ASSESSMENT OF THE GROWTH AND SURVIVAL OF A BLACK SPRUCE PORTFOLIO TRIAL: IMPLICATIONS FOR REFORESTATION UNDER CLIMATE CHANGE

by

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ABSTRACT

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The purpose of this study is to assess the performance of black spruce seedlings at a genetic trial designed to select seed sources adapted to several climate change scenarios. Height variability among trees is attributed to seed source effects, block effects, and seed source-by-block interaction effects. Seed sources originating from areas to the south west of the study site appeared to have greater mean heights. There was no significant difference in survival among seed sources.

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INTRODUCTION

The Intergovernmental Panel on Climate Change has confirmed in the Fifth Assessment Report that the global climate system is unequivocally warming (IPCC 2013). The warming trend is resulting in changes to climate patterns, such as temperature and precipitation patterns. It is projected that Ontario will experience rising temperatures in the next century, as well as changes in total annual precipitation amounts (McDermid et al. 2015).

Climate is the main factor in determining the vegetation in a region (Crowe and Parker 2008). Tree populations have evolved with their respective local climates, ensuring that growth and dormancy events are synchronized with seasonal weather variations (Morgenstern 1996). Tree populations are adapted to the characteristics of their region, including the climate. Rapid and sustained changes in temperature and precipitation may impact tree survival and forest productivity. Thomson et al. (2009) demonstrate that the optimal growing condition of black spruce in Ontario has the potential to shift northwards under climate change.

To meet social and economic objectives, forest management requires that forests are regenerated after harvesting (OMNRF 2017). Seeds of local provenances are generally used to regenerate forests to ensure that trees have the necessary adaptive traits to survive in the region (Mullin and Bertrand 1999). The nature of forest management, however, entails rotation periods that are decades long. With the threat of climate change, trees that are - adapted to a region today may not be in the future.

A solution to regenerating productive forests under a changing climate is to match current seed sources to future climate scenarios (Crowe and Parker 2008). This involves predicting what the climate may be for a region and choosing a seed source that has the adaptive traits required to survive in that environment. Unfortunately, the future climate is difficult to predict; there are currently several different greenhouse gas emission scenarios and numerous climate models, each combination of which yields a different prediction of future climate (IPCC 2013). Forest regeneration requires substantial investment and so decisions must be certain, otherwise the selected seed source may do poorly in the future climate and investments may be lost.

To reduce the risk associated with matching seed sources with uncertain futures, Crowe and Parker utilize modern portfolio theory (Crowe and Parker 2008). This approach requires that assets are invested in several plausible outcomes, rather than just one, to maximize return and minimize risk (Markowitz 1952). The set of seed sources selected to regenerate the forest are optimally adapted to multiple, equally probable futures; hence, not all seed sources will perform equally well across all the plausible futures, but for each plausible future some seed sources will perform well (Crowe and Parker 2008).

In 2012, three separate black spruce provenance trials designed to select seed sources pre-adapted to several climate change scenarios were established in Dryden, Sault Ste. Marie, and Kakabeka, Ontario (Nsiah 2014). Selection of the seed sources was based on the seed source portfolio selection model. The objective of this study is to analyze the Sault Ste. Marie trial and (1) determine if there are any significant differences between any of the seed sources in height and survival rate; and (2) conduct an early evaluation of which seed sources may be potentially adaptable for reforestation given the present climate and future climate uncertainty.

LITERATURE REVIEW

THE BOREAL FOREST OF CANADA

The boreal forest of Canada occupies 270 million ha and has a range that extends continuously from Alaska to Newfoundland, occurring in 8 provinces and 2 territories (Brandt et al. 2013). The boreal forest is economically, ecologically, socially and culturally significant to Canada as outlined by Brandt et al. (2013). Much of Canada's timber and pulp and paper products for domestic and export markets come from forestry operations in the southern portion of the boreal zone. The boreal forest is characterised by cold-tolerant tree species such as *Abies*, *Larix*, *Picea*, and *Pinus* but also *Populus* and *Betula* (Brandt 2009).

BLACK SPRUCE

Black spruce (*Picea mariana* (Mill) B.S.P.) is a typical boreal species (Brandt 2009). Viereck and Johnston (1990) highlight the climate characteristics of this tree species. The climate for black spruce can be characterized as cold with a moisture regime varying from humid to dry sub-humid. Annual precipitation ranges from 380 to

760 mm in most of the black spruce range but can be as high as 1520 mm (maritime provinces) to as low as 150 mm (western Alaska).

In Canada and the United States, black spruce is commercially harvested for high quality pulp with balanced strength properties (Viereck and Johnston 1990). It is also harvested for lumber, Christmas trees and some non-timber products.

Genetic variation in black spruce is clinal, primarily along a north-south geographical gradient (Morgenstern 1978). Differences in photoperiod response, productivity, and survival rate have been shown to be related to the geographical area of seed origin (Viereck and Johnston 1990).

ADAPTIVE TRAITS

Adams (2007) explains that the Earth's biomes and the ranges of individual plant species are fundamentally determined by climate. The annual growth cycle of boreal tree species is limited to and regulated by climate, ensuring that the sequence of physiological and phenological events that occur during the periods of active growth and winter dormancy are synchronized to seasonal temperature patterns (Morgenstern 1996). Genetic variability and natural selection result in local tree populations developing traits that allow them to become highly adapted to their respective location on a geographic gradient (Morgenstern 1996).

THE BOREAL FOREST IN A CHANGING CLIMATE

In the Fifth Assessment Report the Intergovernmental Panel on Climate Change confirms that the global climate system is unequivocally warming, thus resulting in changing climate patterns (IPCC 2013). Warming is projected across all of Ontario for the next century and it is probable that warming will be greater in the winter than in the summer, and greater in the north than in the south (McDermid et al. 2015). It is also predicted that the entire province may experience changes in total precipitation, with some areas becoming wetter and others becoming drier.

Joyce & Rehfeldt (2017) have developed a model that estimates that black spruce in the boreal forest will see an early and sustained range contraction along the southern limits as well as decline within persistent habitat. They predict that most of the managed boreal forest in Canada will become vulnerable to extirpation as early as 2030 and the entire managed boreal forest is projected to be at elevated risk by 2060. Growing evidence suggests that the pace of climate change is surpassing the ability of North American tree species to migrate northward (Zhu et al. 2012).

CLIMATE CHANGE ADAPTATION STRATEGIES

The results of a study on the genetic responses to climate in *Pinus contorta* suggest that maintaining current forest productivity in the face of climate change will require a redistribution of species and genotypes across the landscape (Rehfeldt et al. 1999).

Assisted migration has been proposed as an approach to mitigate the impacts of climate change (Pedlar et al. 2011). Assisted migration (AM) involves the establishment of plantations of widespread, and commercially valuable, tree species using seed sources that will be climatically adapted for the duration of the plantations lifespan (Pedlar et al. 2012). For AM to be feasible, it must then be determined what seed source should be used for reforestation, given that it is difficult to predict a future climate. The process is complex as selecting a seed source for optimal height growth does not ensure optimal survival (Morgenstern & Mullin 1990).

Crow and Parker (2008) utilize modern portfolio theory to select an optimal set of seed sources to be used in regenerating forests. The method they employ selects genetic material that is optimally adapted to multiple, equally probably future climates. Their method is based on the portfolio selection theory developed by Markowitz (1952).

The portfolio theory has been used to establish jack pine (*Pinus banksiana* Lamb.) provenance trials in northwestern Ontario and black spruce (*Pinus mariana* (Mill.) B.S.P.) provenance trials in northwestern and northeastern Ontario. With regards to the jack pine provenance trials, Hawken (2014) found significant differences in height and survival between the seed sources used to establish the Dryden site and Penner (2015) found a significant difference in height, but not survival, between the seed sources used to establish the Fort Frances site. With regards to the black spruce provenance trial, Nsiah (2014) found that southern sources may be suitable for future reforestation programmes in the Ontario Boreal Forest Region.

MATERIALS & METHODS

The height was recorded of black spruce (*Picea mariana* (Mill) B.S.P.) planted in the seed source portfolio test in Sault Ste. Marie, ON. The height was measured with a height pole and the mortality of the tree was recorded. The data was collected October 10, 2017. The black spruce trees were in the seedling stage.

STUDY SITE

The test is in the Ontario Forest Research Institute (OFRI) Nursery & Arboretum located at 2051 Third Line W., Sault Ste. Marie, ON. The precise location of the south-east corner of the plot is 46.54523°N 84.45660°W (Figure 1).

TEST ESTABLISHMENT

The Sault Ste. Marie test was planted with 10 seed sources from the northern Ontario and Great Lakes region (Table 1; Figure 2). These seed sources were selected with the focal point seed zone method and a simplified version of the portfolio modeling approach (Nsiah 2014). They are predicted to be adapted to different future climate scenarios. The test was planted in the late summer of 2012.

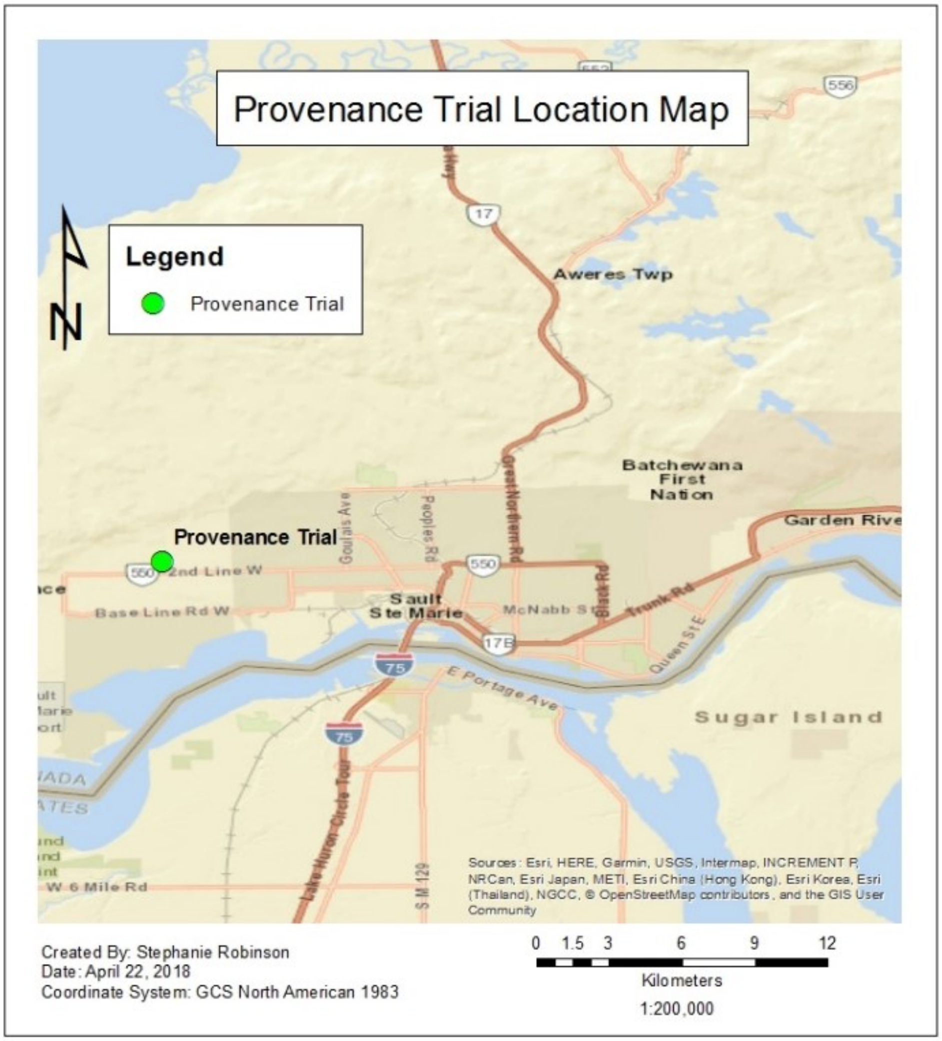

Figure 1. The Sault Ste. Marie black spruce seed source portfolio test location at the OFRI Nursery & Arboretum, Sault Ste. Marie, ON.

A randomized complete block experimental design was used to establish the test (Figure 3). The test is divided into 9 blocks with the 10 seed sources randomly planted in each block as plots of 16 trees (4 x 4 trees). There are 12 seed source plots replicated per block for a total of 1728 trees. The seed source plots in each block are arranged as follows: 9 of the plots are each planted with a different seed source, 2 of the plots are planted with the same seed source (source 6) and 1 plot is planted with a mix of all the seed sources together. This combination of seed source plots is replicated for each block but are arranged differently between blocks due to random assignment.

The mixed seed source plot in each block is planted with all seed sources. Some of the seed sources are planted twice in the same mixed plot due to a limited number of seed sources. The seed sources that are planted twice and the arrangement of the seed sources within the mixed plot varies between blocks (Figure 3).

A spacing of 1.5 m x 1.5 m was used as a planting distance between each tree. One border row was established as a buffer along the perimeter of the blocks to minimize edge effect. The plot is 39 m wide and 117 m long.

Table 1. Geographic parameters of black spruce seed sources and the planting sites (Source: Nsiah 2014).

Seed Source	**Seed Source Origin**	**Longitude**	**Latitude**
3	Espanola Area	-81.77	46.267
6	Algoma Forest	-84.38	46.617
8	Upper Peninsula, MI	-87.50	46.133
9	Northeast WI	-88.43	45.367
13	Northeast MN	-93.87	48.100
14	Cloquet MN	-92.47	46.700
16	Tamarack, MN	-93.12	46.633
17	Nashwauk, MN	-93.17	47.383
18	Big Falls, MN	-93.80	48.183
20	Bemidji, MN	-94.88	47.467

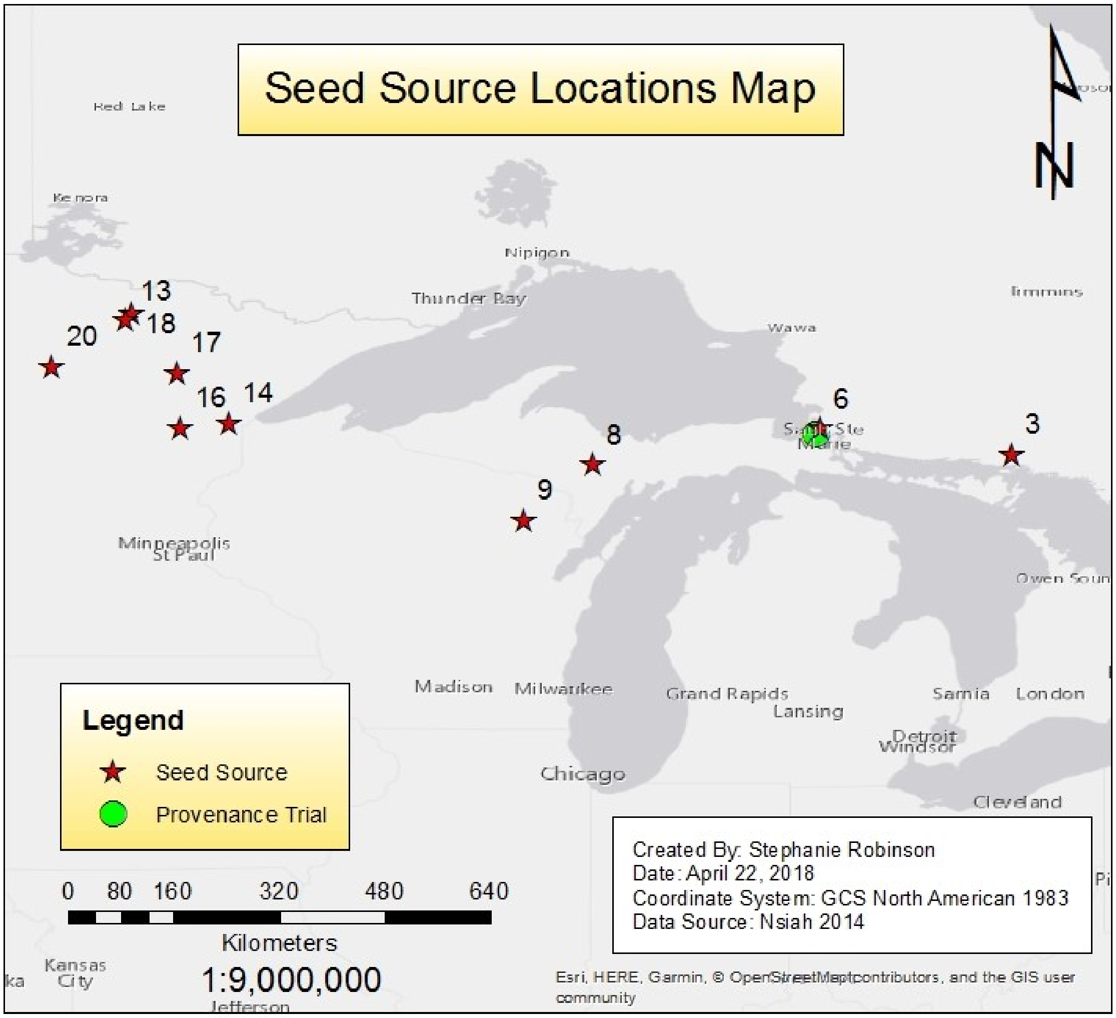

Figure 2. Location of the 10 seed sources selected for the Sault Ste. Marie portfolio test.

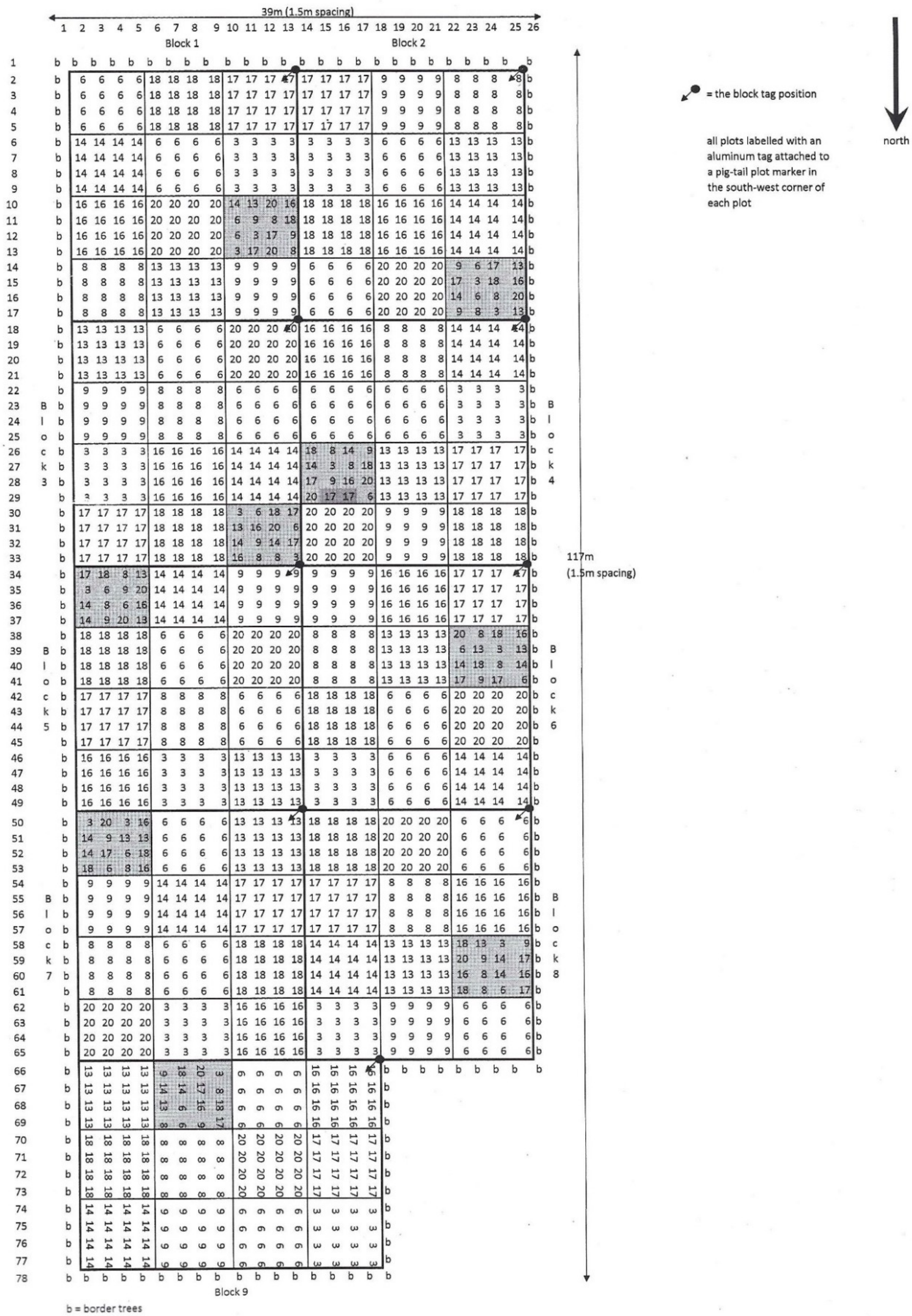

Figure 3. Layout of the trees in the Sault Ste. Marie black spruce seed source portfolio test.

The test is located in a heavily tended area surrounded mostly by grass (Figure 4). A small plantation of mature jack pine stand to the west of the test and is positioned halfway along the length of the test. A natural deciduous stand is found just to the east of the test, again positioned halfway along the length of the test. A field of tended grass is located to the north and west of the test.

Figure 4. Position and orientation of the Sault Ste. Marie black spruce seed source portfolio test (Source: Google Maps).

Grass and sedges grow in the test site with the vegetation becoming taller, and at times over-taking the black spruce seedlings, more on the east side of the test than the west. The black spruce seedlings vary in height and condition (Figure 5).

Figure 5. Sault Ste. Marie black spruce seed source portfolio test (Source: personal photo).

STATISTICAL ANALYSIS

The height and survival data were analyzed using IBM's Statistical Package for the Social Sciences (SPSS) software (IBM Corp. 2017). The SPSS software was used to calculate and compare the means and standard deviations of height and survival as well as to perform an analysis of variance for height and survival.

To test for statistical differences in height among seed sources an analysis of variance (ANOVA) in the form of randomized complete block design was performed on the height data using the General Linear Model procedure of SPSS software (IBM Corp. 2017). Seed source and block were treated as random factors.

An intraclass correlation coefficient was calculated for height to determine how much of the variance was attributed to provenance effect. To calculate the ICC, variance components were estimated using the variance components procedure, ANOVA method (Type III Sum of Squares), of SPSS (IBM Corp. 2017). The variance components were input into the following equation:

$$\text{ICC} = \frac{\delta^2\text{seed source}}{\delta^2\text{seed source} + \delta^2\text{block} + \delta^2\text{seed source X block} + \delta^2\text{error}} \times 100$$

where ICC is intraclass correlation coefficient, δ^2 seed source is the seed source variance estimate, δ^2 block is the block variance estimate, δ^2 seed source X block is the seed source by block interaction variance estimate and δ^2 error is the error variance estimate.

The survival rate per seed source plot was calculated by block and then mean survival rate was determined by seed source and by block. To test for statistical differences in survival among seed sources a one-way ANOVA was performed on the seed source mean survival rate (IBM Corp. 2017). To test for statistical differences in survival among blocks a one-way ANOVA was performed on the blocks mean survival rate.

The intraclass correlation coefficient was calculated for the seed source survival ANOVA and the block survival ANOVA. To calculate the ICC the mean square error and degrees of freedom values were identified from the ANOVA tables and than were input into the following equation:

$$\mathrm{ICC} = \frac{s_{A^2}}{s_{A^2} + s^2} \times 100$$

Where,

ICC = intraclass correlation coefficient

$s^2 = \mathrm{MS}_{\text{within groups}}$

$$\mathrm{s}_{\mathrm{A}^2} = \frac{\mathrm{MS}_{\text{between groups}} - \mathrm{MS}_{\text{within groups}}}{(\text{total degrees of freedom} + 1)/(\text{between groups degrees of freedom})}$$

RESULTS

AMONG-PLOT VARIATION

Of all the seed source plots in the test seed source 8 (MI) had the greatest average tree height at 87.5 cm. The local seed source (Algoma Forest) had a below average height of 73.1 cm, ranking it as second last out of eleven sources. The mixed plot (M) had an average height of 79.5 cm, ranking it as the fourth greatest mean height. The seed source with the lowest average height was seed source 20 (Bemidji, MN) with an average height of 71.9 cm. The average height for all seed sources is 78.1 cm. The number of trees that were analyzed were 1218 in total.

Table 2. Descriptive statistics for seed source mean heights (cm) in all plots in a decreasing order.

Seed Source	Mean Height (cm)	N	Std. Deviation	Std. Error of Mean	Minimum Height (cm)	Maximum Height (cm)
8	87.534	118	25.5624	2.3532	23.0	155.0
3	86.617	98	22.0616	2.2286	43.0	150.0
9	80.343	108	19.6048	1.8865	39.0	130.0
M	79.534	104	24.7931	2.4312	32.5	153.5
13	77.865	100	23.5423	2.3542	37.0	149.0
16	77.535	101	23.2265	2.3111	31.0	130.5
18	77.265	98	19.2995	1.9495	36.5	124.5
14	75.811	102	23.0225	2.2796	24.5	144.5
17	74.033	90	20.0101	2.1092	31.0	123.0
6*	73.119	206	19.4499	1.3551	30.5	140.5
20	71.866	93	20.3593	2.1112	33.0	120.0
Total	78.077	1218	22.3354	0.6400	23.0	155.0

(* Local seed source)

The seed source effect and the block effect are significant (Table 3). There is also a significant seed source x block interaction. The interaction effect signifies that there may be differences in seed source height performance between blocks. A one-way ANOVA by block determined that there is a significant seed source effect on height in blocks 1, 2, 3, and 4 (Table 5). The variation expressed in height among seed sources is approximately 3 (intraclass correlation coefficient = 0.031894) (Table 4).

Table 3. A two-way analysis of variance of height for seed source and block effects among all plots.

Source	Sum of Squares	df	Mean Square	F	Sig.
Seed Source	24142.846	10	2414.285	2.915	0.003
Block	18696.829	8	2337.104	2.878	0.007
Seed Source*Block	69061.568	80	863.270	1.984	0.000
Error	486971.697	1119	435.185		

Table 4. Variance estimates generated in SPSS for all seed source plots and the calculated intraclass correlation coefficient.

Component	Estimate
Var(SeedSource)	15.939
Var(Block)	13.075
Var(SeedSource * Block)	35.546
Var(Error)	435.185
ICC	0.031894

Table 5. A one-way analysis of variance of height for seed source effects by blocks among all plots.

Block	Sum of Squares	df	Mean Square	F	Sig.
1	16948.545	10	1694.854	3.240	0.001
2	10077.898	10	1007.790	2.312	0.015
3	26328.534	10	2632.853	5.106	0.000
4	15052.340	10	1505.234	4.001	0.000
5	3963.316	10	396.332	0.986	0.459
6	3794.983	10	379.498	1.116	0.357
7	6813.749	10	681.375	1.661	0.097
8	6645.390	10	664.539	1.747	0.082
9	8273.987	10	827.399	1.709	0.084

The mean height of blocks 1, 2, and 3 are all above the average of 78.1 cm (Table 6). Block 4 is below the average height with a height of 77.7 cm. Block 3 had the greatest mean height of all the blocks with a height of 87.0 cm. Block 6 had the lowest mean height with a mean height of 71.3 cm.

The mean survival rate of the seed sources established in the single and mixed plots is 70.4% (Table 7). Seed source 8 (MI) has the greatest survival rate with a mean of 81.9%. The local seed source, seed source 6 (Algoma Forest), has the third greatest survival mean with 71.5% which is above-average. The mixed plot has an above average survival mean of 72.2% which ranks it as third. The seed source with the lowest survival rate is seed source 17 (Nashwauk, MN) with a survival mean of 62.5%.

Table 6. Descriptive statistics of seed source mean height (cm) by blocks in all plots in a decreasing order.

Block	Mean Height (cm)	N	Std. Deviation	Std. Error of Mean	Minimum Height (cm)	Maximum Height (cm)
3	87.034	148	25.6841	2.1112	30.5	155.0
1	80.111	149	24.5421	2.0106	24.5	141.0
2	79.202	147	21.7970	1.7978	27.0	144.5
5	78.970	133	20.0408	1.7378	31.0	135.0
4	77.688	125	21.6157	1.9334	40.0	139.0
9	77.430	149	22.5217	1.8450	32.5	149.0
8	75.053	104	20.1990	1.9807	32.5	123.0
7	73.750	136	20.7427	1.7787	23.0	131.0
6	71.264	127	18.5288	1.6442	31.5	126.0
Total	78.077	1218	22.3354	0.6400	23.0	155.0

Table 7. Descriptive statistics of seed source mean survival (%) in all plots in a decreasing order.

Seed Source	Mean Survival (%)	Std. Deviation	Std. Error of Mean	Minimum Survival Mean (%)	Maximum Survival Mean (%)
8	81.944	10.5718	3.5239	62.5	100.0
9	75.000	14.6575	4.8858	56.3	100.0
M	72.222	17.7083	5.9028	50.0	100.0
6*	71.528	12.1478	4.0493	43.8	84.4
14	70.833	17.6777	5.8926	31.3	87.5
16	70.139	20.1987	6.7329	31.3	93.8
13	69.444	22.1951	7.3984	37.5	100.0
18	68.056	21.0664	7.0221	37.5	93.8
3	68.056	18.8654	6.2885	43.8	93.8
20	64.583	26.8823	8.9608	12.5	93.8
17	62.500	25.7694	8.5898	25.0	87.5
Total	70.391	19.1410	1.9237	12.5	100.0

(* Local seed source)

A one-way analysis of variance for tree survival by seed source reveals that there are no significant differences between any of the seed sources in survival rate (Table 8). The variation expressed in survival among seed sources is 0% (intraclass correlation coefficient = - 0.38575) (Table 8). There are also no significant differences between any of the blocks in survival rate (Table 9). The variation expressed in survival among blocks is approximately 7% (intraclass correlation coefficient = 0.06555) (Table 9).

Table 8. A one-way analysis of variance of mean survival by seed source in all plots.

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**	**ICC**
Between Groups	2406.881	10	240.688	0.632	0.782	-0.3858
Within Groups	33498.264	88	380.662			
Total	35905.145	98				

Table 9. A one-way analysis of variance of mean survival by block in all plots.

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**	**ICC**
Between Groups	5113.242	8	639.155	1.868	0.075	0.0656
Within Groups	30791.903	90	342.132			
Total	35905.145	98				

MIXED PLOTS

Of the seed sources established in the mixed plots, seed source 8 (MI) had the greatest average tree height at 94.5 cm (Table 10). The local seed source, seed source 6 (Algoma Forest), had the lowest average height with 66.6 cm. The average height for all seed sources in the mixed random plots is 79.5 cm. The total number of trees that were analyzed in the mixed random plots was 104.

There are no significant seed source effects, block effects, or seed source*block interaction effects in the mixed random plot design (Table 11). The variation expressed in height among seed sources is approximately 6% (intraclass correlation coefficient = .060535) (Table 12).

Table 10. Descriptive statistics for seed source mean heights (cm) in mixed plots in decreasing order.

Seed Source	**Mean Height (cm)**	**N**	**Std. Deviation**	**Std. Error of Mean**	**Minimum Height (cm)**	**Maximum Height (cm)**
8	94.533	15	18.4802	4.7716	68.5	135.0
17	87.111	9	28.2099	9.4033	55.0	129.0
9	87.050	10	22.3712	7.0744	62.5	122.0
16	85.188	8	32.9599	11.6531	32.5	126.0
14	80.636	11	32.1139	9.6827	36.0	153.5
20	75.550	10	27.0334	8.5487	32.5	103.0
18	74.444	9	24.4009	8.1336	32.5	125.0
13	71.333	12	22.0323	6.3602	37.0	102.5
3	68.688	8	18.3594	6.4910	52.0	102.0
6*	66.625	12	12.9319	3.7331	44.5	85.5
Total	79.534	104	24.7931	2.4312	32.5	153.5

(* Local seed source)

Table 11. A two-way analysis of variance of height for seed source and block effects within mixed plots.

Source	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Seed Source	8423.402	9	935.934	1.619	0.130
Block	7400.379	8	925.047	1.604	0.142
Seed Source*Block	31969.575	55	581.265	1.106	0.389
Error	16298.875	31	525.770		

Table 12. Variance estimates generated in SPSS for mixed plots and the calculated intraclass correlation coefficient.

Component	Estimate
Var(Block)	34.623
Var(SeedSource)	38.694
Var(SeedSource * Block)	40.103
Var(Error)	525.770
ICC	.060535

The mean survival rate for seed sources established in the mixed random plots is 71.7% (Table 13). The seed source with the greatest survival rate is seed source 8 (MI) with a survival mean of 83.3%. The local seed source, seed source 6 (Algoma Forest), had a survival rate of 72.2% ranking it with the fourth greatest survival rate. The seed source with the lowest survival rate was seed source 17 (Nashwauk, MN) with a survival rate of 61.1%.

Table 13. Descriptive statistics of seed source mean survival (%) in mixed plots in decreasing order.

Seed Source	Mean Survival (%)	Std. Deviation	Std. Error of Mean	Minimum Survival (%)	Maximum Survival (%)
8	83.33	35.355	11.785	0	100
13	83.33	35.355	11.785	0	100
20	83.33	35.355	11.785	0	100
6	72.22	36.324	12.108	0	100
3	66.67	35.355	11.785	0	100
9	66.67	43.301	14.434	0	100
14	66.67	50.000	16.667	0	100
16	66.67	50.000	16.667	0	100
18	66.67	43.301	14.434	0	100
17	61.11	41.667	13.889	0	100
Total	71.67	39.697	4.184	0	100

A one-way analysis of variance for tree survival by seed source reveals that there are no significant differences between any of the seed sources by survival rate (Table 14). The variation expressed in survival among seed sources is 0 (intraclass correlation coefficient = - 0.065662).

Table 14. A one-way analysis of variance of mean survival by seed source for mixed plots.

	Sum of Squares	df	Mean Square	F	Sig.	ICC
Between Groups	5805.556	9	645.062	0.384	0.940	-0.066
Within Groups	134444.444	80	1680.556			
Total	140250.000	89				

A one-way analysis of variance for tree survival by block reveals that there are significant differences between the blocks in survival rate (Table 15). An examination of Table 16 reveals that there is a wide range of survival rates between the blocks. Blocks 5 and 9 have the greatest survival rates with survival means of 100% each. The block with the lowest survival rate was block 7 with a survival rate of 45%. The variation expressed in survival among blocks is approximately 14% (intraclass correlation coefficient = 0.13495).

Table 15. A one-way analysis of variance of mean survival by block for mixed plots.

	Sum of Squares	df	Mean Square	F	Sig.	ICC
Between Groups	30000	8	3750.000	2.755	0.010	0.135
Within Groups	110250	81	1361.111			
Total	140250	89				

Table 16. Descriptive statistics of block mean survival (%) in mixed plots in decreasing order.

Block	Mean Survival (%)	Std. Deviation	Std. Error of Mean	Minimum Survival (%)	Maximum Survival (%)
5	100.00	0.000	0.000	100	100
9	100.00	0.000	0.000	100	100
2	80.00	25.820	8.165	50	100
3	75.00	35.355	11.180	0	100
6	70.00	48.305	15.275	0	100
4	65.00	41.164	13.017	0	100
1	55.00	43.780	13.844	0	100
8	55.00	49.721	15.723	0	100
7	45.00	43.780	13.844	0	100
Total	71.67	39.697	4.184	0	100

DISCUSSION

The Sault Ste. Marie provenance trial was previously designed to observe the growth responses of black spruce populations predicted to be potentially adaptable for reforestation under future climate uncertainty (Nsiah 2014). The main objective of the present study is to determine if there are any significant differences between any of the seed sources in height and survival rate.

The results derived from the height data collected at the provenance trial demonstrate that mean height variability among the trees is attributable to seed source effect, block effect, and seed source x block interaction effect. An examination of the seed source effects on mean height within each block reveals variation between seed sources in blocks 1, 2, 3, and 4. The significant block effect could potentially be attributed to environmental variance among blocks, since blocks on the southeast end of the trial (blocks 1, 2 ,3 and 5) generally have greater mean heights compared with blocks on the northwest end of the trial (blocks 4, 6, 7, and 9). While no obvious differences in terrain, species competition or soil between blocks are noted, the southern blocks are surrounded by stands of mature trees while the northern blocks are not and are therefor potentially exposed to environmental perturbations, such as cold temperatures.

A study that previously measured and analyzed height and survival at the Sault Ste. Marie portfolio test demonstrated that mean monthly temperatures were the best predictors for spring height and survival of the seed sources, and April and August precipitations, February maximum and August minimum temperatures combine as strong predictors for black spruce growth and survival at the Sault Ste Marie site (Nsiah 2014). A study of range-wide black spruce provenance trials in the northern Ontario/Lake States region found that temperature variables were generally stronger predictors of seed source height growth than precipitation variables (Thomson et al. 2009). More specifically, it was found that three spring-summer climate variables (May, June, and July mean minimum temperatures) and two winter variables (February mean minimum temperature and March mean maximum temperature) produced the strongest and most consistent relationships with height growth (Thomson et al. 2009).

As noted above, winter temperature variables, specifically, mean minimums and mean maximums, are important to growth and survival. Unseasonably warm days in late winter and early spring can result in loss of cold hardiness and can cause winter damage when seasonal temperatures return (Man et al. 2009; Man et al. 2013). Northern Ontario black spruce (*Picea mariana* (Mill.) B.S.P.), among other boreal species, were found to be vulnerable to freezing temperatures following quick loss of cold hardiness during spring dehardening in a controlled study (Man et al. 2017). Maximum cold hardiness of black spruce is below -40 °Celsius (Man et al. 2017). In the present study, the seedlings in the blocks at risk for cold exposure may have experienced either extreme cold (below -40 °C) or unseasonably warm temperatures resulting in winter damage therefor affecting height growth. This hypothesis can be verified by examining past climate data for the area.

Generally, seed sources from the south of the provenance trial, specifically Michigan, Espanola, and Wisconsin, have the greatest mean heights. Seed sources 8 (Michigan) and 9 (Wisconsin), both southerly sources, showed higher growth consistently between the present study and the previous (Nsiah 2014). This is consistent with the results of previous studies demonstrating that seed sources with higher growth rates originate from sample areas to the south of the target areas (Parker 1992; Parker et al. 1994; Thomson et al. 2009). The seed sources with below average mean heights originate from areas to the northwest of the provenance trial which is consistent with the previously mentioned studies.

The mixed plots had above-average height, but they were out-performed by the southern seed sources (Michigan, Espanola, and Wisconsin). This is because the mixed plots contain high proportions of poorer performing seed sources. To maximize the performance of the mixed plots the poor performers must be removed.

The local seed source (6), has a below-average mean height and is much lower than most other seed sources, aside from seed source 20 (Bemidji, MN) which is the most western seed source. This is consistent with the results of the previous study demonstrating that the local seed source did not show the best height growth (Nsiah 2014). The assumption is that local seed sources are best suited to reforestation programs as they have the necessary adaptive traits for the region (Rehfeldt 1983; Mullin and Bertrand 1999). This assumption appears to be inconsistent with the results of the present study as most of the other seed sources are performing better, in terms of height growth, compared to the local seed source. Though seed source 6 has the lowest mean height relative to the other seed sources, it has a greater-than-average survival rate which is a consistent result between the present and previous study (Nsiah 2014). The poorer performance of the local seed sources versus southern seed sources may be explained by the phenomenon of adaptive lag which occurs when the migration rate of a species is too slow to keep up with geographic climate change (Thomson et al. 2009). If this was the case than the optimal range of the Algoma Forest seed source is already shifting.

Though there are no significant differences between any of the seed sources in survival rate, seed sources from south of the provenance trial (Michigan and Wisconsin) had the highest survival rate of all seed sources. Also, there is a significant difference between block survival rates in the mixed random plot variation. This is most likely due to the very small sample size within the mixed random plot variation.

CONCLUSION

Seed source as well as block appear to affect the tree heights in the Sault Ste. Marie portfolio trial. Seed sources that originate from areas to the south west of the trial appear to perform well compared with northerly seed sources and the local seed source. The results of the present study provide a snap shot in time of how the seed sources in the provenance trial are progressing. Continued monitoring under a changing climate and of a wider array of variables can assist with making predictions of which seed sources may perform well in future climate change reforestation initiatives.

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