REPORT

Caribou Range Restoration Project Treatment Sites

Caribou Range Restoration Project: Follow-up Monitoring in the Little Smoky Caribou Range 17-ERPC-05

Submitted to:

Petroleum Technology Alliance of Canada

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Executive Summary

To meet habitat targets within boreal caribou ranges, the federal Recovery Strategy for the Woodland Caribou, Boreal Population in Canada (Environment Canada 2012) identifies coordinated actions to reclaim woodland caribou habitat as a mitigation step to meeting current and future caribou population objectives. Actions include restoring industrial landscape features such as roads, seismic lines, pipelines, cut-lines, and cleared areas in an effort to reduce landscape fragmentation and the changes in caribou population dynamics associated with changing predator-prey dynamics in highly fragmented landscapes. Based on the federal recovery strategy habitat targets and current range conditions, it is expected that boreal caribou range plans in Alberta will have a requirement to restore significant amounts of habitat along linear disturbance features. Habitat restoration (i.e., mechanical site preparation, planting and/or seeding of tree species) as well as implementing access control measures are considered the primary mechanisms to enhance the rate of recovery of linear disturbance features to naturally occurring vegetation. Through the Alberta Caribou Action Plan (GOA 2016), the Alberta government has committed to restoring 10,000 km of seismic lines within the Little Smoky and À La Peche caribou ranges over the next five years.

As caribou habitat restoration initiatives have become more widespread across Alberta in the last decade, key uncertainties have been recognized regarding what treatment types are appropriate for habitat restoration, how to measure success, and timelines to reach functional habitat. To that end, a collaborative research initiative was initiated by Golder Associates with support from the Foothills Landscape Management Forum (FLMF), the Petroleum Technology Alliance of Canada (PTAC) and the Government of Alberta to monitor the vegetation attributes on restoration treatment sites implemented from 2001 to 2007, as part of the Caribou Range Restoration Project in the Little Smoky caribou range.

The study approach for this project attempted to understand how planted and naturally regenerating tree seedling species (primarily black spruce and lodgepole pine) responded to site treatments in order to answer the following questions:

1) Are planted seedlings significantly taller compared to naturally regenerating seedlings on treated sites?

2) What are the main environmental and ecological conditions impacting seedling growth on treated and naturally revegetating seismic lines?

3) Are planted seedlings or naturally regenerating seedlings on treated sites significantly taller than seedlings on untreated naturally revegetating lines?

Growth patterns (i.e., individual tree height-age trajectories) were also modelled for both planted and naturally regenerating tree species to determine their growth trajectories within both treated and naturally revegetating sites.

Permanent vegetation sampling plots along regenerating seismic lines were sampled in 2008, 2015, and 2017. A total of 126 plots were sampled over the three survey years; 59 of these plots occurred on naturally revegetating lines while the remaining 67 plots occurred on seismic lines that had received some form of preparation treatment to speed vegetation recovery (i.e., treated lines). A variety of parameters representing physical site properties and vegetation community conditions were measured at each plot including conifer seedling height and leader growth. Data analysis was made up of three main components using the data collected during the three survey years:

1) Planted seedling growth was compared to naturally regenerating seedling growth along treated seismic lines using a mixed effects linear regression.

2) Candidate linear models were created and assessed using AIC to determine which environmental, ecological, and treatment conditions had the greatest impact on conifer seedling growth on regenerating seismic lines.

3) Conifer seedling height and leader growth measurements were used to create growth trajectories for seedlings growing on treated and naturally revegetating seismic lines.

Along treated seismic lines, planted black spruce seedlings showed greater leader growth and higher average heights than the naturally regenerating spruce seedlings growing on the same lines. Planted black spruce seedlings were tallest and showed the greatest leader growth at lowland sites, and both naturally regenerating and planted individuals performed better at lowland sites than at upland sites. The candidate models created to explain variation in seedling height and leader growth indicated that seismic line age (i.e., time since disturbance or treatment occurred) was likely the most important factor affecting seedling growth. Site treatment also had a significant effect on black spruce seedling height and leader growth but had a variable effect depending on the site type that the treatments were applied to. Black spruce seedlings seemed to benefit from a mound and planting treatment if they occurred in lowland sites whereas they appeared to gain limited benefits from mounding treatments when they were applied in upland sites. Lodgepole pine seedling growth was most affected by seismic line age but line orientation was also identified as an important factor in explaining variation in pine seedling height.

Growth trajectories created using the heights and leader growth measurements of conifer seedlings indicated that treatments did not speed up the time required for seedlings growing at upland sites to reach height thresholds, compared to naturally revegetating sites. Treatments applied to lowland sites did however speed up the time required for black spruce seedlings to reach height thresholds compared to non-treated lowland sites. Black spruce seedlings growing in lowland habitats were projected to reach the 1.4 m, 2.7 m, and 5.0 m thresholds by age 17.7, 27.8, and 43, respectively, and were projected to reach these thresholds approximately 2 years faster than seedlings growing on naturally revegetating lines sites. Lodgepole pine seedling growth trajectories did not seem to benefit from treatments applied to upland sites as seedlings growing on naturally revegetating lines were projected to reach height thresholds faster than equivalent seedlings growing on treated lines.

Applying mounding treatments to upland habitats seemed to have little benefit to black spruce or lodgepole pine seedling growth and instead seemed to act as a detriment to seedling regeneration at these sites. These results suggest that treatment applications need to be more targeted to natural regenerative systems and applied based on an understanding of site limiting factors and conditions to achieve the most optimal results. Thus, consideration for whether an upland site should be planted with seedlings, seeded, or left for natural seed ingress, as well as which species to introduce within upland sites of higher mineral and lower moisture content, and the use of coarse woody debris or other soil enhancements, or placement of seedlings lower down in a mound, should be considered in future restoration trials within upland sites.

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1.0 INTRODUCTION

1.1 Background

Woodland caribou (*Rangifer tarandus caribou*) are listed as 'Threatened' on Schedule 1 of the *Species at Risk Act* (SARA) (SARA 2017) and by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (COSEWIC 2017). In Alberta, all populations of woodland caribou are listed as threatened under the *Alberta Wildlife Act* (Alberta Environment and Parks [AEP] 2017) and are designated as "At Risk" (AEP 2017). Given the current status and continued decline of woodland caribou populations, a number of federal and provincial recovery plans and strategies have been initiated to facilitate the maintenance or recovery of woodland caribou populations in Canada (Government of Alberta [GOA] 2011, 2017a; British Columbia Ministry of Environment [BC MoE] 2011; Environment Canada [EC] 2012).

At the national level, the federal Recovery Strategy for the Woodland Caribou, Boreal Population in Canada (EC 2012) outlines that all boreal caribou populations are to be self-sustaining and have a minimum of 65% undisturbed habitat in their range (EC 2012). To meet the undisturbed habitat target within boreal caribou ranges, the federal strategy (EC 2012) identifies caribou range planning, specifically coordinated actions to reclaim woodland caribou habitat, as a mitigation step to meeting current and future caribou population objectives. Actions include restoring industrial landscape features such as roads, seismic lines, pipelines, cut lines, and cleared areas in an effort to reduce landscape fragmentation and the changes in caribou population dynamics associated with changing predator-prey dynamics in highly fragmented landscapes.

Currently, specific range plans for the West Central Alberta caribou ranges, including the Little Smoky caribou range, have not yet been finalized. However, based on the federal recovery strategy and Alberta's draft Woodland Caribou Range Plan (GoA 2017a) Alberta Environment and Parks (AEP) will lead a provincial habitat restoration program, with participation from cross-ministry partners in integrated resource management and in partnership with industry, indigenous peoples, and a third party restoration agent to restore significant amounts of linear disturbances. Habitat restoration (i.e., mechanical site preparation, planting and/or seeding of tree species) as well as implementing access control measures are considered the primary mechanisms to enhance the rate of recovery of linear disturbance features to naturally occurring vegetation (ACCGB 2008; GOA 2013). It is hypothesized that implementation of these types of treatments will benefit woodland caribou by reducing the lag time for vegetation (specifically trees and shrubs) to reach a height where human and predator use is reduced, and the linear disturbance can be considered on a trajectory to becoming restored functional caribou habitat. Restoration standards and outcomes have been described in the Provincial Restoration and Establishment Framework for Legacy Seismic Lines in Alberta (GOA 2017b). Functional habitat, in regard to habitat restoration of historical linear disturbances, has been defined by the Canadian Association of Petroleum Producers (CAPP 2015) as: "The application of techniques on anthropogenic disturbances that deter the interaction between caribou and their predators in the near term, and supports habitat recovery in the long-term".

Although caribou habitat restoration activities have been implemented on a variety of linear disturbances in Alberta since 2002, (e.g., Diversified Environmental Services [DES] 2004; CRRP 2007a; Golder 2010, 2012a, 2012b; Oil Sands Leadership Initiative [OSLI] 2012a) very little information has been gathered on the effectiveness of these treatments in accelerating the recovery of vegetation on these linear disturbances to functional caribou habitat. Several organizations, including the Foothills Landscape Management Forum (FLMF), the Petroleum Technology Advisory Council (PTAC) / Canadian Association of Petroleum Producers (CAPP), Foothills Research Institute (fRI), Canada's Oil Sands Innovation Alliance (COSIA), Regional Industry Caribou Collaboration (RICC), University of Alberta, Alberta Environment and Parks (AEP), BC Oil and Gas Research and Innovation Society Research and Effectiveness Monitoring Board (e.g., Golder 2017) and associated members, have been engaged in efforts to implement, examine and potentially test the efficacy of habitat restoration as a key management lever for woodland caribou conservation. One area of focus has been to assess the effectiveness of past treatment initiatives, including natural revegetation recovery, as a means to help inform the design and cost of restoring historic linear disturbances. These types of assessments are designed to look at the relative successes and failures of habitat restoration treatments relative to site conditions (i.e., ecosite) and treatment type, including seedling survival, seedling growth rates, unintended consequences, human use, animal use, line of sight, density, crown closure, and primary prey browse species presence.

1.2 Caribou Range Restoration Project

A Caribou Range Restoration Project (CRRP) was first established within Alberta in 2001 (Szkorupa 2002) in an effort to address growing concerns with the relationship between industrial development and declining local caribou populations. At that time, research from James (James 1999) suggested wolves were gaining a predation advantage using linear features created by industry, and that indirect habitat loss for boreal caribou was occurring through the avoidance of habitat adjacent to human disturbance (Dyer 1999; Neufeld 2006; Oberg 2001). In addition, seismic lines were reported to have very slow reforestation rates (Revel et al. 1984; Osko and MacFarlane 2000), with slow tree regeneration attributed to root damage from the original disturbance, compaction of the soil in tire ruts, insufficient light reaching the forest floor, introduction of competitive seed mixes (i.e., plant seed mixes), drainage of sites, and repeated disturbances (e.g., all-terrain vehicles) on seismic lines (MacFarlane 1999 and 2003; Sherrington 2003). Rehabilitation of existing anthropogenic disturbances within caribou range was expected to reduce the degradation of functional habitat over the long-term, with caribou no longer exhibiting avoidance of the disturbance feature (e.g., Oberg 2001). The CRRP piloted techniques with the objectives of promoting revegetation of these linear features, while discouraging access for predator, primary prey, and human use.

The CRRP was a multi-stakeholder group initiated and steered by the provincial government agency Alberta Sustainable Resource Development (ASRD), and the Boreal Caribou Committee (BCC) (Dzus 2001). Although the CRRP was not extended beyond 2007, the project did incorporate silviculture methods based on knowledge of silviculture treatments from the forest industry, focusing on access control treatments and enhancing the vegetation recovery rate of historical seismic lines, pipelines, and lease roads. Treatments included tree/shrub seedling planting, seeding of tree species, tree/shrub transplanting, mounding, spreading of woody debris, and soil de-compaction. Based on the outcome of treatments and learnings on linear restoration, the CRRP prepared a Guidance Document (CRRP 2007a) which included recommended practices for implementing a habitat restoration program, from the planning through to the treatment stages. A monitoring protocol document for revegetation (unpublished) (CRRP 2007b) was also prepared, but no long-term monitoring of treated sites was implemented. It was recognized at the beginning of the program that restoring linear development features is not equivalent to replanting a typical monoculture or mixed stand forestry cutblock. Linear development features vary with respect to the width and type of initial disturbance, compaction levels, soil types, moisture regimes, and light levels. In addition, restoration objectives often differ, including discouraging predator and human access, and the establishment of vegetation which is not preferred browse for moose or deer.

A number of initiatives and trials established since the CRRP have focused on establishing vegetation and access control treatments on linear development features located within caribou ranges. Restoration programs have been developed under requirements to meet project approval conditions (provincially through *Alberta Environmental Protection and Enhancement Act* approval conditions for in-situ projects and federal pipeline approvals through the National Energy Board) as well as voluntary programs. Habitat restoration programs have included implementing treatments to encourage native vegetation establishment such as creating microsites using an excavator, seedling planting (tree and shrub species, frozen seedlings) (e.g., Golder 2005; DES 2004; Enbridge 2010; Golder 2010;

Golder 2011; Golder 2012a; OSLI 2012), spreading coarse woody debris (Vinge and Pyper 2012; Pyper and Vinge, 2012) and tree-felling (Cody 2013; OSLI 2012).

2.0 OBJECTIVES

As caribou habitat restoration initiatives have become more widespread across Alberta in the last decade, key uncertainties have been recognized regarding what treatment types are appropriate for habitat restoration, how to measure success, and timelines to reach functional habitat. A trajectory for restored habitat has not been clearly defined in either provincial or federal caribou recovery strategies.

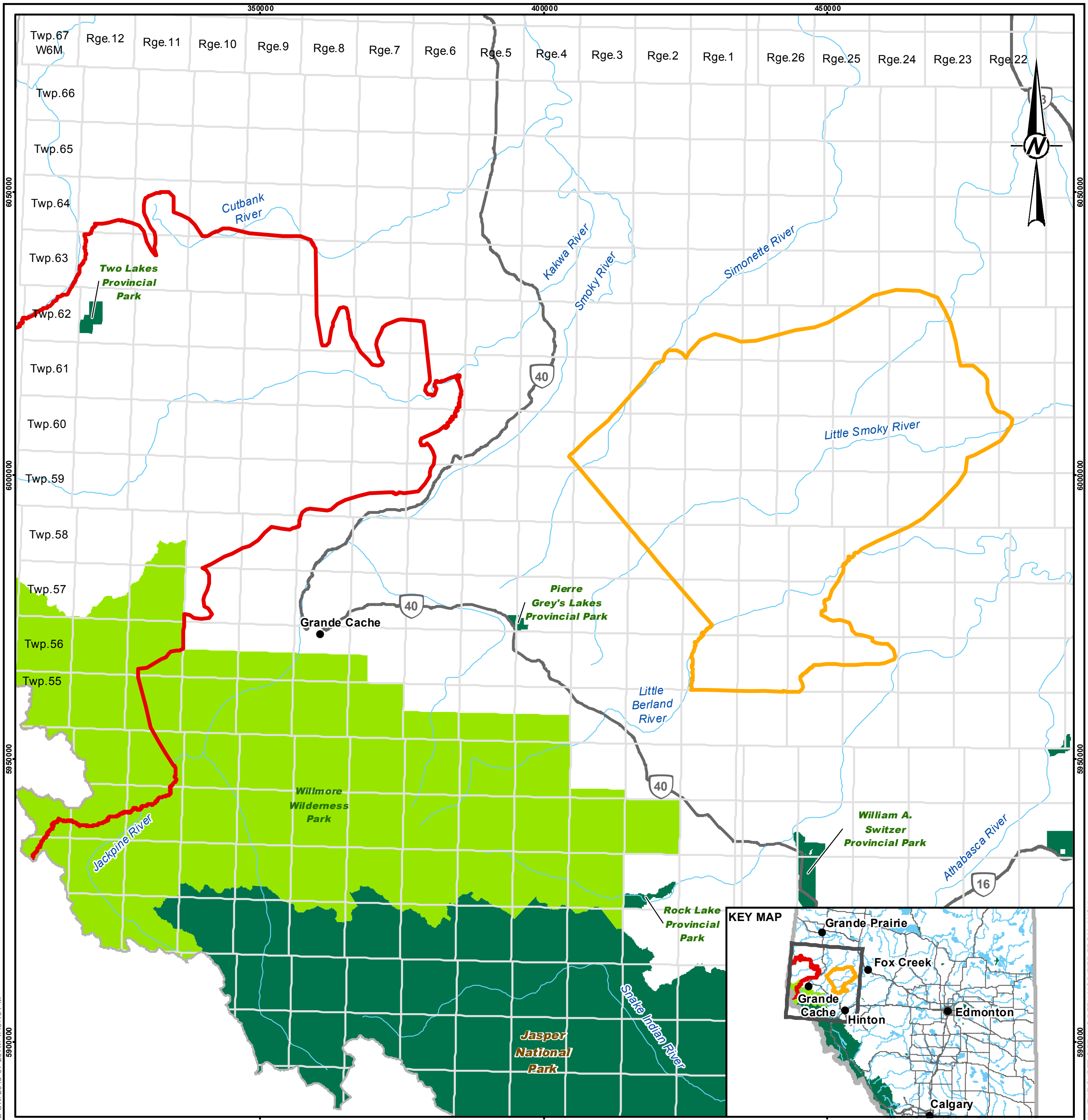
To that end, a collaborative research initiative was initiated by Golder Associates with support from the FLMF, PTAC and the Government of Alberta in 2015 to monitor the vegetation attributes on previously treated sites (from 2001 to 2007) from the CRRP in the Little Smoky caribou range. The treatment sites selected had 9 to 13 growing seasons since initiation of treatment. The purpose of this study is to provide a basis for answering the question of whether or not treating historic linear disturbances through mechanical site preparation, planting and/or seeding of tree species, as well as implementing access control measures, is an effective means of accelerating the natural rate of vegetation recovery on linear disturbances. Understanding the effectiveness of past treatment initiatives is of considerable importance, as vegetation height has been shown to be a significant factor in reducing both human and predator use of linear disturbance features (Dickie 2015; Finnegan et al. 2014). Secondly, understanding the rate of vegetation recovery following the implementation of treatments will inform the time required to achieve functional habitat restoration (e.g., 15 to 25 years for the purposes of meeting critical habitat goals in range planning, as opposed to 40 years).

Given the lack of long-term monitoring results for habitat restoration treatments implemented throughout Alberta, the data collected from treated CRRP sites also provides valuable information that can be used to determine the growth trajectory expectations of seedlings across a range of site conditions (i.e., ecosites) and treatment types.

In 2017, Golder was provided additional funding through PTAC to build off of the 2015 data analysis in an effort to move from a relative comparison of past treatments to natural recovery of vegetation on legacy seismic lines, to a scientifically defensible real comparison given the costs associated with treatment implementation. This 2017 Project filled a data gap, where increasing the number of vegetation plots on naturally regenerating seismic lines refined the vegetation growth trajectories within lowland and upland habitats. The 2017 data collection on naturally regenerating seismic lines revisited locations of existing monitoring sites in the Little Smoky and Redrock-Prairie Creek ranges (from CRRP files), where 236 monitoring plots were established in 2006. The ultimate goal was to assess the vegetation growth trajectories across a variety of ecosite phases, comparing leader growth and seedling height between natural recovery and treatment sites.

3.0 STUDY AREA

The area selected for this study is represented by the Little Smoky and Redrock-Prairie Creek caribou ranges, which are located along the eastern slopes of the Rocky Mountains in west-central Alberta, extending from near Fox Creek, Alberta west to Grande Cache, Alberta (Figure 1). This area is a highly disturbed landscape as a result of intensive land use including forestry, oil and gas exploration and production, and recreation. The area is also transected by an intensive historical seismic footprint, as well as numerous pipelines, roads and trails.



LEGEND

- ● POPULATED PLACE
- PRIMARY HIGHWAY
- WATERCOURSE
- NATIONAL OR PROVINCIAL PARK
- WILLMORE WILDERNESS PARK

CARIBOU RANGE

- LITTLE SMOKY
- REDROCK-PRAIRIE CREEK

0 25 50

1:1,000,000 KILOMETRES

REFERENCES

ALBERTA TOWNSHIP SYSTEM © GOVERNMENT OF ALBERTA 2014. ALL RIGHTS RESERVED.POPULATED PLACES OBTAINED FROM IHS ENERGY INC. NATIONAL ROAD NETWORK CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENCE – CANADA. PARKS AND PROTECTED AREAS OBTAINED FROM ALBERTA PARKS, GOVERNMENT OF ALBERTA. HYDROGRAPHY FROM ALTASCAN.
DATUM: NAD83 PROJECTION: UTM ZONE 11

CLIENT
PETROLEUM TECHNOLOGY ALLIANCE CANADA

PROJECT
SEISMIC LINE MONITORING - LITTLE SMOKY AND REDROCK PRAIRIE CREEK CARIBOU RANGES

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-12-14
DESIGNED	MT
PREPARED	BP
REVIEWED	VC
APPROVED	PB

TITLE
STUDY AREA LOCATION

PROJECT NO.	CONTROL	REV.	FIGURE
1784118	10	0	1

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25mm

The study area is primarily located within the Upper Foothills Subregion, with a small section intersecting with the Lower Foothills Subregion to the north and the Subalpine Subregion to the west (Natural Regions Committee 2006). As the study area spans three different subregions, there is wide variability in topography and landscape conditions, ranging from gentling undulating to rolling hills in the Lower Foothills to rolling and inclined landscapes in the Subalpine (Natural Regions Committee 2006). Upland vegetation in the Upper Foothills Subregion is predominantly comprised of closed coniferous forests dominated by pure or mixed stands of lodgepole pine, black spruce and white spruce. In the Lower Foothills these sites typically contain a greater proportion of deciduous or mixedwood stands in association with lodgepole pine (Natural Regions Committee 2006). Upland sites in the Subalpine Subregion are similar to that in the Upper Foothills Subregion and are typically comprised of closed lodgepole pine forests. Wetlands in the both the Upper and Lower Foothills subregions are characterized by a mix of stunted black spruce and larch stands, interspersed with shrubby or graminoid fens (Natural Regions Committee 2006).

4.0 METHODOLOGY

4.1 Approach and Sampling Design

2015 Approach

The initial premise behind this study was to compare treated sites ranging in age from 9 to13 years post treatment to a range of naturally revegetated sites to determine if there were significant differences in vegetation height, specifically tree species regeneration (regen) height and Robel pole value (Golder 2015). Detailed vegetation data by strata, as well as soils and age since disturbance data were collected within the Little Smoky caribou range on naturally revegetated seismic lines in 2008 through a wildlife use study initiated by ConocoPhillips Canada (CPC), Suncor Energy Inc. (Suncor) and CAPP (Golder 2009). While this study primarily involved the use of remote cameras to assess how natural revegetation along linear disturbances affect caribou, predator and alternate prey species mobility and use of these disturbed landscape features, detailed vegetation and soils data were collected on selected sites to provide a broader context for evaluating the vegetation attributes relative to wildlife use. Power analyses using robel pole value and tallest seedling regeneration height data from the 2008 study (Golder 2009) were completed to determine the number of plots per sample unit that needed to be collected in order to have sufficient power for statistical analysis for this study. Both analyses utilized a beta value of 0.20 and an alpha level of 0.05. Sites were split into upland and lowland groups to reduce the amount of within group variability associated with ecological site conditions, resulting in four treatment groups (treatment/control x upland/lowland).

Based on the results of the power analysis, it was recommended that 40 plots per sample unit be collected in order to detect a 2 m difference in the tallest regeneration height between treatment groups, and a 100 cm difference in Robel pole value. Thus, a total of 160 plots were recommend for monitoring; 80 treated sites and 80 untreated (natural revegetation) sites, both groups to be split into upland and lowland, for a total of 40 plots per treatment group. For natural revegetation untreated sites, data from 2013 was provided from the fRI. However, as the data collected on untreated sites by fRI was intended for a different use (i.e., human and wildlife use of seismic lines relative to vegetation height), the variables collected were at a different level of resolution than that collected at treated sites and no specific information on age, tree species or vegetation strata were provided. Statistical comparisons of regeneration height between treated and untreated sites using the variables identified in the power analysis could not be completed with the dataset provided.

However, an alternative approach focusing primarily on data collected on treated sites was used to understand how planted and naturally regenerating tree seedling species (black spruce and lodgepole pine), responded to site treatment in order to answer the following questions:

- Are planted seedlings significantly taller compared to naturally regenerating seedlings on treated sites?

- Is the average current year's leader growth significantly greater for planted seedlings compared to naturally regenerating seedlings on treated sites?
- Are planted seedlings, or naturally regenerating seedlings, on treated sites significantly taller than seedlings on untreated naturally recovering lines?

Thus, the hypotheses being tested were that both tree seedling height and leader growth will be greater for planted trees compared to naturally regenerating trees and that seedling height on treated lines will be taller compared to untreated naturally recovering lines.

Additionally, growth patterns (i.e., individual tree height-age trajectories) were modelled for both planted and naturally regenerating tree species on treated sites using mean leader growth, mean height and age to determine their respective trajectories. These trajectories provide a basis for comparing the time it takes to reach a specific height threshold, which provides insight into how effective planting is as a treatment option. The mean maximum age and height of lodgepole pine and black spruce from untreated natural recovery sites were also calculated to provide a relative comparison that could be plotted on the respective height – age growth trajectories.

2017 Approach

Seedling sampling in 2017 focused on naturally revegetating sites. Obtaining data on seedling height and growth rates on naturally revegetating lines facilitated a comparison of how treating seismic lines may impact the recovery rate of vegetation on those lines. Data analyses were expanded in 2017 to include a broader assessment of what kind of environmental, ecological, and treatment conditions had the greatest impact on seedling growth along seismic lines. The growth trajectories that were previously created using predominately data from treated lines were also rerun and bolstered by incorporating the 2017 data from naturally revegetating sites. Separate growth trajectories were created for treated sites and for naturally revegetating lines to gain a better perspective on if, and how much, treating seismic lines can accelerate the growth of conifer seedlings occurring on these features.

4.2 Data Sources and Collection Methods

Treated Seismic Lines

In 2015, 67 survey plots (i.e., sites) were established along treated seismic lines at which data on the vegetation community and physical attributes of the line were collected. Treated sites were selected from a range of sites treated under the CRRP program. Selection of treated sites to revisit in 2015 was determined through a review of information on the locations of existing treatment sites in the Little Smoky Range (CRRP 2007b; 2007c; 2007d), along with sampling data collected through the fRI caribou program, in conjunction with a review of recent imagery to identify the most suitable monitoring locations. Where possible, sites were selected to be a minimum of 200 to 300 m apart to reduce the effects of spatial correlation among survey sites.

Field surveys were completed by two crews (comprised of one Golder Vegetation Ecologist and one Aseniwuche Environmental Corporation [AEC] assistant) between August 27 and September 3, 2015. The majority of the treatment sites in the Deep Valley area (CRRP 2007c) were accessed by truck and foot via the Deep Valley Road, while remote sites in the area furthest to the east and southeast (CRRP 2007b) were accessed by helicopter. Data collection methods used at treated sites followed the same protocols used during previous monitoring studies in the region (CRRP 2007e; Golder 2009). Information collected at each treated site in 2015 included:

- ecosite phase (classified according to Beckingham et al. (1996) or wetland type (according to Halsey et al. 2004) within the adjacent forest stands on either side of the seismic line;
- width of linear feature and visual measurement of line of sight (using Robel pole);

- tree revegetation data (mean height, number of stems, diameter of tallest tree, age of tallest tree, % crown closure) within a 1.78 m radius plot;
- vegetation data (mean height and cover class by strata; species identification and cover estimates of shrubs and dominant understorey vegetation, as well as terrestrial lichens);
- cursory soils information (as soil disturbance on seismic lines, related to various techniques used over the years, may have affected vegetation growth) from a representative location;
- wildlife sign (trail, pellets, browsing), presence of game trails and their estimated usage levels; and
- human activity on line (e.g., all-terrain vehicle [ATV] trail).

Field photos of monitoring sites surveyed in 2015 are provided in Appendix A.

Naturally revegetating Seismic Lines

Data from naturally revegetating seismic lines came from three different sources:

- data from the 2008 ConocoPhillips, CAPP and Suncor Project (Golder 2009) on naturally revegetating seismic lines within the Little Smoky Caribou range and in the Upper Foothills subregion (21 plots);
- data collected in 2015 on naturally revegetating seismic lines (4 plots); and
- data collected by Greenlink Forestry Inc. (Greenlink) in 2017 on naturally revegetating seismic lines within the Upper Foothills, Subalpine, and Lower Foothills subregions (41 plots).

The data collected in 2008 for the ConocoPhillips, CAPP and Suncor Project generally followed the methods described for 2015 and summarized wildlife use, vegetation communities, and physical attributes of seismic lines within the Little Smoky Caribou range (see Golder 2009 for detailed description of methods).

The four naturally revegetating lines surveyed in 2015 were initially identified within the CRRP database as ‘to treat’, but field visits indicated that no treatments had been applied to these lines. The four plots were surveyed following the same methods described above for the treated lines in 2015 but were included in the naturally revegetating line group for analysis.

In 2017, Greenlink revisited monitoring plots on naturally revegetating seismic lines that were originally established during 2005 in the Red Rock-Prairie Creek caribou range of western Alberta (Figure 2). In 2017, Greenlink resurveyed 41 of these monitoring plots, largely following methods used in 2005 and during Golder’s 2015 data collection at treated sites (Golder 2015). Information collected at each 2017 naturally revegetating monitoring site included:

- site information including location information (i.e. GPS UTM coordinates) and site photos (i.e. up and down seismic line);
- tree revegetation data (count and height of all trees within macro plot, leader growth and previous year’s leader growth on all trees, number of whorls for 10 tallest conifer seedlings);
- vegetation data (% cover of: shrubs, grasses, downed woody debris, forbs);
- visual measurement of line-of sight (using Robel pole);
- estimate of soil drainage class, moisture regime, nutrient regime and organic matter depth; and

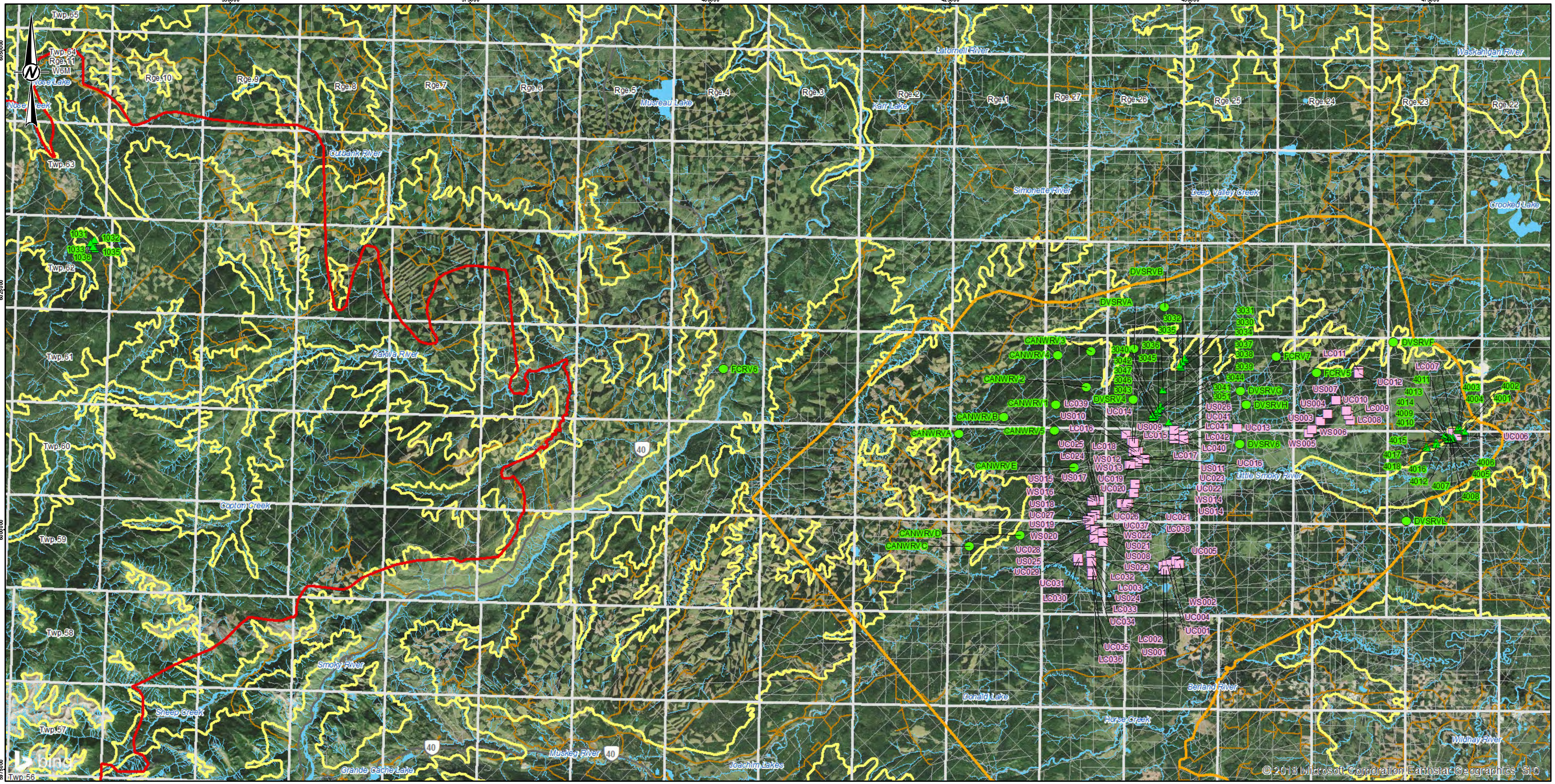
- incidental note of tags, providing date of seismic line disturbance and human activity on line (e.g., all-terrain vehicle [ATV] trail).

A summary of general site information collected at each 2017 plot is presented in Appendix B.

All Seismic Lines

All survey plot data from 2008, 2015, and 2017 were compiled and site locations were digitized using a Geographic Information System (GIS). The location of 2008, 2015, and 2017 plots in the study area is provided in Figure 2, with associated historical treatment types provided on Figures 3a, and 3b.

CRRP documents and data were reviewed to incorporate information on treatment date, treatment type (i.e., site preparation and planting method), species planted, planting density and stocking type (where available). When records on line age (i.e., the number of years since line was cleared or treated) were not available, an age was assigned to the line based on the oldest regenerating conifer seedling measured at that site (determined through counting whorls). Line orientation (i.e., the direction that line ran on the landscape) was determined for each survey plot and a wet area mapping layer created from Ducks Unlimited Canada's Canadian Wetland Inventory (DUC 2017) was used in GIS to assign a "Wet Index" value to each of the survey plots. The wet index values were assigned to each survey plot (both treated and natural revegetating plot) based on the depth to ground water from the surface, as estimated by the wet area mapping layer.



LEGEND

- 2008 SAMPLE PLOT (NATURALLY REGENERATING)
- 2015 SAMPLE PLOT (TREATED)
- 2017 SAMPLE PLOT (NATURALLY REGENERATING)
- NATURAL SUBREGION

CARIBOU RANGES

- LITTLE SMOKY
- REDROCK-PRAIRIE CREEK

BASE DATA

- LOCAL ROAD
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- SEISMIC LINE
- WATERCOURSE
- WATERBODY

0 15 30

1:400,000 KILOMETERES

REFERENCE(S)

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DATUM: NAD83 PROJECTION: UTM ZONE 11

CLIENT
PETROLEUM TECHNOLOGY ALLIANCE CANADA

CONSULTANT

Golder Associates

YYYY-MM-DD	2018-01-26
DESIGNED	MT
PREPARED	BP
REVIEWED	VC
APPROVED	PB

PROJECT
SEISMIC LINE MONITORING - LITTLE SMOKY AND REDROCK-PRAIRIE CREEK CARIBOU RANGES

TITLE
LOCATION OF 2008, 2015 AND 2017 NATURALLY REVEGETATING AND 2015 RESTORATION TREATMENT SAMPLE PLOTS

PROJECT NO.	CONTROL	REV.	FIGURE
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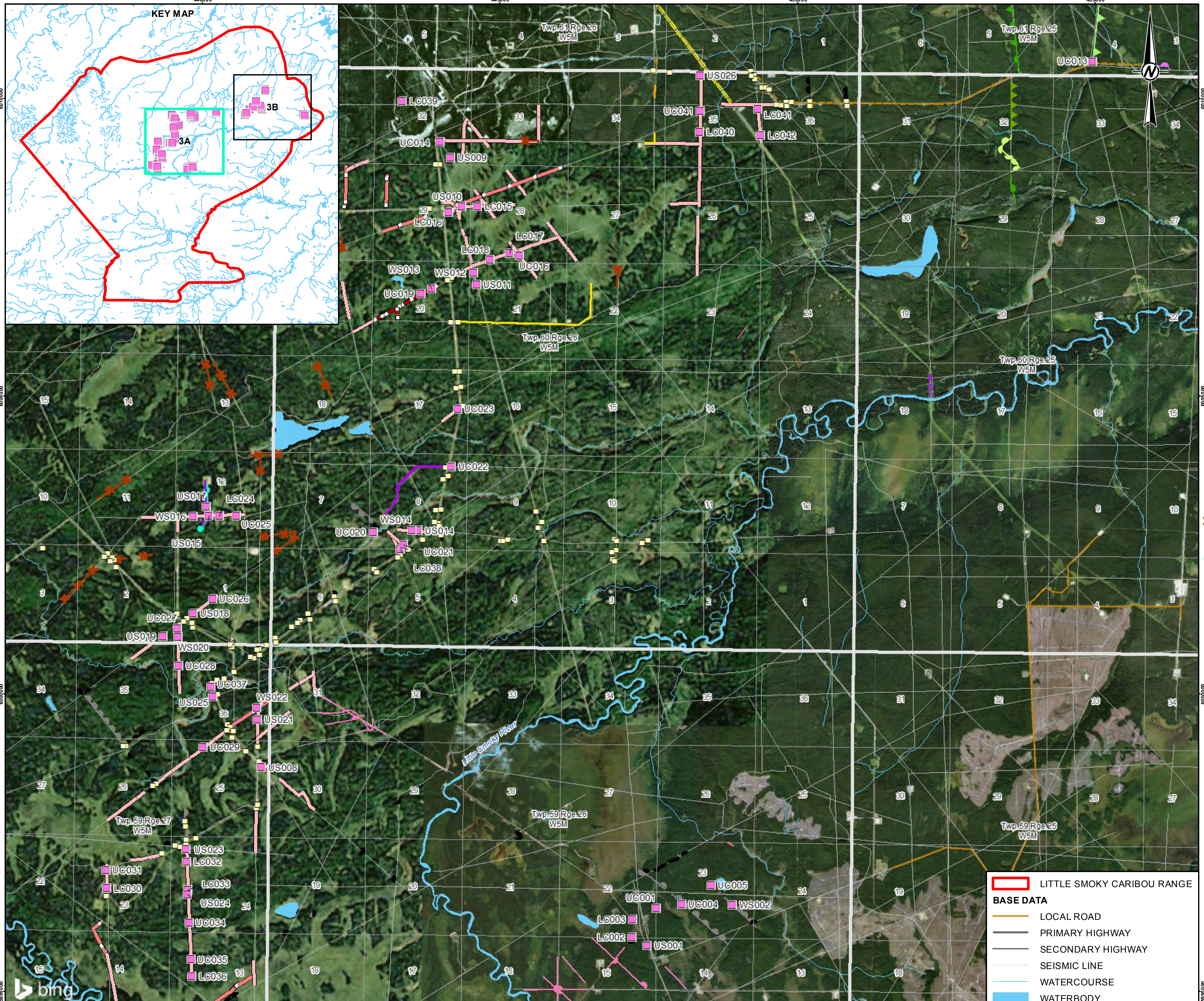

LEGEND

2015 SAMPLE PLOT (TREATED)

TREATMENT TYPE

- PLYWOOD FENCE LOCATION
- 2001 SUMMER PLANTED
- 2001 SUMMER PLANTED: PIPELINE
- 2002 EXCAVATOR MOUNDED
- 2002 EXCAVATOR MOUNDED: 2003 SPRING PLANTED
- 2002 EXCAVATOR MOUNDED: 2005 SUMMER PLANTED
- 2002 SUMMER PLANTED
- 2002 SUMMER PLANTED: LEASE ROAD
- 2002 RIPPER TOOTH
- 2002 RIPPER TOOTH: 2005 SUMMER PLANTED
- 2002/2003 4 m AVOIDANCE/WOODY DEBRIS: 2003 SUMMER PLANTED
- 2002/2003 4 m AVOIDANCE/WOODY DEBRIS
- 2002/2003 TRADITIONAL SEISMIC/WOODY DEBRIS
- 2003 EXCAVATOR MOUNDED: 2003 SUMMER PLANTED
- 2003 SPRING PLANTED
- 2003 SPRING PLANTED: AVOIDANCE
- 2003 SPRING PLANTED: PIPELINE
- 2003 SUMMER PLANTED
- 2003 SUMMER PLANTED: PIPELINE
- 2003 WOODY DEBRIS/TRADITIONAL SEISMIC: 2003 SUMMER PLANTED
- 2005 SUMMER PLANTED
- DUAL PATH MOUNDER
- DUAL PATH MOUNDER 1 PASS
- DUAL PATH MOUNDER 3 PASS
- EXCAVATOR MOUNDED
- FELLED TREES
- MOUNDING
- PLANTED AS IS
- WINTER ACCESS
- WOODY DEBRIS/EXCAVATOR MOUNDED

0 2 4

1:65,000 KILOMETRES

REFERENCES

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DATUM: NAD83 PROJECTION: UTM ZONE 11

CLIENT
PETROLEUM TECHNOLOGY ALLIANCE CANADA

PROJECT
SEISMIC LINE MONITORING - LITTLE SMOKY AND RED ROCK-PRAIRIE CARIBOU RANGES

TITLE
DEEP VALLEY 2015 TREATMENT MONITORING PLOTS ON SEISMIC LINE SEGMENTS

CONSULTANT

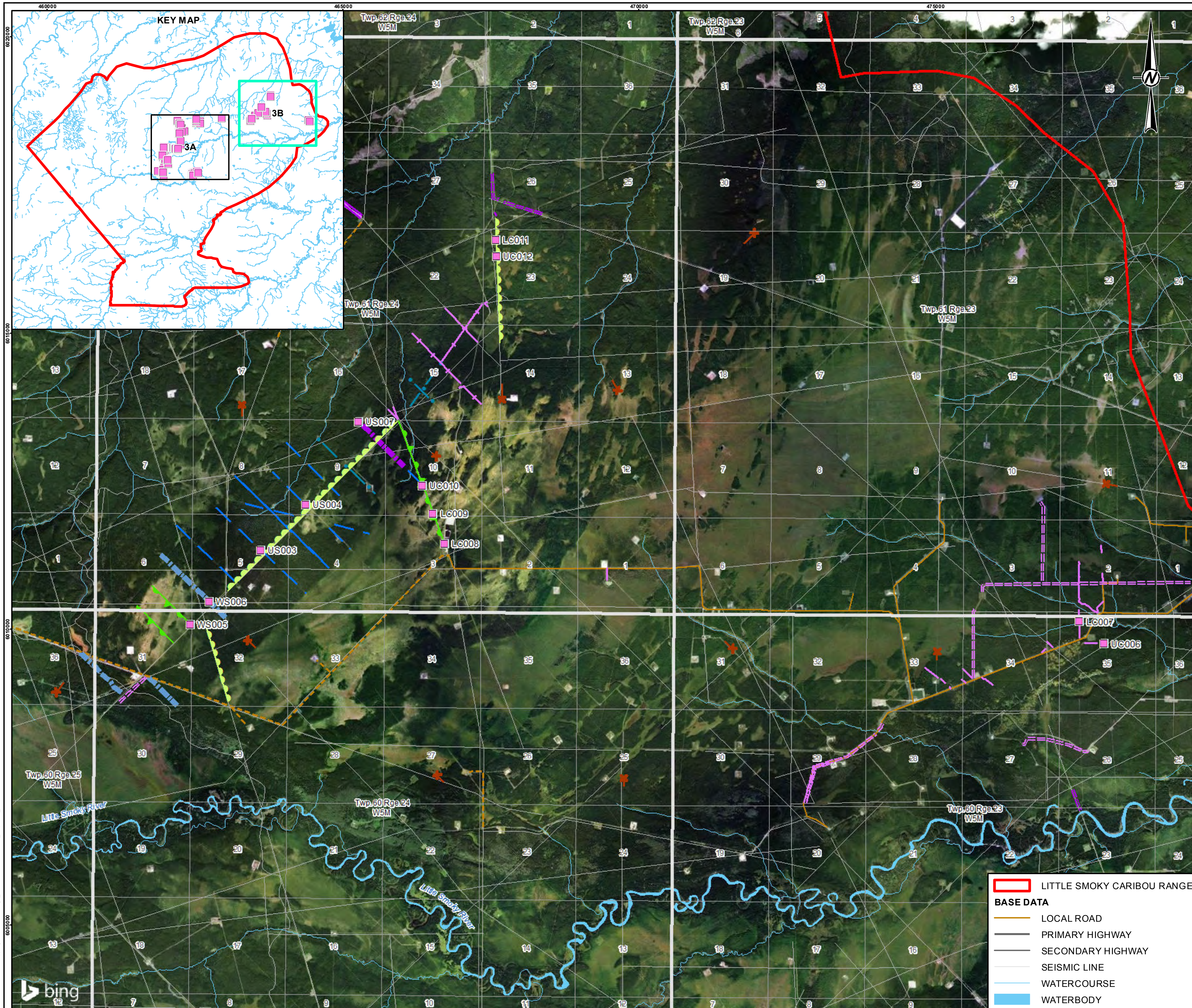
Golder Associates

YYYY-MM-DD	2018-01-26
DESIGNED	MT
PREPARED	BP
REVIEWED	VC
APPROVED	PB

PROJECT NO.	CONTROL	REV.	FIGURE
1784118	10	0	3A

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm

PATH: I:\2017\1784118\Mapping\MXD\Wildlife\Fig3_Wildlife2017Treatments_Mapbook_Rev0.mxd PRINTED ON: 2018-01-26 AT: 1:19:14 PM



LEGEND

- 2015 SAMPLE PLOT (TREATED)

TREATMENT TYPE

- PLYWOOD FENCE LOCATION
- 2001 SUMMER PLANTED
- 2001 SUMMER PLANTED: PIPELINE
- 2002 EXCAVATOR MOUNDED
- 2002 EXCAVATOR MOUNDED: 2003 SPRING PLANTED
- 2002 EXCAVATOR MOUNDED: 2005 SUMMER PLANTED
- 2002 SUMMER PLANTED
- 2002 SUMMER PLANTED: LEASE ROAD
- 2002 RIPPER TOOTH
- 2002 RIPPER TOOTH: 2005 SUMMER PLANTED
- 2002/2003 4 m AVOIDANCE/WOODY DEBRIS: 2003 SUMMER PLANTED
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- 2002/2003 TRADITIONAL SEISMIC/WOODY DEBRIS
- 2003 EXCAVATOR MOUNDED: 2003 SUMMER PLANTED
- 2003 SPRING PLANTED
- 2003 SPRING PLANTED: AVOIDANCE
- 2003 SPRING PLANTED: PIPELINE
- 2003 SUMMER PLANTED
- 2003 SUMMER PLANTED: PIPELINE
- 2003 WOODY DEBRIS/TRADITIONAL SEISMIC: 2003 SUMMER PLANTED
- 2005 SUMMER PLANTED
- DUAL PATH MOUNDER
- DUAL PATH MOUNDER 1 PASS
- DUAL PATH MOUNDER 3 PASS
- EXCAVATOR MOUNDED
- FELLED TREES
- MOUNDING
- PLANTED AS IS
- WINTER ACCESS
- WOODY DEBRIS/EXCAVATOR MOUNDED

0 2 4

1:65,000 KILOMETRES

REFERENCES

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DATUM: NAD83 PROJECTION: UTM ZONE 11

CLIENT
PETROLEUM TECHNOLOGY ALLIANCE CANADA

PROJECT
SEISMIC LINE MONITORING - LITTLE SMOKY AND RED ROCK-PRAIRIE CARIBOU RANGES

TITLE
FOX CREEK AREA 2015 TREATMENT MONITORING PLOTS ON SEISMIC LINE SEGMENTS

CONSULTANT

Golder Associates

YYYY-MM-DD	2018-01-26
DESIGNED	MT
PREPARED	BP
REVIEWED	VC
APPROVED	PB

PROJECT NO.	CONTROL	REV.	FIGURE
1784118	10	0	3B

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25mm

4.3 Data Analyses

4.3.1 Overview

In total, 67 treated plots (i.e., lines that received one or a combination of the treatment types described in Section 1.2) were surveyed in 2015. Seismic line treatment types were combined for analysis since the majority of lines received the mounding and planting treatment (53 of the 67 lines included in the analysis) and the sample size for lines with other treatment types (e.g., planting only, slash rollback) was too low to facilitate statistical comparison. Survey plots were therefore either classified as “treated” or “naturally revegetating”.

Data from treated lines were combined with data from naturally revegetating lines that were surveyed in 2008 (ConocoPhillips, CAPP and Suncor Project [Golder 2009]), 2015 (Golder 2015), and in 2017. All survey plots (i.e., both treated and naturally revegetating lines) were filtered for the presence of black spruce, tamarack, and/or lodgepole pine (i.e., lines that did not have black spruce or lodgepole pine seedlings present were excluded from the analysis). This yielded a total of 13 lines from 2008, four lines from 2015, and 36 lines from 2017, for a total of 53 naturally revegetating lines for inclusion in the analysis. Of the 41 plots surveyed in 2017, snow conditions prevented accurate collection of seedling age and height info at two plots while three other plots had no target seedling species present at the site, reducing the number of plots included in analysis to 36. All 67 treated plots sampled in 2015 had at least one of the three seedling species present so all treated plots were included in the analysis.

The 120 survey plots placed along seismic lines (67 plots along treated lines and 53 plots along naturally revegetating lines) occurred in 20 different ecosite phases or wetland types across three Natural Subregions (Table 1). To simplify the analysis, two broad land cover categories were created, upland and lowland, and each surveyed line was grouped into one of the two categories. Through this method, lines that occurred in rare ecosite types which lacked sufficient sample size to analyze separately were combined with other ecosite types and incorporated into data analysis. The upland land cover category was restricted to moisture regimes ranging from xeric to mesic, while the lowland category restricted to moisture regimes ranging from subhygric to hydric.

Data analyses were separated into three main components. The first component assessed seedling growth along treated seismic lines and compared growth metrics in planted individuals to growth metrics for naturally regenerating (through natural ingress) seedlings growing along these treated lines. The second component took a holistic approach to determine the effect of various environmental, ecological, and anthropogenic factors on conifer seedling growth metrics, growing on both treated and naturally revegetating seismic lines. The primary growth metrics assessed for conifer seedlings were height and leader growth (the current year’s growth). The third component used the leader growth and height metrics collected for individual seedlings on treated and naturally revegetating seismic lines to create growth trajectories for conifer seedlings along these lines. Growth trajectories were used to estimate the time required for regenerating seismic lines to reach ecologically important height thresholds in their recovery following results reported in Dickie (2015; et al. 2017).

Table 1: Summary of land cover at combined treated and naturally revegetating (natural) survey plots surveyed in 2008, 2015 and 2017.

			Number of Survey Plots		
Natural Subregion	**Ecosite/Wetland Code[a]**	**Ecosite Description**	**Natural Plots**	**Treated Plots**	**All Plots**
Lower Foothills					
lowland					
	h1	Labrador tea subhygric (black spruce-lodgepole pine)	2	0	2
	j1	Labrador tea/horsetail (black spruce-white spruce)	2	0	2
upland					
	c3	hairy wild rye submesic (aspen-white spruce-lodgepole pine)	1	0	1
	e3	low bush cranberry (aspen-white spruce-lodgepole pine)	1	0	1
	f3	bracted honeysuckle (aspen-white birch)	1	0	1
All Lower Foothills			***7***	***0***	***7***
Sub-alpine					
upland					
	d1	spruce/heather-mesic/poor (Engelmann spruce)	5	0	5
All Sub-alpine			***5***	***0***	***5***
Upper Foothills					
lowland					
	BTNN	wooded bog	0	1	1
	FTNN	wooded fen	1	18	19
	h1	Labrador tea-subhygric (black spruce-lodgepole pine)	11	14	25
upland					
	b1	bearberry/lichen-subxeric/poor	8	0	8
	c1	hairy wild rye-aspen (submesic/medium)	2	0	2
	c3	hairy wild rye submesic/medium (aspen-white spruce-lodgepole pine)	1	0	1
	d1	Labrador tea mesic (lodgepole pine-black spruce)	7	31	38
	e1	tall bilberry/arnica (lodgepole pine)	8	2	10

Table 1: Summary of land cover at combined treated and naturally revegetating (natural) survey plots surveyed in 2008, 2015 and 2017.

			Number of Survey Plots		
Natural Subregion	**Ecosite/Wetland Code[(a)]**	**Ecosite Description**	**Natural Plots**	**Treated Plots**	**All Plots**
	e2	tall bilberry/arnica (aspen-white spruce-lodgepole pine)	2	0	2
	e3	tall bilberry/arnica (white spruce)	3	1	4
	e4	tall bilberry/arnica (alpine fir)	1	0	1
	f1	bracted honeysuckle (lodgepole pine)	1	0	1
	f3	bracted honeysuckle (white birch-white spruce-lodgepole pine)	1	0	1
	f4	bracted honeysuckle (white spruce)	1	0	1
All Upper Foothills			***47***	***67***	***114***
Grand Total			**59**	**67**	**126**

[(a)] Ecosite and wetland type codes from Beckingham et al. 1996; Halsey et al. 2004

4.3.2 Planted vs. Natural Seedlings on Treated Seismic Lines

The first component of the analysis determined how leader growth and height differed between the planted and naturally regenerating seedlings on treated seismic lines. Analysis was restricted to only black spruce, since pine and tamarack were not planted at a high enough frequency to facilitate statistical comparisons. For black spruce, mixed effects regression models were created to explore the effects of environmental and ecological conditions on seedling growth at treated sites and to determine if planted black spruce perform better than naturally regenerating individual seedlings along treated seismic lines. A detailed description of the methods used for this analysis is outlined in the PTAC Caribou Range Restoration Treatment Sites Monitoring Report (Golder 2015).

4.3.3 Seedling Growth on Treated/Naturally Revegetating Seismic Lines

Treated and naturally revegetating survey plots with measured seedlings for either black spruce, tamarack, or lodgepole pine were included in this component of the analysis. Only the treated plots that received the mounding and planting or the mounding, planting, and slash-rollback treatments were included in the analysis. A series of general linear regression models using R (R Core Team 2015) were created to test for the effects of various explanatory variables describing environmental, ecological, and treatment-specific conditions, on the height and the leader growth of the three seedling species. At each survey plot, an average seedling height and average seedling leader growth measurement was calculated for each seedling species present. Both planted and naturally regenerating seedlings were included in these averages. Average seedling height and average leader growth for the three species was used as the response variable in the linear models and a separate suite of candidate models was created for each species of interest (i.e., black spruce were analyzed separately from tamarack and from lodgepole pine).

The explanatory variables (i.e., fixed effects) explored within the linear models included: seismic line width, seismic line orientation, land cover category (i.e., upland vs. lowland), treatment type, site wetness index, soil drainage category, depth of organic soil, shrub cover class, and graminoid cover class. Fixed effects included in the candidate models were selected based on their perceived importance to seedling growth on seismic lines. Several of the fixed effects selected for analysis (e.g., site wetness index, line orientation, land cover category) had previously been identified by van Rensen et al. (2015) as important factors in determining seismic line regeneration rates. Competition with understory vegetation and organic soil depth have been identified as important factors in determining the growth and success of conifer seedlings (Amaranthus et al. 1996; Brandeis et al. 2001; Caccia and Ballere 1998; Dodet et al. 2011). For analysis, the shrub percentage cover and graminoid percentage cover, measured at each sample plot, were converted into cover class ([<1%]; [1-5%]; [6-25%]; [26-50%]; [>50%]) and included in the model as a fixed effect.

To reduce the number of candidate models, explanatory variables were grouped into categories based on conspecific traits (e.g., seismic line width and seismic line orientation were grouped into a “Line Attributes” category) (Table 2). Candidate models for each seedling species of interest were created using all combinations of the four explanatory variable categories (16 candidate models were created for each seedling species). A null model which contained no fixed effects was also included as a candidate model for each species. For all categorical variables, a reference level of the variable was set prior to running the linear regression models (e.g., north-south was used as the reference level for the seismic line orientation variable and all other orientations were compared to the north-south orientation) (Table 2).

Table 2: Description of fixed effects included in candidate models explaining variation in seedling height and leader growth.

Explanatory Variable Category	Fixed Effects Included in Category	Fixed Effect Type	Description of Fixed Effect	Reference Level for Fixed Effect
Line Attributes	seismic line width	continuous variable	width of seismic lines measured at sample plots to nearest metre	n/a
	seismic line orientation	categorical variable	orientation of seismic line on the landscape based on cardinal direction; each line assigned to one of four categories (N-S, E-W, NE-SW, or NW-SE)[a]	N-S
Competition	grass cover class	categorical variable	percent cover of grass species at each survey plot, converted to cover class[b]	Cover Class E (>50% grass cover)
	shrub cover class	categorical variable	percent cover of shrub species at each survey plot, converted to cover class[b]	Cover Class E (>50% shrub cover)
Hydrology and Soil Conditions	site wetness index	categorical variable	each survey plot assigned a wetness index category based on digitized wet area mapping information for Alberta; each site assigned a category between 0 and 4[c]	Category 1 (ground water 0 - 0.1 metres below surface)
	soil drainage	categorical variable	soil drainage category assessed while in the field; each plot assigned one of three drainage categories[d]	Category C (imperfectly and poorly drained soils)
	organic soil depth	continuous variable	depth of organic material measured from the soil surface to the beginning of the A-horizon (measured to the nearest cm)[e]	n/a
Site Conditions	treatment category	categorical variable	each plot assigned one of two categories (“treated” or “naturally revegetating”) based on line conditions	Naturally revegetating
	land cover category	categorical variable	ecosite classification combined into two broad categories (upland or lowland); each plot assigned a land cover category based on ecosite present	Lowland
	treatment:land cover interaction	categorical variable	interaction term between the land cover type and the treatment type	Naturally regenerating lowland sites

[a] N-S = north-south, E-W = east-west, NE-SW = northeast-southwest, NW-SE = northwest-southeast

[b] Cover classes defined as the following: A = <1%; B = 1-5%; C = 6-25%; D = 26-50%; E = >50%

[c] Wetness Index Categories: **1** = water 0.0 - 0.1m from surface; **2** = water 0.1 - 0.25 m from surface; **3** = water 0.25 - 0.5 m from surface; **4** = water 0.50 – 1.0 m from surface; **0** = water too deep to detect (i.e., upland, dry habitat). Wet area mapping layer created from Ducks Unlimited Canada’s Canadian Wetland Inventory (DUC 2017)

[d] drainage categories: A = rapidly drained soils ; B = well and moderately-well drained soils; C = imperfectly and poorly drained soils. Neither ‘very rapidly drained’ nor ‘very poorly drained’ soils were encountered during data collection.

[e] Organic soil depth was collected at all survey plots sampled in 2015 and 2017 but not at the 13 naturally revegetating seismic lines sampled in 2008. Survey plots sampled in 2008 were still included in linear models but had blank values for organic soil depth.

n/a = not applicable, < = less than, > = greater than

Age of line (i.e., the number of years since line was cleared or treated) was included as a covariate in each candidate model since seedling height and leader growth were predicted to be directly related to the time since last disturbance on the line. Following tests for normality using the Shapiro-Wilk test, both seedling height and leader growth for black spruce, lodgepole pine, and tamarack were log transformed to meet the assumptions for parametric testing.

Model selection was based on an information-theoretic approach (i.e., Akaike's Information Criteria [AIC]). The AIC values for each model were corrected for small sample size (AICc) and candidate models were compared to one another through their AIC values. The model receiving the lowest AIC value was considered the highest ranked or most supported model (Burnham and Anderson 2002). Model predictions (i.e., how fixed effects impacted seedling height or leader growth) were obtained using parameter estimates from the highest ranking model(s) for each seedling species.

4.3.4 Height – Age Trajectory Models for Seedlings

Height–age growth trajectory models using mean height and leader growth parameters were developed for planted and naturally regenerating black spruce and lodgepole pine seedlings on upland and lowland site types. To predict height using leader growth, the annual incremental increase in mean leader growth had to be derived as leader growth is not constant over time and, instead, is presumed to incrementally increase on an annual basis as a tree grows larger. A natural log regression of age and mean leader growth was used to derive the equation to predict the annual incremental increase in mean leader growth for naturally regenerating black spruce and lodgepole pine seedlings (Table 3). The natural log regression models were run using only naturally regenerating individuals sampled in 2008 and 2017 since there was insufficient variation in the age of planted seedlings measured in 2015 (the majority of planted seedlings were determined to be 9 or 10 years of age) and age was not consistently collected for naturally regenerating seedlings during the 2015 survey year. Models were derived using 63 lodgepole pine seedlings from 25 survey plots and 121 black spruce seedlings from 25 survey plots.

Site type and organic matter depth were included as explanatory variables in the regression models for black spruce and for lodgepole pine to increase the explanatory power of the model. Although site type and organic matter depth may be related to each other, adding organic depth measurement provided a finer-scale indication of how the environmental conditions may affect leader growth. Including both variables in the models increased the amount of variation in leader growth explained and therefore increased the reliability of the model when used to create the height-trajectory models. Coefficient estimates produced by the model for each of the explanatory variables (age, organic depth, and site type) were used to create an equation to explain annual incremental increase in seedlings. A 95% confidence interval was also created for each of the coefficients produced by the models.

The annual incremental increase equations derived for naturally regenerating seedlings (see Table 3 for equations) were used to build the resulting height – age trajectory models. Although the equations were derived using only naturally regenerating individuals, they were used to create the growth trajectories for both the naturally regenerating seedlings as well as the treated seedlings. This represents a conservative approach as the leader growth for planted seedlings would likely increase at a faster rate compared to naturally regenerating seedlings, particularly in lowland habitat where planted individuals were placed on mounds, in choice microsite conditions. Due to small sample sizes detected at lowland sites, an annual incremental increase equation for lodgepole pine and resulting height – age trajectory model could only be calculated for upland sites (only six individuals measured for height, leader growth, and age at lowland sites).

Table 3: Model equations for predicting annual incremental increase of leader growth for naturally regenerating seedlings.

Tree Species	Site Type	Equation	Sample Size	R^2 for model	P-Value
Black Spruce	Upland	y = -3.041+13.421*(ln(age)+0.150(Avg. Organic Depth)	121	0.468	<0.001
	Lowland	y = -3.041+13.421*(ln(age)+(-4.240*(1)) + 0.150(Avg. Organic Depth)			
Lodgepole Pine	Upland	y = 3.647+9.139*(ln(age)+(-.040*(Avg. Organic Depth))	63	0.374	<0.001

Notes: y = predicted annual incremental increase in mean leader growth, x = age, ln = natural log

Using the annual incremental increase equations, the predicted annual leader growth was modelled over time using mean leader growth and mean age of tree seedlings, averaged across all survey plots as the starting point. Projected leader growth for both black spruce and lodgepole pine seedlings were calculated up to 100 years in age. Mean leader growth and mean age values were derived from all measured individuals and included both planted and naturally regenerating individuals when both were present. Mean leader growth and age values were calculated separately for treated seismic lines and for naturally revegetating seismic lines so that unique trajectories could be created for the two varieties of lines. Projected leader growth values were created for both species (black spruce and lodgepole pine) and separately for upland and for lowland individuals using the appropriate annual incremental equation listed in Table 3.

Once projected leader growth values had been established for each seedling type up to age 100, the total height of the seedlings were estimated for the same time period. For each year in age (x), the predicted height was determined using the estimated leader growth from the previous year (x-1). Similar to the leader growth projections, the starting point used to build the height projections was the mean height of all measured seedlings, averaged across all survey plots. Once height estimates had been made for each year, a growth trajectory model (i.e., growth curve), which showed the estimated seedling height through time, up to 100 years of age, was created.

Six separate growth curves were created for the various seedling types of interest. Each growth curve was displayed as the estimated seedling height at each year of seismic line recovery plus 95% confidence intervals showing the projected lower and upper limits of growth for regenerating seedlings. The six growth curves included:

Black Spruce

- Seedlings growing on treated lines in upland habitat
- Seedlings growing on treated lines in lowland habitat
- Seedlings growing on naturally revegetating lines in upland habitat
- Seedlings growing on naturally revegetating lines in lowland habitat

Lodgepole Pine

- Seedlings growing on treated lines in upland habitat
- Seedlings growing on naturally revegetating lines in upland habitat

Growth curves could not be built for lodgepole pine seedlings occurring in lowland habitat due to small sample size. The growth curves for all treated sites were built using only data from planted individuals present at the site since accurate age estimates (i.e., based on number of whorls) were not collected for the naturally regenerating individuals at treated sites.

5.0 RESULTS

5.1 General Observations for Surveyed Treated and Natural Revegetating Sites

Treated Survey Lines

A total of 67 treated sites (34 upland and 33 lowland sites) were visited in 2015. Overall, treated lines were found to have little to no recent signs of ATV/UTV use and more than half of the wooden fences installed for access control were found to be in relatively good condition (Golder 2015). Wildlife sign, including tracks or scat, were recorded at 38 of the 67 treated sites visited. A total of 14 of these sites with wildlife sign also had established game trails. Mounding was the primary site treatment applied to seismic lines (69% of upland sites and 85% of lowland sites) (Table 4) and black spruce was the primary species planted on the mounds. One observation noted from the field was that mounds degraded over time and were more obviously degraded in upland sites compared to lowland sites. Mounding also provided suitable microsites for naturally regenerating seedlings and both planted and naturally regenerating individual seedlings could be present on mounds, which made it challenging to discern planted from naturally regenerating individuals as planted seedlings were not tagged or marked in any way.

Field observations of planted black spruce seedlings noted increased mortality and necrotic symptoms in planted seedlings associated with very dry or very wet sites. Conversely, planted and naturally regenerating seedlings were found to be doing very well in transitional sites (e.g., h1 Labrador-tea subhygric lodgepole pine-black spruce ecosites). However, in several cases, it was noted that black spruce seedlings planted on mineral soil often had necrotic symptoms and occasionally poor lateral root development, likely arising from a lack of adventitious root development (e.g., Golder 2015, Figure 4) (Tim Vinge, pers. comm.). These observations are likely reflective of the drier site conditions present in upland sites, as well as the relative lack of organic matter, and possibly lower light regimes. The mounds in particular tended to be very dry which would inhibit rooting, as evidenced by the lack of lateral rooting on many of the planted seedlings on the upland mounds.

Figure 4: Unhealthy, spindly black spruce seedlings growing at treated upland site UC028, sampled in 2015.

Upland sites tended to have a greater percent cover of mineral soil and cobbles and stones (11.20% and 4.63%, respectively) compared to lowland sites (0.03% and 0.03%, respectively). Organic matter depth was also considerably less on upland sites (1.69 cm) compared to lowland sites (53.73 cm) (Table 4). In general, the upland sites had greater canopy closure than the lowland sites. As black spruce was the primary tree species planted on both upland and lowland treated lines, the poor growth on upland sites may be attributed to the nature of the treatments applied to these sites (e.g., mounding and planting of black spruce on the mounds) in combination with other factors, such as reduced solar insolation, and decreased moisture or nutrient availability for the planted black spruce (Lavoie et al. 2007a).

Through a new restoration framework for legacy seismic lines (GOA 2017b), the Government of Alberta has set minimum height targets for achieving successful conifer seedling stocking on regenerating linear features. The target height for seedlings differs depending on the site type and ranges from 60 cm in upland dry and low-density treed lowland sites to 80 cm in upland/transitional sites for seedlings 8-10 years old (GOA 2017b). Average age for treated sites sampled in the current study was 9.2 and 9.4 years for upland and lowland sites, respectively (Table 4). Average conifer seedling height measured at both upland treated sites (38.52 ± 2.54 cm) and lowland treated sites (55.39 ± 4.44 cm) were lower than the target heights outlined in the restoration framework.

Table 4: General Site Characteristics and Treatments Applied to Treated Upland and Lowland Sites.

Site Characteristics	Upland	Lowland
Sample Size	34	33
Drainage	rapid to moderately well	imperfectly to poorly
Moisture Regime	subxeric to mesic	subhygric to hydric
Mean Depth of Organic Layer (cm)	1.69	53.73
Mean Percent Surface Water	0.00	0.73
Mean Percent Mineral Soil	11.20	0.03
Mean Percent Cobbles & Stones	4.63	0.03
Mean Percent Organic Matter	80.89	97.70
Mean Percent Decaying Wood	3.91	1.52
Average Conifer Seedling Height (cm) ± SE	38.52 ± 2.54	55.39 ± 4.44
Average Age of Line (years)	9.2	9.4
Seismic Line Orientation (Number of sites)		
E-W	10	11
NE-SW	9	6
N-S	9	12
NW-SE	7	4
TREATMENT TYPE SUMMARY (Number of sites per treatment type)		
Mound - No Plant	1	1
Mound+Plant	23	28
Mound+Slash Rollback+Plant	1	1
Plant	6	1
Rip+Plant	1	0
Slash Rollback	1	1
Slash Rollback+Plant	1	1

Note: SE = standard error

Naturally Revegetating Lines

A total of 59 naturally revegetating survey sites were visited between 2008, 2015, and 2017 (Table 5). The majority of naturally revegetating sites occurred in upland habitat types (43 of 59 sites) and nine of the 59 sites (15%) had evidence of recent ATV use on the seismic lines. Of all naturally revegetating sites surveyed in 2008 and 2015, 12 of the 18 plots showed evidence of wildlife use (i.e., either scat or game trail present). Information on wildlife use along seismic lines was not explicitly collected in 2017 but when the same plots were initially established in 2006, 36 of 41 plots had evidence of wildlife game trails present.

In general, naturally revegetating sites had lower cover of organic material in both lowland and upland habitat, compared to the treated sites (Table 4 and 5). Average organic soil depths in upland habitats were much higher at naturally revegetating sites compared to treated sites in the same habitat type (upland treated = 1.69 cm; upland naturally regenerating = 7.74 cm). Mean mineral soil coverage measured at treated upland sites was higher (11.20%) compared to the mineral soil cover at upland naturally revegetating sites (2.00%).

Table 5: General Site Characteristics of Naturally Revegetating Upland and Lowland Sites.

Site Characteristics	Upland	Lowland
Sample Size	43	16
Soil Drainage	imperfectly to well	imperfectly to poorly
Moisture Regime	submesic to mesic	hygric to subhydric
Mean Depth of Organic Layer (cm)	7.74	17.67
Mean Percent Surface Water	0.04	0.03
Mean Percent Mineral Soil	2.00	0.81
Mean Percent Cobbles & Stones	0.47	0.09
Mean Percent Organic Matter	67.45	84.65
Mean Percent Decaying Wood	1.12	2.64
Average Conifer Seedling Height (cm) ± SE	120.67 ± 14.78	74.13 ± 15.29
Average Age of Line (years)	19.2	18.9
Seismic Line Orientation (Number of sites)		
E-W	6	2
NE-SW	11	6
N-S	13	4
NW-SE	13	4

5.2 Planted vs. Natural Seedlings on Treated Seismic Lines

The results of the mixed effect regression model comparing the heights of planted black spruce seedlings to naturally revegetating black spruce seedlings along treated seismic lines indicated that planted seedlings were significantly taller (mean height = 53.80 ± 1.81 [SE] cm) compared to naturally regenerating seedlings (mean height = 18.70 ± 0.69 cm) (X2(1) = 307.78, p < 0.001). Site type had a significant effect on black spruce seedling height (X2(1) = 6.85, p = 0.009). Individual planted seedlings associated with lowland sites were significantly taller (mean height = 29.90 ± 1.51 cm) than individuals growing in upland sites (mean height = 24.56 ± 1.01 cm). Lowland sites on average had taller seedlings, with planted individuals being taller than naturally regenerating individuals (Figure 5). Treatment age, shrub cover and depth to water did not have a significant effect on the height of all black spruce seedlings (planted and naturally regenerating individuals) measured on seismic lines.

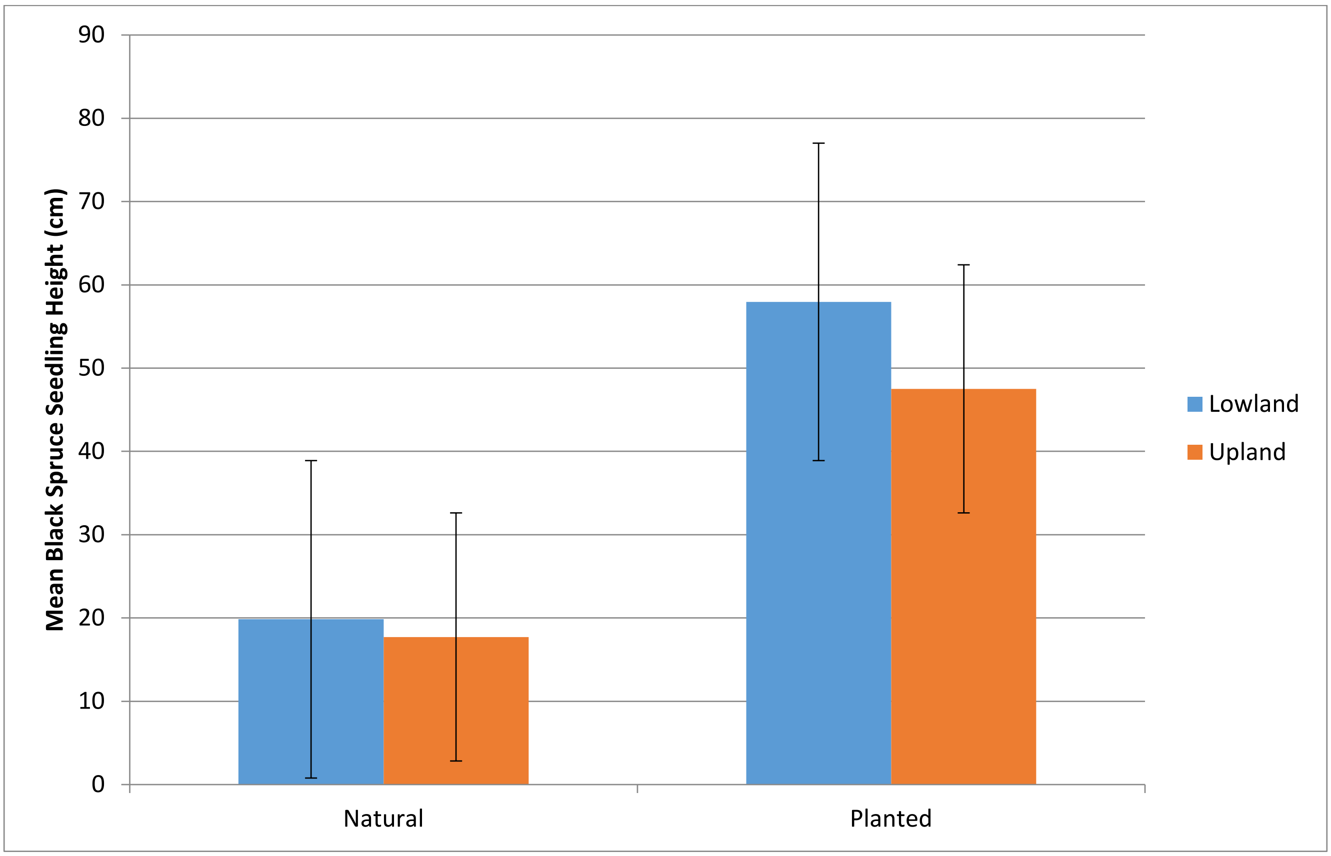

Figure 5: Comparison of Planted and Naturally Regenerating Black Spruce Seedling Mean Height +/- Standard Error on Lowland and Upland Sites.

Leader growth of black spruce seedlings showed similar patterns to those observed in the total height analysis. Black spruce seedling type ($X2_{(1)}$ = 20.64, p < 0.001) was found to have a significant effect on leader growth with planted individuals showing greater leader growth (4.98 ± 0.28 cm) than naturally regenerating individuals (3.45 ± 0.13 cm). Leader growth was also significantly affected by site type ($X2_{(1)}$ = 4.62, p = 0.03) with greater leader growth recorded at lowland sites (4.36 ± 0.23 cm) compared to upland sites (3.42 ± 0.10 cm). On average, lowland sites had greater seedling leader growth, with planted leader growth greater than naturally regenerating leader growth (Figure 6).

When the model for leader growth was initially run, shrub cover class showed a significant effect on leader growth in black spruce seedlings ($X2_{(3)} = 38.81$, $p < 0.001$). Upon closer inspection, the effect appeared to be largely driven by measurements for two outliers occurring in plots with <1% shrub cover. As these two seedlings were the only individuals recorded that occurred at sites with less than 1.0% shrub cover, the points were removed from the dataset and the model was re-run. Model results following the removal of the two outlier points indicated that shrub cover did not have a significant effect on leader growth ($X2_{(2)} = 1.94$, $p < 0.38$). Treatment age and depth to water were also found to not have a significant effect on the leader growth of black spruce seedlings (planted and naturally regenerating).

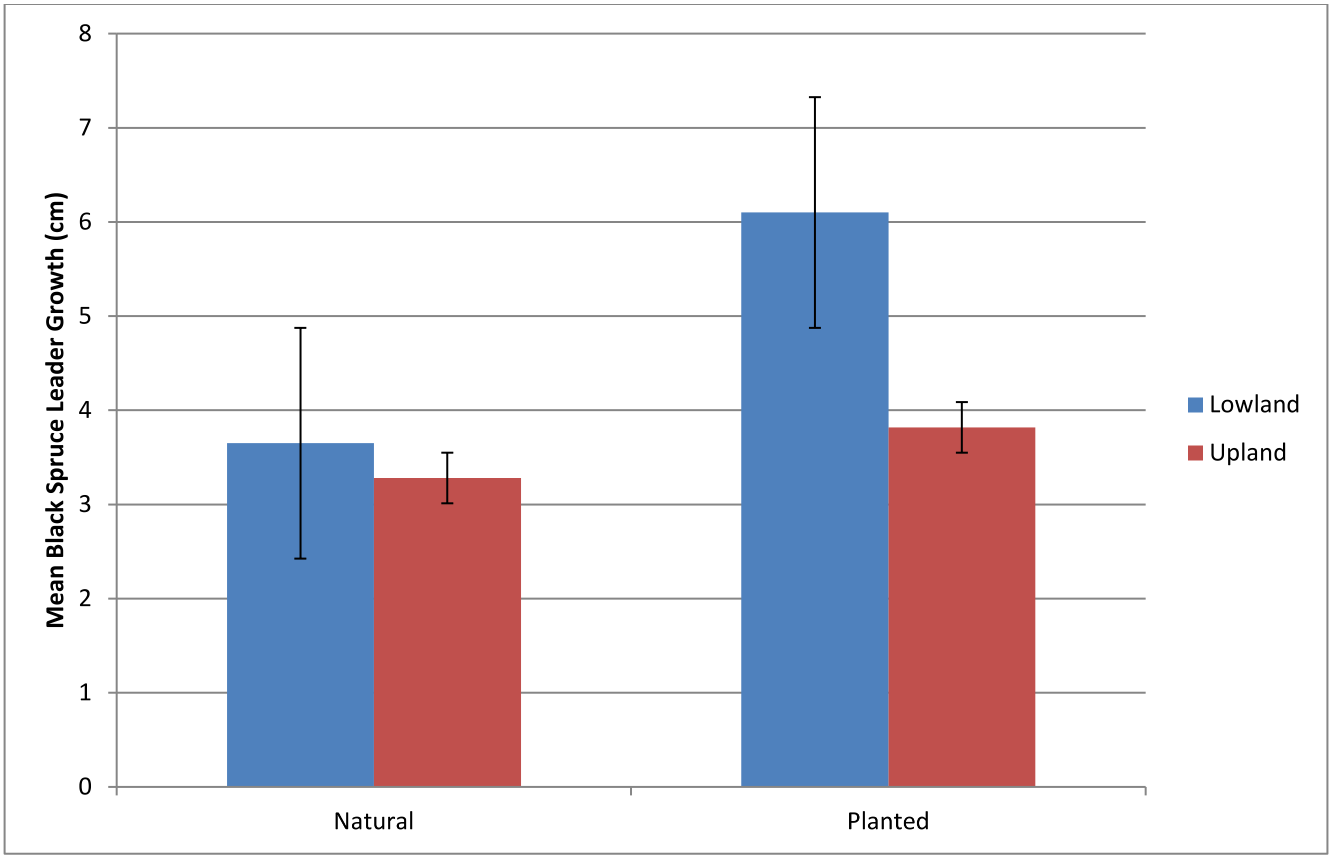

Figure 6: Comparison of Planted and Natural Black Spruce Mean Leader Growth +/- Standard Error on Lowland and Upland Sites.

5.3 Seedling Growth on Treated/Naturally Revegetating Seismic Lines

The data included in the seedling growth analysis on both treated and naturally revegetating seismic lines was restricted to only those survey plots that contained at least one individual from one of the three target conifer species (lodgepole pine, black spruce, and tamarack) and had a reliable age estimate for the seismic line that the plot occurred on (104 plots in total). Analysis included all naturally revegetating plots that met these criteria, but the treated sites included in the analysis were restricted to only those that received the mound+plant or the mound+slash rollback+plant treatments (52 of 67 treated plots). Table 6 provides a summary of all of the survey plots that were included in the analysis and the seedling attributes that were measured at these plots.

Table 6: Conifer seedling characteristics observed at treated and naturally revegetating survey plots in 2008, 2015, and 2017.

Species	Seismic Line Treatment Type	Number of Sites with Observations	Average Age of Sites with Observations (years)	Seedlings Included in Analysis	Average Seedling Height (cm ± SE)	Average Seedling Leader Growth (cm ± SE)
Black Spruce	Treated	52	9.3	534	44.64 ± 3.23	5.64 ± 9.74
	Naturally Revegetating	45	19.1	766	103.74 ± 16.65	13.98 ± 1.87
Lodgepole Pine	Treated	19	9.7	94	34.36 ± 5.63	6.00 ± 0.72
	Naturally Revegetating	32	18.5	244	131.7 ± 31.66	11.89 ± 1.75
Tamarack	Treated	17	9.8	91	49.14 ± 6.46	8.20 ± 1.32
	Naturally Revegetating	6	19.0	46	122.57 ± 38.24	11.72 ± 2.95

Note: SE = standard error

Separate suites of candidate models were created and tested to determine which environmental, ecological and treatment conditions had the greatest impact on seedling height and leader growth for the three target species. AIC was used to determine which candidate model(s) explained the most variation in seedling height or leader growth. The top model(s) were summarized to determine the direction and magnitude of the effect of explanatory variables on the response.

Black Spruce

There were two candidate height models that received a delta AIC value of less than 2.0, indicating that both of these models received significant support for being the best model for explaining variation in black spruce seedling height. Both candidate models included the “Site Conditions” explanatory variable category which included fixed effects representing land cover type (upland vs. wetland), treatment type (treated vs. naturally revegetating) and an interaction term between land cover and treatment type. The top model (i.e., the model that received the lowest AIC value) contained only the Site Conditions explanatory variable category while the model assigned the second lowest AIC value (i.e., second best model) contained both the Site Conditions and the Line Attributes categories.

When the top model was run, parameter coefficients indicated that neither site type (upland: $\beta = 0.119$, $P = 0.115$) nor treatment type (upland: $\beta = 0.141$, $P = 0.115$) had a statistically significant effect on black spruce seedling height but the interaction term between these two fixed effects did have a significant effect on the height (treated/upland: $\beta = -0.305$, $P = 0.006$). Age of seismic line also had a significant effect on black spruce seedling height with older lines supporting taller seedlings ($\beta = 0.024$, $P < 0.001$). The significant interaction term between treatment and land cover type indicated that the mounding and planting treatment had different impacts on black spruce seedling height depending on if the treatment was applied at upland sites or at lowland sites. At lowland sites, the mounding and planting treatments had a positive impact on seedling growth whereby treated plots (average height: 54.28 ± 5.85 cm) were similar in height to those that occurred on naturally revegetating lines (average height: 72.86 ± 13.64 cm) despite being approximately half the age (average age of treated line = 9.4 years; average age of natural lines = 18.9 years). At upland sites, black spruce seedlings did not appear to benefit from treatment as the seedlings (average height: 32.48 ± 2.84 cm) were, on average, much shorter than the black spruce seedlings growing on naturally revegetating upland sites (average height: 121.76 ± 23.66 cm).

Parameter estimates from the second best model showed similar results as the top model for the fixed effects representing the interaction between land cover and treatment type (treated:upland: β = -0.278, $P = 0.012$) and line age (β = 0.026, $P < 0.001$). The fixed effect representing seismic line width did not have a statistically significant effect on black spruce height (β = -0.033, $P = 0.164$) but the line orientation did; lines with a NW-SE orientation contained black spruce seedlings that were significantly taller (NW-SE: β = 0.171, $P = 0.028$) than seedlings that occurred on lines with an E-W orientation.

There were two top-rated models for black spruce leader growth which received a delta AIC value under 2.0. The highest ranked model (delta AIC = 0.0) contained the Site Conditions variable category and the second best model (delta AIC = 0.4) contained only the Competition category. The top model contained fixed effects for land cover, treatment type, an interaction between treatment type and land cover, and line age. Line age again had a significantly positive impact on black spruce leader growth (β = 0.031, $P < 0.001$) whereby leader growth was higher on older lines compared to younger lines. Like the top-ranked black spruce height model, the fixed effects for land cover (upland: β = -0.011, $P = 0.881$) and treatment type (treated: β = 0.079, $P = 0.081$) did not have a significant effect on leader growth alone but the interaction term between these two effects did (treated:upland: β = -0.283, $P = 0.005$). The disparity in leader growth between treated sites and naturally revegetating sites was quite pronounced in upland land cover, where average leader growth for treated sites (average leader growth: 3.37 ± 0.27 cm) was much lower than upland naturally revegetating sites (average leader growth: 13.76 ± 1.98 cm). Although leader growth at lowland sites was higher in naturally revegetating sites (average leader growth: 14.38 ± 3.30 cm) compared to lowland treated sites, the seedlings growing in areas that had been mounded and planted seemed to perform better (average leader growth: 7.45 ± 0.96 cm) than those that were growing in upland areas that had been mounded and planted.

Lodgepole Pine

A single candidate model for lodgepole pine height was selected by AIC as the best model. The top model contained fixed effects for line width, line orientation, and line age. When the top model was run, the coefficient values indicated that line width did not have a statistically significant effect on lodgepole pine height (β = -0.058, $P = 0.122$) but line age and line orientation did. Not surprisingly, older seismic lines were associated with taller pine seedlings (age: β = 0.034, $P < 0.001$). Pine seedlings growing on seismic lines with a NE-SW orientation were significantly shorter than seedlings growing on seismic lines with an E-W orientation (NE-SW: β = -0.578, $P < 0.001$) but no other significant differences were detected between the other orientations (i.e., N-S and NW-SE) compared to the E-W lines.

AIC identified two top models for explaining lodgepole pine leader growth, one of which was the null model which contained no fixed effects. Since the null model was ranked among the top models for explaining variation in lodgepole pine variation, this indicates that fixed effects included in the candidate models likely do not have a significant impact on lodgepole pine leader growth and as a result, the coefficients for the top models were not explored further.

Tamarack

A single candidate model describing variation in tamarack seedling height was assigned a delta AIC value less than 2.0. The top model contained just one fixed effect, representing age of the seismic line. Similar to the trends observed for black spruce and for lodgepole pine, survey plots on older seismic lines contained significantly taller tamarack seedlings than plots that occurred on younger lines (β = 0.030, $P < 0.001$).

Three candidate models for tamarack leader growth received a delta AIC value of less than 2.0. The top model contained the Line Attributes variable category, the second best model contained only a fixed effect for seismic line age and the third best model was the null model, containing no fixed effects. With the null model selected among the top models for explaining variation in tamarack leader growth, there is little support for any of the fixed effects selected for assessment having a significant impact on this growth metric.

5.4 Height – Age Trajectory Models for Seedlings

The results of the height – age trajectory models for black spruce and lodgepole pine provides a means for evaluating the relative amount of time (i.e., years) required for a seedling to reach specific height thresholds. As these predicted height – age trajectory models are based entirely from modelling the annual incremental change in leader growth and applying that model to the mean leader growth present at the current age of the trees to predict height, these models are not intended to be used in the same manner as traditional site index curves or growth intercept models. However, these models were compared to the provincial subregion-based site index curves for black spruce (Huang 1997) and lodgepole pine (Huang et al. 1997) to assess if the predicted height – age trajectory models were in line with the standard approach (i.e., were not grossly under or overestimating the height – age trajectory).

As a means of assessing functional regeneration of seismic lines, height thresholds of 1.4 m, 2.7 m, and 5.0 m were chosen as potential key indicators that influence the use of seismic lines by predators such as wolves, and human use. Research by both Dickie (2015), Dickie et al. (2016; 2017), and Finnegan et al. (2014) has reported that once vegetation reaches certain heights, the vegetation either slows down predators and/or acts as a deterrent to both human and predator use. Finnegan et al. (2014) found that at vegetation heights greater than 1.4 m, movement rates of both wolves and adult grizzly bears decreased by 70%, and that a change point in human use occurs at vegetation heights of approximately 2.0 m, after which human use decreases dramatically. Within the Little Smoky caribou range, Finnegan et al. (2014) classified seismic lines with vegetation heights less than 1.4 m as high human/predator use, vegetation heights between 1.4 m and 2.0 m as moderate human/predator use, and seismic lines with vegetation height greater than 2 m as low human/predator use.

When travelling on linear features, wolf travelling speed decreased by 20% after linear features reached a height of 1.0 m in summer, and travelling speed decreased by 26% after lines reached 2.7 m in winter (M. Dickie pers. comm.). When on linear features, wolves selected and moved faster on linear features with shorter vegetation compared to features with taller vegetation. Dickie et al. (2017) reported that wolves would no longer preferentially select linear features over undisturbed habitat when the average vegetation height on the linear features exceeded 5.0 m. They also found that wolves gained movement efficiencies by travelling on linear features until the vegetation on these features reached a height of 4.9 m, at which point they travelled at a similar speed on the features as they would through undisturbed habitat (Dickie et al. 2017).

5.4.1 Black Spruce

The results of the height – age trajectory models for black spruce on both lowland and upland sites appear to provide a reasonable estimate of height when compared to the provincial site index curves for black spruce in the Upper Foothills Subregion (Huang 1997). The predicted height of approximately 6.0 m (naturally revegetating) to 6.2 m (treated) at age 50 for lowland sites and 8.2 m (treated) to 8.6 m (naturally revegetating) at age 50 for upland sites is within the boundaries of the predicted site index at age 50, which ranges from 3 m to 26 m (Huang 1997). However, as these results fall towards the lower bound of the site index curve for black spruce in the Upper Foothills Subregion, this may indicate that the predicted height – age trajectory model is underestimating growth of black spruce. This may be attributed to the fact that the majority of the sites sampled are located in more nutrient poor ecosystems (e.g., d1 Labrador-tea mesic lodgepole pine-black spruce ecosites) under low light regimes and are often lacking in required levels of organic matter.

At upland sites, black spruce seedlings were projected to reach the height thresholds of 1.4, 2.7, and 5.0 m faster in naturally revegetating sites compared to treated sites. The projected age to reach 1.4 m in height was approximately 13 years for naturally revegetating sites compared to approximately 15.5 years for treated sites (Figure 7). To reach the height threshold of 2.7 m, treated sites required approximately 23 years whereas naturally revegetating sites would reach this threshold at approximately 21 years after disturbance. The 5.0 m threshold on seismic lines would be reached after 33 and 35 years for naturally revegetating and treated lines, respectively.

Based on the results from the current work and previous reports (Golder 2015), it appears that black spruce seedlings growing in upland conditions may not significantly benefit from site treatments. The previous summary report focused on treated seismic lines only and created separate growth curves for naturally regenerating seedlings and for planted seedlings. Comparisons between growth curves showed that black spruce seedlings planted on mounds received only a slight benefit in their growth trajectory compared to the naturally regenerating seedlings occurring on the same lines. At upland sites where treatments were applied, the majority received the mounding and planting treatment (25 of 36 treated plots). Upland sites were typically associated with well or moderately well drained soils so seedlings at these sites would be at a lower risk of stress due to flooded conditions and a high water table compared to plots that occurred in lowland habitat. Creating drier microsite conditions by creating mounds may not benefit black spruce seedlings at upland sites and instead could have the opposite effects where black spruce growing on top of mounds would be stressed due to lack of moisture in the soil.

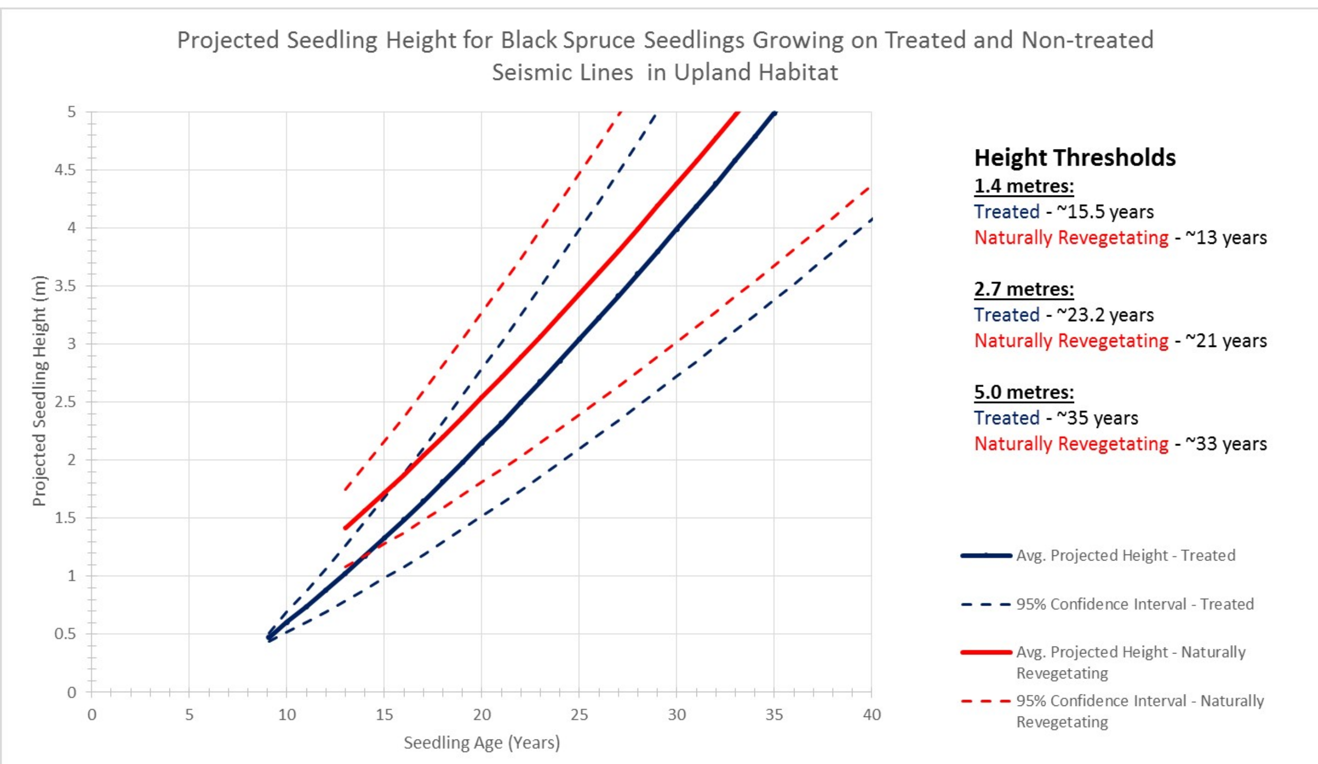

Figure 7: Projected growth curve for black spruce seedlings regenerating at upland survey plots.

Projected growth curves predicted that black spruce seedlings growing on treated seismic lines in lowland would reach the 1.4 m, 2.7 m, and 5.0 m thresholds faster than naturally revegetating lines although the difference in time required was small. Seedlings on treated seismic lines were projected to reach the 1.4 m threshold by approximately 17.7 years of age whereas seedlings growing on naturally revegetating lines were projected to reach 1.4 m in height by 19.6 years (Figure 8). To reach the 2.7 m height threshold, black spruce on treated lines required approximately

27.8 years compared to 29.3 years for individuals growing on naturally revegetating lines (Figure 8). Naturally revegetating lines would reach 5.0 m in height after approximately 44.5 years compared to 43 years for treated lines. Variation in the estimates was quite high (wide confidence intervals) due to the large range of heights observed for individuals growing in lowland habitat.

Previous findings that focused on treated sites only showed that black spruce seedlings that were planted as a part of treatments in wetland habitat were taller and showed higher growth rates than the naturally regenerating seedlings growing along the same treated seismic lines (Golder 2015). Growth curves created using only the seedlings from treated sites showed that planted seedlings were expected to be, on average, 1.5 m taller than naturally regenerating seedlings on treated wetland sites (Golder 2015).

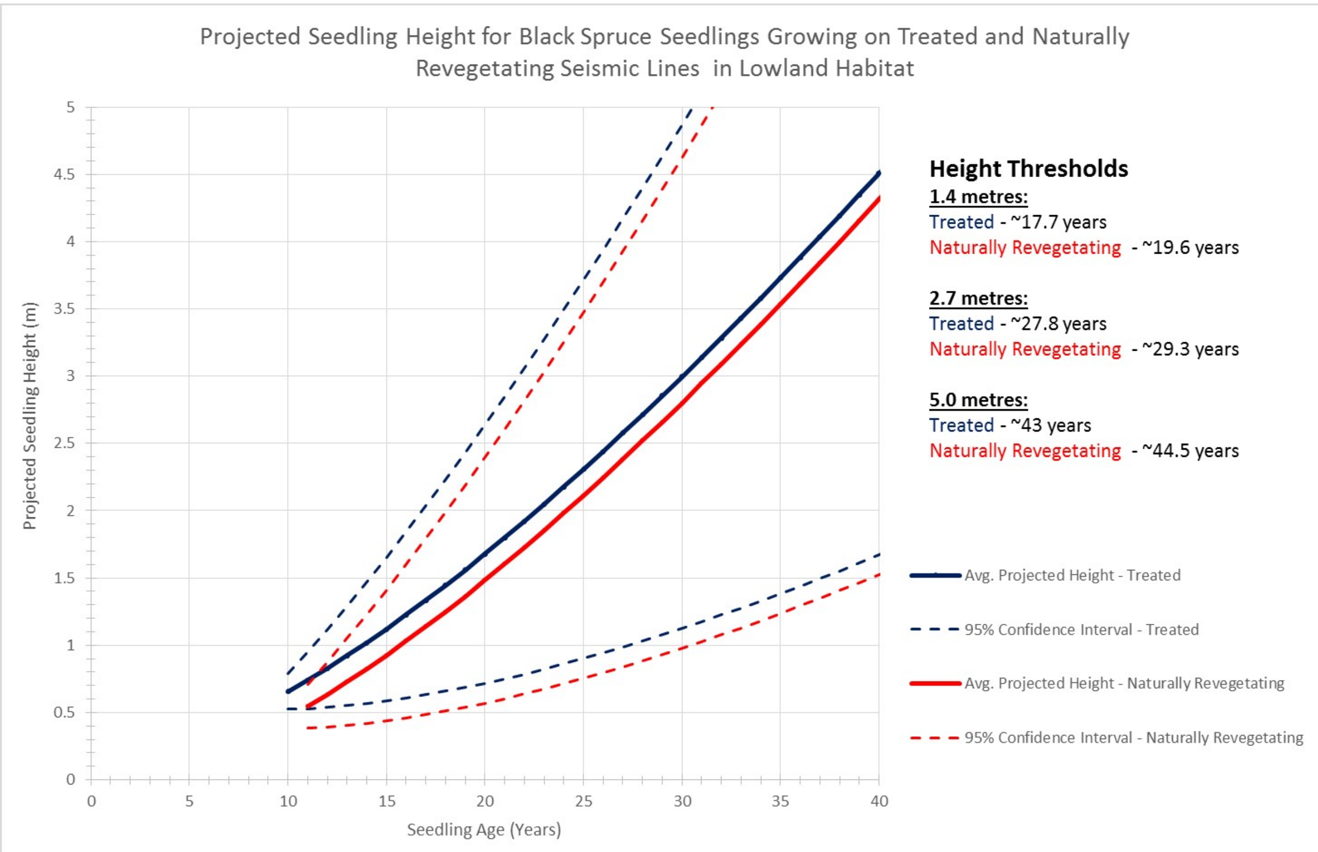

Figure 8: Projected growth curve for black spruce seedlings regenerating at lowland survey plots.

5.4.2 Lodgepole Pine

The results of the height – age trajectory model for lodgepole pine on upland sites appear to provide a reasonable estimate of height when compared to the provincial site index curves for lodgepole pine in the Upper Foothills Subregion (Huang et al. 1997), as the predicted upland height of approximately 7.5 m (treated sites) and 8.4 m (naturally regenerating) at age 50 is within the boundaries of the predicted site index at age 50, which range from 6 to 28 m (Huang et al. 1997). Although the explanatory power of the annual incremental change in leader growth model for lodgepole pine was quite high (R^2=0.374, $p < 0.001$), the results of the height – age trajectory model fall towards the lower bound of the site index curve for lodgepole pine in the Upper Foothills Subregion, which may indicate that the predicted height – age trajectory model is underestimating growth of lodgepole pine. This may also be attributed to the fact that the majority of the treated sites sampled are located in more nutrient poor ecosystems (e.g., d1 Labrador-tea mesic lodgepole pine-black spruce ecosites).

Based on the height – age trajectory model, lodgepole pine seedlings at naturally regenerating sites are predicted to reach 1.4 m height by approximately age 10, 2.7 m height by age 19, and 5.0 m by an approximate age of 32.5 (Figure 9). In comparison, pine seedlings growing on treated lines would reach the 1.4, 2.7, and 5.0 m thresholds by age 16, 24, and 37, respectively.

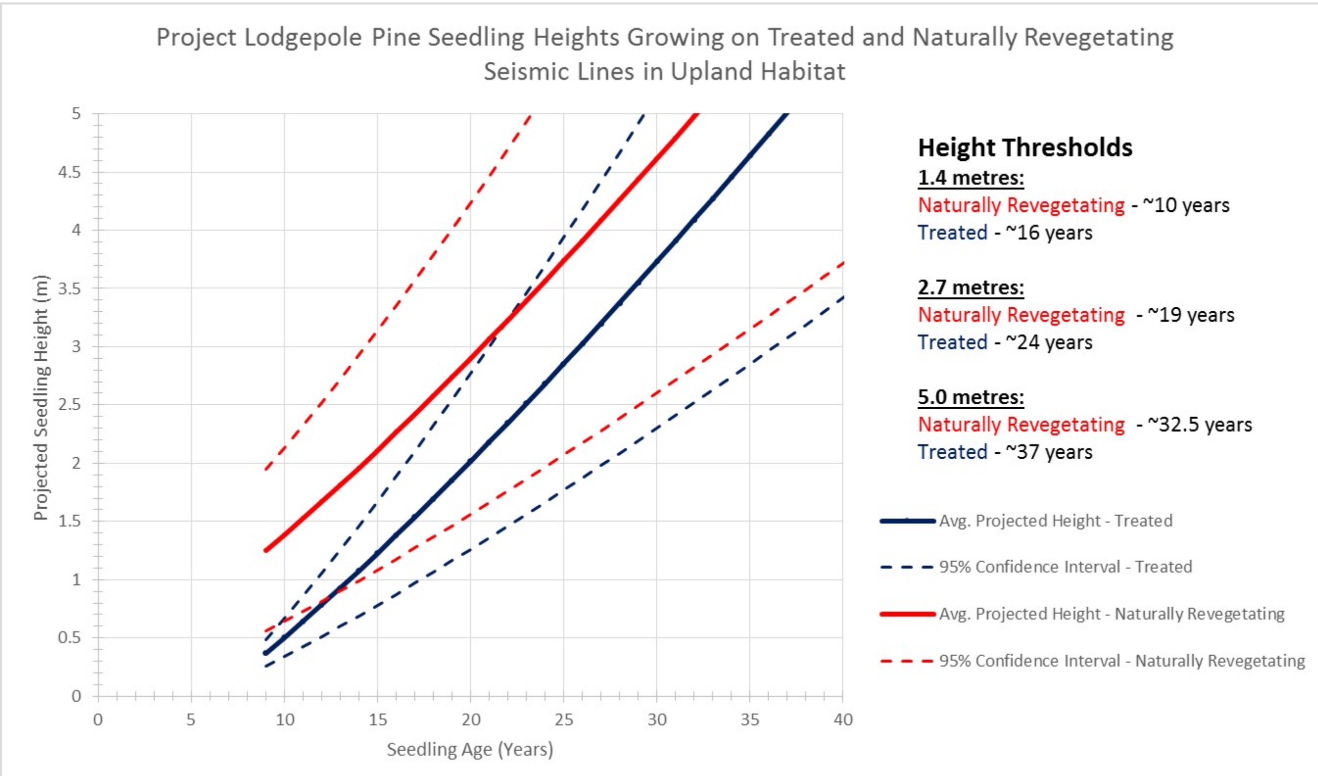

Figure 9: Projected growth curve for lodgepole pine seedlings regenerating at upland survey plots.

6.0 DISCUSSION

Through the Alberta Caribou Action Plan (GOA 2016), the Alberta government has committed to restoring 10,000 km of seismic lines within the Little Smoky and À La Peche caribou ranges over the next five years. To effectively implement restoration programs in this area of the province, the benefits and/or constraints of different methods of restoration need to be explored first so that appropriate treatment methods can be applied. An abundance of research has gone into assessing vegetation recovery following forestry harvest and the silviculture techniques that are effective in expediting recovery of forest stands. Comparatively few studies have focused on assessing the effectiveness of restoration measures in accelerating vegetation recovery, particularly with regards to what treatments (e.g., access control, site preparation, planting seedlings, seeding) are applied, where, and under what conditions. Our work provides a preliminary assessment of how effective silviculture treatments can be in expediting vegetation recovery on deactivated seismic lines and identifies the conditions where different treatment techniques can be used to maximize recovery.

Factors Affecting Seedling Growth on Regenerating Seismic Lines

Although few comprehensive long-term studies have been completed on the natural recovery of seismic lines, a study by Revel et al. (1984) in the Boreal Foothills, Boreal uplands and Sub-alpine natural subregions of Alberta found that the natural recovery of trees on seismic lines was generally poor as evidenced by slow growth rates. Few conifer seedlings attained a height of 2.0 m in the period of 10 to 30 years, primarily a result of the cutting or re-shooting of lines. Additionally, growth rates of regenerating trees on seismic lines was much lower compared to trees in clear cuts, as regenerating lodgepole pine and black spruce seedlings on seismic lines reached a maximum height of 0.47 m and 1.32 m, respectively at age 11, compared to 6.5 m and 2.5 m (at age 15), for regenerating lodgepole pine and black spruce on a clear cut (Revel et al. 1984). In general, natural recovery and regeneration of tree cover along seismic lines is affected by competition from ground cover such as grasses and shrubs, time since disturbance, method of disturbance during seismic line creation, species composition of adjacent forest and human/wildlife use of the lines (Revel et al. 1984).

More recent research by van Rensen et al. (2015) investigating the factors influencing natural regeneration of trees and shrubs on seismic lines found that there was an inverse relationship between regeneration to 3 m and terrain wetness, line width, proximity to roads (as a proxy for human use) and lowland ecosites. Model predictions of future regeneration rates on seismic lines also suggested that regeneration of trees and shrubs on at least one-third of existing seismic lines would fail to reach 3.0 m height after 50 years (van Rensen et al. 2015), which illustrates the importance of accelerating natural recovery trajectories on seismic lines.

In our current study, time since disturbance was one of the most important factors affecting seedling growth in all three conifer species measured. As expected, older seismic lines tended to support taller seedlings with superior leader growth measurements compared to lines that had experienced disturbance more recently (i.e., younger lines). Line orientation also had a significant effect on black spruce and lodgepole pine seedling height. Black spruce seedlings seemed to benefit from growing on lines that received more sunlight (i.e., average height was greater on NE-SW lines compared to E-W). Counterintuitively, lodgepole pine were significantly taller on E-W running lines (i.e., more shaded lines) than pine seedlings growing on lines associated with greater exposure to sunlight (i.e., NE-SW lines). Lodgepole pine is considered a shade intolerant species that grows best in open conditions and, though well suited to dry upland conditions, may not fare well on seismic lines with taller adjacent canopies. We expected to see lodgepole pine growth to be lowest on E-W lines where light levels would be lowest (van Rensen et al. 2015). Although it is unclear what may have caused the opposite trend to be observed in this study, there were two outlier sites that occurred on NE-SW running lines with extremely short lodgepole pine seedlings (average heights were 1.0 cm and 2.8cm) The plots fell well below the average for lodgepole pine seedling height on NE-SW oriented plots (average height = 41.00 cm) and likely played a role in impacting the statistical results.

Out of the three conifer seedling species assessed, black spruce seedlings seemed to be most impacted by treatment type applied to seismic lines. Results from the linear candidate models showed that black spruce seedling height and leader growth seemed to benefit from mounding and planting treatments in lowland habitat but the opposite appeared to occur when the treatments were applied in upland habitat. At lowland sites, where growing conditions can be too wet for optimal black spruce growth, implementing mounding treatments, as expected, improved the microsite conditions for black spruce by providing a drier growing environment. This phenomenon was reflected in the growth measurements taken at the treated sites sampled in this study where planted individuals at lowland sites were significantly taller and had greater leader growth than the naturally regenerating seedlings growing at the same sites (Section 5.2). Results from the age – growth trajectories and the linear regression models also indicated that black spruce seedlings growing in lowland habitat experienced accelerated growth when treatments were applied, compared to naturally revegetating lines.

Forestry research on silvicultural practices has shown that site preparation such as mounding is an effective treatment for increasing survival and growth of spruce species, as site preparation creates a better substrate and drainage for tree growth and can also decrease competition and increase soil temperature (Macadam & Bedford 1998; Roy et al. 1999; Londo and Mroz 2001; MacIsaac et al. 2004; Thiffault et al. 2010; Lafleur 2011). A study by Macadam and Bedford (1998) on mounding in the Sub-boreal Spruce Zone of west central British Columbia reported that hybridized white spruce on mounded sites experienced increased growth rates compared to wetter, untreated sites. This is also supported by research conducted by Vinge and Lieffers (2011) in the same survey area as the current study, which found that mounding lowland sites encouraged naturally regenerating black spruce individuals.

Clear benefits of mounding and planting black spruce in upland habitat were not detected during the current study. Average seedling heights for individuals growing on treated upland sites in the current site (38.52 ± 2.54 cm) were lower than the target seedling heights set by the provincial restoration framework (60 cm for upland dry sites at age 8-10) (GOA 2017b). Growth trajectories provided little evidence that applying site preparation treatments to upland sites had a positive impact on conifer seedling regeneration. For both lodgepole pine and black spruce, individuals growing on upland naturally revegetating sites were projected to reach ecological height thresholds in fewer years than individuals growing on upland treated sites. Linear models also indicated that mounding and planting treatments in upland sites did not seem to benefit seedling growth with individuals performing worse at treated sites than those growing in naturally revegetating sites. Disparity in the seedling performance at upland treated sites and upland naturally revegetating sites could be attributed to two main factors: 1) the site conditions present at the treated sites prior to treatment and 2) the techniques used to treat these upland sites.

When the site conditions were compared between the treated upland sites and the naturally revegetating upland sites, soil characteristics at the treated sites were generally more inhospitable to black spruce growth than the naturally revegetating sites (Tables 4 and 5). Percentage cover of cobbles, and mineral soil were higher at treated sites compared to naturally revegetating sites and the depth of organic matter was much lower in treated uplands compared to naturally revegetating upland sites. A lack of organic matter and an abundance of mineral soil and cobbles presented challenging growing conditions for black spruce at treated plots (Government of British Columbia 2002) and these site conditions likely played a role in the reduced performance of planted and naturally regenerating seedlings at these plots. The growth of black spruce has been shown to be strongly influenced by both moisture and nutrient conditions, with poorer growth occurring on dry, gravelly sites or wet peaty sites (Lowry 1974; Lavoie et al. 2007a). While the site preparation techniques used at treated sites likely improved growing conditions from what was present at these sites prior to treatment (i.e., reducing soil compaction through mounding was better than leaving the site untreated), these sites likely would have further benefited from treatment techniques that targeted soil quality in these areas.

Planting on top of mounds in uplands was generally implemented as a strategy by the CRRP to increase available growing degree days for seedlings, as the top of the mounds warm up earlier in the spring compared to the adjacent ground. However, as indicated by this study, where black spruce was planted on top of mounds in very dry, nutrient poor sites it tended to have poor growth, as evidenced by poor lateral root growth, poor color and relatively low leader growth rates. In several cases black spruce seedlings planted on mineral soil in upland sites often had necrotic symptoms and occasionally poor lateral root development, likely arising from a lack of adventitious root development (e.g., Photos C-16 and C-17, Appendix A) (Tim Vinge, pers. comm.). Creating drier microsites for planted seedlings by mounding likely suppresses growth rather than facilitating growth for species like black spruce growing in upland habitat. Similar trends for upland habitat were observed by Vinge and Lieffers (2011) in the same study region, where black spruce was found to have relatively poor growth on both treated (e.g., mounded) and untreated sites. Not all microsites that are conducive for the establishment of black spruce are the same as those required for optimal growth, as indicated by Lavoie et al. (2007b). For example, optimal growth of black spruce is associated with moderately drained soils and moderate organic layer (to provide nutrients), as opposed to mineral soil substrates (Lowry 1974; Lavoie et al. 2007a). Planting seedlings lower down on the interface of mounds or in the mound holes may improve growth by addressing moisture limitations.

The effect of site preparation on lodgepole pine seedlings seemed inconclusive at best, since treatment type was not identified as an important factor in models created for pine height or leader growth (i.e., mounding and planting did not significantly impact pine seedling growth), and growth trajectory models indicated that naturally revegetating lines would reach height thresholds faster than treated lines would. Since lodgepole pine tend to thrive in drier, upland conditions, they are unlikely to greatly benefit from mounding as a site preparation the same way that black spruce seedlings in lowland habitats would benefit. Unfortunately, due to low sample sizes of plots in these alternate treatment types (only 14 of 67 treatment plots sampled were not mounded and planted), the effectiveness of these non-mounding treatments could not be assessed in this study.

Treatment Recommendations

Rehabilitating disturbed and degraded forestry sites that occur in upland areas can be challenging due to the high compaction of the soil and the lack of organic matter and nutrients for regenerating seedlings. Moisture can also be a limiting factor on upland sites, due to loss of organic material and tree roots from the trees at the adjacent ecosite drawing water contributing to deficiencies (Vinge pers. comm.). Site preparation techniques in these areas should be site-specific and should focus on promoting moisture retention, increasing the presence of organic matter, and alleviating soil compaction.

In upland areas, using site preparation methods like ploughing the lines and breaking up the soil will allow moisture to penetrate deeper into the soil and site profile (Vinge pers. comm; Government of British Columbia 2002). Deep plowing can also sever the tree roots from the adjacent ecosite, contributing to less moisture loss. Wood applications either from spreading coarse woody debris across the site, felling trees, and/or applying mulch will help create micro-sites that will retain moisture (Vinge pers. comm.). At sites where natural regeneration of conifer seedlings is limited, soil amendments that increase the presence of organic matter at these sites (i.e., either redistribute organic matter at the site or bring in organic matter from elsewhere) may be helpful in promoting seedling growth and regeneration (Government of British Columbia 2002). Seeding grasses and forbs may also increase the presence of organic matter at these sites since these plants will enhance organic matter depth through root decomposition (Government of British Columbia 2002). Plotnikoff et al. (2002) found that winged subsoiling (i.e., ploughing) and seedling grasses and legumes seemed to benefit planted lodgepole pine seedlings and promoted forest re-establishment.

The site preparation techniques listed above would likely benefit lodgepole pine growth more than a mounding treatment would in these upland habitat types. Mounding could continue to be used as a site preparation technique on uplands where human access control is a consideration, such as at intersections with roads. In areas where access control is less of a concern, consideration for treatment sites to be ripped up, creating troughs and hollows to capture moisture and create microsites, and woody debris applications should be incorporated (Vinge pers. comm).

Taking all these factors into consideration, the treatment of sites must be tailored to site conditions and site limiting factors to achieve the best results in the most cost effective manner possible. Combinations of treatments should be employed and tailored to meet the objectives of the area in question and planted species should be selected based on site conditions. For example, in this study area, mounding and planting was found to be an effective treatment approach for lowland sites, though there is a need to be more strategic about where black spruce is planted, such as targeting transitional h1 Labrador-tea subhygric lodgepole pine – black spruce sites. Addressing poor growth conditions through site treatments, particularly in upland areas, will encourage the growth of planted and naturally regenerating conifer seedlings and will ultimately speed up the recovery process.

Consideration for planting other species should be employed, such as planting tamarack on lowland sites or, given the site specific conditions that may limit revegetation on upland sites such as a lack of moisture and sufficient organic layer, planting or seeding early-seral stage species such as pine and alder. Pine may not thrive in conditions with less sunlight, but does well on nutrient and moisture deficient sites. Alder can also be planted which is a fast growing low shrub that fixes its own nitrogen (Bayne et al. 2011), allowing it to establish on severely disturbed sites. Alder could also help create a functioning organic layer quickly. Applying both woody debris and mounding treatments will re-create hump and hollow terrain that is common on undisturbed lowland sites and may limit human travel that will help protect planted seedlings and natural revegetation.

Implementing mechanical site preparation and planting seedlings are relatively expensive, therefore how and where treatments are applied needs to be carefully considered. Site limiting factors need to be identified, and treatments recommended that are tailored to address those factors, with an emphasis on promoting the natural restoration processes.

Growth Trajectories and Outlook for Habitat Recovery

The majority of the research to date on the recovery of seismic lines has focused on understanding wildlife use and response to linear disturbance features (James and Stuart-Smith 2000; Oberg 2001; James et al. 2004; Golder 2009; Latham et al. 2011a, 2011b, Finnegan et al. 2014; Dickie et al. 2016; 2017). Recent research by Dickie (2015) and Dickie et al. (2016; 2017) has shown that vegetation height is a significant factor affecting wolf travel along seismic lines. On average, wolf travelling speed decreased with increasing vegetation height, and wolves were found to select linear features with shorter vegetation compared to taller vegetation. Most of the benefits to movement efficiency gained by wolves travelling on linear features was lost once vegetation on these features reached at least 50 cm in height (Dickie et al. 2017); compared to features with next to no vegetation present, wolves traveled 1.5 to 1.7 km/hr slower on linear features with vegetation that exceeded 50 cm in height (Dickie et al. 2017). Of particular note, wolf travelling speed in summer decreased by 20% once vegetation reached a height of 1.0 m and wolf travelling speed in winter decreased by 26% once vegetation reached a height of 2.7 m (Dickie pers. comm.). Movement rates along linear features was also greater than rates in forested habitat until at least 34% of the linear feature supported vegetation greater than 4.9 m in height, at which point wolf movement rates were similar between forested areas and on linear features. Wolf selection of linear features varied by season and changed with different heights of vegetation present. In general, wolves would select linear features during the summer unless vegetation on the features exceeded 5.0 m in height, but some individuals would avoid linear features once vegetation heights reached 3.0 m (Dickie et al. 2017). During the winter, wolves would stop selecting linear features over other land cover categories if the vegetation heights on the linear feature exceeded 50 cm.

Finnegan et al. (2014) also reported similar results, where the movement rates of both wolves and grizzly bears decreased by up to 70% on seismic lines where vegetation height exceeded 1.4 m. Additionally, human use of seismic lines was significantly affected by vegetation height, with moderate to high intensity use by humans declining markedly once vegetation height exceeded 2.0 m (Finnegan et al. 2014). Both studies used GPS collar data to estimate changes in predator travel speeds but identified different vegetation height thresholds, possibly due to differences in the study area location. Finnegan et al. (2014) conducted their study in west-central Alberta, in the same areas as this present study, whereas Dickie's (2015) study was located in northeastern Alberta. Thus, the results from this research provide a preliminary benchmark for when seismic lines can be considered to influence predator movement rates along revegetating linear disturbances, which can then be applied as preliminary threshold values to evaluate if treatment of seismic lines can accelerate the recovery time of vegetation, specifically as it pertains to tree regeneration.

The identification of preliminary vegetation height benchmarks (i.e., 1.4 m, 2.7 m, and 5.0 m) and this study's findings on time to achieve these heights has direct implications for resource managers preparing range-level habitat planning under the federal recovery strategy for boreal woodland caribou (EC 2012). Specifically, the study findings on vegetation heights over time suggest that vegetation height should be a criterion considered when defining and mapping linear disturbances (for caribou). Environment and Climate Change Canada's methods for mapping habitat disturbance defined anthropogenic disturbances as "any human-caused disturbance to the natural landscape that could be identified visually from Landsat imagery at a scale of 1:50,000" (EC 2011, p.16). This study provides quantitative estimates of time required for trees to grow in order to reduce predator movements (i.e., habitat that no longer enhances predator use). Environment and Climate Change Canada (EC 2012) currently does not provide a definition for 'restored habitat' but does indicate that critical habitat presents biophysical attributes required to support caribou life processes (EC 2012). Knowing that planted black spruce on treated lowland sites reaches 1.4 m by age 18 and 2.7 m by age 27, and that previously burned areas are considered critical habitat 40 years post-fire (EC 2012) suggests that linear disturbances could be considered critical habitat 40 years after the implementation of restoration treatments, though benefits of improved habitat condition would presumably be realized before 40 years.

In general, treatments applied to regenerating seismic lines did not seem to have a significant impact on the growth trajectories of the conifer seedlings growing on these lines as compared to sites that were experiencing natural revegetation. Naturally revegetating lines were projected to reach the 1.4, 2.7, and 5.0 m height thresholds sooner than equivalent treated lines in all scenarios, with the exception of lowland black spruce. Although these are preliminary assessments of the effectiveness of applying site preparation treatments to recovering seismic lines, these results seem to suggest that applying treatments to seismic lines in an effort to expedite the recovery process may not have the same positive effects on recovery as is currently believed. Our results should, however, be assessed with a few important caveats.

Soil and growing conditions at treated and naturally revegetating sites were quite different and could have driven the growth patterns observed at both types of sites. Increased organic depth and decreased cobbles and mineral soils at naturally regenerating sites provide better growing conditions for black spruce seedlings compared to the treated sites. As outlined earlier in the discussion section, treatment types applied through the CRRP focused heavily on mounding and planting methods which seemed to be an effective treatment type for lowland sites but less so when applied to upland areas. Both black spruce and lodgepole pine seedlings seemed to struggle at upland sites that had been mounded which certainly would have impacted the growth trajectories created for these sites. If more site-appropriate treatments had been applied to a greater number of upland treated plots, with a focus on soil enhancements and properties, growth trajectories may have predicted better seedling growth at these sites. Also, due to low variation in the age of planted seedlings, growth curves for treated sites needed to be built using the annual incremental increase formulas from naturally revegetating sites. As a result, growth trajectories for seedlings on treated lines may be an underestimate of the true growth potential, particularly for planted seedlings at lowland sites which seemed to benefit from the mounding treatments that they received.

Caveats aside, our study reiterates the importance of evaluating site specific conditions when considering treatment options prior to implementing any treatment program aimed at expediting linear feature restoration. Due to the high costs of executing site preparation treatments and the seemingly underwhelming benefits gained from treating sites, as observed in the current study, we recommend that significant planning and cost-benefit analyses be conducted prior to implementing restoration programs targeting seismic lines in caribou habitat.

7.0 RECOMMENDATIONS

Through the course of completing the current retroactive monitoring study, a number of key learnings and recommendations around the general program, including specifics on the monitoring protocol, data collection, data management, and sample design, have been identified to facilitate the implementation of future programs. These learnings and recommendations are outlined below.

- In this study the best effort was made to compare vegetation data from treated and natural regeneration vegetation, but a lack of standardized data collection protocols made statistical comparisons in data challenging. Standardized monitoring protocols, including level of detail in data to collect, should be developed and applied to facilitate comparison of data and results from different sources, which would allow for greater understanding of the effectiveness of restoration treatments on vegetation growth trajectories.
- Collecting accurate age measurements (i.e., based on number of whorls) for conifer seedlings is important if growth trajectories are to be created in the future. Programs aiming to create growth trajectories for regenerating seedlings should collect information on the height, leader growth, and age of a subset of seedlings within each survey plot so that accurate projections can be made.
- Vegetation growth trajectories take time to develop. To address uncertainties around trajectories and timelines to reach thresholds, data should be stored in a centralized location that can be easily accessible and updated through time. Having a fully compiled dataset, which includes age of treatments, treatment details, age of trees on naturally regenerating plots, and site conditions should be incorporated to the monitoring data.
- Permanent sampling plots (i.e., plot centre) should be established so that treatment and natural regenerating sites can be re-monitored over time. Permanent sample plots should consider a paired sampling design (e.g., treated and untreated plots established on the same line which control for age since disturbance, type of disturbance, line orientation, and site type) to control site condition variables (Figure 10). Sampling design should also consider size of plots and number of plots to account for variability along narrow seismic lines.
- Tagging planted trees (use zip ties) to reduce the difficulty in identifying planted versus naturally regenerating individuals, particularly in older sites will become increasingly important.

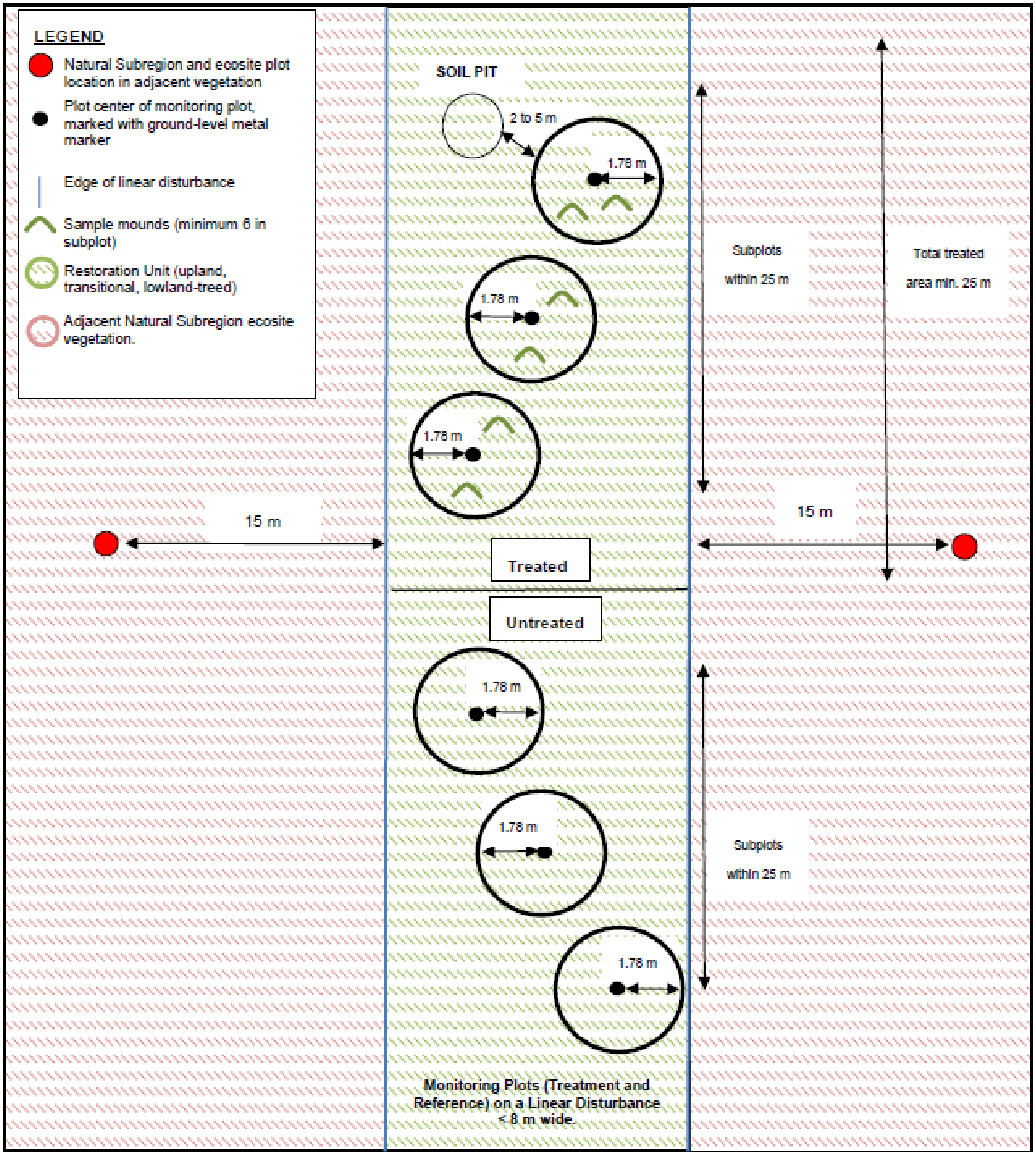

Figure 10: Paired Treatment and Reference Plot Layout on a Linear Disturbance < 8 m wide. Modified from BC Habitat Restoration Monitoring Framework.

8.0 CONCLUSION

In summary, planted black spruce seedlings on treated sites were significantly taller and had significantly greater leader growth compared to naturally regenerating individuals. Line age and treatment type had the greatest impact on black spruce seedling growth of all factors included in analysis, whereas line orientation and cover by competitive plant species (i.e., grasses and shrubs) had the greatest effect on lodgepole pine seedling growth. None of the explanatory variables explored seemed to have a significant effect on tamarack seedling height and leader growth.

The results from the height-age trajectory models showed that treated site trajectories showed similar or reduced growth rates compared to naturally revegetating sites. Treating seismic lines on wetter sites through mounding and planting of black spruce seemed to accelerate the rate of recovery in these areas but growth trajectories for upland sites indicated that treatments were not effective in speeding up the recovery process for this species with naturally revegetating sites requiring shorter periods of time to reach height thresholds. Lodgepole pine seedlings at naturally regenerating sites were predicted to reach 1.4 m height by approximately age 10, 2.7 m height by age 19, and 5.0 m by an approximate age of 32.5 (Figure 9). In comparison, pine seedlings growing on treated lines would reach the 1.4, 2.7, and 5.0 m thresholds by age 16, 24, and 37, respectively.

Treating upland sites did not appear to accelerate the rate of recovery over natural vegetation recovery for either lodgepole pine or black spruce. Applying mounding treatments to upland habitats seemed to have little benefit to black spruce or lodgepole pine seedling growth and instead seemed to act as a detriment to seedling regeneration at these sites. These results suggest that treatment needs to be more targeted to natural regenerative systems and applied based on an understanding of site limiting factors and conditions to achieve the most optimal results. Thus, consideration for whether an upland site should be planted with seedlings, seeded, or left for natural seed ingress, as well as which species to introduce within upland sites of higher mineral and lower moisture content, and the use of coarse woody debris or other soil enhancements, or placement of seedlings lower down in a mound, should be considered in future restoration trials within upland sites.

The results from this research provide a preliminary benchmark for the timeline needed for historical seismic lines to be considered habitat which slows down or influences predator movements. The results could be applied as preliminary targets to evaluate if treatment of seismic lines can accelerate the recovery time of vegetation, specifically as it pertains to tree revegetation. The study findings suggest that vegetation height should be a criterion considered when defining and mapping linear disturbances (for caribou).

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