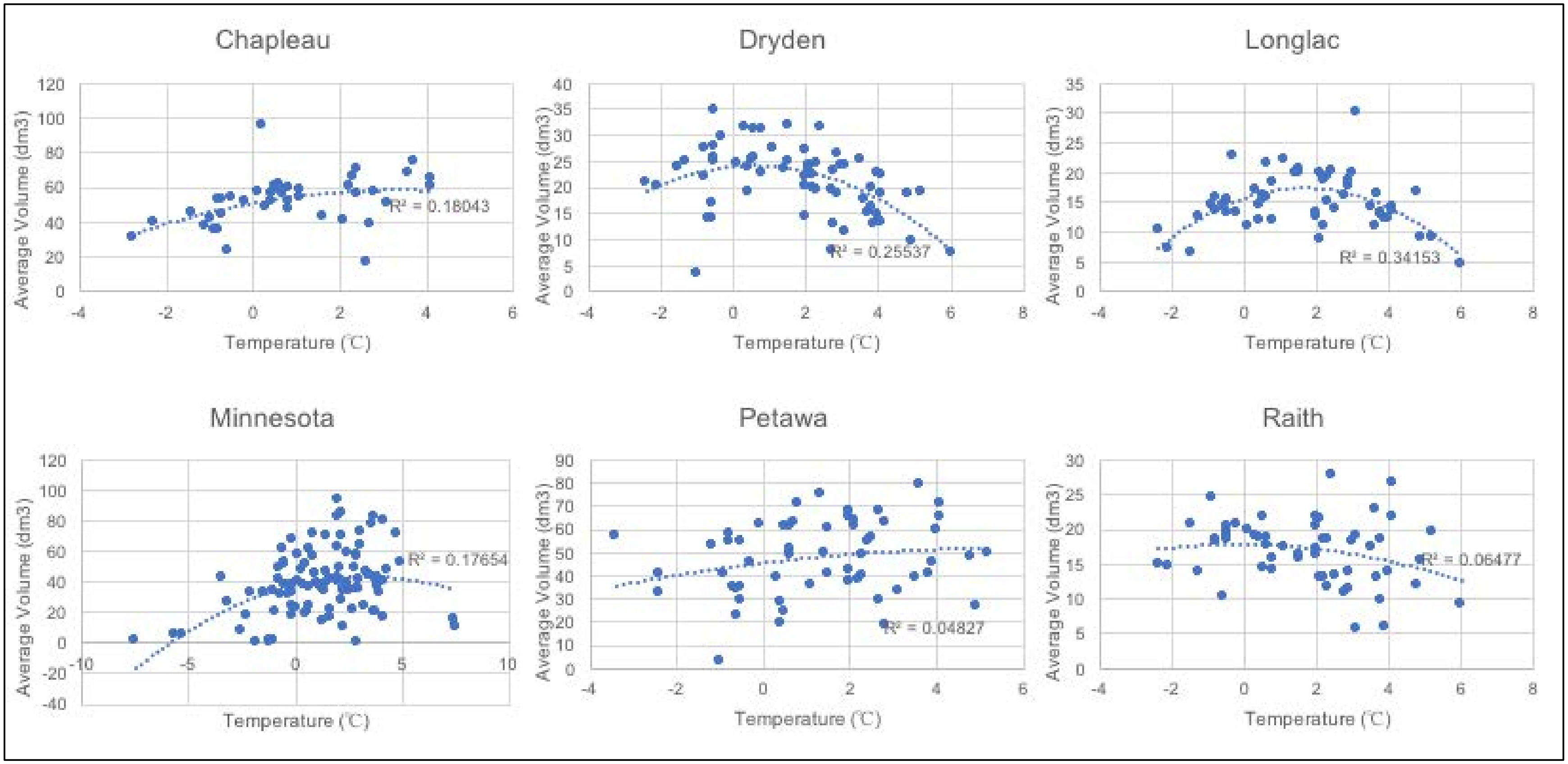

Figure 10. Average Temperature Spring

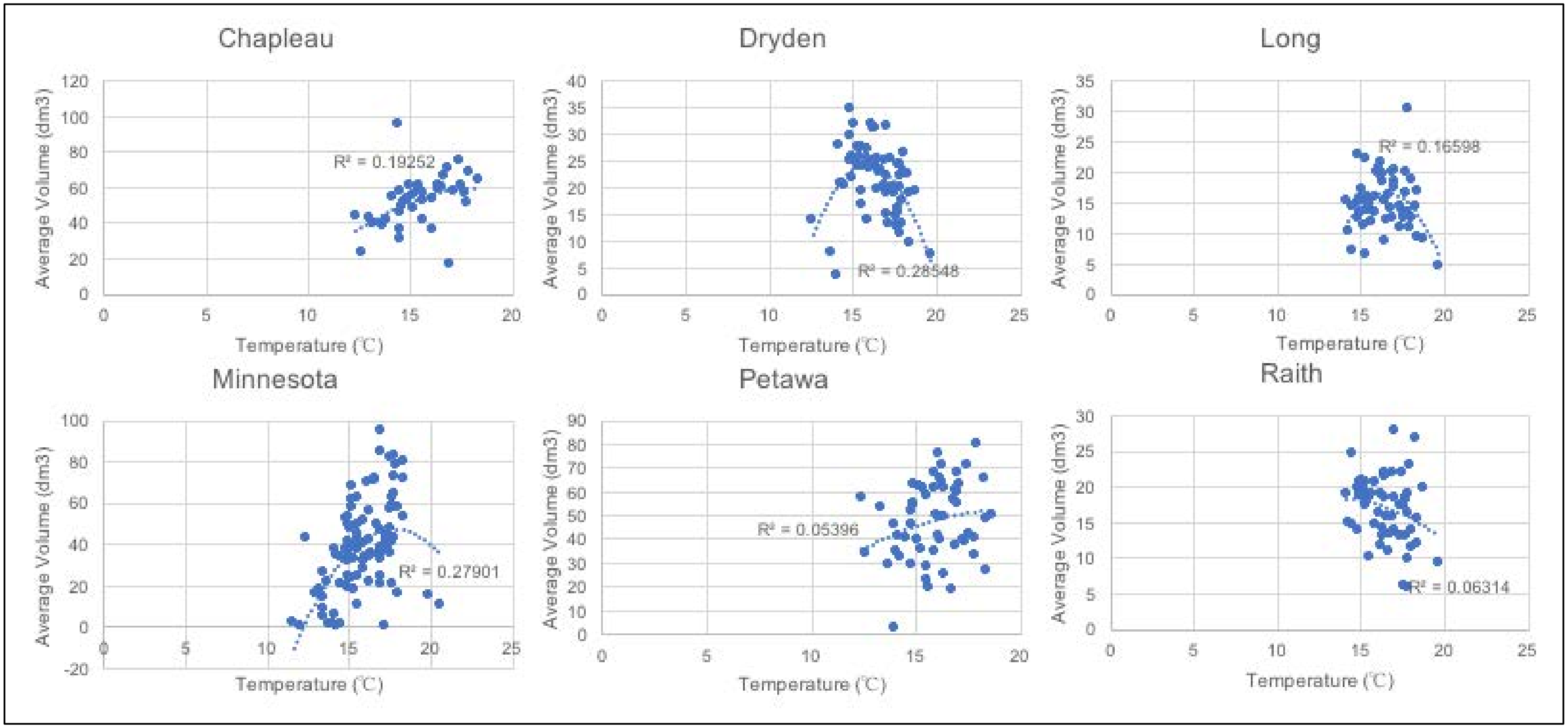

Figure 11. Average Temperature - Summer

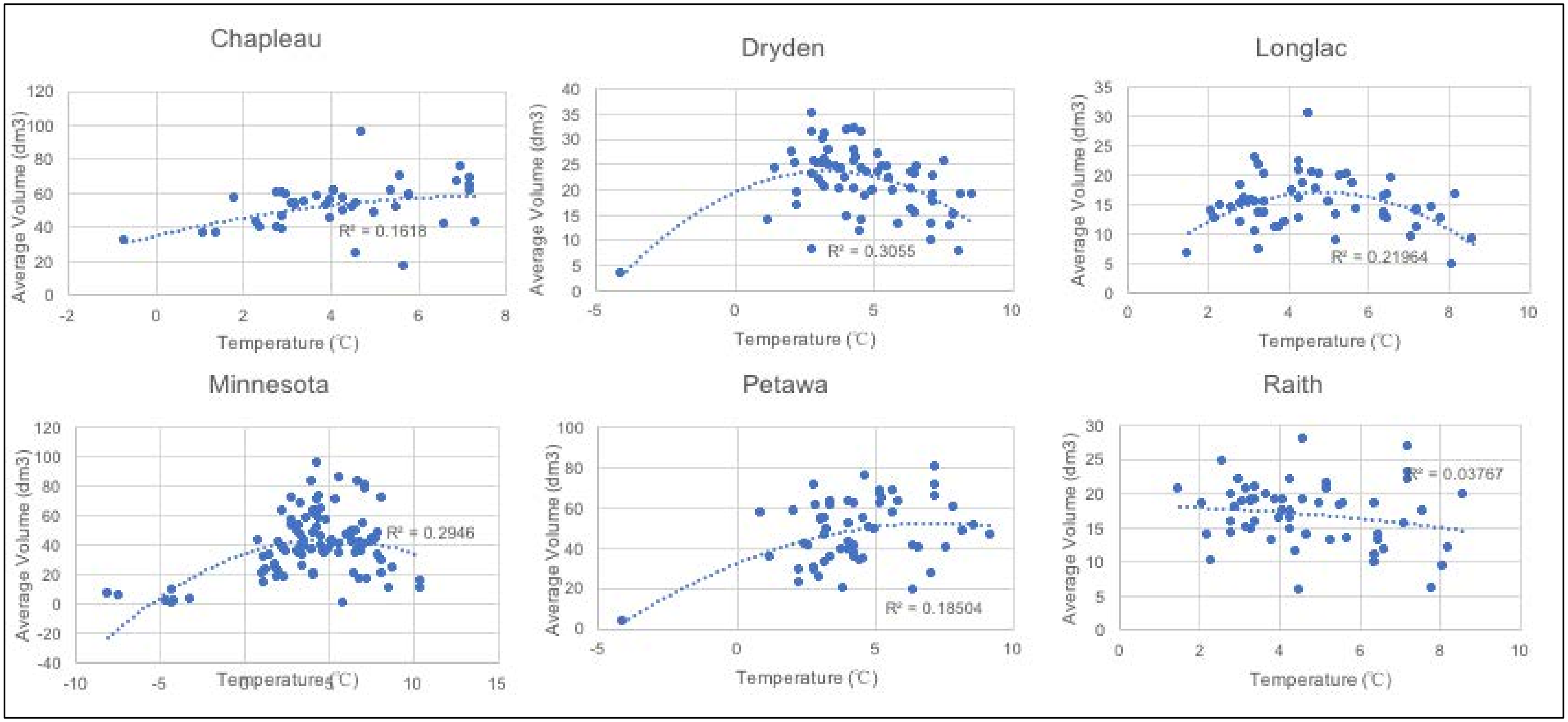

Figure 12. Average Temperature - Autumn

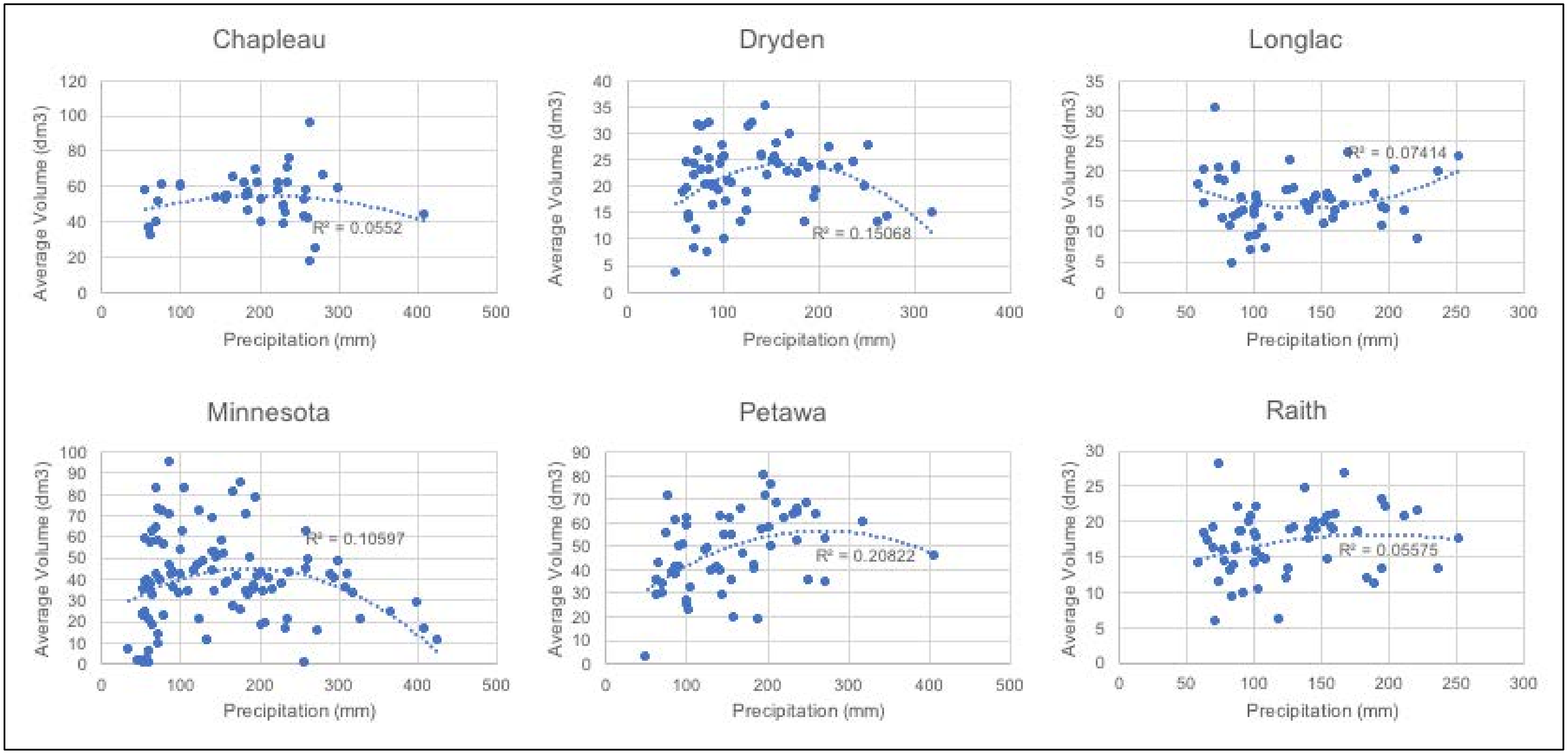

Figure 13. Precipitation - Winter

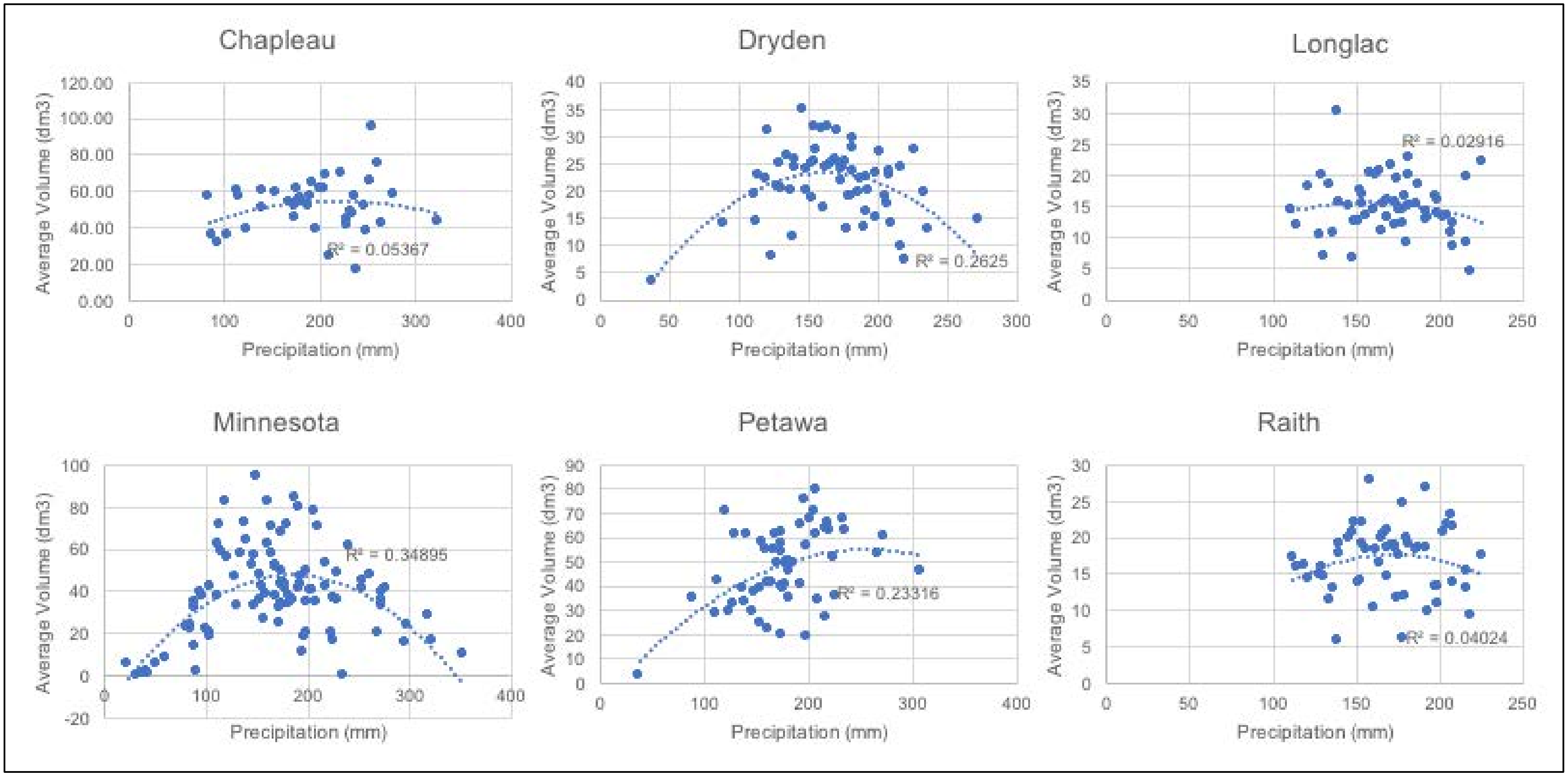

Figure 14. Precipitation - Spring

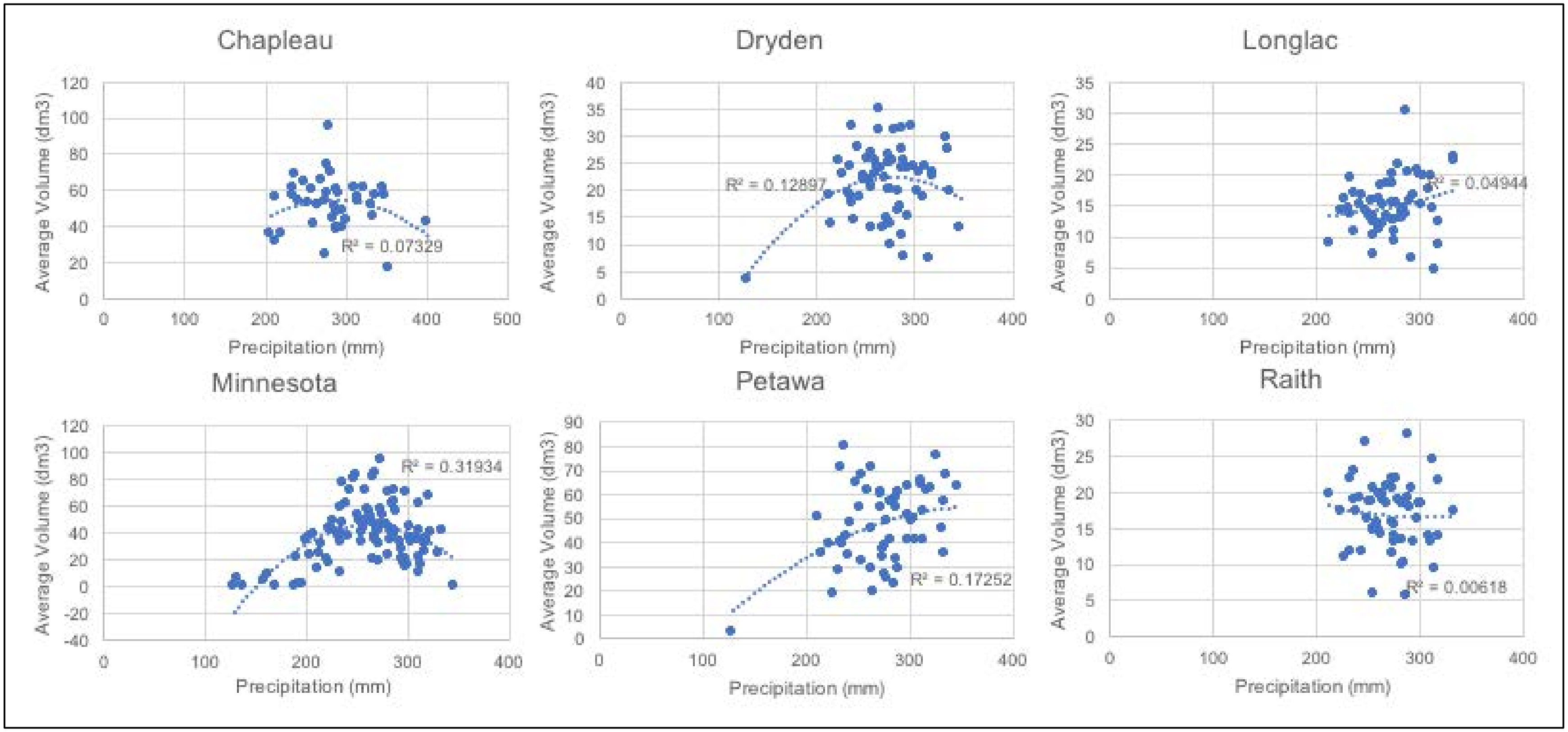

Figure 15. Precipitation - Summer

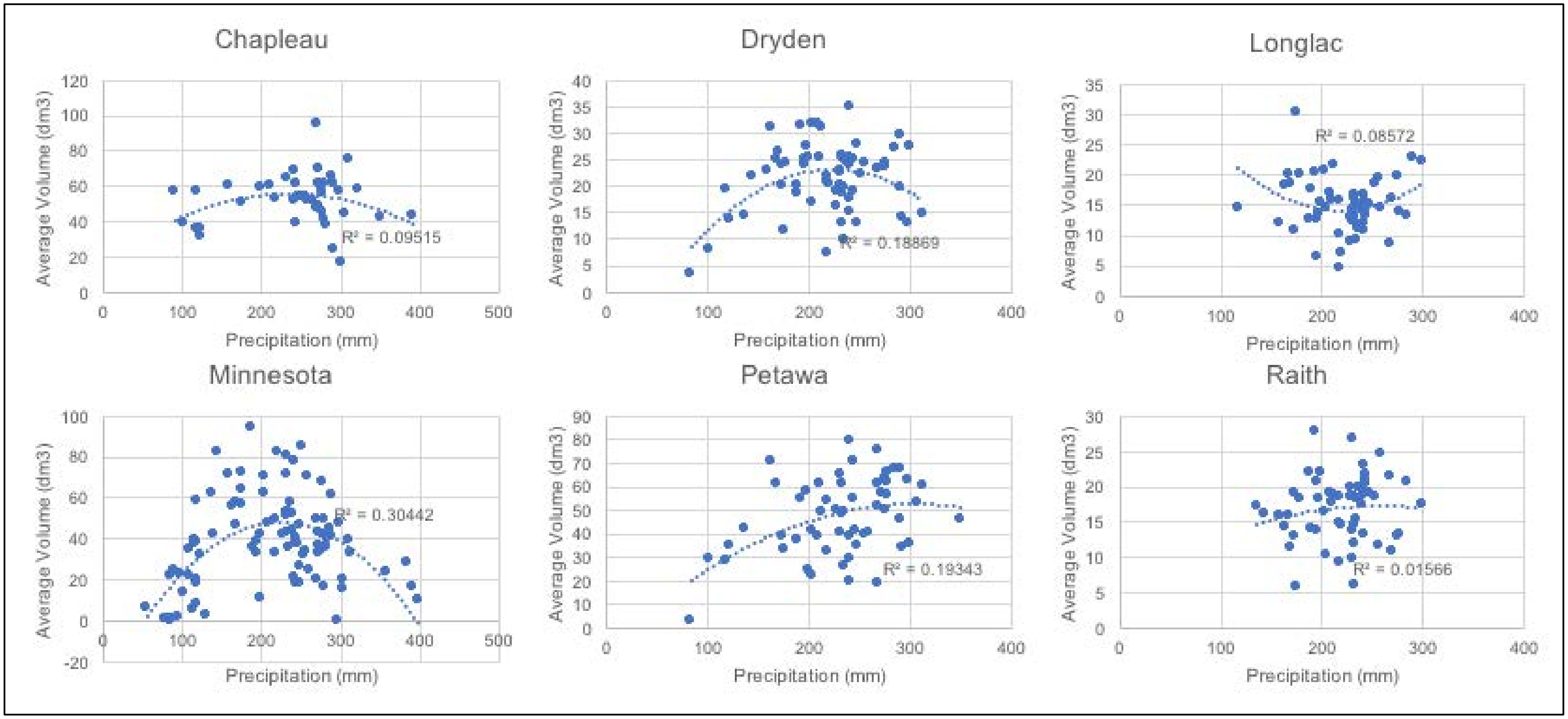

Figure 16. Precipitation - Autumn

Table 4. R^2 values for climate variables across test locations with the highest average selected

variable	r-value						
	Chapleau	Dryden	Longlac	Minnesota	Petawa	Raith	Average
tmax_wt	0.1269	0.3412	0.2005	0.2135	0.1783	0.0458	0.2121
Tmax_sp	0.1752	0.2255	0.2608	0.2201	0.0268	0.0462	0.1817
Tmax_sm	0.1472	0.1833	0.1349	0.2913	0.0204	0.0475	0.1554
Tmax_at	0.1933	0.3007	0.2361	0.2773	0.1690	0.0425	0.2353
Tmin_wt	0.0928	0.2366	0.1635	0.2468	0.1556	0.0449	0.1791
Tmin_sp	0.0925	0.2377	0.3352	0.1629	0.0651	0.0785	0.1787
Tmin_sm	0.1520	0.1856	0.0607	0.1803	0.0834	0.0548	0.1324
Tmin_at	0.1429	0.2935	0.0996	0.3112	0.1986	0.0389	0.2091
Tave_wt	0.1143	0.2994	0.1920	0.2543	0.1712	0.0420	0.2062
Tave_sp	0.1804	0.2554	0.3415	0.1765	0.0483	0.0648	0.2004
Tave_sm	0.1925	0.2855	0.1660	0.2790	0.0540	0.0631	0.1954
ave_at	0.1618	0.0306	0.2196	0.2946	0.1850	0.0377	0.1783
PPT_wt	0.0552	0.1507	0.0741	0.1060	0.2082	0.0558	0.1188
PPT_sp	0.0527	0.2625	0.0292	0.3490	0.2332	0.0402	0.1853
PPT_sm	0.0733	0.1290	0.0494	0.0319	0.1725	0.0062	0.0912
PPT_at	0.0952	0.1887	0.0857	0.3044	0.1934	0.0157	0.1735

CAUCHY FUNCTIONS

Cauchy functions can be used to find the optimal temperatures for each test site. Autumn average temperatures were found to have the highest r^2 value and were used as the x-axis data. Lorenzian 3-Parameter can be used to determine the X_0 value of each of these functions, which is the peak of the curve or the optimal growing temperature for a particular test site based on the rate of growth as the y-value (average volume (dm^3)). The Cauchy functions for Chapleau, Dryden, Longlac, Minnesota, Petawa, and Raith are shown below in figures 17-22. The X_0 values were determined for each site and are displayed in figure 23.

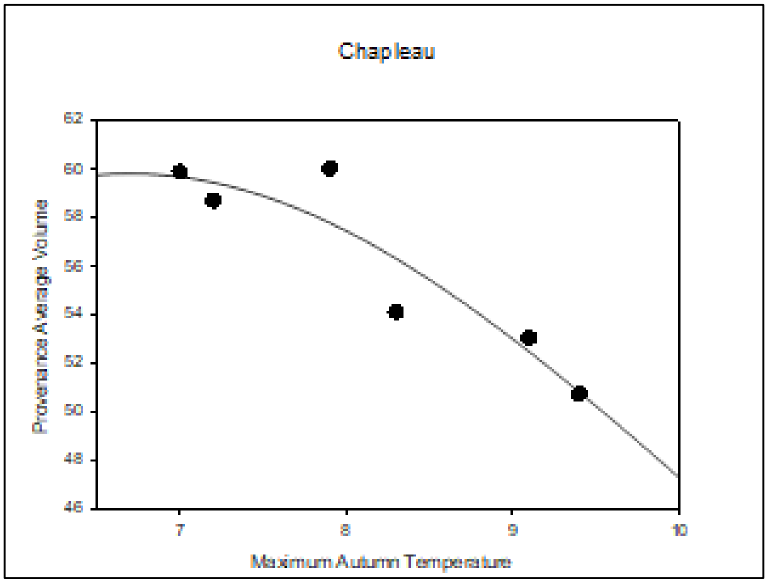

Figure 17. Cauchy function of Chapleau provenances using maximum autumn temperature and current climate data

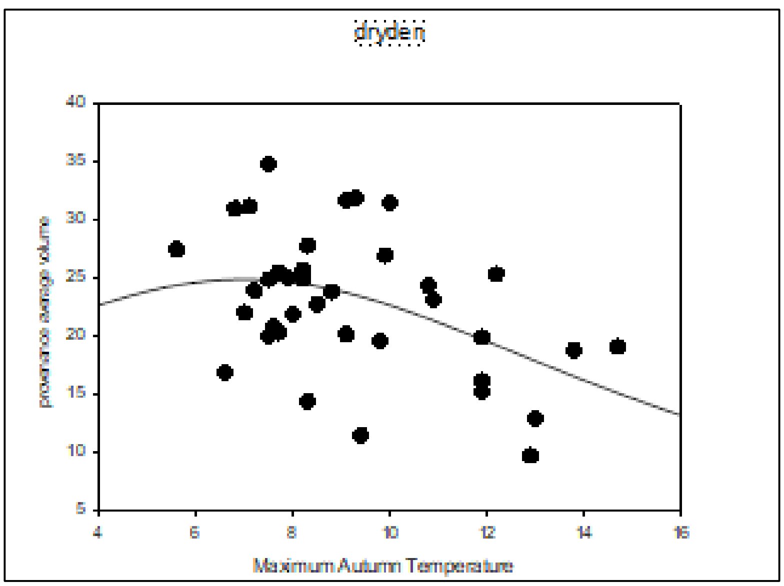

Figure 18. Cauchy function of Dryden provenances using maximum autumn temperature and current climate data

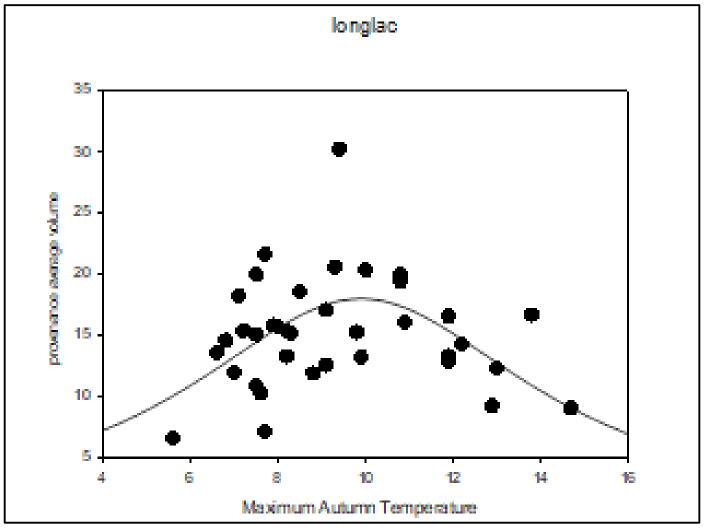

Figure 19. Cauchy function of Longlac provenances using maximum autumn temperature and current climate data

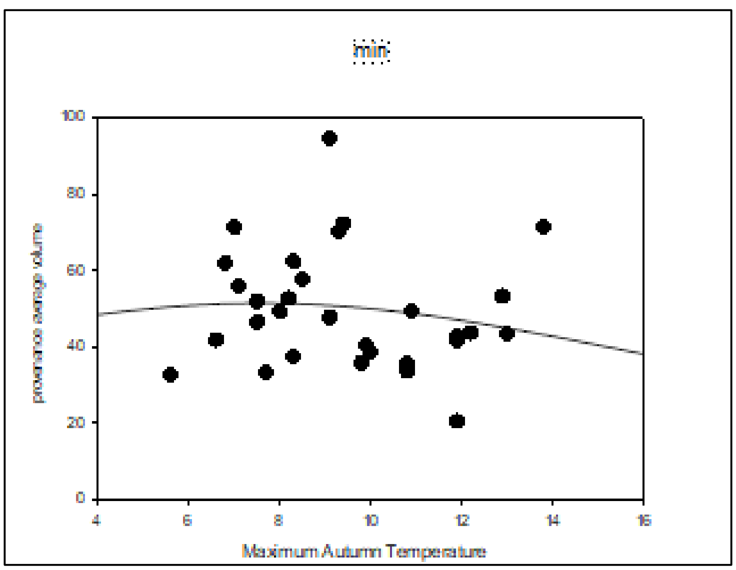

Figure 20. Cauchy function of Minnesota provenances using maximum autumn temperature and current climate data

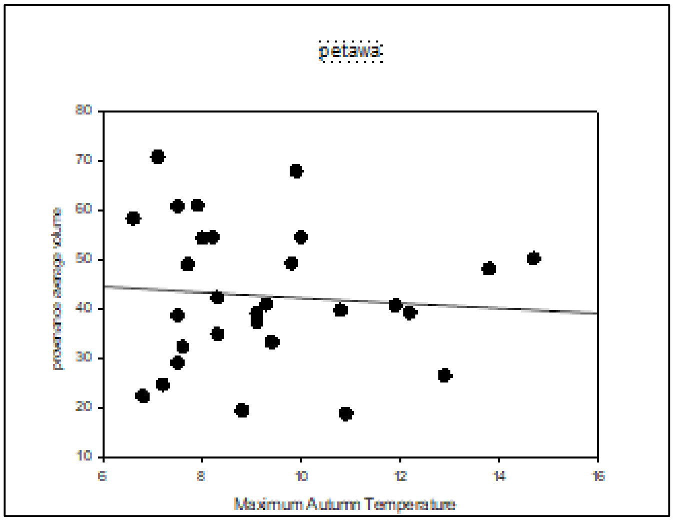

Figure 21. Cauchy function of Petewa provenances using maximum autumn temperature and current climate data

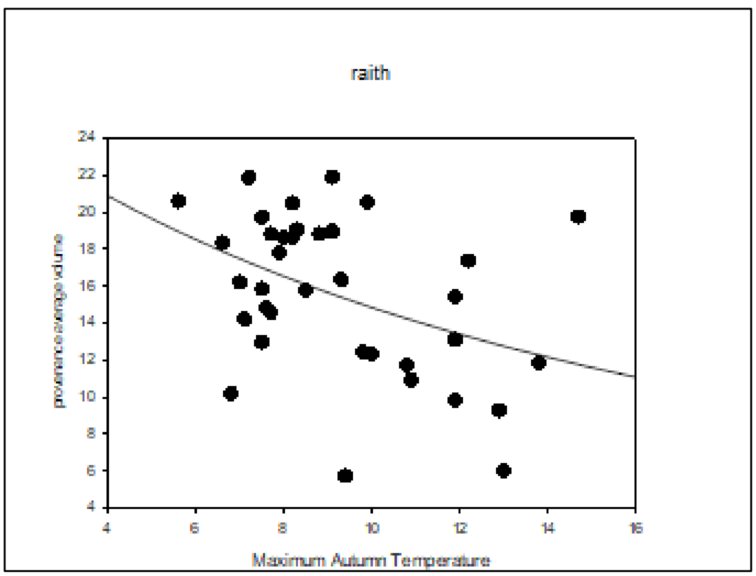

Figure 22. Cauchy function of Raith provenances using maximum autumn temperature and current climate data

Table 5. X_0 values for each test site

Test site	X_0 value
Chapleau	6.70
Dryden	6.99
Longlac	9.90
Minnesota	7.57
Petawa	-128.52
Raith	-25.65

The X_0 values for Chapleau, Dryden, Longlac, and Minnesota can be used to determine the difference in temperatures between the sites and the optimal temperatures for each site. Petawa and Raith have values far outside the natural range due to error arising from insufficient data to normalize the curves and so have been left out of further analysis.

Table 6. Average volume (dm^3) of each provenance within each test location with selected optimal (highest average volume) within each test site highlighted

Provenance	Chapleau	Dryden	Longlac	Minnesota	Petawa	Raith
6906	53.05	31.65	17.06	47.82	39.25	18.97
6907		23.84	11.88		19.51	18.83
6908		24.94	15.35		54.63	20.51
6909		21.85	15.67	49.27	54.41	18.67
6910		34.81	15.06	51.99	29.18	19.75
6911		23.11	16.09	49.46	18.83	10.94
6912		26.98	13.25	40.30	67.98	20.57
6913		24.41	19.42	33.68	39.80	11.76
6914	54.12	27.80	15.16	37.43	34.94	19.07
6915		25.70	13.29	52.72		18.66
6917	60.03	25.01	15.81		61.05	17.81
6918		25.53	21.65		49.06	18.83
6919		30.98	14.57	62.09	22.41	10.21
6920		16.88	13.62	41.89	58.39	18.35
6921		27.44	6.59	32.73		20.61
6922	58.70	23.93	15.37		24.73	21.88
6923		24.90	19.96	46.55	60.90	15.85
6924		31.17	18.25	56.08	70.84	14.21
6925		19.97	10.84		38.72	12.98
6927	59.89	22.01	11.99	71.37		16.22
6928		22.77	18.58	57.81		15.81
6930	50.74	11.49	30.24	72.33	33.34	5.73
6931		20.17	12.58	94.62	37.27	21.90
6932		31.86	20.60	70.25	41.03	16.35
6936		20.83	10.30		32.34	14.85
6937		20.32	7.11	33.34		14.57
6941		18.80	16.69	71.53	48.20	11.88
6942		19.06	9.04		50.26	19.77
6943		25.35	14.27	43.75	39.31	17.40
6944		12.88	12.33	43.39		6.00
6945		15.15	16.56	20.56		13.12
6947		9.69	9.22	53.36	26.60	9.28
6948		19.90	13.33	42.73	40.76	15.45
6949		16.16	12.81	41.72		9.84
6953		19.59	15.27	35.83	49.31	12.45
6954		31.43	20.33	38.69	54.67	12.31
6957		24.32	20.01	35.60		
6975		14.41		62.37	42.32	

INCREASE IN MAXIMUM AUTUMN TEMPERATURE BETWEEN CURRENT AND RCP 45S

Maximum autumn temperature is expected to increase significantly in the near future as displayed in Table 6. Present temperatures of each provenance compared to the predicted RCP 45S Tmax_at (°C) are displayed below in Table 7. Each provenance will raise in temperature between 2.6 to 2.8 degrees.

Table 7. maximum autumn temperatures - present vs predicted future

Provenance	Present Tmax_at (ºC)	RCP 45S Tmax_at (ºC)	Average Increase(ºC)
6906	9.1	11.9	2.8
6907	8.8	11.6	2.8
6908	8.2	11.0	2.8
6909	8.0	10.7	2.7
6910	7.5	10.2	2.7
6911	10.9	13.6	2.7
6912	9.9	12.7	2.8
6913	10.8	13.6	2.8
6914	8.3	11.0	2.7
6915	8.2	10.9	2.7
6917	7.9	10.7	2.8
6918	7.7	10.4	2.7
6919	6.8	9.6	2.8
6920	6.6	9.3	2.7
6921	5.6	8.4	2.8
6922	7.2	10.0	2.8
6923	7.5	10.2	2.7
6924	7.1	9.9	2.8
6925	7.5	10.3	2.8
6927	7.0	9.8	2.8
6928	8.5	11.3	2.8
6930	9.4	12.2	2.8
6931	9.1	11.8	2.7
6932	9.3	12.0	2.7
6936	7.6	10.2	2.6
6937	7.7	10.3	2.6
6941	13.8	16.6	2.8
6942	14.7	17.5	2.8
6943	12.2	14.9	2.7

6944	13	15.7	2.7
6945	11.9	14.7	2.8
6947	12.9	15.6	2.7
6948	11.9	14.6	2.7
6949	11.9	14.6	2.7
6953	9.8	12.5	2.7
6954	10.0	12.8	2.8
6957	10.8	13.5	2.7
6975	8.3	11.2	2.9
average	**9.3**	**12.05**	**2.7**

Temperatures are projected to increase in the future due to climate change. Therefore, a comparison was done for each test site by comparing the present Tmax_at x °C to the RCP 45S Tmax_at x °C and the difference between each was compared to the optimal growth temperature. The values that are closest in value to the optimal temperature have been highlighted in yellow. Furthermore, all temperatures within a +/- 0.5 °C value of the optimal growth temperature were highlighted in blue. Both of these value types were selected for further analysis in determining ideal seed sources for each test site.

Table 8. Chapleau current and RCP 45S temperatures compared to optimal growth.

Provenance	Present Tmax_at (°C)	RCP 45S Tmax_at (°C)	Optimal growth temperature	Difference between current temperature and optimal growth	Difference between RCP 45S temperature and optimal growth
6906	9.1	11.9	6.7	2.4	5.2
6907	8.8	11.6	6.7	2.1	4.9
6908	8.2	11.0	6.7	1.5	4.3
6909	8.0	10.7	6.7	1.3	4.0
6910	7.5	10.2	6.7	0.8	3.5
6911	10.9	13.6	6.7	4.2	6.9

6912	9.9	12.7	6.7	3.2	6.0
6913	10.8	13.6	6.7	4.1	6.9
6914	8.3	11.0	6.7	1.6	4.3
6915	8.2	10.9	6.7	1.5	4.2
6917	7.9	10.7	6.7	1.2	4.0
6918	7.7	10.4	6.7	1.0	3.7
6919	6.8	9.6	6.7	0.1	2.9
6920	6.6	9.3	6.7	-0.1	2.6
6921	5.6	8.4	6.7	-1.1	1.7
6922	7.2	10.0	6.7	0.5	3.3
6923	7.5	10.2	6.7	0.8	3.5
6924	7.1	9.9	6.7	0.4	3.2
6925	7.5	10.3	6.7	0.8	3.6
6927	7.0	9.8	6.7	0.3	3.1
6928	8.5	11.3	6.7	1.8	4.6
6930	9.4	12.2	6.7	2.7	5.5
6931	9.1	11.8	6.7	2.4	5.1
6932	9.3	12.0	6.7	2.6	5.3
6936	7.6	10.2	6.7	0.9	3.5
6937	7.7	10.3	6.7	1.0	3.6
6941	13.8	16.6	6.7	7.1	9.9
6942	14.7	17.5	6.7	8.0	10.8
6943	12.2	14.9	6.7	5.5	8.2
6944	13.0	15.7	6.7	6.3	9.0
6945	11.9	14.7	6.7	5.2	8.0
6947	12.9	15.6	6.7	6.2	8.9
6948	11.9	14.6	6.7	5.2	7.9
6949	11.9	14.6	6.7	5.2	7.9
6953	9.8	12.5	6.7	3.1	5.8
6954	10.0	12.8	6.7	3.3	6.1
6957	10.8	13.5	6.7	4.1	6.8
6975	8.3	11.2	6.7	1.6	4.5
average	9.3	12.05	6.7	2.6	5.35

Table 9. Dryden current and RCP 45S temperatures compared to optimal growth.

Provenance	Present Tmax_at (°C)	RCP 45S Tmax_at (°C)	Optimal growth temperature	Difference between current temperature and optimal growth	Difference between RCP 45S temperature and optimal growth
6906	9.1	11.9	6.99	2.11	4.91
6907	8.8	11.6	6.99	1.81	4.61
6908	8.2	11.0	6.99	1.21	4.01
6909	8.0	10.7	6.99	1.01	3.71
6910	7.5	10.2	6.99	0.51	3.21
6911	10.9	13.6	6.99	3.91	6.61
6912	9.9	12.7	6.99	2.91	5.71
6913	10.8	13.6	6.99	3.81	6.61
6914	8.3	11.0	6.99	1.31	4.01
6915	8.2	10.9	6.99	1.21	3.91
6917	7.9	10.7	6.99	0.91	3.71
6918	7.7	10.4	6.99	0.71	3.41
6919	6.8	9.6	6.99	-0.19	2.61
6920	6.6	9.3	6.99	-0.39	2.31
6921	5.6	8.4	6.99	-1.39	1.41
6922	7.2	10.0	6.99	0.21	3.01
6923	7.5	10.2	6.99	0.51	3.21
6924	7.1	9.9	6.99	0.11	2.91
6925	7.5	10.3	6.99	0.51	3.31
6927	7.0	9.8	6.99	0.01	2.81
6928	8.5	11.3	6.99	1.51	4.31
6930	9.4	12.2	6.99	2.41	5.21
6931	9.1	11.8	6.99	2.11	4.81
6932	9.3	12.0	6.99	2.31	5.01
6936	7.6	10.2	6.99	0.61	3.21
6937	7.7	10.3	6.99	0.71	3.31
6941	13.8	16.6	6.99	6.81	9.61
6942	14.7	17.5	6.99	7.71	10.51
6943	12.2	14.9	6.99	5.21	7.91
6944	13	15.7	6.99	6.01	8.71
6945	11.9	14.7	6.99	4.91	7.71
6947	12.9	15.6	6.99	5.91	8.61
6948	11.9	14.6	6.99	4.91	7.61
6949	11.9	14.6	6.99	4.91	7.61
6953	9.8	12.5	6.99	2.81	5.51
6954	10.0	12.8	6.99	3.01	5.81
6957	10.8	13.5	6.99	3.81	6.51
6975	8.3	11.2	6.99	1.31	4.21

average	9.3	12.05	6.99	2.31	5.06

Table 10. Longlac current and RCP 45S temperatures compared to optimal growth.

Provenance	Present Tmax_at (°C)	RCP 45S Tmax_at (°C)	Optimal growth temperature	Difference between current temperature and optimal growth	Difference between RCP 45S temperature and optimal growth
6906	9.1	11.9	9.9	-0.8	2.0
6907	8.8	11.6	9.9	-1.1	1.7
6908	8.2	11	9.9	-1.7	1.1
6909	8.0	10.7	9.9	-1.9	0.8
6910	7.5	10.2	9.9	-2.4	0.3
6911	10.9	13.6	9.9	1.0	3.7
6912	9.9	12.7	9.9	0.0	2.8
6913	10.8	13.6	9.9	0.9	3.7
6914	8.3	11.0	9.9	-1.6	1.1
6915	8.2	10.9	9.9	-1.7	1.0
6917	7.9	10.7	9.9	-2.0	0.8
6918	7.7	10.4	9.9	-2.2	0.5
6919	6.8	9.6	9.9	-3.1	-0.3
6920	6.6	9.3	9.9	-3.3	-0.6
6921	5.6	8.4	9.9	-4.3	-1.5
6922	7.2	10.0	9.9	-2.7	0.1
6923	7.5	10.2	9.9	-2.4	0.3
6924	7.1	9.9	9.9	-2.8	0
6925	7.5	10.3	9.9	-2.4	0.4
6927	7.0	9.8	9.9	-2.9	-0.1
6928	8.5	11.3	9.9	-1.4	1.4
6930	9.4	12.2	9.9	-0.5	2.3
6931	9.1	11.8	9.9	-0.8	1.9
6932	9.3	12.0	9.9	-0.6	2.1
6936	7.6	10.2	9.9	-2.3	0.3
6937	7.7	10.3	9.9	-2.2	0.4
6941	13.8	16.6	9.9	3.9	6.7
6942	14.7	17.5	9.9	4.8	7.6
6943	12.2	14.9	9.9	2.3	5.0
6944	13.0	15.7	9.9	3.1	5.8

6945	11.9	14.7	9.9	2.0	4.8
6947	12.9	15.6	9.9	3.0	5.7
6948	11.9	14.6	9.9	2.0	4.7
6949	11.9	14.6	9.9	2.0	4.7
6953	9.8	12.5	9.9	-0.1	2.6
6954	10.0	12.8	9.9	0.1	2.9
6957	10.8	13.5	9.9	0.9	3.6
6975	8.3	11.2	9.9	-1.6	1.3
average	9.3	12.05	9.9	-0.6	2.15

Table 11. Minnesota current and RCP 45S temperatures compared to optimal growth.

Provenance	Present Tmax_at (°C)	RCP 45S Tmax_at (°C)	Optimal growth temperature	Difference between current temperature and optimal growth	Difference between RCP 45S temperature and optimal growth
6906	9.1	11.9	7.57	1.53	4.33
6907	8.8	11.6	7.57	1.23	4.03
6908	8.2	11.0	7.57	0.63	3.43
6909	8.0	10.7	7.57	0.43	3.13
6910	7.5	10.2	7.57	-0.07	2.63
6911	10.9	13.6	7.57	3.33	6.03
6912	9.9	12.7	7.57	2.33	5.13
6913	10.8	13.6	7.57	3.23	6.03
6914	8.3	11.0	7.57	0.73	3.43
6915	8.2	10.9	7.57	0.63	3.33
6917	7.9	10.7	7.57	0.33	3.13
6918	7.7	10.4	7.57	0.13	2.83
6919	6.8	9.6	7.57	-0.77	2.03
6920	6.6	9.3	7.57	-0.97	1.73
6921	5.6	8.4	7.57	-1.97	0.83
6922	7.2	10.0	7.57	-0.37	2.43
6923	7.5	10.2	7.57	-0.07	2.63
6924	7.1	9.9	7.57	-0.47	2.33
6925	7.5	10.3	7.57	-0.07	2.73
6927	7.0	9.8	7.57	-0.57	2.23
6928	8.5	11.3	7.57	0.93	3.73

6930	9.4	12.2	7.57	1.83	4.63
6931	9.1	11.8	7.57	1.53	4.23
6932	9.3	12.0	7.57	1.73	4.43
6936	7.6	10.2	7.57	0.03	2.63
6937	7.7	10.3	7.57	0.13	2.73
6941	13.8	16.6	7.57	6.23	9.03
6942	14.7	17.5	7.57	7.13	9.93
6943	12.2	14.9	7.57	4.63	7.33
6944	13.0	15.7	7.57	5.43	8.13
6945	11.9	14.7	7.57	4.33	7.13
6947	12.9	15.6	7.57	5.33	8.03
6948	11.9	14.6	7.57	4.33	7.03
6949	11.9	14.6	7.57	4.33	7.03
6953	9.8	12.5	7.57	2.23	4.93
6954	10.0	12.8	7.57	2.43	5.23
6957	10.8	13.5	7.57	3.23	5.93
6975	8.3	11.2	7.57	0.73	3.63
average	9.3	12.05	7.57	1.73	4.48

CHAPLEAU ANALYSIS

Table 12. Chapleau comparison of provenance and test latitude of suitable provenances for current temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site	Location of Provenance In Relation To Test Site
6919	0.1	50.32	47.96	2.36	north
6920	-0.1	50.73	47.96	2.77	north
6922	0.5	50.22	47.96	2.26	north
6924	0.4	50.88	47.96	2.92	north
6927	0.3	50.83	47.96	2.87	north

Table 13. Chapleau comparison of provenance and test latitude of suitable provenances for RCP 45S temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site	Location of Provenance In Relation To Test Site
6921	1.7	51.47	47.96	3.51	north

Table 14. Chapleau comparison of provenance and test elevation of suitable provenances for current temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance elevation (m)	Test Site elevation (m)	Difference in elevation Between Provenance and Test Site (m)	Location of elevation of provenance In Relation To Test Site
6919	0.1	400	472	-72.00	lower
6920	-0.1	380	472	-92.00	lower
6922	0.5	400	472	-72.00	lower
6924	0.4	350	472	-122.00	lower
6927	0.3	340	472	-132.00	lower

Table 15. Chapleau comparison of provenance and test elevation of suitable provenances for RCP 45S temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site (m)	Location of Provenance In Relation To Test Site
6921	1.7	400	472	-72.00	lower

Table 16. Chapleau current temperature summary of suitable provenances

Provenance	Latitude of Provenance In Relation To Test Site	Latitude of elevation In Relation To Test Site
6919	north	lower
6920	north	lower
6922	north	lower
6924	north	lower
6927	north	lower

Table 17. Chapleau RCP 45S summary of suitable provenances

Provenance	Latitude of Provenance In Relation To Test Site	Latitude of elevation In Relation To Test Site
6919	north	lower

DRYDEN ANALYSIS

Table 18. Dryden comparison of provenance and test latitude of suitable provenances for current temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site	Location of Provenance In Relation To Test Site
6919	-0.19	50.32	49.92	0.40	north
6920	-0.39	50.73	49.92	0.81	north
6922	0.21	50.22	49.92	0.30	north
6924	0.11	50.88	49.92	0.96	north
6927	0.01	50.83	49.92	0.91	north

Table 19. Dryden comparison of provenance and test latitude of suitable provenances for RCP 45S temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site	Location of Provenance In Relation To Test Site
6921	1.41	51.47	49.92	1.55	north

Table 20. Dryden comparison of provenance and test elevation of suitable provenances for current temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance elevation (m)	Test Site elevation (m)	Difference in elevation Between Provenance and Test Site (m)	Location of elevation of provenance In Relation To Test Site
6919	-0.19	400	383.00	17.00	higher
6920	-0.39	380	383.00	-3.00	lower
6922	0.21	400	383.00	17.00	higher
6924	0.11	350	383.00	-33.00	lower
6927	0.01	340	383.00	-43.00	lower

Table 21. Dryden comparison of provenance and test elevation of suitable provenances for RCP 45S temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site (m)	Location of Provenance In Relation To Test Site
6921	1.7	400	383	17	higher

Table 22. Dryden current temperature summary of ideal provenances

Provenance	Latitude of Provenance In Relation To Test Site	Latitude of elevation In Relation To Test Site
6919	north	higher
6920	north	lower
6922	north	higher
6924	north	lower
6927	north	lower

Table 23. Dryden RCP 45S temperature summary of ideal provenances

Provenance	Latitude of Provenance In Relation To Test Site	Latitude of elevation In Relation To Test Site
6921	north	higher

LONGLAC ANALYSIS

Table 24. Longlac comparison of provenance and test latitude of suitable provenances for current temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site	Location of Provenance In Relation To Test Site
6912	0.0	46.77	49.75	-2.98	south
6930	-0.5	48.8	49.75	-0.95	south
6953	-0.1	47.62	49.75	-2.13	south
6954	0.1	47.7	49.75	-2.05	south

Table 25. Longlac comparison of provenance and test latitude of suitable provenances for RCP 45S temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site	Location of Provenance In Relation To Test Site
6910	0.3	49.67	49.75	-0.08	south
6918	0.5	49.42	49.75	-0.33	south
6919	-0.3	50.32	49.75	0.57	north
6922	0.1	50.22	49.75	0.47	north
6923	0.3	50.4	49.75	0.65	north
6924	0.0	50.88	49.75	1.13	north
6925	0.4	49.83	49.75	0.08	north
6927	-0.1	50.83	49.75	1.08	north
6936	0.3	51.27	49.75	1.52	north
6937	0.4	51.1	49.75	1.35	north

Table 26. Longlac comparison of provenance and test elevation of suitable provenances for current temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance elevation (m)	Test Site elevation (m)	Difference in elevation Between Provenance and Test Site (m)	Location of elevation of provenance In Relation To Test Site
6912	0.0	370	312	58	higher
6930	-0.5	370	312	58	higher
6953	-0.1	680	312	368	higher
6954	0.1	400	312	88	higher

Table 27. Longlac comparison of provenance and test elevation of suitable provenances for RCP 45S temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance elevation (m)	Test Site elevation (m)	Difference in elevation Between Provenance and Test Site (m)	Location of elevation of provenance In Relation To Test Site
6910	0.3	300	312.00	-12.00	lower
6918	0.5	460	312.00	148.00	higher
6919	-0.3	400	312.00	88.00	higher
6922	0.1	400	312.00	88.00	higher
6923	0.3	350	312.00	38.00	higher
6924	0.0	350	312.00	38.00	higher
6925	0.4	380	312.00	68.00	higher
6927	-0.1	340	312.00	28.00	higher
6936	0.3	60	312.00	-252.00	lower
6937	0.4	61	312.00	-251.00	lower

Table 28. Longlac current temperature summary of suitable provenances

Provenance	Latitude of Provenance In Relation To Test Site	Latitude of elevation In Relation To Test Site
6912	south	higher
6930	south	higher
6953	south	higher
6954	south	higher

Table 29. Longlac RCP 45S temperature summary of suitable provenances

Provenance	Latitude of Provenance In Relation To Test Site	Latitude of elevation In Relation To Test Site
6910	south	lower
6918	south	higher
6919	north	higher
6922	north	higher
6923	north	higher
6924	north	higher
6925	north	higher
6927	north	higher
6936	north	lower
6937	north	lower

MINNESOTA ANALYSIS

Table 30. Minnesota comparison of provenance and test latitude of suitable provenances for current temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site	Location of Provenance In Relation To Test Site
6909	0.43	49.75	47.19	2.56	north
6910	-0.07	49.67	47.19	2.48	north
6917	0.33	49.00	47.19	1.81	north
6918	0.13	49.42	47.19	2.23	north
6922	-0.37	50.22	47.19	3.03	north
6923	-0.07	50.40	47.19	3.21	north
6924	-0.47	50.88	47.19	3.69	north
6925	-0.07	49.83	47.19	2.64	north
6936	0.03	51.27	47.19	4.08	north
6937	0.13	51.10	47.19	3.91	north

Table 31. Min comparison of provenance and test latitude of suitable provenances for RCP 45S temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance Latitude	Test Site Latitude	Difference in Latitude Between Provenance and Test Site	Location of Provenance In Relation To Test Site
6921	0.83	51.47	47.19	4.28	north

Table 32. Minnesota comparison of provenance and test elevation of suitable provenances for current temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance elevation (m)	Test Site elevation (m)	Difference in elevation Between Provenance and Test Site (m)	Location of elevation of provenance In Relation To Test Site
6909	0.43	210	400	-190	lower
6910	-0.07	300	400	-100	lower
6917	0.33	470	400	70	higher
6918	0.13	460	400	60	higher
6922	-0.37	400	400	0	equal
6923	-0.07	350	400	-50	lower
6924	-0.47	350	400	-50	lower
6925	-0.07	380	400	-20	lower
6936	0.03	60	400	-340	lower
6937	0.13	61	400	-339	lower

Table 33. Minnesota comparison of provenance and test elevation of suitable provenances for RCP 45S temperatures

Provenance	Difference Between Current and Optimal Temperatures	Provenance elevation (m)	Test Site elevation (m)	Difference in elevation Between Provenance and Test Site (m)	Location of elevation of provenance In Relation To Test Site
6921	0.83	400	400	0	equal

Table 34. Minnesota current temperature summary of suitable provenances

Provenance	Latitude of Provenance In Relation To Test Site	Latitude of elevation In Relation To Test Site
6909	north	lower
6910	north	lower
6917	north	higher
6918	north	higher
6922	north	equal
6923	north	lower
6924	north	lower
6925	north	lower
6936	north	lower
6937	north	lower

Table 35. Minnesota RCP 45S temperature summary of suitable provenances

Provenance	Latitude of Provenance In Relation To Test Site	Latitude of elevation In Relation To Test Site
6909	north	equal

DISCUSSION

Following this analysis, the maximum autumn temperature was found to be the most statistically significant regression variable. Autumn temperature is an important variable in the growth of vegetation as this variable determines the vegetation dormancy onset date (DOD) (Yang et al. 2015). This DOD determines the length of the growing season as warmer temperatures would delay the onset of frost (Yang et al. 2015). Furthermore, this temperature controls several climatic factors, including carbon loss, energy and water cycles (Zhu et al. 2012, Yang et al. 2015). These small autumnal changes can have significant effects on the structure and functions of ecosystems (Zhu et al., 2012).

Maximum autumn temperatures increased from an average of 9.30 ºC under current climatic conditions to an average of 12.05 ºC under future RCP 45S predicted temperatures. On average, the increased temperatures for each provenance will increase by an average of 2.7 ºC. This warming will have significant effects on the growth of each provenance within each test location, causing a positive or negative shift according to the location of the source. Assisted migration is recommended as dispersal rates will be unable to match such drastic range impacts. Ideal sources were determined for each test site in Table 5.

Within the Chapleau site, when comparing current temperatures to optimal seed sources for these two ideal seed sources, 6919 and 6920 were determined with a temperature difference of 0.1 and -0.1, respectively. Each of these seed sources come from a northern latitude but a lower elevation than the test site. Three other provenances 6922, 6924, 6927 fell within the +/- 0.5 range, and each was from a northern latitude and lower elevation. When comparing RCP 45S growth, the most ideal seed source had a temperature difference of 1.7 degrees and was from a northern latitude and lower elevation. 100% of each optimal seed source came from a lower elevation. This large gap in predicted temperature will likely result in reduced growth.

Within the Dryden site, when comparing current temperatures to optimal seed sources provenance, 6927 was determined as the ideal seed source with a difference of 0.01 degrees between its average temperature and the optimal temperature. This seed source was located north in latitude and lower in elevation than the test site. Four other provenances 6919, 6920, 6922, and 6924 fell within the +/- 0.5 range. Provenance 6919 and 6929 were located north in latitude and higher in elevation than the test site. Provenance 6920 and 6924 were located north in latitude and lower in elevation than the test site. When comparing RCP 45S growth, the most ideal seed source had a temperature difference of 1.41 degrees and was from a northern latitude and higher elevation.

Within the Longlac site, provenance 6912 was determined as the ideal seed source with a difference of 0 degrees between its average temperature and the optimal temperature. This seed source was located south in latitude and higher in elevation than the test site. Three other provenances 6930, 6953, and 6954 fell within the +/- 0.5 range. Each of these provenances was located South in latitude and higher in elevation than the test site. When comparing RCP 45S growth the most ideal seed source, provenance 6924, had a temperature difference of 0 degrees and was from a northern latitude and higher elevation. Nine other provenances fell within the +/- 0.5 range 6910, 6918, 6919, 6922, 6923, 6925, 6927, 6936, and 6937. Provenance 6910 was from a southern latitude and lower elevation, while provenance 6918 was from a southern latitude and a higher elevation. Provenances 6919, 6922, 6923, 6925, and 6027 were from a lower latitude and a higher elevation. Finally, provenances 6936 and 6937 were from a northern latitude and a lower elevation.

Within the Minnesota site, provenance 6936 was determined as the ideal seed source with a difference of 0.03 degrees between its average temperature and the optimal temperature. This seed source was located north in latitude and lower in elevation than the test site. Nine other provenances 6909, 6910, 6917, 6918, 6922, 6923, 6924, 6925, and 6937 fell within the +/- 0.5 range. Provenance 6909, 6910, 6923, 6924, 6925, and 6937 were located north in latitude and lower in elevation than the test site. 6917 and 6918 were located north in latitude and higher in elevation while provenance 6922 was located north in latitude and lower in elevation. When comparing RCP 45S growth the most ideal seed source, provenance 6921, had a temperature difference of 0.83 degrees and was from a northern latitude and equal elevation.

CONCLUSION

The importance of assisted migration and the likely decline of plant species without human assisted migration cannot be emphasized enough. Within each of the four analyzed test locations, the majority of the seed sources that most closely matched the optimal growth temperature were from provenances that were located either south in latitude, lower in elevation or both. Within Chapleau 100% of the closest matching sources for both current and future temperatures came from lower elevations. In Dryden, current temperatures 60% of optimal sources come from a lower latitude. While future data predicts that the best match is from a northern higher site, this value is far from the optimal seed source and is, therefore, an inaccurate predictor. In Longlac current temperatures and their ideal sources are 100% from southern sources. Future temperatures predict 20% of ideal sources to come from sources lower in latitude or elevation. Finally, in Min 70% of optimal seed sources stem from lower elevations. Similar to Longlac, while the optimal seed source for future temperatures is northern and higher this value is not close to the optimal temperature and is therefore likely inaccurate.

While this study has determined that in the future, seeds should be sourced from sites southern in latitude and lower in elevation, further studies could be done to improve this theory. By increasing the number of test sites so that a greater range of latitudes could be analyzed, a more accurate map could be made so that sites can be planted with optimal seeds. Finally, I recommend that this provenance data becomes available to the industry. If all forestry companies replanted harvested sites with seeds ideally suited to the future conditions, the genetic diversity of black spruce and optimal growth across its range could be preserved.

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