Assisted Migration in the Sub-Boreal Spruce Zone

A Forest Research Establishment Note (Draft)

Scope And Objectives

In British Columbia, policy regarding tree seed transfer and stocking standards has been rapidly evolving in response to a need to develop climate change mitigation strategies such as assisted migration. The Chief Forester's Consolidated Standards for Seed Use (effective August 6, 2018)[1] and guidelines on Climate Based Seed Transfer (CBST) Areas of Use (April 10th, 2019)[2] provide the framework for operational use of non-indigenous seed sources, generally limiting their use to about 10% of total planted stock. Many forest managers are already planting non-indigenous Douglas-fir (*Pseudotsuga menziesii*) and western larch (*Larix occidentalis*) in accordance with these new policies.

While the Chief Forester's guidance on climate adaptation enables operational trials of non-indigenous planting stock, formal researched regarding expected survival and growth is limited. In 2018, the Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (FLNRORD) initiated a climate adaptation trial in, or close to, the Sub-Boreal Spruce (SBS), moist cold (mc2) biogeoclimatic variant near Burns Lake, B.C., with western larch, Douglas-fir, lodgepole pine - *Pinus contorta*, hybrid white spruce - *Picea glauca x engelmannii*, and western red cedar – *Thuja plicata*. Neither western larch nor western red cedar are indigenous to the area, and Douglas-fir (*Pseudotsuga menziesii*) is relatively rare. The project directly addresses the paucity of information on the survival and growth of non-indigenous seed sources, that might be better adapted to future climate conditions. It is expected that results from this trial will help inform climate mitigation strategies and support government standards on assisted migration. This research note describes the study design, trial establishment, and survival results after one growing season.

Study Design

Overview

The project is part of a broader initiative to build knowledge and capacity for climate-informed tree species adaptation and is being implemented jointly by FLNRORD's Harvesting and Silviculture Practices Branch, Forests for Tomorrow (FFT), and Tree Improvement Branch. It supplements a larger, long-term climate change research study known as the Assisted Migration Adaptation Trial being undertaken in B.C and neighboring states in the U.S.[3] It is expected that lessons learned in this first phase of the project in the sub-boreal spruce zone, will be used to guide the establishment of similar trials in other parts of the province.

In this study, three different seed sources for each of five species, were selected from across their natural range in B.C. The climate-based tree species selection tool and *CBST Areas of Use* maps[4] were used in conjunction with the Province's Results database to identify suitable seedlots and recently logged areas that might be used in the trial. Seven sites were chosen and 10 blocks, each with 15 plots, were demarcated, staked, and planted in the spring/summer of 2019 (Table 1). In each plot, 36 trees of a single species and seedlot were planted. An additional area of approximately 4 ha was planted around each block using a random mix of roughly equal amounts of each species and seedlot. In total approximately 118,000 trees were planted. Prior to planting, excessive slash at two sites (FID0 and FID2) was removed and piled outside the trial boundaries using an excavator equipped with a brush blade. Two other blocks (FID11 and FID15) were previously disc trenched. Climate stations were installed at six sites, and soil temperature sensors were established at three sites. In the fall of 2019, survival surveys were completed after one growing season, and climate and temperature data were downloaded at that time.

Trial Locations

The study is a randomized, replicated trial, confined to the SBSmc2 biogeoclimatic unit[5] in the Nadina and Skeena Stikine Districts (figure 1). Potentially eligible cutblocks from within the SBSmc2 were identified in 2017 and their suitability field checked in 2018 using a combination of field reconnaissance and UAV (unmanned aerial vehicle) imagery. Sites FID6, 7, 11, and 15 are transitional to SBSdk and FID2 is transitional to the ESSFmc. Selected sites were recently logged, sufficiently large to accommodate the trial, circum mesic, unplanted, not prone to growing season frost (except FID11), and easily accessible. From within the seven sites, six mesic blocks were selected as well as a frost block (FID11), a wetter block (SBSmc2/05-06), a drier block (SBSmc2/02-03,) and a demo block that is not formally part of the trial (Table 1). FFT staff ensured that there was a mechanism to relieve licensees of their reforestation obligations on these sites and submitted a sowing request in time to have the seedlings grown and ready for planting in the spring of 2019.

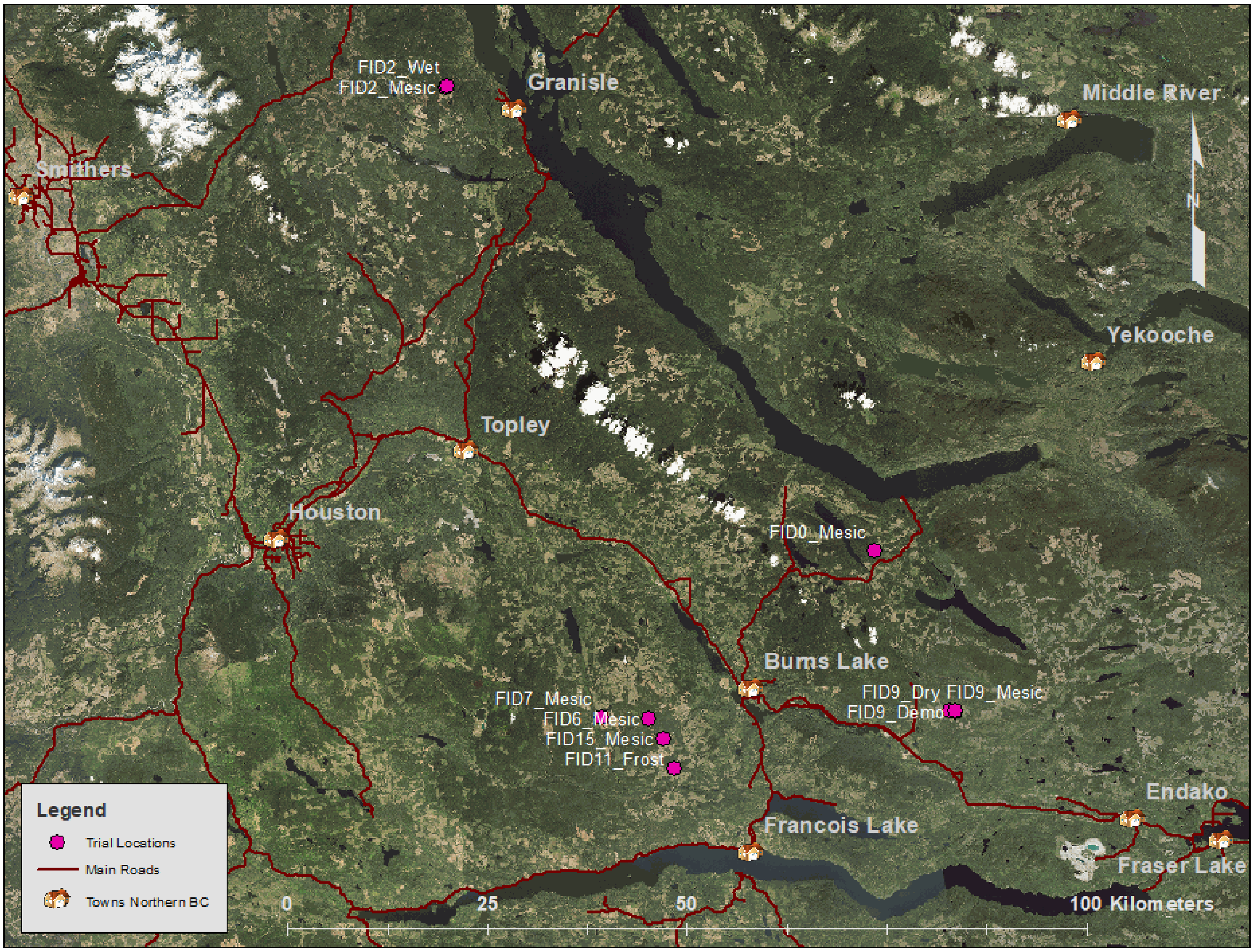

Figure 1. Names and locations of trial sites.

Table 1. Sites selected and tasks completed for the climate adaptation species trial (FID0 – Augier/Pinkut, FID2- Granisle Connector, FID 6 – Maxan, FID 7 – Colleymount, FID 9 – Hannay, FID 11 and 15 – Maxan).

Tasks Performed (Yes - Y or No - N)	FID0	FID2	FID6	FID7	FID9	FID11	FID15
Site Selected	y	y	y	y	y	y	y
Dry, Mesic, Wet, Demo, Frost (D, M, W, De, F)	M	M, W	M	M	D, M, De	F	M
FLNRO Inspection	y	y	y	y	y	y	y
UAV Image Acquisition	y	y	y	y	y	y	y
Orthomosaic Created	y	y	y	y	y	y	y
Digital Elevation Model Created	y	y	y	y	y	y	y
Hillshade Created	y	y	y	y	y	y	y
Contours Created	y	y	y	y	y	y	y
Trial Boundary Created	y	y	y	y	y	y	N
Replication Boundary Created	N	N	N	N	Y	N	N
Layout Completed	Y	y	Y	Y	Y	Y	Y
Site Preparation Completed	Y	y	n/a	n/a	n/a	Previous	Previous
Climate Station Installed	Y	Y	Y	Y	Y	Y	N
Planting Completed	y	y	y	y	y	y	y
Survival Surveys Completed	y	y	y	y	y	y	y

The frost block was added to the trial to obtain a preliminary indication of the degree to which these species and seedlots are frost hardy. It was selected based on topography, a mature tree barrier at the base of the hill, and existing frost-resistant plants on site.

UAV Imagery And Analysis

At each of the seven sites described above, UAV imagery was acquired in the summer of 2018 of the selected locations using a DJI Matrice 600 hexacopter equipped with a Sony A7R 36 megapixel RGB camera. Post processing of this imagery was completed with Agisoft Phtotoscan software and ArcGIS to produce three principal products for each site: a georeferenced ortho-mosaic (at a resolution of one or two cm per pixel), a terrain model (hillshade), and contours (0.5 to 1.0 m contour interval). Examples for each product are shown in figures 2 to 5.

The UAV imagery was valuable in helping determine the best location for a trial because the associated terrain model helped identify areas of potential cold air ponding; and the orthomosaics helped reveal slash loading and distribution, and brush cover and distribution which allowed for more accurate selection of an appropriate trial site. This imagery will also be a permanent visual record of the trial areas and will help in understanding and communicating results in the future (figure 2).

Figure 2. Photographic detail in a clip of the orthomosaic for FID9 blown up to a scale of 1:50.

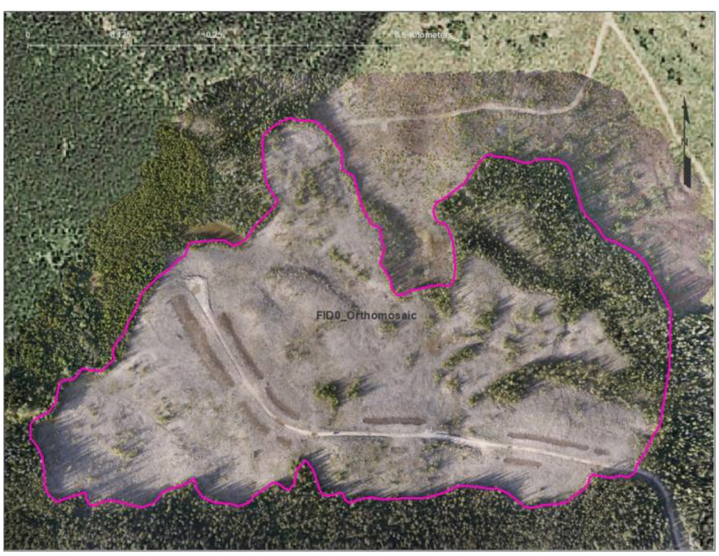

Figure 3. A georeferenced ortho-mosaic for FID0 near Pinkut Creek in the Nadina District.

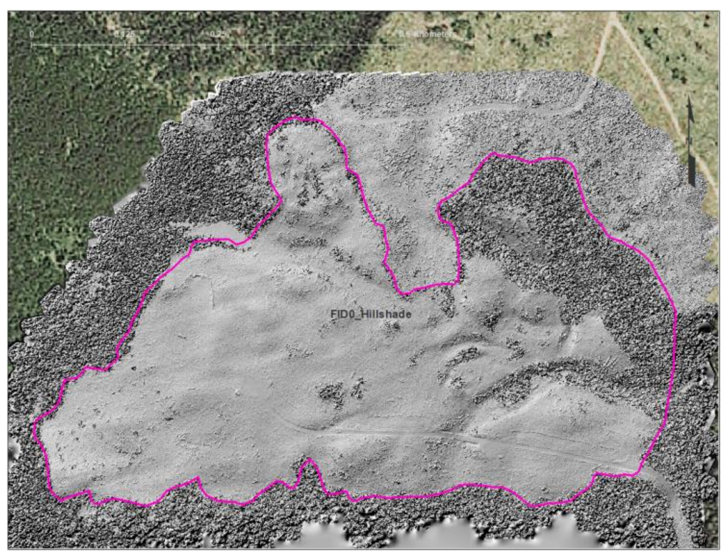

Figure 4. A georeferenced terrain model represented as a hillshade for FID0 near Pinkut Creek in the Nadina District.

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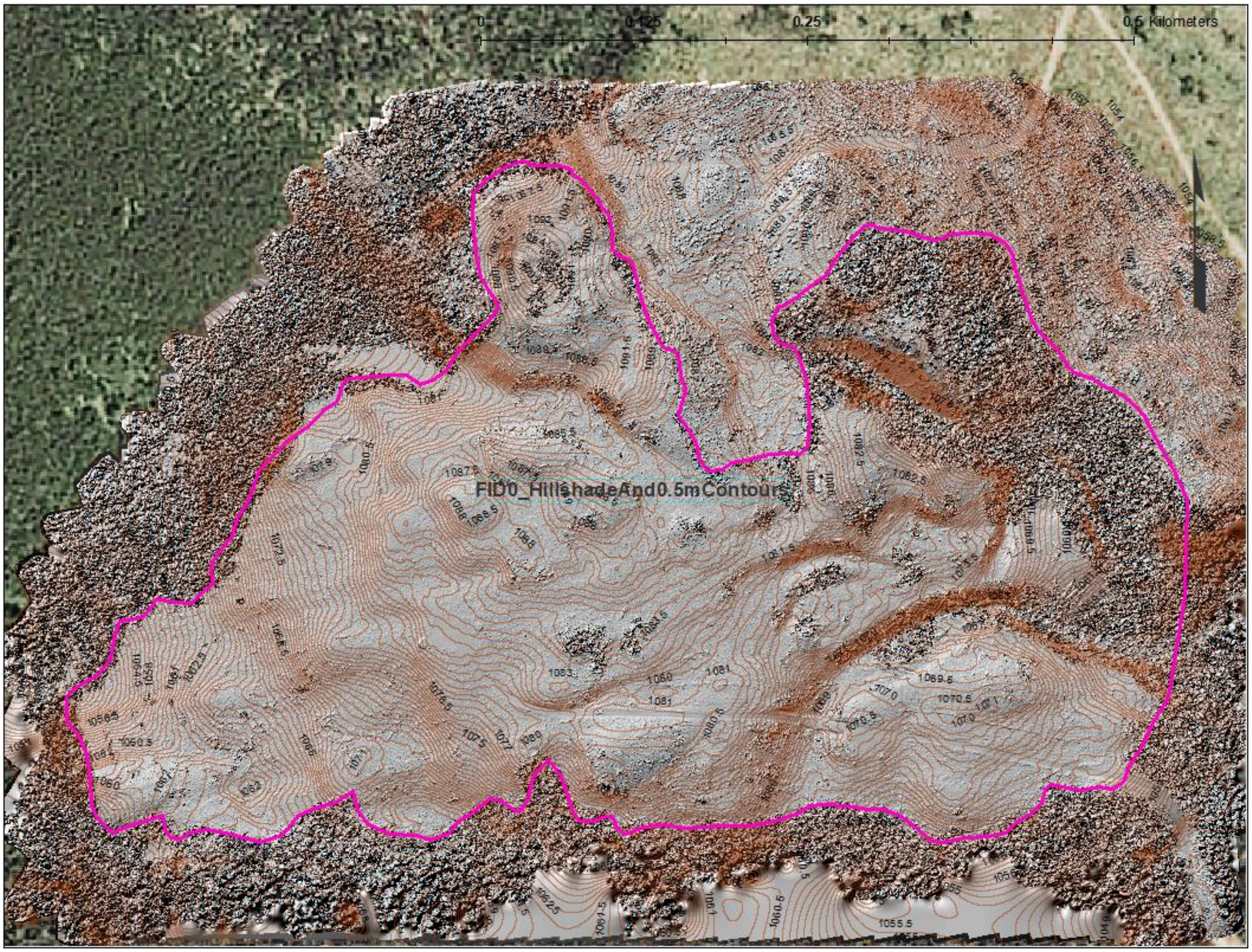

Figure 5. Contours (0.5m contour interval) overlain on a hillshade for FID0 near Pinkut Creek in the Nadina District.

Climate Stations And Temperature Sensors
Solar powered climate stations were erected in the spring and summer of 2019 on six of the trial sites at the locations shown in figure 6 (FIDs 0, 2, 6, 7, 9 and 11). Each station was equipped with a solar panel, a HOBO U30 Station data logger[6], and smart sensors that plug into the data logger including an anemometer, wind vane, rain gauge, and air temperature sensor (figure 7). During construction instrumentation was oriented in the same direction and at the same height at every site in accordance with recommendations made by Vanessa Foord (FLRNORD climatologist). Once construction was finished, the data logger was enabled and data were recorded continuously at the following intervals: ???? Will to provide Data logging start dates varied from site to site beginning in June and ending ?? Hardy. On Oct. 31st, 2019 once all survey work had been completed, data was downloaded to a data shuttle and the instrumentation was put into hibernation mode. An exception was at the Granisle site where the data logger was never enabled because a wire on the solar panel plug was severed. Additionally, an expansion board was missing for the wind direction sensor.

LogTag® TRIX-8[7] temperature loggers were also deployed (figure 8, see also https://logtagrecorders.com/products/lti-hid/) at three of the sites (FIDs 6, 7, and 11) to obtain air temperature at 10 cm above the ground surface (figures 9 to 11). These devices feature high resolution temperature readings, for a temperature range of -40°C to +85°C, with an 8000 reading memory and up to 3 years of battery life. A total of 13 LogTags were set out on wire pigtails to keep them at the correct height. Data from these devices were download using a LTI-HID Desktop USB Interface Cradle on Nov. 1st , 2019[8].

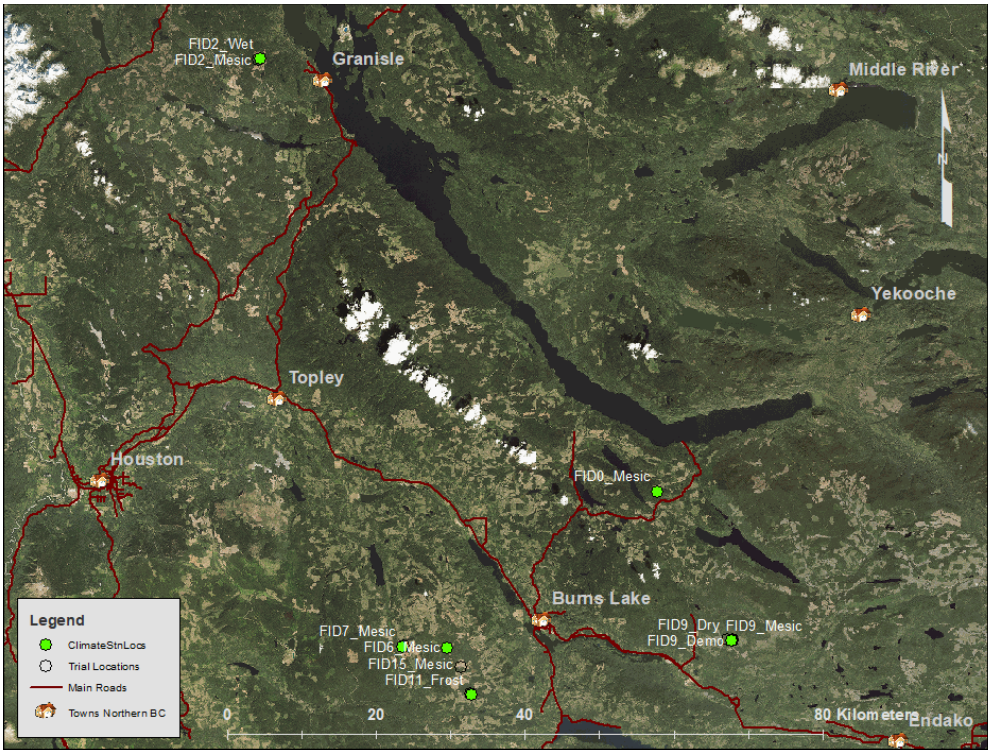

Figure 6. Climate station locations.

Figure 7. Climate station construction.

Figure 8. Temperature sensor.

Figure 9. Locations of LogTag temperature sensors in FID7.

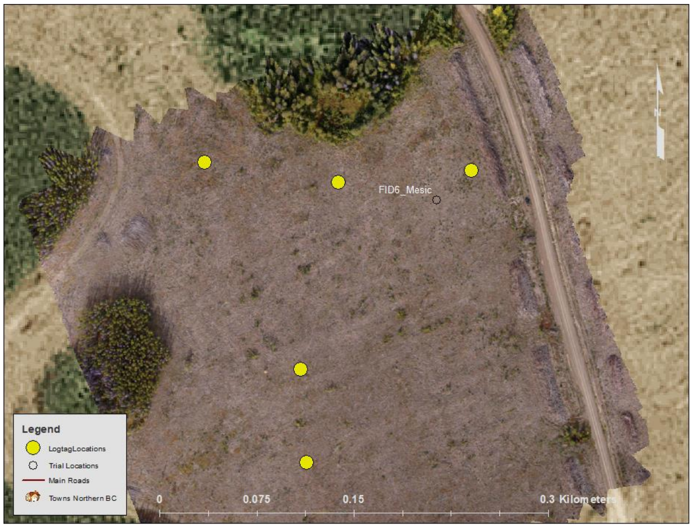

Figure 10. Location of LogTag sensors in FID6

Figure 11. Locations of LogTag sensors in FID11.

Trial Block Design

The design of each of the 10 blocks established on the seven different sites is shown in figure 12. Except at the frost site, each block measures 72m x 36m and contains a group of 15 plots, each with 36 trees spaced 2m apart, in an area measuring approximately 10m by 10m. Each plot represents a unique combination of species and seedlot (e.g. Sx 39619). At each site, one to three blocks were established as shown in table 1. Each block is relatively uniform in terms of site series and ecological potential. At the frost prone site, the block is longer (~258m x 28m) and each of the 15 combinations of tree species and seedlot was planted in a single line so that each species/seedlot combination extends along the frost gradient from the top of the slope to the bottom where cold air ponding is most likely (figure 13). Espacement between lines and trees is 2m thus requiring ~ 130 trees to be planted along each line.

Figure 12. Block and plot design at each trial site.

Figure 13. Block design at the frost prone site (FID11).

Which species and seedlot were assigned to which plots was randomly generated for each Trial Block (see figure 14 and table 2) using the statistical software R. Since the demonstration Block (FID9_Demo) was not intended to be a formal part of the trial, this block was not randomized and instead designed so that each of the 3 seed sources were grouped together in the same row (figure 15). This was done to provide a better visual reference on survival and growth for each seed source.

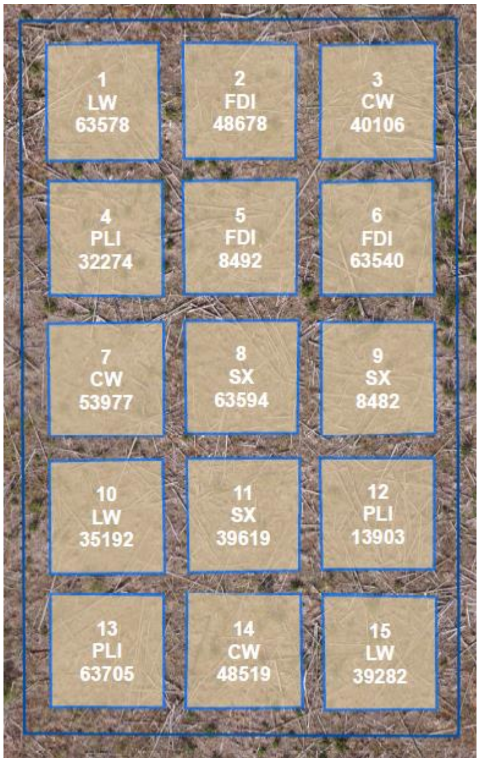

Figure 14. Random species/seedlot allocations for FID6 plots.

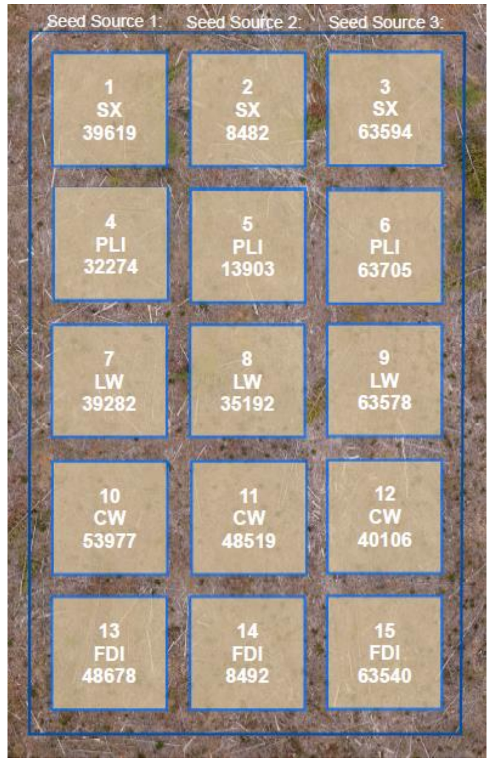

Figure 15. Species/seedlot allocations for FID9_Demo.

Table 2. An example of the randomized species and seedlot assignments, in the FID0 and the FID15 blocks.

Site	ID	Area	Block	Plot	Species	Seedlot	SeedSource	SeedSourceBGC	SeedClass
FID0	1001	Augier/Pinkut	Mesic	1	PLI	63705	3	SBSmw	A
FID0	1002	Augier/Pinkut	Mesic	2	LW	39282	1	MSdm1	B
FID0	1003	Augier/Pinkut	Mesic	3	PLI	32274	1	SBSmc2	B
FID0	1004	Augier/Pinkut	Mesic	4	SX	8482	2	SBSdw1	B
FID0	1005	Augier/Pinkut	Mesic	5	FDI	63540	3	SBSdh1	B
FID0	1006	Augier/Pinkut	Mesic	6	FDI	48678	1	SBSdw3	B
FID0	1007	Augier/Pinkut	Mesic	7	LW	63578	3	ICHmk1	A
FID0	1008	Augier/Pinkut	Mesic	8	LW	35192	2	ICHmw5	B
FID0	1009	Augier/Pinkut	Mesic	9	CW	40106	3	ICHmk2	A
FID0	1010	Augier/Pinkut	Mesic	10	PLI	13903	2	ICHmc2	B
FID0	1011	Augier/Pinkut	Mesic	11	FDI	8492	2	ICHmk3	B
FID0	1012	Augier/Pinkut	Mesic	12	CW	48519	2	ICHmm	B
FID0	1013	Augier/Pinkut	Mesic	13	SX	39619	1	SBSmc2	B
FID0	1014	Augier/Pinkut	Mesic	14	SX	63594	3	SBSdk	A
FID0	1015	Augier/Pinkut	Mesic	15	CW	53977	1	ICHmc2	B
FID15	1016	Maxan	Mesic	1	CW	53977	1	ICHmc2	B
FID15	1017	Maxan	Mesic	2	SX	8482	2	SBSdw1	B
FID15	1018	Maxan	Mesic	3	LW	39282	1	MSdm1	B
FID15	1019	Maxan	Mesic	4	LW	63578	3	ICHmk1	A
FID15	1020	Maxan	Mesic	5	SX	39619	1	SBSmc2	B
FID15	1021	Maxan	Mesic	6	CW	40106	3	ICHmk2	A
FID15	1022	Maxan	Mesic	7	SX	63594	3	SBSdk	A
FID15	1023	Maxan	Mesic	8	FDI	8492	2	ICHmk3	B
FID15	1024	Maxan	Mesic	9	CW	48519	2	ICHmm	B
FID15	1025	Maxan	Mesic	10	PLI	32274	1	SBSmc2	B
FID15	1026	Maxan	Mesic	11	PLI	63705	3	SBSmw	A
FID15	1027	Maxan	Mesic	12	FDI	63540	3	SBSdh1	B
FID15	1028	Maxan	Mesic	13	PLI	13903	2	ICHmc2	B
FID15	1029	Maxan	Mesic	14	LW	35192	2	ICHmw5	B

Maps depicting the seedlot and species combination for each block were produced and provided to the planting crew to help ensure that seedlings were planted in the correct locations.

At the frost site, each species/seedlot combination was planted as a continuous line rather than in a square plot (figure 15). As was the case with the FID9_Demo site, this approach was chosen to provide a better visual reference on survival and growth for each seed source.

Figure 15. Line layout and seedlots at the frost site (FID11).

Operational Block Design

Four additional blocks, each approximately one hectare in size, were established in association with each Trial Block and planted on an operational basis. One of them was a climate-based seed transfer (CBST) block in which each seedlot was planted in lines rather than square plots (similar to the frost site) but there were two lines for each of the 15 seedlots (figure 16). To assist planters, alternating blue and pink ribbon was used to mark the beginning, middle, and end of each line. The order in which the seedlots were established was always the same starting from left to right.

Figure 16. Seedlot configuration for the CBST blocks.

In each of the other three Operational Blocks all five species were planted on a mixed-bag basis, but only one provenance per species was used in each block. In Operational Block 1 a seed source geographically closest to the planting site was used for all five species, in Operational Block 2, the second closest seed source was used, and in Block 3, the furthest seed source was used. Figure 17 is an example of how the various blocks were arranged.

Figure 17. Overview of a trial site showing the trial block (blue rectangle), operational blocks one to three (green outline), and the CBST block (green outline with pink and blue dots).

Blocks 1, 2, and 3 were approximately 100m x 100m in size but site characteristics and operational practicalities required different configurations to be used at different locations so they were not always square. The CBST block was normally 60m wide x 159m long (30m wide replicated twice for 30 lines of 79 trees) but in FID15, a 90m x 106m configuration was used (30m wide replicated 3 times for 45 lines of 53 trees). On average, 2500 trees/ha were planted at 2m inter-tree spacing in all four Operational Blocks.

Layout And Staking

Locations of both the Trial Block and Operational Block boundaries were identified on high resolution UAV imagery prior to layout. Georeferenced pdf maps of the sites were produced from the imagery and provided to layout crews. Boundaries were all flagged with winter grade ribbon in the spring of 2019, prior to planting, but no permanent marking was established. The CBST portion of the Operational Blocks also had 0.75m or 1.0m tall metal pigtails established at the beginning, middle, and end of each line with alternating pink and blue ribbon tied to them, and the seedlot allocation for that line written on the ribbon. The 72m x 36m Trial Blocks were more permanently demarcated as follows:

- Angled, aluminum metal stakes two metres in length were pounded into each corner of each Trial Block and then flagged with orange ribbon. It is expected that these stakes will persist for at least five years.
- Smaller half inch diameter aluminium tubes, 1.2m in length, were also pounded into the northwest corner of each of the 15 plots in each Trial Block.
- At all spots where individual trees were to be planted, a two to three inch diameter dot was

sprayed painted onto the ground using tree marking paint in every plot, in all the Trial Blocks in the study. Paint colour alternated between plots to remind planters that a new seedlot was required at in that plot. Spray painting was done to ensure that planters did not vary substantially from the desired intertree spacing.

Site Preparation
The sites at Granisle (FID2_Mesic and Wet) and Pinkut (FID0) had heavy and moderately heavy slash loads respectively. To help ensure that more precise planting espacement could be achieved in the Trial Block section of the sites, the treatment area boundary was ribboned and a site preparation contractor was engaged to pile the slash off-site using an excavator fitted with a rake and thumb (figure 18). The piles created for both these sites were to be burned as well, however, this was not completed.

Figure 18. Site preparation at the Granisle site (FID2).

Two other sites (FID11 and FID15) had also been previously operationally disc trenched by licensees managing the area. Disc trenching was relatively light with shallow trenches and very small, or no, berms (figure 19). It was expected that the slash at all other sites could be moved aside by planters without any requirement for site preparation.

Figure19. Disc trenching (FID15) at a scale of 1:100.

Planting

Planting Specifications
Seedlings for planting (1+0 PSB 412's) were grown at a variety of nurseries (Arbutus, IFS, Landing, and MTIDA) in 2018 and were ready for delivery and planting in the spring of 2019. An experienced planting contractor, Whanau Forestry Ltd., was engaged to undertake the planting. On the Operational Blocks they were paid on a piece rate basis but on the Trial Blocks and CBST Blocks, they were paid an hourly rate because productivity was difficult to predict. In addition to appropriate transport, thawing, and storage, key contract specifications for the Operational Blocks were as follows:

- Plant designated seedlots for all five species as an intimate admixture.
- Target espacement of two metres.
- Plant trees in the best possible spot with respect to survival and growth with an espacement tolerance of 30 cm in any direction. At the Granisle site, a 50 cm tolerance was used because of heavy slash.
- No planting in unfavourable substrates.
- Plant trees greater than 1m from acceptable existing natural conifers.
- Scalping and screefing not required.
- Plant trees as received with no further root or top pruning or culling.
- At the planting spot, ensure root exposure to drying is minimal and fill in and compact soil around the roots so that air pockets are prevented.
- No planting within three metre of slash piles that have not been burned.
- Record keeping, inspections, and reporting all required.
- Standard performance penalties for unacceptable planting[9].

Standards for the Trial Blocks were the same except that seedling were to be planted at spray painted spots and existing naturals were treated as ghost trees (not respected).

Seedlings Planted

A total of 117,639 trees were planted in this study. Table 3 summarizes the number of seedlings delivered from the nurseries and planted for each combination of species and seedlot. The original intent was to have all species/seedlot combinations equally represented in the Operational Blocks, CBST lines, and the Trial Blocks. According to the records maintained by the planting contractor, however, the number of seedlings delivered from the nurseries was more than expected and contained unequal amounts of each seedlot/species combination. To compensate for this, it was necessary for the planting contractor to use the operational blocks as overflow areas, planting them with different amounts of each species/seedlot (as much as 30% different). Based on field inspections, the numbers of seedlings for each species/seedlot on the CBST lines and frost lines were also different by as much as 5%. The number of seedlings planted for each species/seedlot combination in the Trial Blocks were identical, however, because planting locations for every tree were demarcated.

Table 3. Number of planted seedling for each species/seedlot combination.

	Nearest		Further		Furthest		
Species	***Seedlot***	***No. Trees***	***Seedlot***	***No. Trees***	***Seedlot***	***No. Trees***	***Total***
Sx	*39619*	**6600**	*8482*	**7590**	*63594*	**8250**	**22440**
Pli	*32274*	**8064**	*13903*	**8820**	*63705*	**7530**	**24414**
Lw	*39282*	**5670**	*35192*	**8820**	*63578*	**9450**	**23940**
Fdi	*48678*	**5040**	*8492*	**5355**	*64540*	**8100**	**18495**
Cw	*53977*	**9450**	*48519*	**9450**	*40106*	**9450**	**28350**
Total Trees		**34824**		**40035**		**42780**	**117639**

Or this one?

	Nearest		Further		Furthest		
Species	***Seedlot***	***No. Trees***	***Seedlot***	***No. Trees***	***Seedlot***	***No. Trees***	***Total***
Sx	*39619*	**6600**	*8482*	**7590**	*63594*	**8250**	**22440**
Pli	*32274*	**8064**	*13903*	**8820**	*63705*	**7530**	**24414**
Lw	*39282*	**5670**	*35192*	**8820**	*63578*	**9450**	**23940**
Fdi	*48678*	**5040**	*8492*	**5355**	*64540*	**8100**	**18495**
Cw	*53977*	**9450**	*48519*	**9450**	*40106*	**9450**	**28350**
Total Trees		**34824**		**40035**		**42780**	**117639**

Post planting inspections revealed that espacement on the CBST and frost lines was not always perfect deviating by as much as 1.25 m from the target of 2.0 m, although such large variations were relatively rare. This likely accounts, in part, for the different numbers of seedlings being planted for various species/seedlot combinations on the Frost Block and CBST lines.

Post-Planting Measurements And Analysis

Weather Data

To date, neither the climate station data for the five stations that are operational, nor the data from the 13 ground-level temperature sensors, have been assessed. Based on field observations, however, June and July were relatively cool and moist in the area in 2019, reducing the probability of growing season frost and drought, and providing conditions that were relatively favourable for seedling survival. Maybe Vanessa or Will have some data they can share to make this less anecodotal?

Seedling Survival After One Growing Season

In late September, 2019, before the western larch had turned colour, a simple survival survey was completed on all nine Trial Blocks and the Frost Block. Block Number, Plot number, Species, Seedlot and Seedling Condition (Good, Fair, Poor, Moribund, Dead, or Missing) were recorded for every planted seedling. Figure 19 is an example of how each of the species looked when seedling condition was considered to be Good (with some variation between seedlots).

Lodgepole Pine Hybrid Spruce Douglas-Fir Western Red Cedar Western Larch

Figure 19. Examples of planted seedlings in good condition in late September, 2019.

In the Trial Blocks, there were 15 plots oriented as shown in the example in figure 20. There were two exceptions to this orientation – FID2 Mesic and Wet at Granisle. At these two sites, the Block axes ran NE–SW as opposed to N–S. Tree assessments in each plot were completed in the same sequence every time beginning with the tree in the northwestern corner as shown in figure 21. At the Granisle Blocks, the sequence started at the west end of the plot. This approach was used because individual trees were not tagged and this protocol will allow tracking of individual trees in the future.

Figure 20. Plot configuration for FID9_Mesic.

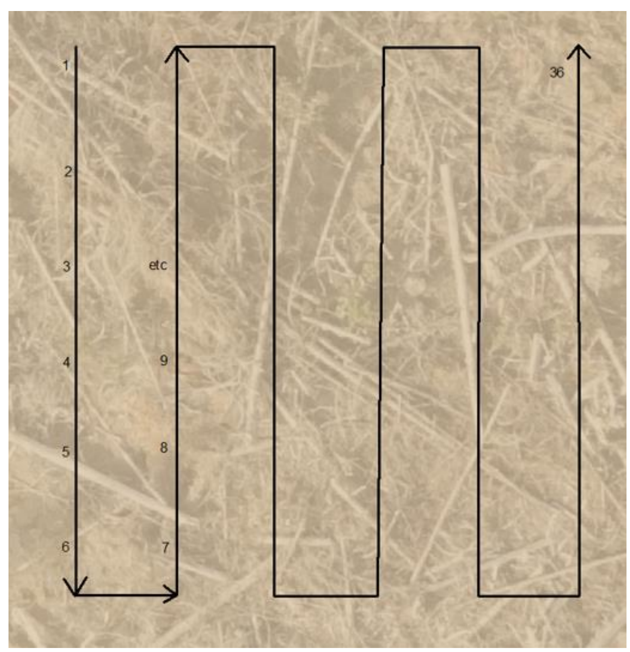

Figure 21. Tree number protocol in each plot.

Heat maps were produced for each Trial Block and the Frost Block to provide a visual representation of survival (figures 22 and 24 are examples). In these examples, the seedlot assignment is shown in figures 23 and 25. Seedlot assignment was randomized, so each unique species/seedlot combination was located in a different plot in each of the Trial Blocks.

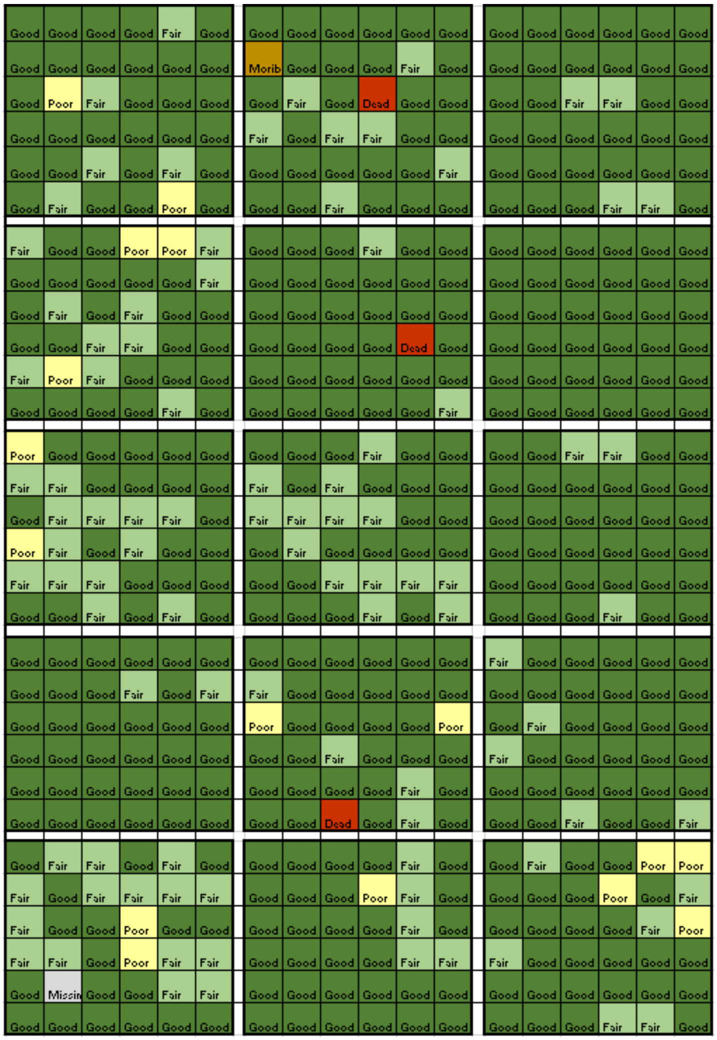

Figure 22. Heat map depicting individual tree condition in FID 7.

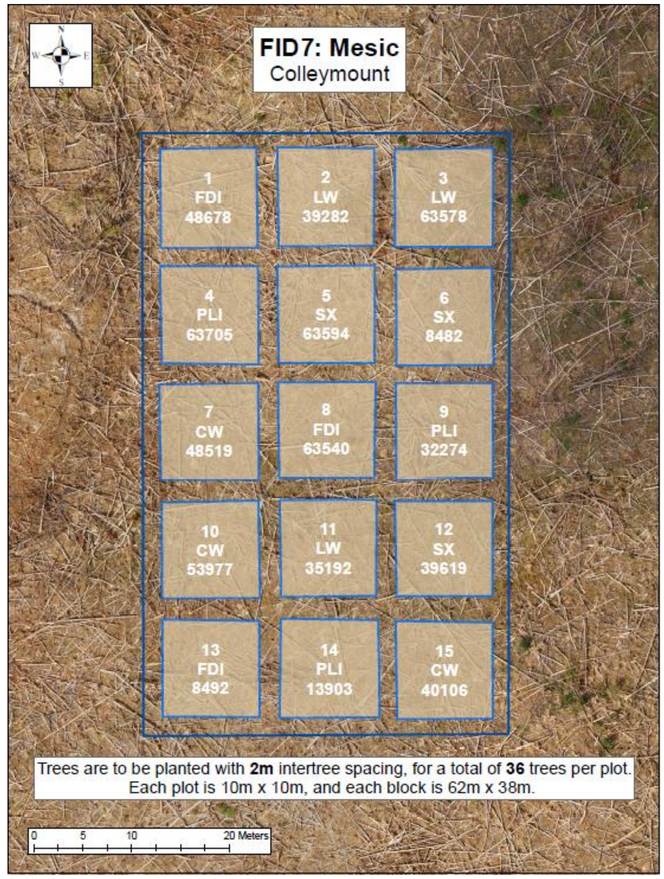

Figure 23. Species and seedlot information for plots at FID7.

In the example in figure 22, overall survival (the proportion of trees that were in good, fair, or poor condition) was excellent at 99%. Only five of the 540 trees that were planted were dead, missing or moribund. Nearly 80% of trees were in good condition, and survival exceeded 96% for all species and seedlots except Lw39282 (with had 94% survival). When trees that were in poor condition were excluded from the survival calculation, the seedlot with the most poor, moribund, dead, or missing trees was Cw 40106 with only 89% survival. Other lower performers were Pli 63705, Lw 35192, and Fdi 8492. In each of these seedlots eight percent of trees were categorized as poor, moribund, dead, or missing (i.e. 92% survival when seedlings in poor condition were not included).

At the FID0 Trial Block (figure 24), overall survival was at 94% including seedlings in poor condition, slightly worse than at FID7. When seedlings in poor condition were not included, survival at FID0 was 82%. Survival of individual seedlots varied from 78 to 100%, including poor seedlings, but when poor seedlings were excluded from the calculation, survival varied from 64% to 100%. The four worst performers when seedlings in poor condition were not included were Sx63594 (50%), Fdi8492 (64%), Fdi63540 (67%), and Lw39282 (69%). None of these poorly performing seedlots came from areas that are in close geographic proximity to the study sites.

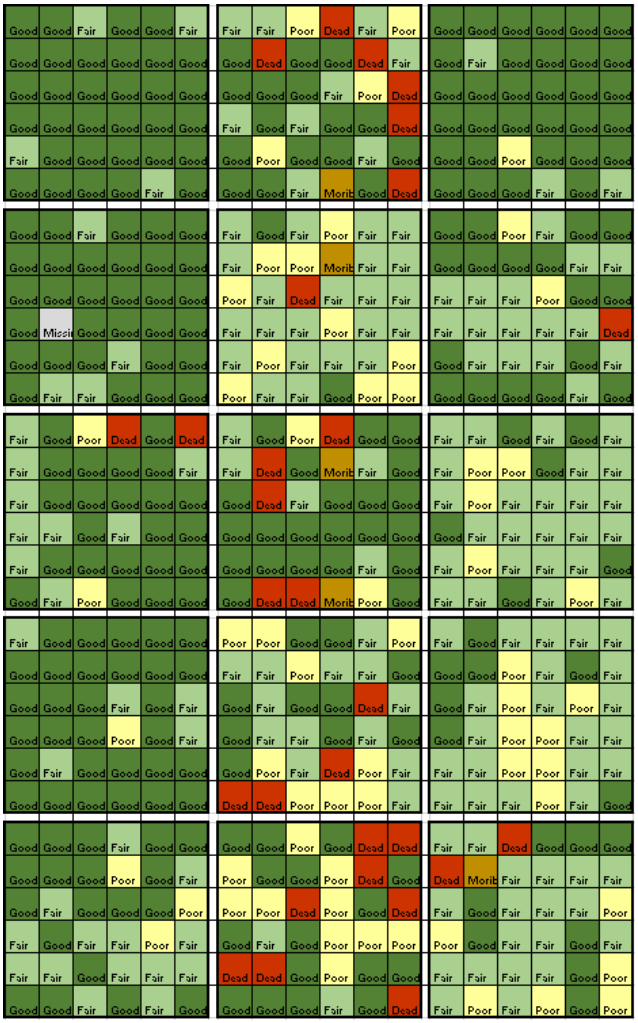

Figure 24. Heat map depicting individual tree condition, FID 7.

Figure 25. Species and seedlot information corresponding to the plots at FID0.

A more comprehensive summary of all survival data for the Trial Blocks and the Frost Block is presented in Table 4. Mean survival for each seedlot in the Trial Blocks is based on 324 trees - one plot of 36 trees in each of nine Blocks. In table 4, the terms closest, further, and furthest refer to the distance a seed source is from the planting site and are used as a very rough approximation of the degree of adaptation required of a particular seed source. Close does not mean the same thing for one species as for another, however, since the lodgepole pine and hybrid white spruce seedlots described as close, for example, are sources from within the local seed transfer zone, whereas the western larch seedlot described as close is from the southern end of the province. Statistics for the Frost Block were separated from the other Blocks in table 4 because site selection was not consistent with the other sites and block design was quite different.

Table 4. Trial Block survival rates (the percent of trees in individual plots that were not moribund, dead, or missing) one growing season after planting.

Species Code Seedlot Relative Distance	Sx 39619 Closest	Sx 8482 Further	Sx 63594 Furthest	Pli 32274 Closest	Pli 13903 Further	Pli 63705 Furthest	Lw 39282 Closest	Lw 35192 Further	Lw 63578 Furthest	Fdi 48678 Closest	Fdi 8492 Further	Fdi 63540 Furthest	Cw 53977 Closest	Cw 48519 Further	Cw 40106 Furthest	Mean
FID0 Pinkut Mesic	100	97	78	100	100	100	81	81	94	97	89	94	92	100	100	94
FID2 Granisle Mesic	100	100	100	100	94	92	100	97	100	94	100	94	94	92	100	97
FID2 Granisle Wet	100	100	100	100	100	100	97	97	100	100	100	100	100	97	100	99
FID6 Maxan Mesic	100	100	100	100	100	100	97	100	100	100	100	100	100	100	100	100
FID7 Colleymont Mesic	100	100	97	100	100	100	94	97	100	100	97	100	100	100	100	99
FID9 Hannay Demo	100	100	100	100	100	100	86	89	100	100	100	100	97	100	100	98
FID9 Hannay Mesic	100	100	100	100	100	100	92	97	97	100	100	100	100	100	100	99
FID9 Hannay Dry	100	100	100	100	100	94	94	97	100	100	97	100	92	100	100	98
FID15 Maxan Mesic	100	100	100	100	100	100	97	89	94	97	100	100	100	100	100	99
Mean	**100**	**100**	**97**	**100**	**99**	**98**	**93**	**94**	**98**	**99**	**98**	**99**	**97**	**99**	**100**	**98**
FID11 Frost	100	100	100	99	100	97	61	43	74	95	96	95	85	89	93	88

For all Trial Blocks combined, excluding the Frost site, survival (including seedlings in poor condition) averaged 98 percent. Overall survival rates for individual seedlots varied from 93% to 100%. The best performers were not necessarily seedlots with an origin closer to the planting site or indigenous to the area. The survival rate for the western red cedar seedlot furthest from the planting site (40106), for example, was 100% as was a hybrid white spruce seedlot (39619) which is indigenous to the area. On average, survival of western larch seedlings (95%) was slightly lower than other species. Two hybrid spruce seedlots, one lodgepole pine seedlot, and one western red cedar seedlot had 100% survival. Survival at the Frost Block was considerably poorer, especially for western larch (59% on average) and western red cedar (89% on average).

Survival At The Frost Block

Although table 4 shows that average survival at the frost site was 88%, as opposed to 98% on the Trial Blocks, this simple statistic is misleading. As can be seen in Figure 26, the condition of surviving seedlings for some seedlots is much different in the Frost Block than in the Trial Blocks. Figure 26 reveals that, for some seedlots, there are a disproportionate number of seedlings in poor and moribund condition. Seedlot Fdi63540, for example, had 124 of 131 seedlings classified as poor, and seedlot Cw40106, had 105 of 133 trees classified as poor. If survival were calculated using only trees in good or fair condition, the **weighted** average for all seedlots combined would be 38%, much less than 88% when seedling that were in poor condition were included (table 5).

Sx 39619	Sx 8482	Sx 63594	Pli 32274	Pli 13903	Pli 63705	Lw 39282	Lw 35192	Lw 63578	Cw 53977	Cw 48519	Cw 40106	Fdi 48678	Fdi 8492	Fdi 63540
Good	Good	Good	Good	Good	Fair	Dead	Moribu	Poor	Fair	Fair	Poor	Poor	Poor	Poor
Good	Good	Good	Fair	Good	Fair	Poor	Poor	Dead	Fair	Fair	Poor	Poor	Poor	Poor
Fair	Fair	Good	Good	Good	Fair	Poor	Poor	Dead	Fair	Poor	Poor	Poor	Moribu	Poor
Fair	Good	Good	Fair	Good	Fair	Poor	Moribu	Poor	Poor	Poor	Poor	Fair	Poor	Poor
Good	Good	Good	Good	Good	Fair	Fair	Dead	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Good	Good	Fair	Good	Good	Poor	Fair	Moribu	Poor	Fair	Fair	Poor	Poor	Fair	Poor
Good	Good	Fair	Fair	Good	Good	Dead	Dead	Poor	Fair	Poor	Poor	Poor	Moribu	Poor
Good	Good	Good	Fair	Good	Good	Poor	Dead	Poor	Poor	Poor	Good	Poor	Poor	Poor
Good	Good	Good	Fair	Good	Poor	Poor	Moribu	Moribu	Poor	Poor	Fair	Poor	Poor	Poor
Good	Good	Good	Good	Good	Good	Poor	Moribu	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Good	Good	Good	Fair	Poor	Good	Moribu	Poor	Poor	Fair	Poor	Fair	Poor	Fair	Poor
Good	Good	Good	Good	Good	Fair	Poor	Poor	Moribu	Fair	Fair	Fair	Moribu	Poor	Poor
Good	Fair	Good	Good	Good	Good	Poor	Dead	Poor	Fair	Fair	Poor	Poor	Poor	Poor
Good	Good	Good	Good	Good	Fair	Moribu	Missir	Poor	Poor	Fair	Fair	Poor	Poor	Poor
Good	Good	Good	Good	Poor	Good	Poor	Fair	Moribu	Poor	Poor	Poor	Fair	Poor	Poor
Good	Good	Good	Fair	Poor	Fair	Moribu	Missir	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Good	Fair	Good	Fair	Fair	Poor	Moribu	Missir	Poor	Poor	Poor	Fair	Poor	Poor	Poor
Good	Fair	Good	Fair	Good	Poor	Moribu	Poor	Poor	Fair	Poor	Fair	Fair	Fair	Poor
Good	Fair	Good	Good	Good	Fair	Moribu	Missir	Poor	Poor	Poor	Fair	Poor	Poor	Poor
Good	Fair	Good	Fair	Fair	Fair	Dead	Moribu	Fair	Fair	Fair	Fair	Fair	Poor	Poor
Fair	Good	Fair	Fair	Fair	Good	Poor	Moribu	Fair	Fair	Fair	Poor	Poor	Poor	Poor
Fair	Good	Good	Good	Poor	Fair	Poor	Poor	Poor	Poor	Poor	Fair	Poor	Poor	Poor
Fair	Good	Good	Fair	Poor	Fair	Fair	Poor	Fair	Fair	Poor	Fair	Poor	Poor	Poor
Fair	Good	Good	Good	Good	Good	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Poor	Poor

Figure 26. Seedling survival heat map by seedlot for the 24 rows furthest upslope at the Frost Block.

Table 5. Number of trees by condition class and percent survival one growing season after planting on the Frost Block.

Species Code	Sx	Sx	Sx	Pli	Pli	Pli	Lw	Lw	Lw	Fdi	Fdi	Fdi	Cw	Cw	Cw	
Seedlot	39619	8482	63594	32274	13903	63705	39282	35192	63578	48678	8492	63540	53977	48519	40106	
Relative Distance	Closest	Further	Furthest	Closest	Further	Furthest	Closest	Further	Furthest	Closest	Further	Furthest	Closest	Further	Furthest	Mean
Good	75	68	79	32	44	29	1	1	1	0	0	0	0	0	1	331
Fair	38	41	40	55	33	33	17	11	19	6	11	1	27	12	18	362
Poor	9	18	9	18	26	45	60	43	76	85	90	124	84	103	105	895
Moribund	0	0	0	1	0	3	19	31	22	4	3	3	19	11	7	123
Dead	0	0	0	0	0	0	23	27	9	1	1	1	0	0	0	62
Missing	0	0	0	0	0	0	8	15	3	0	0	2	1	3	2	34
Totals	122	127	128	106	103	110	128	128	130	96	105	131	131	129	133	1807
Wtd % Survival G, F, P	100	100	100	99	100	97	61	43	74	95	96	95	85	89	93	88
Wtd Average G, F	93	86	93	82	75	56	14	9	15	6	10	1	21	9	14	38

It is too early to tell if the seedlings in poor condition will eventually succumb but it was clear, based on field assessments, that frost was the most likely cause for the poor condition of most seedlings on the Frost site (figure 27). A careful look at the Douglas-fir, western red cedar, and lodgepole pine seedling in the pictures in figure 27, however, reveals that, while the tops were often dead, some live limbs were still present after the growing season. Whether these seedlings would die was not always clear.

Surprisingly, survival statistics in table 5 indicate that hybrid white spruce was most resistant to frost at this site. Whether this was correlated with the species and seedlot alone, or some other factor, such as the physiological condition of the seedlings when they were shipped from the nursery, is unknown. Based on the number of seedlings in poor condition in Table 5, western larch, Douglas-fir, and western red cedar were all heavily influenced by frost.

Figure 27. Examples of frost damage on four species on the Frost Block.

Other Possible Analyses? ANOVA to evaluate the significance of survival means and any correlation with seedlot, site, or nursery? Maybe too early and no budget for this.

Other Survival Factors

Minor ungulate browsing on some western red cedar and Douglas-fir, and minor terminal bud damage caused by grouse, was observed on a few Trial Blocks, but to date, there has been no significant pest damage at any of the sites in this study. Brush, excessive soil moisture, and natural regeneration, however, are factors at some sites. FID2_Mesic, FID2_Wet, FID6_Mesic, FID9_Demo, and possibly FID9_Mesic are potential brush sites (example figure 28). If meaningful comparisons of seedlot survival and growth are to be made, brush competition at these sites will need to be addressed in the next two to three years to ensure it is not a confounding factor.

There were two sites where higher soil moisture levels were apparent – FID 2_Wet and FID9_Demo (example figure 29). At FID9_Demo, soil moisture in some patches was higher in the fall than what might be expected on a mesic site, however, this seemed to be seasonal. This Block is not a formal part of the study so there will be no impact on survival and growth statistics for the trial. FID2_Wet was chosen because of its moist soil conditions and, although it is a small sample, will provide some indication of the potential impacts of higher soil moisture on survival and growth relative to the larger sample of mesic sites in the other Trial Blocks. After one growing season, differences in survival at this site were not appreciable.

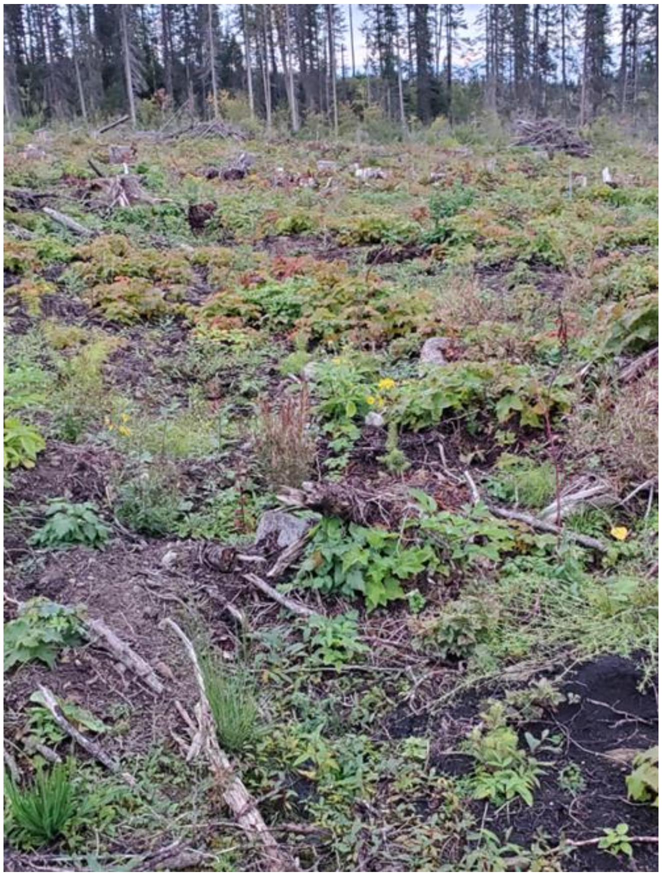
Figure 28. Brush development one growing season after site preparation on FID2_Wet.


Figure 29. Excessive moisture and puddling at FID2_Wet.

In Trial Blocks FID9_Dry, FID11_Frost, and FID6_Mesic there were also instances where existing conifer advance regeneration occurred. Natural stocking levels were not high at these sites but these trees will have a competitive influence on planted seedlings in some locations (example figure 30), and so should be removed in the future.


Figure 30. Advance regeneration and ingress one growing season after planting on FID9_Dry.

Next Steps

The positive initial survival results, and replicated, randomized nature of this trial, suggest that it is well placed to provide statistically significant, science-based data to support decisions on using selected non-indigenous seed sources to mitigate climate change impacts. There are several tasks that must be completed before this can be achieved however:

- The weather station at the Granisle site (FID2_Wet) should be repaired and data collection initiated in the spring before seedlings flush.
- Both the LogTag temperature sensors and working climate stations, which are in hibernation mode over the winter, will need to be restarted well before seedlings flush.
- Climate station data and temperature sensor data already collected, will need to be analysed to better characterize the environmental conditions that trees from non-indigenous seed sources can tolerate (or thrive in).

- Script for the statistical software environment *R*,[10] should be developed to extract, collate, and summarize pertinent climate station data so that this task can be automated as much as possible, and to facilitate future data extraction at these sites and any other trials across the province that rely on climate station data.
- Survival/brushing assessments should be completed at the end of the second or third growing season. Seedlings are most susceptible to mortality in the first few years making closer scrutiny more important during this period. Growing season conditions in 2019 were good but this may not be the case in subsequent years. Brush hazard is high on a few sites and earlier intervention, based on an assessment of brush competition, could be important.
- Tree tagging in the Trial Blocks (perhaps at every 5th tree) will make tracking the performance of individual trees over time easier when these sites are re-measured. If a survival survey were completed at the end of the second growing season, tagging could be done then in conjunction with the survey.
- It is likely that a brushing treatment will be required on some sites (notably FID0, FID2_Mesic and Wet, FID6, and FID9_Mesic and Demo) in the third growing season, where sitka alder, thimbleberry, aspen, and a variety of herbs and grasses are likely to compete with planted seedlings.

In addition to the more imperative tasks noted above, there will be on-going maintenance and some discretionary work that could be done. On-going maintenance will include:

- Collection of weather and ground temperature data for another two or three years.
- Survival and growth assessments.
- Moving or replacing tree tags.
- A possible second brush treatment at one or two sites.
- Data analysis and reporting.

Discretionary tasks might include:

- A Free Growing assessment in the Operational and CBST Blocks (mandatory if government holds the obligation to ensure that a free growing stand is established on these sites).
- Results database reporting.
- Brushing of the Operational and CBST Blocks as required.
- Removal of any competing natural conifer regeneration in the Trial Blocks in conjunction with brushing where appropriate.
- Acquisition and processing of UAV imagery concomitant with survival surveys. In addition to providing a visual reference of the Trial Blocks, the UAV imagery can be used to characterize individual tree allometry in a way that is more difficult or time consuming to do on the ground including tree height, crown diameter or area, crown closure, exact tree espacement, and high precision stocking estimates on both the Trial Blocks and Operational Blocks. Much of this processing can be automated.

In summary, early results indicate that the establishment of the assisted migration trail of lodgepole pine, hybrid white spruce, western larch, Douglas-fir, and western red cedar in the SBSmc2 biogeoclimatic unit has had a good start. Seedling survival in the Trial Blocks has been 98% to date but there are already clear indications that environmental parameters and site conditions will play important roles in future survival and growth. The potential for results from this trial to inform climate mitigation strategies and government policy on assisted migration in the future is high.

Data Storage

I don't think this section is necessary. All data will be posted to the dropbox link we used before, which, at the time was (64.2 Gb). Most of it will be the same but there are a few new shp files, spreadsheets, and documents. The original drone imagery and processing files are quite large (0.5 Tb) and have not been posted on dropbox. All imagery, maps, climate station data, logtag data, and documents pertaining to the project prior to Feb have been provided to Will on an external hard drive. The additional/changed files can be stored on this as well if Will drops it off at some point.

Probably don't want a signature in here either?

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Date: February, 2020.

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