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Survivability and Growth of Winter-Planted Black Spruce (Picea mariana [Mill.] B.S.P.) Seedlings on a Boreal Fen in Northwestern Alberta, Canada

FINAL REPORT

To

The Oil Sand Leadership Initiative

By

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February 2012

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DISCLAIMER

The study on which this report is based on was funded by the Oil Sand Leadership Initiative (OSLI) Land Stewardship Working Group, comprised of ConocoPhillips Canada, Shell Canada, Statoil, Suncor Energy Inc., Nexen Inc., and Total E&P Canada. The views, statements and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as the statements, conclusions, or opinions of the members of the OSLI.

ABSTRACT

Winter planting of frozen black spruce seedlings was studied in a northern Alberta wetland supported by the Oil Sand Leadership Initiative (OSLI) Land Stewardship Working Group, comprised of ConocoPhillips Canada, Shell Canada, Statoil, Suncor Energy Inc., Nexen Inc., and Total E&P Canada. The major objective is to address accessibility issues in oil sands wetland restoration processes. Close to 500 1+0 black spruce frozen container seedlings were winter-planted at a small wetland area on February 22, 2011 at -17°C immediately after a total of 260 mounds were generated. On each mound two seedlings were planted at either 4 cm or 8 cm deep, i.e. the depth from the top of seedling plug to soil surface. Another group of 240 black spruce seedlings from the same stock was spring-planted in May 25, 2011 after operational thawing. Seedlings' survival, first year new height growth, and damages to terminal bud and side branch were measured in September 2011.

More than 94% of the seedlings survived in all planting treatments although the seedlings winter-planted to 4 cm had 4-5% less survival rate. There was no difference in survival between the seedlings winter-planted to 8 cm and spring-planted. Winter planting induced substantial damage to terminal bud (46%) and branch (58-86%) although planting to 8 cm resulted in less branch damage. All seedlings had a very healthy height growth in 2011 (10-20 cm) and there was no difference between the different planting depths although the spring-planted grew 4-7 cm more.

The results suggest that winter-planting of frozen black spruce container stocks is a feasible option for northern Alberta wetlands although similar trials should be conducted before other species can be applied. A planting depth of more than 8 cm is beneficial and critical to enhance the performance of the winter-planted seedlings. Our findings also suggest that a temperature of -15°C may be a safe operational threshold for transporting and planting frozen black spruce container stocks. Although this study has proved the feasibility of winter planting, significant improvement in winter-planting performance may also be achieved through reducing seedling bud damage (e.g. better stress tolerance, different seedling sizes and planting depths) and increasing mound stability after site preparation.

INTRODUCTION

Across Alberta there are large districts of linear-disturbed boreal wetland forest areas**.** Of particular importance are areas in northern regions of Alberta where oil sand, conventional oil, and gas exploration processes occur, as the accumulation of decades of activity has caused the size of these linear disturbed areas to increase rapidly. The reclamation of these areas has been largely unsatisfactory due to poor access and inadequate forest regeneration from excessive moisture resulted after the disturbance. Exploration of different innovative ways to enhance the reforestation processes are thus very important in ensuring successful reclamation/restoration of these disturbed areas.

This study exams the possibility of operationally winter-planting black spruce (Picea mariana [Mill.] B.S.P.) on a wetland when ground remains frozen. This unique idea helps to address the accessibility issues in wet areas during growing season-an idea, to our knowledge, that has not been operationally tested anywhere in the boreal world, in spite of some previous pioneering works at normal sites (e.g. unpublished results at Manning from A.D. Startsev). We have chosen black spruce because of its natural proven ability to survive and grow in wet areas in northwestern Alberta.

This research project has been designed to accomplish the following two major objectives.

1. To test the survivability and growth of winter-planting frozen black spruce container seedlings, relative to spring planting
2. To test the effectiveness of two planting depths for the winter planting survivability and initial growth.

Three planting treatments were thus designed and implemented at a small wetland area in Grande Prairie, Alberta.

1. Winter planting to 4 cm (i.e. the top of seedling plug is placed 4 cm below the soil surface)
2. Winter planting to 8 cm
3. Spring planting

MATERIALS AND METHODS

1. Experimental Site and preparation

The experimental site of close to one hectare locates at the Evergreen Park of Grande Prairie, Alberta, Canada (118°47'41"W, 55°10'15"N). It is in a small patch of depression with dominantly black spruce of average about 6 m tall and minor components of tamarack and willow. Ground surface is covered with various peat mosses and Labrador tea. The fibrous organic soil is all peat moss of >1.5 m deep, with water table around the surface during the summer. There appears to be some sub-water flow through the site.

The site was mulched and cleared in January 2011, leaving all main stems on site. On the planting date of February 22, 2011, the site was mounded using a Hitachi ZX 200LC excavator with a 36 inch digging bucket at an approximate spacing of 4x4 m. The average inversed mound is about 90x60x60 cm (length/width/depth) and a total of 260 mounds were generated. A gentle pressing has been applied on each mound after created in order to stabilize the mound.

2. Seedling production, storage and transportation

Black spruce seedlings of 1+0 stock (seed lot #: Millar Western 28-79-14-4-97) were produced in 412A Styrofoam Containers under standard production regimes in the growing season of 2010 at Bonneville Forest Nursery (Bonneville, Alberta, Canada). They were winter-conditioned in the fall of 2010 with an average height of 25.7 cm and ground stem diameter of 3.9 mm before frozen-stored at -2-3°C in bundles of 10 seedlings.

For the winter-planted seedlings, the bundles in boxes were thawed at room temperature to a point when the seedlings could be separated one week before the planting date in order to facilitate the individual-tree planting when seedlings remain frozen in the winter. The seedlings were then wrapped with plastic sheets individually, and then placed back to the frozen storage. A preliminary test using the same batch of black spruce seedlings has indicated that there is no change in root growth capacity and survival (100%) from this gentle thawing, wrapping and re-freezing process.

The winter-planted seedlings were shipped from Bonneville to Grande Prairie 5 days before the planting date in the back of a pickup truck with the cover of a reflective tar and ~10 cm snow. They were left in the truck overnight before moving to a temporary storage of -5°C. Two temperature sensors were placed beside the roots of seedlings (i.e. inside boxes) and one exposed to air temperature to monitor temperature fluctuations during the shipping, handling and planting operation. On the planting date, the seedlings were moved to the planting site, again under the cover of tarp and snow, and immediately transferred in the snow cache (10-15 cm snow cover) on site.

For the spring-planted seedlings, they were thawed a week before the planting date (May 25, 2011) according to the normal operational procedures at room temperature, shipped to the planting site by a pickup truck under the cover of a reflective tarp.

3. Planting operation

The winter planting was conducted on the February 22, 2011. To ensure the consistent planting depth and quality, only one experienced planter was used (also for both winter- and spring-plantings). Within less than half an hour after a mound was completed, two seedlings were planted on each mound with ~40 cm apart: one with the top of the seedling plug 4 cm below the soil surface and another 8 cm below. A pig-tail metal post with a unique label was then placed beside each planted seedling. Effort was tried to place some snow cover over the planted seedlings; however, the idea was abandoned due to unrealistic amount of work.

The spring planting was conducted on the May 25, 2011 by the same planter following the common industry standard. One seedling was planted on each mound at a depth of 4 cm below the soil surface with a ~40 cm distance from each of the two winter planted seedlings (i.e. a total of three seedlings on each mound).

4. Seedling measurements in September 2011

Each planted seedling was accessed or measured in the middle of September 2011 for the following.

1. Survival
2. Damage to the terminal bud
3. Number of dead branches
4. New height growth (cm), as measured by the length of the top newly flushed portion
5. Total height from the ground (cm)
6. Ground stem diameter (mm)

5. Statistical analysis

The statistical differences among the planting treatments in percent mortality (or survival) and damage to terminal bud and branch were tested using a *z*-test statistic in a pair-wise fashion between each pair of percent ratios (Weimer 1993).

The differences in quantitative parameters (height and diameter) among the planting treatments were tested through an analysis of variance (ANOVA). The least significant difference between different means was determined either using a t-test or a Duncan Multiple Range Test (alpha=0.05). For the analysis of the average number of branches damaged, we presented the mean and standard error but did not attempt to analyze the statistical significance due to uncertain distribution of the data set.

RESULTS AND DISCUSSION

1. 2011 weather conditions in the planting area (Grande Prairie)

The yearly trend in temperature fluctuation of 2011 in Grande Prairie was not untypical (Figs 1-2). From January to February there were several cold events with minimum temperature dropped below minus 30°C (Fig. 2). The minimum temperature on our winter planting date (February 22nd) was -17°C (Fig. 1), which dropped to -30°C in a few days (Fig. 2). The average temperature reached to close to10°C in the late May when we conducted our spring planting (Fig. 2). The summer highs of 20-25°C are normal for this area and the minimum temperature started to drop below freezing point in early September when we conducted our year-end field measurements (Fig. 2).

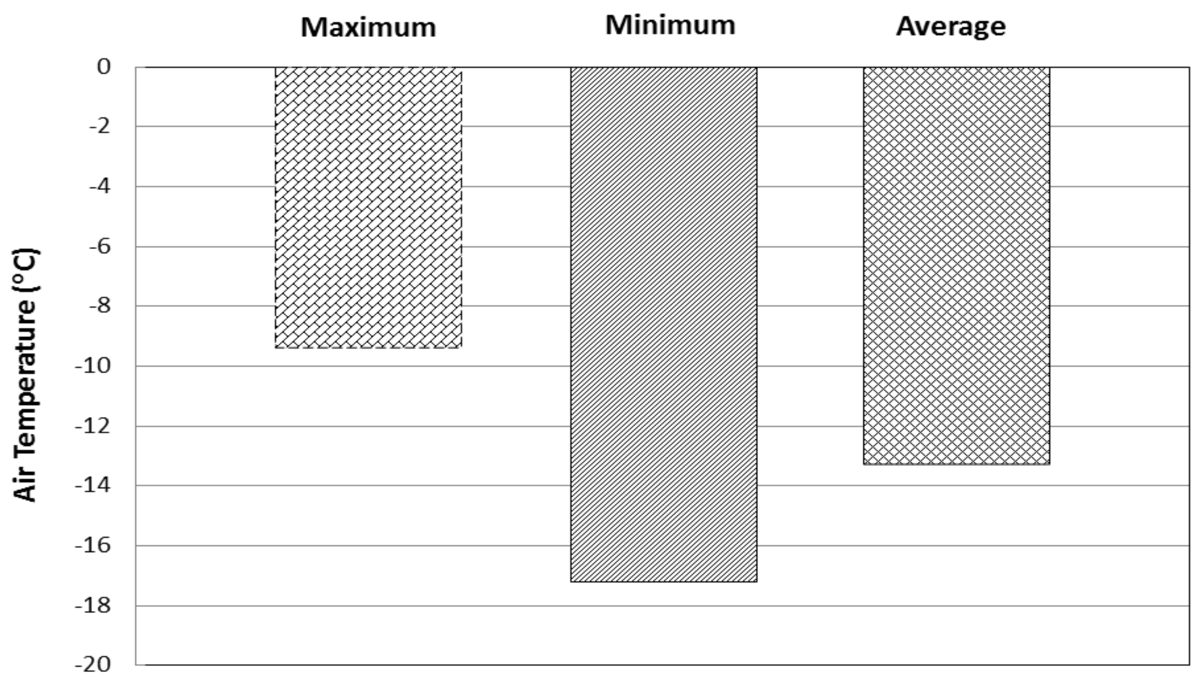

Figure 1. Maximum, minimum and average temperature on February 22, 2011 at Grande Prairie airport

A winter temperature of -17°C or above represents the majority of winter dates in northern Alberta (refer to Fig. 2), and thus the results of this trial should be able to apply to the future potential planting operation for most part of our winter. Our spring planting at 10°C is typical operationally. By the time of our field measurements in September, the seedlings should have ceased the above-ground growth and started to develop dormancy due to the freezing temperature (Fig. 2). At that time we also noticed the formation of firm terminal buds in all seedlings.

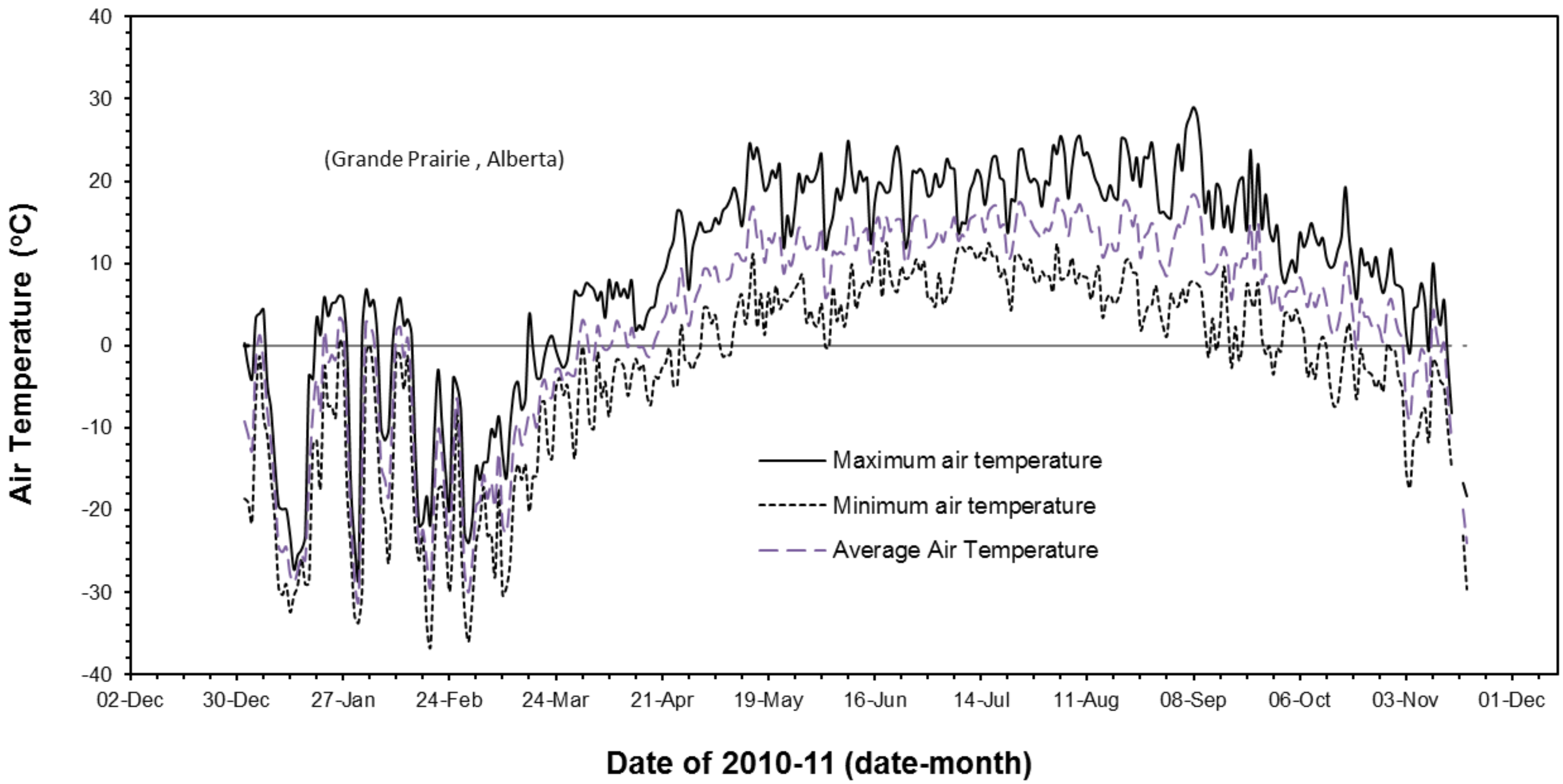

Figure 2. Daily temperature (maximum, minimum, and average) at Grande Prairie airport in 2011

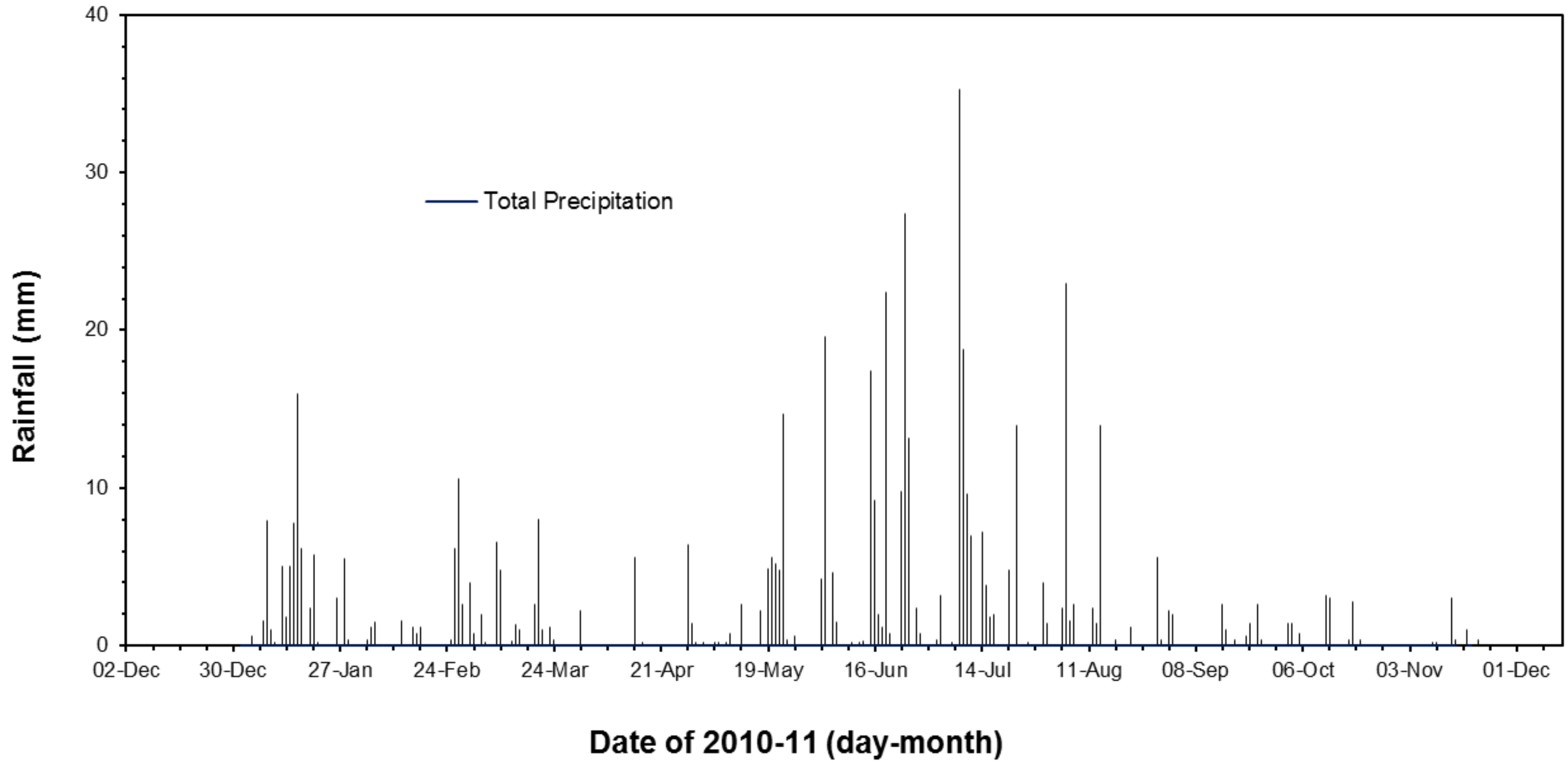

Figure 3. Daily total precipitation in 2011 at Grande Prairie airport

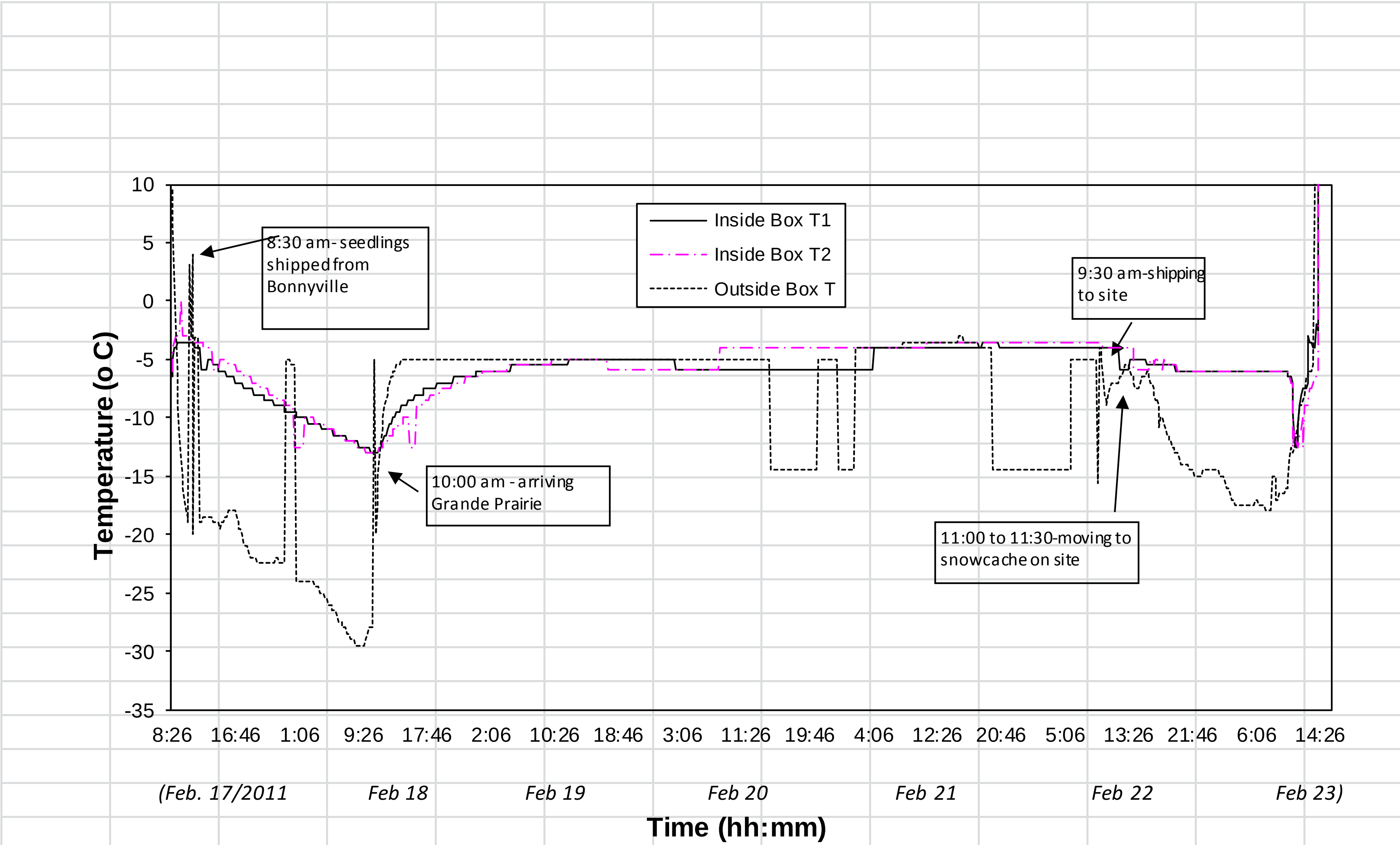

Figure 4. Temperature changes during winter seedling transportation and planting

There were evenly distributed major snow events both before and after our winter planting (Fig. 3). For example, there were 14 days with a total precipitation of more than 50 mm in January to March (Fig. 3). Regular significant daily rainfalls (from 10-35 mm) were evenly distributed almost throughout the entire summer months (Fig. 3). The planted seedlings should not have experienced any major drought stress in this study period.

2. Temperature changes during winter seedling transportation and planting

When transported in a pickup truck under the cover of tard and snow for more than 24 hours, the temperature inside the seedling boxes gradually dropped from -3°C at the pickup point to -12°C, in spite of the cold ambient air temperature of -20-30°C (Fig. 4). The temperature returned back to -5°C after placing back in frozen storage. Throughout the planting date (February 22nd) the seedling temperature (i.e. inside boxes) was maintained at -5°C to -7°C (Fig. 4).

It was initially concerning about the fact that seedlings were exposed to -12°C during the transportation since seedling roots may be fatally damaged. A literature search found that the roots of frozen-stored spruces can indeed tolerate as low as -15°C without significant damage. We conducted a small preliminary test on the root growth potential after freezing our planting stock to -15°C and 20°C for 3 hours. No impact (-15°C) or only minor impact (-20°C) was found on the root growth capacity. The fact that most our winter-planted seedling did survive supports our results.

3. Mound settling over the growing season

There were substantial amount of cracking and settling on some of the mounds, in particular on those that were tall and loose. This cracking exposed the roots of some seedlings and may have contributed partially some of the mortality in winter-planted seedlings. High mounds with straight sides, should thus be avoided since this facilitates the erosion of the peat along these high straight edges. Mounds could be compressed even more to help the settling, and should be constructed of decomposed peat (black) rather than the less decomposed (brown) surface peat.

4. Seedling mortality

We planted close to 250 seedlings for each planting treatment (Table 1). The survival rate ranges from 94-99%, with the winter planting to 4 cm depth having the significantly higher mortality 5.7%% (Fig. 5). There was no statistical difference in mortality between the spring planting (1%) and the winter planting to 8 cm (2%, Fig. 5).

5. Damage to terminal bud and branch after planting

There was substantial damage to terminal buds in all winter-planted seedlings (45%) but no differences were found between the different winter-planting depths (Table 1 and Fig. 6).

However, the damage level to branches was statistically much higher in the 4-cm planting depth (86%) in comparison to the 8-cm (58%); while the damage was 10% in the spring planted.

Table 1. The numbers and percentages of black spruce seedlings originally planted, subsequently survived, or suffered from the dead terminal bud or branch(es) one growing season after the field planting in 2011. The standard error of the mean is shown in the bracket, and for each parameter respectively the ratios with the same letter do not differ significantly as determined by a z-test (alpha=0.05).

		Winter Planting (4 cm)	Winter Planting (8 cm)	Spring Planting
Total Number of Planted Seedlings		246	255	241
Seedlings Survived	**Number**	232	250	240
	Percentage	94.4% b	98.0% a	99.5% a
Seedlings with Dead Terminal Bud	**Number**	103	115	14
	Percentage	44.4% a	46.0 a	5.8% b
Seedlings with Dead Branch(es)	**Number**	200	144	25
	Percentage	86.2% a	57.6% b	10.4% c

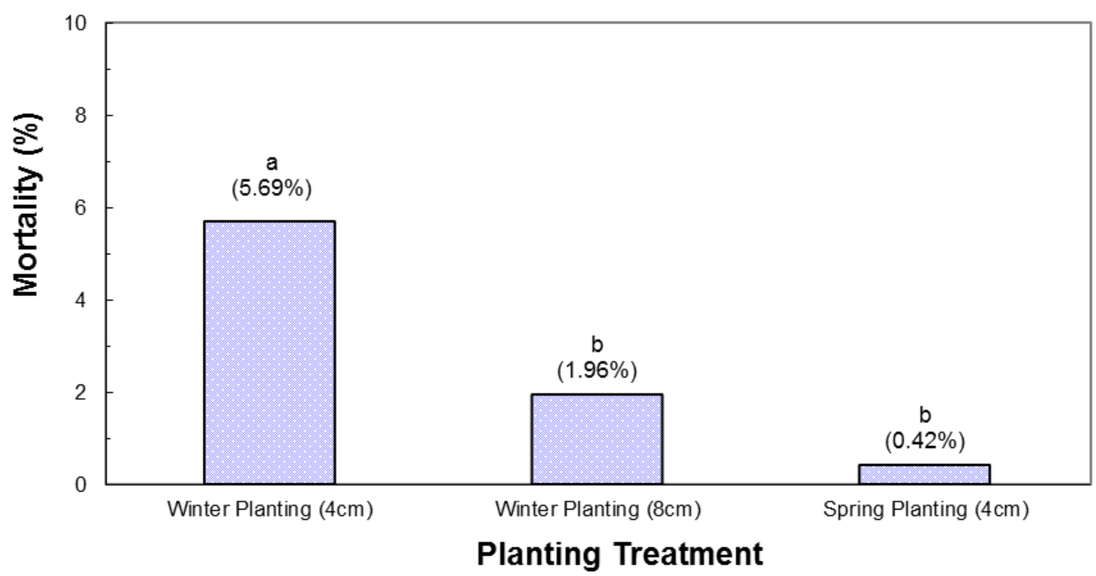

Figure 5. Percent mortality (%) of black spruce seedlings one growing season after different planting treatments. The percentage values with the same letter above do not differ significantly (P=0.05) as determined by a z-test..

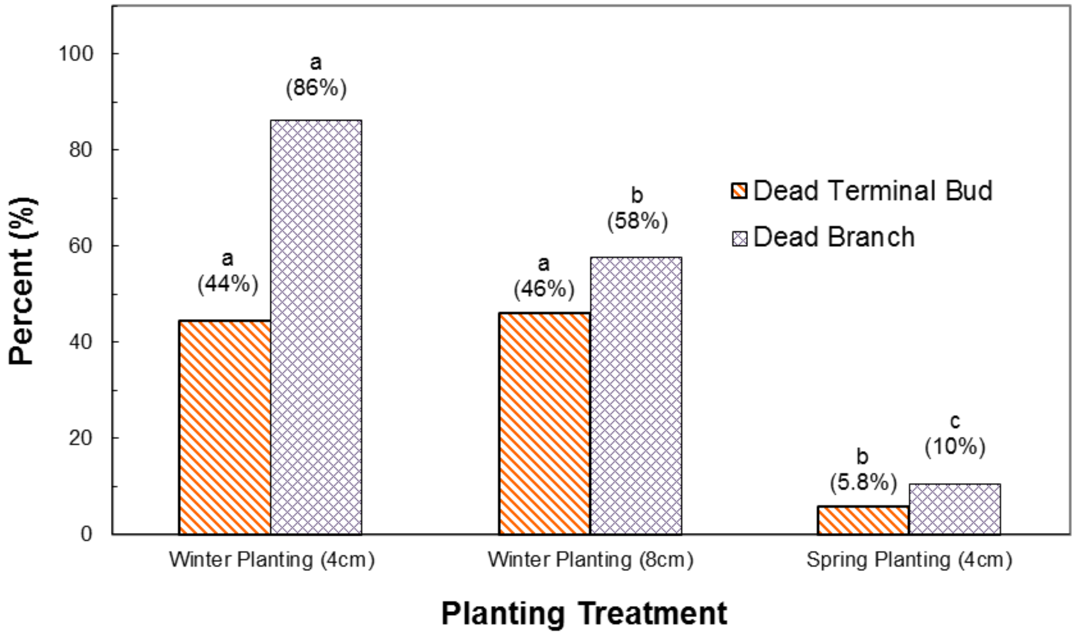

Figure 6. Percentage of black spruce seedlings with a dead terminal bud or branch(es) one growing season after different planting treatments. The values with the same letter above do not differ significantly as determined by a z-test (P=0.05).

Table 2. Average number of dead branches of black spruce seedlings in different planting treatments one growing season after the field planting in 2011. The standard error of the mean is included in the bracket, and no statistical comparisons are made due to the uneven distribution.

Group	**Average Number of Dead Branches**		
	Winter Planting (4 cm)	**Winter Planting (8 cm)**	**Spring Planting**
All Seedlings	0.86 (0.088)	0.83 (0.073)	0.13 (0.026)
Seedlings with Dead Terminal Bud	1.49 (0.15)	1.37 (0.10)	1.07 (0.074)
Seedlings with Normal Terminal Bud	0.34 (0.074)	0.36 (0.087)	0.071 (0.022)

The average number of dead branches was 0.85 for the winter-planted seedlings, in contrast to the 0.13 for the spring-planted (Table 2). There were dead branch(s) in virtually every seedling when the seedling also had a dead terminal bud. There appears to be no difference in the average number of branches damaged between the two different planting depths (Table 2).

6. New height growth and final seedling size

All seedlings had a very healthy height growth in 2011 (10-20 cm). Among the wintered planted seedlings, the differences were in general insignificant between two planting depths, except the minor difference in the seedlings with normal terminal buds (Fig. 7). The seedlings with the terminal bud damage had lower height growth relative to normal seedlings. The spring planted seedling had a significant much better height growth (4-7 cm more) relative to the winter-planted (Fig. 7).

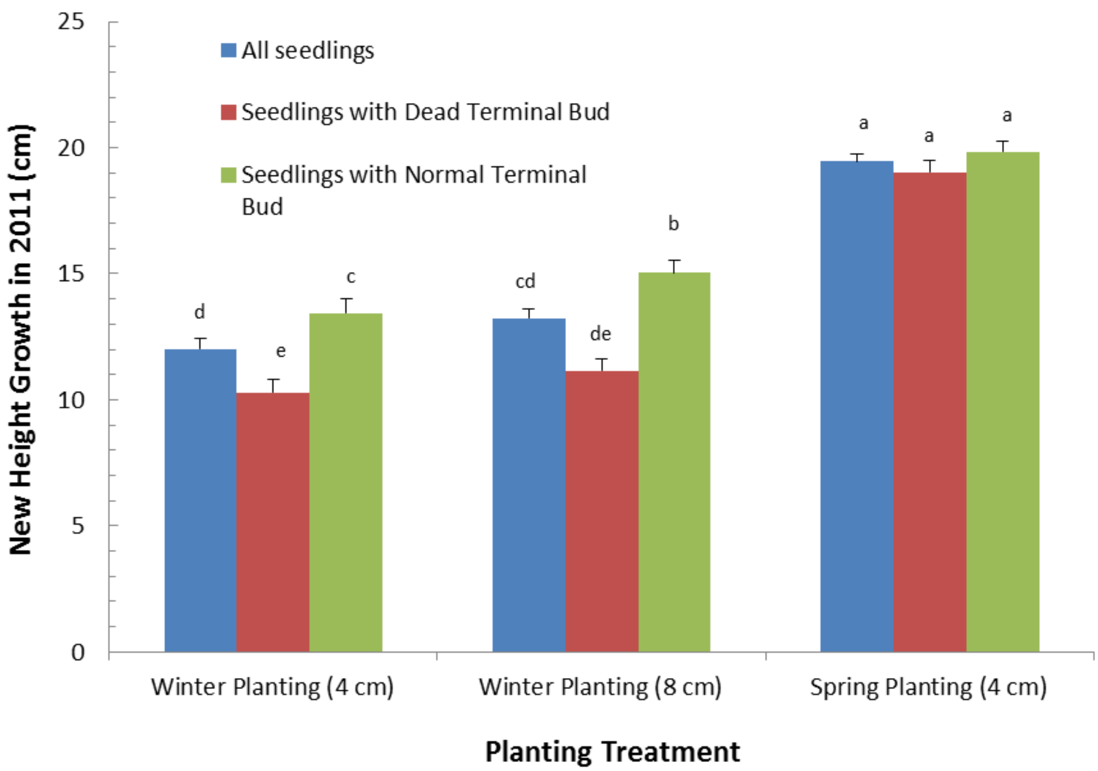

Figure 7. Average new height growth of black spruce seedlings in different planting treatments one growing season after the field planting in 2011, presented separately for the all seedling, the seedlings with dead terminal bud and the seedlings with normal terminal bud. The vertical is the standard error of the mean, and the means with the same letter do not differ significantly as determined by a Duncan Multiple Range Test (alpha=0.05)

Within the winter-planted seedlings, there was little difference in seedling final sizes (both height and ground stem diameter) between the two planting depths (Table 3). Although the spring-planted seedlings were 7-12 cm taller (due to their better new growth after planting), they had similar ground stem diameter as the winter-planted seedlings.

Table 3. Average height (cm) and ground stem diameter (mm) of black spruce seedlings in different planting treatments one growing season after the field planting in 2011. The standard error of the mean is shown in the bracket, and the means with the same letter do not differ significantly as determined by a Duncan Multiple Range Test (alpha=0.05).

Group	**Average Total Height (cm)**		
	Winter Planting (4 cm)	**Winter Planting (8 cm)**	**Spring Planting**
All Seedlings	31.3 (0.55) c	31.2 (0.51) c	40.3 (0.45) a
Seedlings with Dead Terminal Bud	27.7 (0.65) d	28.0 (0.66) cd	40.0 (0.76) a
Seedlings with Normal Terminal Bud	34.3 (0.75) b	33.8 (0.66) b	40.6 (0.57) a
	Average Ground Diameter (mm)		
	Winter Planting (4 cm)	**Winter Planting (8 cm)**	**Spring Planting**
All Seedlings	5.58 (0.068) b	5.88 (0.24) ab	5.78 (0.068) ab
Seedlings with Dead Terminal Bud	5.47 (0.097) b	5.45 (0.094) b	5.41 (0.084) b
Seedlings with Normal Terminal Bud	5.67 (0.095) ab	6.25 (0.44) ab	6.05 (0.10) a

7. Overall assessment of winter planting and planting depth

It is obvious that winter-planted seedlings survived well (over 94%) either according to industrial standards or in comparison to the spring planting (Table 1 and Fig. 5). In fact when planted deeper at 8 cm the winter planting survival rate was similar to the spring planting. This suggests that the winter planting is a viable option for northern Alberta wetlands.

Planting depth is a critical factor in improving winter planting performance since it had not only enhanced the survival rate but also reduced the damage level to the branches (Table 1 and Fig. 5). However, different planting depths had not impacted the new height growth and the damage to the terminal buds.

The exposure of roots to -12°C for over several hours (Fig. 4) has not impacted the survival of the winter-planted seedlings and thus -15°C may be used as a threshold of exposure for the frozen seedlings during their transportation. Extensive exposure to the low temperature should be avoided and the seedlings should be placed on the ground snow cache as soon as feasible. Placing seedlings in the back of a pickup truck or any isolated structure from the ground for an extensive period of time (e.g. 24 hours) in the cold winter conditions is not recommended.

The damage to the terminal buds (46%) and branch (58-86%) in the winter planted seedlings (Table 1) was highly substantial, which may have contributed to the slower height growth in comparison to the spring-planed seedlings (Fig. 7). Although many different factors may have contributed to the damage, a better quality of the seedlings (i.e. higher freezing and drought tolerance, seedling sizes) and optimum planting depth may be two useful areas for future improvement.

CONCLUSIONS AND RECOMMENDATIONS

This black spruce winter planting project has been implemented successfully according to the original proposal, and the major objectives accomplished. The results have been statistically analyzed and presented. Based on the current results and findings, the following are our major conclusions and recommendations.

1. Winter-planting of frozen black spruce container stocks is a feasible option for northern Alberta wetlands since 98% of the deep-planted seedlings (8 cm) survived, equally as well as the spring-planted ones.

   Recommendations:

   1) Since the results are very encouraging and the experimental setup is highly valuable, it would be very useful to us to continue to monitor the development and growth of the planted seedling over the next 4 years since it takes that long for the full impacts be assessed for tree seedlings.

   2) Since different species may respond differently, it is recommended that similar trials be conducted before any other species can be applied to winter planting

   3) It may be also a good idea that a similar trial be conducted for the implementation in the areas far northerner than Grande Prairie.

2. A planting depth of 8 cm (or maybe more) is beneficial and critical to enhance the performance of the winter-planted seedlings.

   Recommendations:

   4) Importance of controlling a planting depth of more than 8 cm should be emphasized and explained in the future operational manual for winter planting.

   5) If future evidence further indicates the need to optimize the planting depth, a further trial may be warranted to further test the impacts of planting depth.

3. A temperature of -15°C may be a safe operational threshold for transporting and planting frozen black spruce container stocks as long as proper cover (e.g. snow cache and tar) is applied and the exposure is less than 24 hours for transferring/transporting period.

   Recommendations:

   6) If the transferring period would be more than 24 hours, the seedlings boxes should be snow-cached on the ground.

4. Terminal buds and branches suffered substantial amount of damage in the winter-planted seedlings. We do not know currently what may have contributed to these damages.

   Recommendations:

   7) Before any large scale of operational winter planting projects, the issue of bud/branch damage should be studied to search for potential solutions. Four aspects may be important: better seedling tolerance, seedling size, optimum planting depth, and snow cover after planting.

5. Excessive tall (e.g. >60 cm) and loose mound in the wetland areas is detrimental to the performance of winter planted seedlings due to the cracking and shifting of the mound from the settling during growing season.

   Recommendations:

   8) Mounding operator should be advised to avoid too deep mounding with sharp edges and to apply a more vigorous pressing than what was used in this study which may be useful to help the settling. A small trial may be useful to clarify this issue.

FINANCIAL REPORT

The Table 4 summarizes the actual OSLI contribution and research expenses by categories, as of December 1, 2011, in comparison to what were proposed in the original proposal. The actual expenses in all major categories are very close to what were proposed, with the exception of travel and GPRC administration fee. We spent more money on travel due to the unexpected trips and logistics in bringing the seedlings during both winter and spring plantings. The GPRC administration fee turned out to be a little higher, which in fact has been used to cover the extra expenses over and above the OSLI contribution ($2,527) in this project.

Table 4. Summary of financial report relative to the proposed expenses by major categories

Category	Proposed	Actual
OSLI Contribution	$34,512.50	$34,512.50
Research Expenses		
Site preparation & mounding (Global Restoration)	$16,100	$15,450.80
Planning, design approval, planting logistics, & report (GPRC)	$7,200	$7,200
Seedlings and planting	$4,925	$3,168.15
Travel	$1,300	$4,246.46
Student Assistance	$900	$898.16
Supplies & miscellaneous	$950	$899.64
GPRC Administration Fee	$3137.50	$5176.88
Total Expenses	**$34,512.50**	**$37,040.09**