INVESTIGATION OF ADAPTIVE VARIATION OF BLACK SPRUCE IN 29-YEAR HEIGHT GROWTH OF BLACK SPRUCE IN A NORTHWESTERN ONTARIO PROVENANCE TRIAL

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

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ABSTRACT

Lawson, M. 2023. Investigation of Adaptive Variation of Black Spruce in 29-year Height Growth of Black Spruce in a Northwestern Ontario Provenance Trial. 27pp.

Key Words: adaptive variation, black spruce, forestry, genetics, Ontario, *Picea mariana*

Seed sources from across northwestern Ontario were used to establish a black spruce provenance trial at the former Thunder Bay Forest Nursery located on 25th Sideroad, Thunder Bay. The heights of these trees were measured at 29 years old. The mean population heights were examined for patterns of variation between provenances based on the mean annual temperature of the seed source. Provenance survival percentage was also calculated. The differences in mean provenance height and provenance survival percentage were not statistically significant. The results of my study do not support the hypothesis that height was influenced by the MAT of the seed source location, as no significant differences in provenance mean height were detected. It is possible that the lack of ability to detect significant differences among provenances results from errors in height measurement, as a previous study of the same test found significant differences in height.

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INTRODUCTION

Black spruce (*Picea mariana*) has a wide range that extends throughout the boreal forest of North America (Farrar 1995). It is a cold-tolerant species that can grow in many different climates and site types (Morgenstern 1978, Parker 1994). It regenerates through seeding and layering, has enough shade tolerance to grow in both pure and mixed uneven aged stands, and can even grow as a pioneer species in open areas following disturbances (Morgenstern 1996). It is an important species for the forest industry due to its high-quality fibre. Black spruce produces merchantable volumes of wood on a wide variety of site types, ranging from bogs to dry uplands (Kole 2007, Morgenstern 1996).

Populations often demonstrate adaptive variation in response to environmental gradients, especially in species with large geographic ranges (Thomson et al. 2009, Hereford 2009, Khalil 1984). Phenology and growth are influenced by genetic factors, giving local populations the ability to adapt over time to their specific environment (Morgenstern 1978, Guo et al. 2022, Villemereuil et al. 2015). Black spruce demonstrates significant genetic variation in quantitative characteristics, and grows in a wide variety of site types, attesting to its potential for local adaption (Beaulieu et al. 2004, Khalil 1984, Kole 2007, Morgenstern and Mullin 1990).

Local adaption arises due to the interaction of genetic processes with environmental factors (Morgenstern 1996). Trees that can sync their physiology with the growing season will have a competitive advantage, leading to changes in the gene frequencies of the local population over time. For example, the timing of physiological processes, such as bud burst, must occur at the right time – trees that flush too early can suffer frost damage, but trees that flush too late waste part of the growing season (Guo et al. 2022). It is generally assumed that local trees have superior survival rates and grow taller when compared to non-local plants due to local adaption (Hancock et al 2013).

The objective of this thesis was to examine whether 29-year height growth of black spruce in a provenance trial located near Thunder Bay, Ontario demonstrates significant adaptation in relation to climate. I expected that there would be a significant difference in height between provenances based on mean annual temperature (MAT) of the seed source, where provenances originating from local, warmer areas would grow larger than provenances from more northern, colder areas. In addition, I expected that higher survival would be seen in provenances from local areas.

LITERATURE REVIEW

ADAPTIVE VARIATION IN BLACK SPRUCE

Knowledge of genetic variation within a tree species is important for silviculture since trees take decades to grow. Genetically superior trees that have beneficial characteristics often pass on these traits to their offspring, giving benefits that last throughout the life of the tree (Larsen 1956). Therefore, seed and planting stock should be well adapted to local conditions and come from superior provenances since trees well adapted to the local environment provide the most economic and ecological benefit (Morgenstern and Mullin 1990).

Regenerating trees that are locally adapted is especially important for black spruce since this species has such a wide ecological range (Khalil 1984). Species that are spread over large, diverse areas tend to form populations with specific adaptions to local climates (Kremer et al. 2012). In some cases, these adaptions can be so specific that a given population might have a tolerable range much narrower than the range of the species, meaning local adaption to one environment may result in decreased fitness in other types of environments (Hereford 2009). It is necessary to understand the geographic variation of tree species if excess tree moralities and reduced growth are to be avoided when regenerating black spruce (Morgenstern 1996).

Patterns of geographic variation in trees arise due to the interaction of genetic processes with environmental factors (Aitken 2004, Guo et al. 2022, Howe et al 2003, Kremer et al. 2012, Morgenstern 1996). In boreal trees, where there are large seasonal differences in temperature and photoperiod, natural selection favours individual trees which are well-synced to these seasonal cycles (Kremer et al. 2012, Morgenstern and Mullin 1990). Natural selection arises in black spruce due to the environmental differences across its range, typically following a clinal variation pattern from south to north, resulting in the adaptive variation of local populations (Morgenstern 1996). In black spruce, clinal variation has been found in traits such as germination rate, survival rate, phenology, and cold hardiness (Bower and Aitken 2006, Kole 2007).

Numerous common garden experiments or provenance tests have been conducted for black spruce to study the adaptive variation of different populations. Common garden experiments involve planting populations from different geographic localities at the same site (Villemereuil et al. 2015). When different populations are tested in the same environment, any differences between the populations must be due to differences in gene frequencies since the environment is consistent for all individuals (Villemereuil et al. 2015, Morgenstern 1978). Other applications of common garden experiments include: (1) determining how far away seed sources can originate from to ensure trees will grow well on the planting site; (2) determining the geographic boundaries of breeding zones; (3) selecting high quality provenances of non-native trees that can be introduced elsewhere; and (4) predicting the ability of populations to adapt to climate change (Aitken 2004, Beaulieu et al. 2004). The section that follows discusses the results of several black spruce common garden experiments. These show the patterns of clinal variation in black spruce of some physiological traits.

BLACK SPRUCE COMMON GARDEN EXPERIMENTS

In a nursery test conducted with 100 black spruce provenances, bud burst showed a clinal trend across the range, with the northern provenances breaking bud before the southern provenances (Morgenstern 1978) (Figure 1).

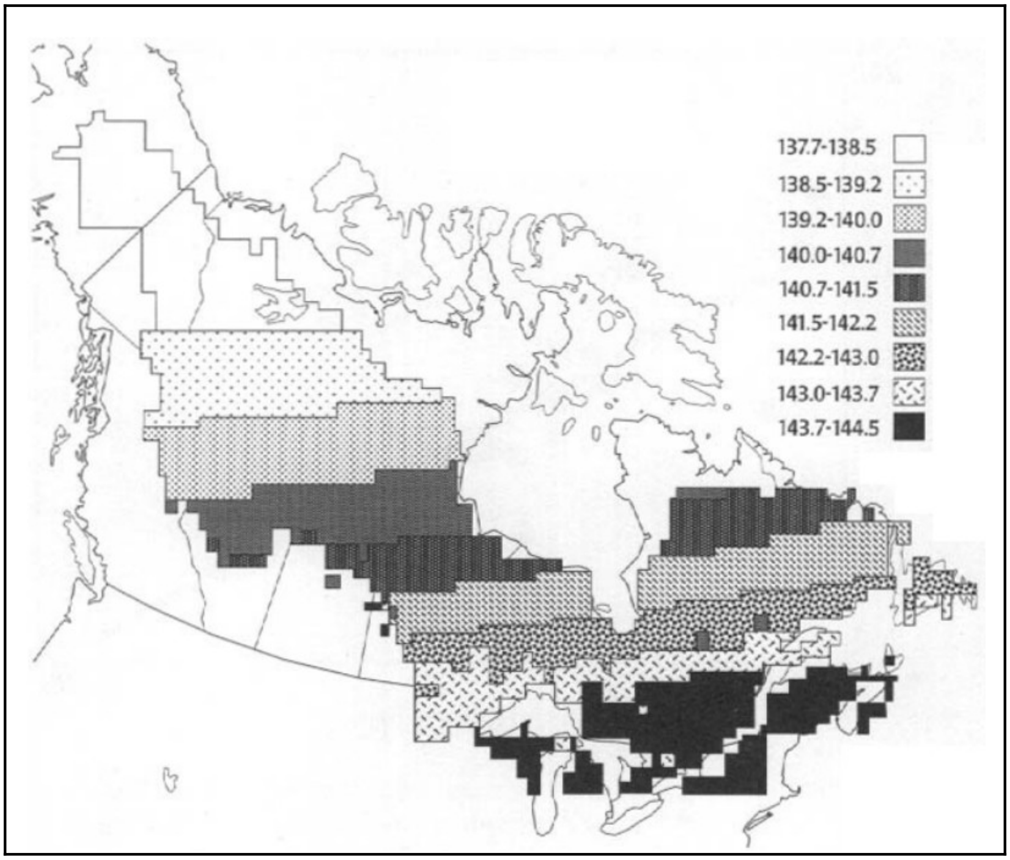

Figure 1. Initiation of growth (bud burst) in 100 black spruce provenances. The scale shows days of the year. Source: Morgenstern (1996).

Typically, trees from northern latitudes initiate growth before southern trees, but northern trees cease growth significantly sooner than southern trees (Morgenstern 1976). In the same nursery test referenced above, growth cessation was found to occur over a period of 77 days (Morgenstern 1978). Provenances from the Boreal region stopped growing first, followed by trees in the Great Lakes – St. Lawrence region and trees from the Acadian region. In total, trees from the Boreal region had a mean growth period of 94 days, 106 days in the Great Lakes – St. Lawrence, and 114 days in the Acadian region. To further illustrate the potential difference in length of growing season between provenances, the first Boreal tree to stop growing was compared to the last Acadian tree to stop growing. The Boreal tree ceased growth on day 136, while the

Acadian tree stopped growth on day 297, a difference of 161 days. As is expected with results like this, mean heights ranked largest to smallest were Acadian, Great Lakes – St. Lawrence, and Boreal. In other words, the trees that grew the longest were also the largest. Generally, trees from the southern parts of a species' range show increased height growth when compared to northern trees, as long as the southern trees do not initiate growth too soon and suffer from frost damage (Howe et al. 2003, Rossi 2015).

Morgenstern and Mullen (1990) again conducted common garden experiments on black spruce, this time focusing on tree height and survival. In this experiment, seeds were collected from 218 different black spruce stands across its range and planted in 29 different test locations. The test locations were spaced throughout black spruces' range as well, however extreme northern test locations were not included. The trees were measured at 11 and 15 years after planting. It was found that in 19 of the 29 test sites, height was significantly correlated with seed source latitude. Provenances from more southern locations generally grew taller than provenances from more northern locations. Survival percentage based on seed source latitude showed less correlation than height growth and was found to be significant in 10 of the 29 locations. Trees from more northern latitudes generally had lower survival percentages in the significant locations. Other climate variables, such as start of growing season, length of the growing season, longitude, summer precipitation, and frost-free period were tested as well. These variables were found to be significantly correlated with height growth and survival in a number of test sites, however latitude was by far the most significant predictor of height growth. Length of growing season was the most significant predictor of survival percentage.

Thomson et al. (2009) examined black spruce provenance height based on mean monthly temperature. In this study, 20 range wide common garden experiments were analyzed. Similar patterns in height growth as described above were found. Northern trees were found to grow the least, while southern trees grew the most. It was found that temperature, more than precipitation, had the greatest influence on overall height growth. Generally, trees grew taller in warmer locations, regardless of temperature of seed source origin, but the temperature of seed source origin influenced overall height.

Khalil (1984) tested black spruce provenances in Newfoundland. It was found that trees from more northern areas burst bud first and grew less than trees from more southern parts of the province. The results also showed a high correlation between seedling performance in the green house and performance of the same trees once planted in the field. Trees with high initial growth in the nursery are likely to keep the high level of growth relative to their peers once planted outside. This information is useful to breeding programs aiming to identify superior provenances.

Guo et al. (2020) studied bud burst and bud set in black spruce in Quebec. This study focused on a smaller area than Morgenstern (1978), consisting of a common garden experiment of black spruce saplings from five provenances. These provenances represented the latitudinal distribution of the boreal forest in Quebec, Canada. In total, 422 seedlings were planted in the southernmost site of the study. The sites show a clear thermal gradient, with the northern sites being the coldest and the southern sites being the warmest. Bud burst began in mid-May and continued over a period of seven days. Similar to Morgenstern’s (1978) results, the northernmost provenances burst bud first before the southernmost provenances in sequential order, moving from north to south. This study shows that clinal variation can be observed in part of the range of black spruce and not just the whole range.

Rossi (2015) also tested black spruce provenances from Quebec across the latitudinal range of the province. Seedlings from six provenances were put into growth chambers set to different temperatures (12, 16, and 20 °C) and photoperiods (14, 18 and 22 h). In this experiment, provenances from colder areas of the province burst bud earlier than provenances from warmer areas, again showing similar results to the experiments described above. Analysis showed that temperature had more of an effect on the initiation of bud break than photoperiod, however the latter was still significant. Warmer temperatures and longer photoperiods caused all provenances to initiate bud break earlier than the tests with colder temperatures and shorter photoperiods. All provenances showed the same modifications of bud break to warmer temperatures. This indicates that local populations of black spruce retain enough plasticity to be used in seed transfers across its range, and that northern provenances are able to take advantage of southern temperatures and longer growing seasons. Southern trees are still likely to perform better in southern areas, however northern trees planted in southern areas will likely grow better than in their local climate due to the longer growing season.

A review of provenance data of boreal tree species (including black spruce) further confirmed that northern trees benefit from southern transfers (Pedlar and McKenney 2017). Northern trees are generally growing at significantly colder temperatures than what is ideal, meaning that a seed transfer to a warmer, southern part of the range resulted in increased height growth for the northern trees. It was found that seed transfers to environments with mean annual temperatures 2.2 and 3.6°C warmer than the seed source origin resulted in peak height growth (Pedlar et al. 2021). However, northern trees were also found to show decreased survival rates when moved to southern regions. Differences between northern and southern sites in soil quality, photoperiod, and the warmer, drier climate were discussed as possible contributing factors.

It is thought that the rise of temperature in spring triggers the initiation of growth, while the formation of buds in spring and cessation of growth in autumn is mainly controlled by changes in day length (Morgenstern 1990, Guo et al. 2020). Provenances from colder regions require lower temperatures to reactivate growth than provenances from warmer regions, meaning individuals in colder regions proceed through the phases of seasonal transition between dormancy and growth faster than individuals in warmer regions (Wang et al. 2011). Earlier growth resumptions are especially more beneficial for photosynthesis in northern trees since the incoming solar radiation is much higher in spring than in fall (Chuine 2010). Longer growing seasons extending into fall provide less photosynthetic benefit and an increased risk of frost damage for northern trees, explaining their observed growing patterns. Individuals from colder regions also finish bud development before warmer regions, likely to avoid exposing still developing buds to cold temperatures (Guo et al. 2020). This explains the larger overall height observed in trees from southern areas. Despite budding later than their northern counterparts, southern trees generally have longer overall growing seasons allowing them to grow taller.

MATERIALS AND METHODS

STUDY SITE AND DATA COLLECTION

This thesis examines variation in growth and survival of black spruce seed sources in a provenance trial near Thunder Bay, Ontario. The trial is located at the former Thunder Bay Forest Nursery, 25th Sideroad, Thunder Bay and contains a total of 50 provenances from across the northwest region (Parker 1994) (Figure 2, Appendix I.). The trial consists of three randomized blocks, with each block containing ten seedlings from each of the 50 seed sources planted at a 2 m spacing. A map of the test layout can be found in Appendix III. In the fall of 2022, the heights for each surviving tree in the first block of the provenance test were collected using a Vertex IV hypsometer. Dead trees and trees with multiple stems or defects were noted.

The mean annual temperature (MAT) of the location of the seed source of each provenance was obtained using ClimateNA (Wang et al. 2016). Annual temperature means from 1961 to 1990 were used.

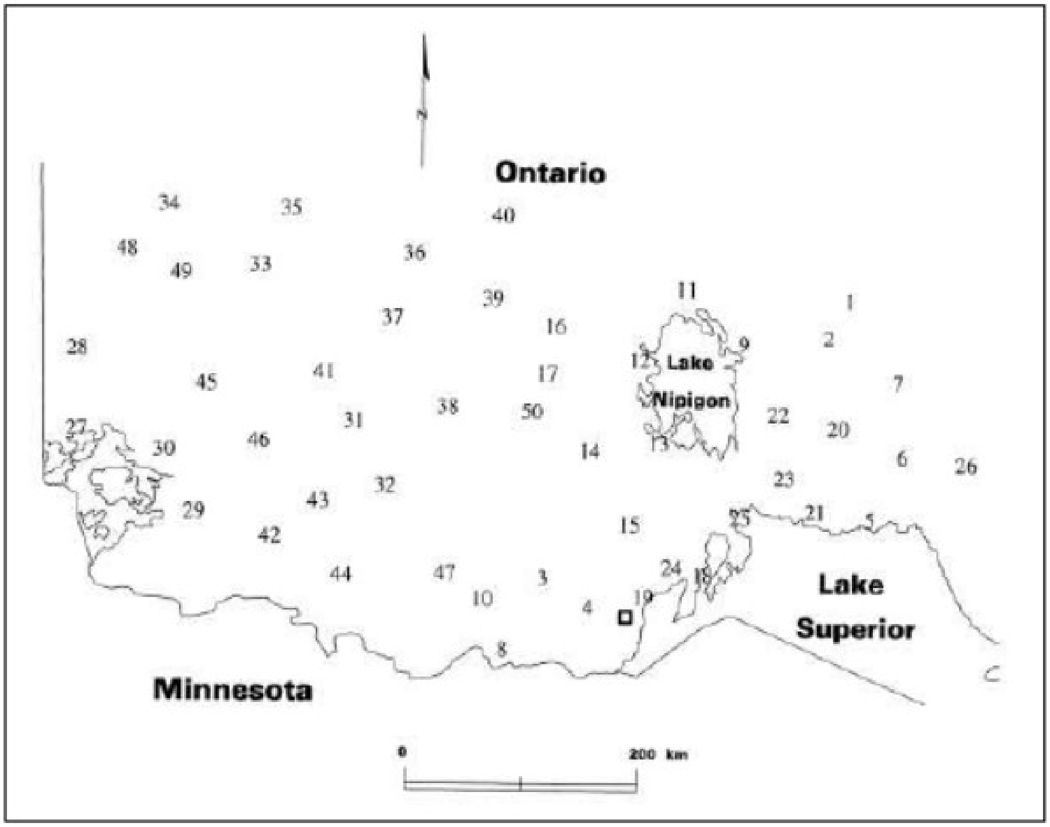

Figure 2. Locations of the seed sources used to establish the common garden experiment at the former Thunder Bay Nursery on 25th Sideroad, Thunder Bay. Source: Parker (1994).

STATISTICAL ANALYSIS

Dead trees were removed from the data for the calculation of the mean height of each provenance. A one-way ANOVA was performed to examine whether mean height varied significantly between provenances. Survival percentage of each provenance was also calculated, and a linear regression test was performed using Excel to examine whether there exists a significant relationship between MAT and seed source height. JASP was used to obtain the ANOVA results (JASP Team 2023).

RESULTS

Average provenance heights ranged from 8.9 m to 11.3 m, and the overall mean height was 10.03 m (Appendix II). Provenance 26 was the shortest and provenance 10 was the tallest. The ANOVA results show that height did not vary significantly among provenances (Table 1).

Table 1. ANOVA results for height of 50 black spruce populations grown in the Thunder Bay common garden experiment.

Variable	Source of Variation	Sum of Squares	df	Mean Squares	F	p
Height	Provenance	89.72	49	1.83	1.04	0.42
	Error	525.27	297	1.77		

The MAT of the seed sources ranged from -0.8 °C for provenance 40 to 2.5 °C for provenance 30. The MAT of the study location is 2.4 °C. The regression for MAT and height was not statistically significant ($R^2 = 0.0098$, $p = 0.23$) (Figure 3).

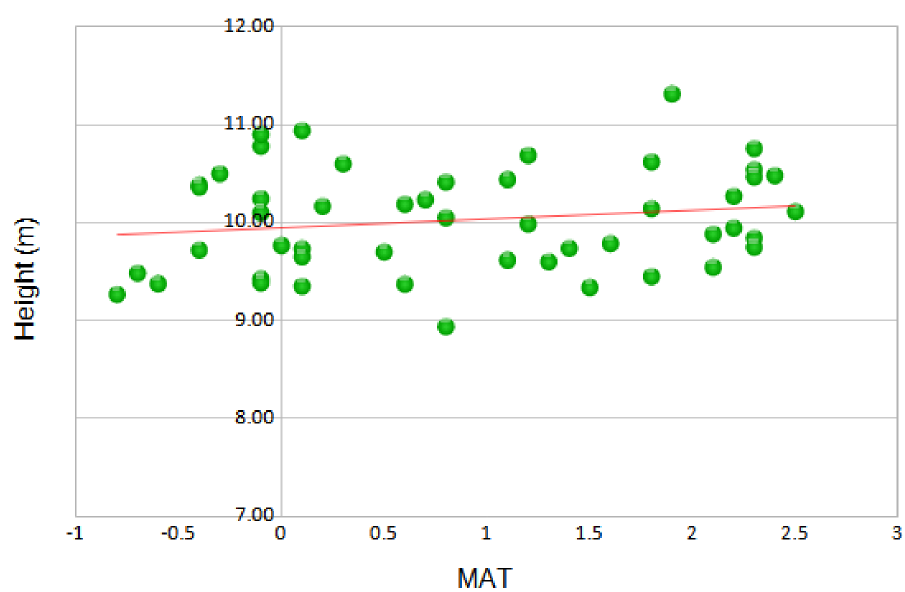

Figure 3. Regression plot of provenance mean height against mean annual temperature (MAT) of the seed source location.

Survival percentage ranged from 30% for provenance 40 to 100% for provenances 32 and 46. The mean survival percentage was 69.4% (Appendix II). While the trendline shows a slight increase in the survival percentage as the MAT of the seed source location increases, a regression test showed low correlation ($R^2 = 0.0119$, $p = 0.52$) (Figure 4).

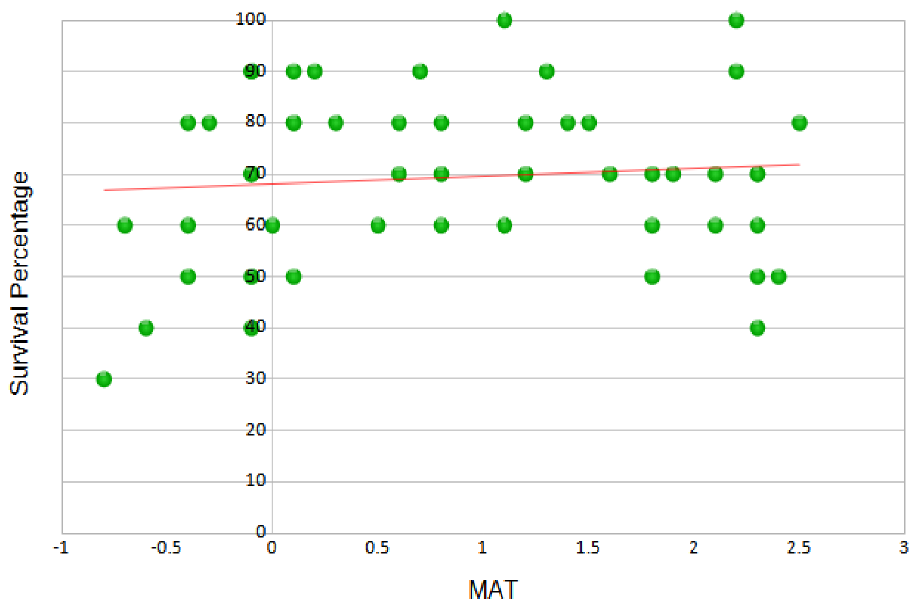

Figure 4. Regression plot of provenance survival (%) against mean annual temperature (MAT) of the seed source location.

DISCUSSION

No significant difference in provenance mean tree height or survival percentage was found in this experiment, contrary to the results found in other black spruce common garden experiments. The insignificant height measurements were especially surprising since this stand had also been measured in a previous undergraduate thesis (Antler 2020). In the previous study, the mean heights between provenances were found to be significantly different based on seed source location.

There are a number of different explanations for these results. The simplest is to consider the challenges of using the Vertex IV hypsometer device and how misuse may have influenced the data. Since the Vertex IV uses ultrasonic signals to determine distances, environmental factors such as humidity, air pressure, surrounding noise, and air temperature can affect measurements (ESRD 2012). For this reason, the device requires frequent calibration. Either mis-calibration or too infrequent calibrations could have influenced the data collected. Another factor is to consider the density of the stand. This made it difficult to determine which treetop corresponds to the tree being measured. Having a partner there for the data collection process fixes this problem somewhat, since the partner can shake the trees, allowing the other partner to identify which treetop is to be measured due to the movement of the tree, however about half of the data in this study was collected by a single person. Another factor to consider is the fact that only a third of the total study was measured. The total study consists of three blocks, but due to time constraints only a single block was measured. This gave 10 trees per provenance instead of 30, or 500 trees measured in total instead of 1500. Perhaps 10 trees per provenance was too small a sample size to determine if significant height differences occurred, or maybe the first block happens to not show any significant results due to chance. Regardless, a larger sample size would have likely given more accurate results (Nestor et al. 2017). The significant provenance height results obtained by Antler (2020) were obtained by measuring two of the three blocks. The whole common garden experiment should be measured before any conclusive results can be made.

Even if the height data collected in this study is accurate however, there is still no guarantee that significant differences in provenance height due to seed source MAT would be found. For example, Morgenstern and Mullen (1990) found that about a third (10 of 29) of their black spruce common garden sites did not show significant height correlation with seed source latitude. Despite this, all the correlations between height and latitude, including the non-significant ones, were negative, meaning that southern provenances showed increased height growth when compared their northern counterparts. Despite being statistically insignificant, figure 2 still shows a slight overall trend upwards in provenance height as seed source MAT increased, agreeing with the results of the Morgenstern and Mullen study. The results in Morgenstern and Mullen (1990) are consistent with this experiment, since comparing provenances in terms of MAT and latitude is similar; as latitude decreases, MAT is expected to increase (southern locations are generally warmer than more northern locations in the northern hemisphere). Possible reasons for the increased height growth of southern provenances are discussed in the literature review.

The second part of this study looked at how MAT of seed source location influenced the average survival percentage of the provenances. The results showed no significant differences in survival percentage between the provenances. These results are more consistent with the literature, since survival percentage is less influenced by temperature than height (Morgenstern and Mullen 1990, Thomson et al. 2009). Like the height results, I found a slight increase in survival percentage as seed source location MAT increased but the correlation was weak (R^2=0.0119, p = 0.52). However, provenance 40, the provenance with the lowest survival rate (30%), happened to be the provenance from the location with the lowest MAT (-0.8 °C). While this may indicate some influence of MAT on survival rate, no clear conclusions can be drawn from this study.

Survival results may be influenced by the study design as well. Since the trees measured in the study were germinated in greenhouse conditions and planted in a relatively well tended site, these trees were likely subjected to less stresses than trees would be when naturally germinating. This could inflate the survival percentage of the provenances, or maybe among-provenance variation in survival only becomes apparent in the presence of certain stressors that were absent in this study.

A few improvements could be made to future studies. For instance, the whole test should be measured, since this will provide the most accurate data from the test site, and hypsometer measurements should be regularly calibrated against a height pole or against an object with a known height to ensure measurement accuracy.

CONCLUSION

The results of my study do not support the hypothesis that height was influenced by the MAT of the seed source location, as no significant differences in provenance mean height were detected. It is possible that the lack of ability to detect significant differences among provenances results errors in height measurement, as a previous study of the same test found significant differences in height.

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APPENDIX I

Table 2. Latitude and Longitude of black spruce provenances
Source: (Parker 1994).

Provenance #	Seed Source	Latitude			Longitude		
1	12.89	50	12	25	86	54	8
2	13.89	49	59	8	87	9	15
3	15.89	48	36	45	90	15	30
4	16.89	48	24	26	89	49	25
5	17.89	48	47	8	86	56	55
6	18.89	49	9	40	86	33	39
7	24.89	49	38	30	86	30	52
8	27.89	48	10	25	90	42	18
9	29.89	50	0	6	88	1	42
10	35.89	48	30	36	90	55	36
11	37.89	50	23	25	88	36	45
12	39.89	49	57	48	89	9	28
13	44.89	49	24	50	89	2	32
14	45.89	49	24	8	89	44	36
15	48.89	48	54	40	89	24	0
16	50.89	50	13	28	90	0	5
17	51.89	49	55	30	90	7	15
18	53.89	48	32	47	88	42	55
19	56.89	48	26	37	89	19	37
20	61.89	49	23	50	87	13	25
21	63.89	48	52	50	87	32	20
22	64.89	49	31	46	87	48	17
23	67.89	49	6	50	87	48	45
24	69.89	48	36	51	89	0	50
25	70.89	48	53	33	88	17	40
26	73.89	49	4	10	85	59	15
27	8.93	49	41	31.6	94	55	42.5
28	11.93	50	12	41.1	94	54	21.4
29	12.93	49	8	51.9	93	45	51.4
30	14.93	49	33	6.2	94	3	11.2
31	25.93	49	41	32.1	92	7	24.2
32	27.93	49	16	8.5	91	50	20.4
33	32.93	50	43	37.1	93	0	48.8
34	37.93	51	7	51	93	56	33.3
35	39.93	51	4	42.2	92	40	17.4
36	42.93	50	45	18.2	91	24	50.9
37	44.93	50	20	59.8	91	40	36.2
38	46.93	49	45	15.8	91	9	16.3
39	48.93	50	25	48.4	90	37	1.6
40	51.93	50	57	40	90	27	20
41	53.93	50	1	9.8	92	23	25
42	60.93	48	58	48	93	0	52.1
43	65.93	49	11	12.9	92	30	49.8
44	67.93	48	42	46.7	92	18	42.8
45	71.93	49	58	18.5	93	36	12.6
46	74.93	49	35	34.1	93	5	18.3
47	84.93	48	41	20.7	91	16	40.2
48	85.93	50	50	54.9	94	22	53.7
49	86.93	50	41	37.2	93	49	48.7
50	21.93	49	41	5.2	90	17	43.7

APPENDIX II

Table 3. Provenance mean height and survival percentage.

Provenance	Mean Height (m)	% Survival
1	9.48	60
2	10.38	60
3	10.69	80
4	9.74	80
5	9.34	80
6	9.35	80
7	10.50	80
8	10.48	50
9	9.43	40
10	11.31	70
11	9.38	40
12	10.24	90
13	10.41	70
14	9.77	60
15	9.70	60
16	10.36	80
17	9.72	50
18	9.94	90
19	9.88	60
20	10.78	50
21	9.79	70
22	10.10	70
23	10.17	90
24	9.60	90
25	9.45	60
26	8.94	80
27	10.76	70
28	9.54	70
29	10.54	50
30	10.11	80
31	9.99	70
32	10.44	100
33	10.05	60
34	9.73	90
35	10.94	50
36	9.65	80
37	10.60	80

Table 4. Provenance mean height and survival percentage continued.

Provenance	Mean Height (m)	% Survival
38	9.37	70
39	9.39	70
40	9.27	30
41	9.62	60
42	10.47	60
43	10.62	50
44	9.84	70
45	10.14	70
46	10.27	100
47	9.75	40
48	10.19	80
49	10.23	90
50	10.90	90
Overall means:	10.03	69.4

APPENDIX III

L.U. Forest Genetics: NW Ontario Black Spruce Provenance Trial   4/7/94   1

BLOCK 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	10.6	34.3	42.10	37.2	16.1	29.2	36.9	32.4	11.8	10.8	48.8	38.9	28.3	14.10	36.8	34.8	22.3	50.7	40.3	6.1
2	26.4	47.3	35.9	25.3	13.2	15.5	7.7	43.5	20.8	19.3	29.1	43.4	40.9	11.5	7.4	6.6	19.9	31.3	40.6	41.9
3	21.8	14.3	37.1	26.10	4.5	15.6	48.2	12.1	7.5	44.3	11.4	36.7	3.1	11.7	8.9	8.2	9.7	41.2	35.8	43.6
4	16.10	40.10	33.3	22.10	25.2	39.2	32.1	6.5	44.10	31.8	11.3	12.6	11.1	42.3	14.8	9.9	8.6	44.7	36.4	20.10
5	9.10	48.7	12.8	38.10	26.9	47.2	30.10	5.10	23.7	26.3	47.7	4.10	41.10	38.8	21.5	13.3	39.10	37.9	7.3	19.6
6	43.3	26.1	13.8	1.10	5.8	15.8	20.7	20.4	42.7	47.10	16.3	19.10	6.2	34.2	33.4	45.10	49.6	49.1	16.9	26.6
7	31.10	41.6	31.7	10.4	47.4	7.8	6.10	22.1	11.9	27.7	21.4	28.6	16.2	9.5	10.3	18.2	34.4	2.7	43.9	41.4
8	7.1	19.7	49.7	16.5	22.9	21.1	12.4	40.4	22.4	13.5	28.10	27.8	10.10	5.7	28.9	43.2	34.5	45.1	5.9	6.3
9	17.5	29.8	12.5	17.7	14.1	27.2	17.1	18.8	21.3	25.8	23.6	4.4	4.6	5.2	2.5	16.6	36.5	29.6	39.5	3.10
10	47.1	33.5	32.10	17.3	37.3	42.9	27.5	34.7	5.1	42.6	30.3	26.2	33.2	13.1	22.6	15.10	40.2	24.7	47.9	12.2
11	43.8	3.5	49.3	46.1	36.3	2.6	39.8	30.7	24.4	30.1	1.7	23.8	25.1	5.6	42.5	2.4	37.6	20.3	13.9	19.1
12	10.7	48.3	44.9	37.10	35.10	47.8	35.6	9.4	45.5	47.6	14.6	4.8	28.4	9.3	8.3	45.4	3.8	4.1	23.2	17.6
13	11.6	44.2	40.5	27.3	7.10	28.5	23.1	44.1	38.3	7.6	30.5	29.10	2.3	6.8	15.3	49.2	1.4	5.3	45.2	31.2
14	31.6	39.9	33.6	5.4	1.8	12.3	42.2	36.10	8.7	6.4	20.2	30.4	24.5	38.5	44.8	49.5	47.5	41.3	33.10	44.5
15	17.10	26.8	15.2	46.8	33.8	14.9	50.9	18.3	8.4	6.7	39.1	14.4	49.9	48.4	18.1	22.5	40.1	27.10	37.5	1.5
16	2.2	3.4	38.6	29.7	41.5	36.2	49.10	21.9	46.2	43.1	45.3	15.7	48.1	48.9	8.1	4.7	3.6	15.4	20.5	50.4
17	29.9	21.10	6.9	35.4	1.6	17.8	32.3	12.7	23.4	32.6	35.1	25.5	36.1	41.8	49.4	24.3	38.2	9.8	50.2	29.4
18	1.9	28.2	15.9	16.8	10.1	41.1	45.9	37.4	17.9	1.3	35.2	8.5	45.8	17.4	33.9	36.6	39.6	43.10	39.3	32.5
19	21.2	45.6	23.5	37.7	14.5	18.9	13.4	21.6	40.7	23.9	30.2	4.9	20.6	43.7	14.7	49.8	26.5	25.10	18.7	27.4

Figure 5. Map of the provenance trial. Each number represents a tree. The number refers to the seed source. Only block 1 was measured in this study, but the whole map has been included.

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20	19.2	24.10	12.10	46.3	29.5	19.5	17.2	46.5	14.2	22.8	4.2	46.6	13.10	32.9	41.7	24.9	32.2	24.8	42.4	26.7
21	27.1	2.10	32.8	30.6	1.2	31.5	50.10	25.4	28.1	24.6	16.7	4.3	18.10	27.6	13.6	22.2	10.2	45.7	35.7	46.7
22	28.7	46.4	44.4	2.9	29.3	21.7	30.9	13.7	50.3	7.2	3.7	50.6	23.10	16.4	44.6	35.5	48.6	38.4	42.1	2.8
23	39.4	7.9	25.9	8.8	11.2	2.1	3.3	42.8	18.5	12.9	34.10	20.9	31.9	10.9	19.8	18.6	40.8	28.8	24.1	48.5
24	9.6	15.1	11.10	48.10	3.2	34.6	8.10	18.4	9.2	22.7	1.1	38.7	37.8	39.7	46.9	20.1	5.5	50.8	46.10	27.9
25	25.6	50.1	9.1	50.5	31.1	24.2	34.9	34.1	32.7	25.7	23.3	38.1	30.8	33.1	31.4	33.7	35.3	10.5	3.9	19.4

BLOCK 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	37.3	46.5	42.4	43.2	47.6	49.1	46.9	5.6	45.7	10.9	5.4	11.4	46.6	15.4	32.6	19.8	13.4	1.5	27.9	36.2
2	20.7	23.2	44.5	3.3	30.5	22.5	22.2	5.5	30.6	14.6	31.2	34.10	35.1	35.3	29.7	20.6	47.8	1.4	32.8	19.7
3	37.6	33.1	45.4	21.2	27.5	39.6	5.8	12.10	46.3	16.3	43.4	9.10	37.10	4.10	47.10	46.2	41.10	17.1	1.6	28.2
4	29.3	17.9	23.6	1.7	3.4	24.9	26.10	30.3	13.8	17.7	38.5	37.2	31.6	11.2	29.9	8.8	38.2	39.4	14.7	11.5
5	25.5	4.5	1.1	19.9	9.6	36.3	15.6	8.10	6.5	15.1	32.10	7.7	20.3	6.8	21.7	15.2	43.9	10.6	48.5	29.8
6	22.6	18.10	2.9	40.9	29.4	40.5	24.1	32.1	3.10	35.6	48.3	48.1	2.6	11.9	14.10	24.2	12.2	37.8	36.5	24.5
7	25.6	11.10	30.9	1.8	29.10	1.9	13.2	8.3	8.1	37.7	8.7	27.2	50.5	24.10	15.10	13.7	33.6	17.3	41.6	48.9
8	2.3	47.1	45.8	6.4	29.2	32.5	49.6	28.10	22.8	28.3	49.8	25.3	50.7	2.10	8.2	18.2	35.2	23.3	38.4	14.2
9	47.5	2.1	20.4	30.1	24.3	6.2	14.8	39.3	42.6	33.10	44.9	16.9	8.4	45.6	46.1	17.4	6.9	13.5	17.6	43.8
10	16.10	30.8	44.3	44.2	33.5	34.2	28.9	15.3	12.4	41.4	36.1	14.5	13.10	47.7	48.8	46.4	20.10	32.9	39.7	48.2
11	11.1	38.7	49.9	43.10	50.1	50.9	38.1	15.5	37.1	47.9	34.5	26.1	20.9	11.8	9.4	14.9	25.7	48.10	8.5	49.4
12	36.10	26.5	45.3	43.3	7.8	20.8	7.3	33.9	15.9	25.4	28.5	24.6	39.8	25.8	20.2	37.9	3.6	33.4	10.10	32.4
13	21.5	33.3	13.9	33.2	12.9	43.7	34.3	18.9	27.7	42.10	10.7	28.8	38.9	49.2	5.1	31.10	31.9	16.6	10.1	50.6

Figure 5. Map of the provenance trial continued.

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14	35.7	4.1	23.4	2.2	28.6	40.8	19.3	6.3	45.5	12.6	5.2	3.2	11.6	13.6	19.10	23.7	18.5	49.3	7.6	40.2
15	42.7	15.8	48.6	13.3	40.7	28.1	4.4	16.2	38.10	30.4	22.10	3.8	7.9	39.9	10.2	12.1	33.7	28.7	12.5	7.5
16	2.5	10.5	7.4	8.6	9.5	34.9	18.6	4.6	14.4	44.7	21.1	10.4	22.9	6.6	37.4	9.8	23.1	38.6	34.1	25.10
17	29.1	7.2	7.10	1.10	9.2	1.2	31.5	40.3	50.10	36.6	12.7	49.10	50.4	45.10	9.7	30.7	18.4	42.1	20.1	35.5
18	27.1	3.7	6.1	16.8	21.3	17.10	41.3	26.3	5.10	43.1	29.6	44.10	2.7	43.5	30.10	3.1	19.1	13.1	23.8	17.5
19	36.8	5.7	34.4	41.1	20.5	41.2	46.7	4.2	33.8	31.7	39.2	22.4	35.4	43.6	11.7	31.8	30.2	34.8	23.10	18.8
20	25.1	18.1	32.3	6.10	16.1	35.10	50.8	16.7	3.9	39.5	24.7	22.3	40.4	36.7	42.5	37.5	27.6	17.8	12.8	14.1
21	12.3	45.9	41.9	22.7	10.3	39.1	21.8	47.2	9.9	9.1	46.8	42.9	47.4	32.2	28.4	42.3	10.8	22.1	39.10	41.8
22	49.7	50.3	24.4	40.6	7.1	19.6	47.3	44.4	9.3	35.8	40.10	34.6	2.8	29.5	38.8	42.2	27.8	1.3	21.9	44.1
23	11.3	34.7	26.2	16.4	4.9	4.8	18.3	36.4	46.10	5.3	4.3	45.2	27.4	25.2	17.2	14.3	2.4	50.2	18.7	26.8
24	40.1	26.9	24.8	8.9	19.2	36.9	49.5	44.6	27.10	16.5	5.9	4.7	31.4	21.4	27.3	32.7	26.6	15.7	25.9	26.4
25	31.1	35.9	19.5	41.7	23.9	26.7	38.3	6.7	21.10	41.5	23.5	45.1	48.4	19.4	3.5	31.3	44.8	21.6	48.7	42.8

BLOCK 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	23.5	32.6	12.6	9.10	27.9	28.1	13.4	9.8	33.1	9.4	40.3	28.3	44.10	37.5	27.4	14.8	2.8	22.3	10.1	17.5
2	5.2	46.4	6.6	34.3	48.3	49.6	12.9	30.7	26.3	26.9	9.2	18.1	45.2	38.7	30.9	45.8	48.4	33.2	48.1	4.3
3	4.6	31.7	12.8	41.10	9.1	26.5	14.1	44.1	47.6	40.4	48.6	23.10	19.9	50.1	2.3	27.1	30.5	20.9	44.8	47.4
4	38.2	4.4	36.8	6.2	19.7	48.8	49.3	43.6	44.5	21.6	45.7	22.5	16.8	43.7	26.4	43.9	19.3	41.3	35.8	29.9
5	33.5	47.7	31.8	8.9	11.8	34.7	17.8	22.7	16.2	42.8	36.9	43.5	20.8	30.3	31.4	5.3	23.6	33.4	6.10	36.3
6	19.10	38.6	20.3	21.8	46.2	17.1	19.4	18.5	25.6	27.2	6.8	31.5	36.10	14.6	48.7	4.10	32.5	45.4	17.3	28.10
7	33.3	35.5	29.2	4.9	27.8	49.10	7.2	23.3	32.10	12.7	42.10	5.10	24.4	29.5	35.7	12.1	19.5	21.9	33.8	48.9

Figure 5. Map of the provenance trial continued.

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8	32.2	28.6	40.9	5.9	34.8	11.5	38.5	44.7	32.9	27.7	13.8	3.8	7.4	19.6	11.2	10.5	8.5	8.7	27.5	17.10
9	25.7	7.1	46.3	37.4	9.9	39.4	6.3	48.10	13.1	28.7	5.1	15.3	38.4	42.9	2.4	10.6	3.2	8.1	40.1	12.3
10	16.4	26.7	24.1	4.8	14.9	15.1	20.4	46.6	15.2	1.9	8.4	47.1	26.10	37.3	5.6	11.4	28.5	13.9	45.9	41.1
11	3.6	6.4	24.3	2.2	46.1	15.4	4.5	3.1	18.10	25.10	42.7	38.10	32.8	37.9	10.7	39.10	33.7	42.5	46.8	43.1
12	50.2	24.7	13.2	18.6	14.3	22.2	11.3	11.6	30.10	48.5	18.7	46.5	17.6	26.1	29.6	42.1	7.3	37.10	13.6	42.3
13	8.3	34.4	35.3	8.2	34.1	6.5	35.10	16.10	37.1	22.1	28.9	34.10	13.5	22.6	3.9	40.6	12.10	33.6	50.10	20.6
14	18.8	38.1	38.8	22.8	31.6	7.7	10.4	18.2	23.8	8.10	41.4	36.2	49.5	2.7	6.9	1.8	22.10	28.4	16.6	43.8
15	3.10	24.8	5.7	2.9	7.9	40.8	46.7	20.10	50.8	41.7	15.6	21.3	44.4	27.10	20.1	27.3	23.4	23.7	5.8	13.3
16	46.10	23.2	1.7	41.6	15.10	3.7	47.5	5.4	48.2	47.3	14.7	29.8	13.10	18.9	17.9	32.4	35.2	24.6	4.1	15.9
17	2.10	15.7	40.7	47.2	9.7	14.2	26.8	17.7	18.3	40.10	5.5	9.5	29.7	28.8	11.7	16.1	36.7	7.6	44.3	49.9
18	16.3	10.10	45.6	30.4	38.3	29.4	1.6	1.10	44.2	21.10	43.3	35.4	49.8	29.3	20.7	31.3	15.8	39.1	22.9	2.1
19	40.5	31.1	49.1	39.5	19.8	12.2	32.3	21.1	37.6	34.6	38.9	17.4	24.2	11.9	25.3	50.5	4.2	21.2	49.4	50.6
20	40.2	23.1	24.9	35.6	12.4	45.1	36.5	1.3	10.9	1.2	22.4	41.5	21.7	15.5	21.5	37.2	21.4	30.1	31.9	6.1
21	45.5	50.4	16.7	41.2	25.1	47.8	10.3	3.4	41.9	14.4	45.10	6.7	25.9	26.2	14.10	26.6	25.2	42.2	36.4	47.10
22	1.1	45.3	39.6	37.8	34.2	13.7	17.2	34.5	34.9	16.5	14.5	37.7	36.6	31.2	19.2	3.5	16.9	10.2	27.6	46.9
23	28.2	33.10	35.1	2.6	43.10	25.4	25.8	9.3	50.7	39.2	1.4	49.2	39.7	19.1	39.9	2.5	7.5	44.9	24.5	11.1
24	10.8	30.2	7.8	23.9	39.8	43.4	35.9	41.8	4.7	1.5	29.10	39.3	32.1	49.7	7.10	29.1	8.8	20.2	30.6	50.9
25	32.7	47.9	30.8	42.4	20.5	11.10	33.9	43.2	9.6	36.1	24.10	8.6	3.3	50.3	18.4	12.5	31.10	25.5	42.6	44.6

Figure 5. Map of the provenance trial continued.