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Natural Recovery on Low Impact Seismic Lines in Northeast British Columbia (BCIP-2016-18)

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REPORT

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Executive Summary

Golder Associates Ltd (Golder) and Explor were supported by the Research and Effectiveness Monitoring Board (REMB) of the BCIP initiative, with funding provided by the BC Oil and Gas Research and Innovation Society (BC OGRIS) to study the natural recovery of vegetation along Low Impact Seismic (LIS) lines in Northeast British Columbia (NE BC). Seisimc activity has been ongoing in NE BC since the 1970s and the region experienced an increased rate and spatial extent of activity in the early 2000s. Boreal woodland caribou also occur throughout the region in several population units, none of which are considered to be self-sustaining under the current Federal caribou recovery strategy. To continuously improve caribou management in the region it is critical to understand whether the LIS lines used to support exploration achieve their intended management objectives of mitigating impacts to caribou.

In this report we tracked the accumulation and measured the recovery trajectories of mulched LIS lines prepared between 2005 and 2015. In a Geographic Information System (GIS) we tallied the total linear kilometer (km) of LIS lines mulched and measured the recovery trajectories of those lines. We used a mensurative approach to estimate LIS line recovery trajectories. We developed a sampling design to compare the influence of forest type, line width, line orientation, and year line was cut on vegetation structural and compositional recovery timing. We also compared whether new lines recovered differently than existing lines. A total of 188 LIS lines were sampled within the Maxhamish, Snake-Sahtaneh and Calendar boreal caribou ranges during the summer of 2016. Age since disturbance ranged from 2 to 11 years, with LIS lines almost exclusively cut by mulchers and running primarily north-south or east-west in orientation. Mulch distribution ranged from none, to scattered or continuous. Line widths ranged from 1.27 m to 7.7 m, averaging 3.2 m, with mulched seismic lines across a variety of forest types. Since 2005, the proportion of very wide LIS lines cut decreased while the proportion of narrower lines increased.

LIS line recovery mirrors general recovery patterns reported for conventional lines wherein upland and deciduous forest types support taller and more recovery of woody biomass compared to lowland and wetland forest types. In contrast, our results show much more rapid recovery to structural states that likely influence wolf use of lines. Controlling for forest type, we show LIS lines typically support shrubs > 0.8 m high within 10 years. Thus, for mulched LIS lines between one and ten years old recovery to shrubs is immediate and higher than the 0.5 m height which has been indicated in recent studies to influence wolf movement. Additionally, over half of sampled LIS lines in lowland ecosites supported black spruce seedlings. Many lowland lines supported seedlings > 0.5 m tall immediately after they were mulched (i.e., 1 year after being mulched). These results confirm that by mulching, LIS line preparation is preventing the ground disturbance impacts from conventional lines.

Line orientation, mulch distribution pattern, and ecosite type all had a significant effect on the average height of vegetation regenerating on LIS lines. Vegetation height was significantly greater on lines with a north-south orientation compared to lines with an east-west orientation. Compared to lines with a continuous mulch distribution, lines with scattered mulch or no mulch supported significantly higher vegetation. Lines that occurred in wetlands, lowlands and upland coniferous ecosites had significantly shorter vegetation compared to lines occurring in deciduous uplands. Neither line width nor age of line had a significant impact on the overall height of vegetation regenerating on LIS lines.

The presence of black spruce seedlings was also significantly influenced by line age and line orientation. Lines with a north-south orientation were significantly less likely to support black spruce seedlings than lines with an east-west orientation. Black spruce seedlings were also more likely to occur on older lines than younger lines Neither line width, the dispersal pattern of mulch, nor the percent cover of tall and low shrubs had a significant effect on the occurrence of black spruce seedlings. However, the height of black spruce seedlings was significantly influenced by line width and mulch distribution pattern, and by ecosite. Seedling height was significantly shorter on wider lines compared to narrower lines. Seedlings were also significantly shorter on lines with scattered mulch distribution compared to plots with a continuous mulch distribution, and along lines in upland coniferous stands compared to lowland stands.

Alder was detected at approximately 19% of plots sampled and willow was detected at approximately 27% of plots sampled on LIS. Results indicated that both willow and alder were significantly more likely to occur on wider lines compared to narrower lines. Willow was also more likely to occur on lines with a scattered mulch compared to a continuous distribution, and somewhat more likely to occur in wetland ecosites than upland deciduous ecosites. Alder was significantly less likely to occur on lines in wetland ecosites compared to upland deciduous ecosites and was significantly less likely to occur on older lines compared to younger lines. Shrub stem counts and height measurements also indicated that stems of both willow and alder were more abundant on wider lines. Shrub stem abundance on LIS lines compared to abundances in adjacent sample plots that occurred in undisturbed habitat indicated that there was not a significant difference in the number of willow stems however, there were significantly more alder stems present on LIS lines. Line age was the only variable that explained a significant amount of variation in alder or willow height, with average heights greater on older lines compared to younger lines.

LIS lines supported fewer game trials than conventional seismic lines in the region. Game trails were present on approximately 16% of the 188 LIS sampled in 2016 but on 64% of conventional seismic lines in the Parker Caribou Range, as measured in 2015.

Based on our results, we provide recommendations on best management and operations practices for LIS line preparation in NE BC. Despite gradual reduction in LIS line widths in NE BC, LIS are likely too wide to prevent triggering behavioural responses in wildlife. We recommend that LIS widths should be targeted to as narrow as possible (≤ 2.0 m mulched). Line width and orientation should also be integrated within seismic survey planning to achieve best results. Mulch should, and could, be managed to foster conifer seedling persistence when in a continuous distribution pattern; with variations dependent upon forest type. Footprint minimization, even when considering LIS programs, needs to be managed. Lastly, although we show short term recovery of vegetation along LIS lines, we can only infer long term recovery trajectory and associated wildlife behaviour response.

Acknowledgements

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1.0 INTRODUCTION

Golder Associates Ltd (Golder) and Explor were supported by the Research and Effectiveness Monitoring Board (REMB) of the BCIP initiative, with funding provided by the BC Oil and Gas Research and Innovation Society (BC OGRIS) to study the natural recovery and wildlife use of Low Impact Seismic Lines in Northeast British Columbia (the Project). This report provides an analysis and interpretation of data collected, and recommendations on best management and operations practices for LIS line preparation in Northeast British Columbia.

Seismic exploration, a principal step in oil and gas exploration, is the process of triggering and interpreting energy waves to map geologic strata and identify hydrocarbon deposits. In forested regions of the world seismic exploration is often facilitated by creating linear corridors, called seismic lines, to provide access for field personnel and equipment. Managing the impacts of seismic lines on wildlife is a perennial challenge for industry and land and wildlife managers in Canada. Of particular concern is the influence of seismic lines on predator-prey relationships between wolves and boreal woodland caribou. Boreal woodland caribou are listed federally as threatened in Canada (Environment Canada 2012) and declines in caribou populations are due in part to seismic lines that increase spatial and temporal overlap between caribou and wolves (McLoughlin et al. 2003, Festa-Bianchet et al. 2011, Hervieux et al. 2013). The Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population in Canada (Environment Canada 2012), identifies coordinated actions to reclaim caribou habitat as a key step to meeting caribou population objectives. Actions include restoring industrial features such as roads, pipelines, transmission lines and seismic lines to reduce fragmentation and associated increased caribou predation pressure. Reliance on habitat restoration as a recovery action for caribou within the federal Recovery Strategy is high. An identified threshold of 65% undisturbed habitat in a caribou range is required to provide a 60% chance that a local population will be self-sustaining. As an effort to reverse and prevent wolf use of seismic lines, habitat restoration is considered a critical component of long-term caribou habitat management in ranges that overlap areas of oil and gas exploration and production (hereafter E&P) activity (Bentham and Coupal 2015).

Where E&P activity is high, seismic lines can accumulate to very high densities. In western Canada, widespread seismic exploration has been ongoing since the early-1950s (Morrell et al. 1995, Rintoul 2007). While definitive numbers are difficult to obtain, millions of kilometers of seismic lines have been created across British Columbia, Alberta, Saskatchewan, and the Yukon and Northwest Territories to date (IHS Seismic Database), and they are the most numerous disturbance type associated with E&P in boreal regions (Schneider 2002, Komers and Stanojevic 2013). Prior to the late-1990s seismic lines were cut between 6 and 8 m wide using bulldozers (Lee and Boutin 2006; conventional seismic lines). By the late-1990s line construction practices began to shift toward preparation of narrower, meandering seismic lines using specialized equipment to more precisely target vegetation removal during construction (Tamarack Solutions 2003, AECOM 2009; low-impact seismic or LIS).

Wolves use conventional lines to access caribou habitat (James and Stuart-Smith 2000, Latham et al. 2011) and use of lines increases wolf search efficiency for prey and encounter rate of caribou (Whittington et al. 2011, DeCesare 2012, Ehlers et al. 2014, Dickie et al. 2016), more so at higher line densities (McKenzie et al. 2012, Dickie et al. 2016, DeMars et al. 2016), which likely increase predation of caribou by wolves. Natural recovery of vegetation along conventional lines can slow wolf movement along and dissuade selection for lines as travel conduits (Dickie 2015), presumably decreasing caribou depredation. Unfortunately, the timing, trajectory, and success of recovery is inconsistent (Kemper and Macdonald 2009*a*, Jorgenson et al. 2010, Lankau 2014, van Rensen 2014). Even decades after construction, conventional lines can remain as open and semi open features with significantly different vegetation structure and composition compared to adjacent, off-line plots (Revel et al. 1984, Lee and Boutin 2006, Kemper and Macdonald 2009*b*, van Rensen et al. 2015). With respect to wolves and caribou, this inconsistency undermines natural recovery as a feasible management strategy for conventional lines. Instead, active reclamation efforts including mounding, seedling planting, treefelling, and other modifications have gained prominence to jump start stalled recovery trajectories, realign successional pathways, and obstruct movement corridors to restore functional habitat along and near existing conventional lines (Golder 2015a).

The shift toward LIS line preparation was meant, in part, to mitigate impacts on wolves and caribou. First, LIS lines were meant to be cut sufficiently narrow so they did not trigger behavioural responses that ultimately alter the predator-prey relationship between wolves and caribou. Second, LIS lines were meant to minimize the intensity of disturbance during line construction to facilitate more rapid and consistent line recovery ensuring observed impacts to wildlife are ephemeral. LIS practices have continued to evolve since their inception, and what constitutes an LIS line today is somewhat loosely defined. Generally, an LIS line is narrower than 6 m wide and employs some mechanism to prevent direct contact with the ground surface while removing vegetation during line construction. Initially LIS lines were constructed with small bulldozers to approximately 5.5 m wide equipped with smear blades or mushroom shoes to elevate cutting blades. LIS practices then shifted to using smaller, low-ground pressure vehicles called mulchers that use maneuverable, rotating drums to convert above-ground vegetation to mulch. Mulched lines have become consistently narrower and are now usually between 1.75 and 3.5 m wide.

For a variety of species, response to seismic lines is driven by line width (Bayne et al. 2005, Carthew et al. 2009 and 2013, Rabanal et al. 2010), but lines must be quite narrow to prevent triggering behavioural responses. For example, American marten avoid and black bears use open seismic lines ≥ 3 m wide (3 – 8 m) but both species treat open lines ≤ 2 m wide as undisturbed interior forest (Tigner et al. 2014 and 2015). Recent work from Alberta provides some evidence that wolves respond differently to LIS than conventional lines, but few data are available to clearly inform on specific widths (Latham et al. 2011, Dickie et al 2016). Inconsistent regulation within and across western Canadian jurisdictions means LIS lines can be cut to a range of widths. Thus, it is possible for a line to be considered a LIS line, but in reality be too wide to prevent triggering behavioural responses in wildlife.

Research from arctic and boreal ecosystems shows that natural recovery of woody vegetation along conventional seismic occurs naturally but more quickly and completely in upland or transitional vegetation communities (specifically mesic sites) and more slowly and incompletely in lowland (bog/fen) vegetation communities with poorly drained organic soils (Lee and Boutin 2006, Kemper and Macdonald 2009*a*, Jorgenson et al. 2010, Lankau 2014, van Rensen et al. 2015, but see Kemper and Macdonald 2009*b*). Despite variation in recovery attributable to site moisture and ecosite, poor and inconsistent recovery along conventional lines is often attributed to the intensity of disturbance to the ground substrate during line construction. Historically conventional line preparation cut into and stripped away soil to create smooth working surfaces for field personnel. Besides removing above ground vegetation, such practices also damage and kill the roots and rhizomes of early successional and sprouting species that would typically recovery quickly in northern ecosystems to jumpstart recovery after disturbance (Bliss and Wein 1972, Felix et al. 1989). High intensity disturbance during line construction can also eliminate microsites necessary for seed germination, seedling retention and the slow the development of plant communities in expected successional pathways (Felix et al. 1992, Emers et al. 1995, Caners and Lieffers 2014). When recovery is altered initially, effects can persist through successional stages leading to much slower recovery timing of vegetation structure than otherwise expected (Revel et al. 1984, MacFarlane 2003) and considerable variation in recovery outcomes even within the same plant community (Emers et al. 1995, Kemper and MacDonald 2009*b*, Lankau 2014). This is especially problematic in lowland ecosites where increases in disturbance to the active soil layer and soil moisture regimes can alter site conditions to favor development of new online vegetation community types (Hernandez 1973, Emers et al. 1995, Williams et al. 2013, van Rensen et al. 2015) or stall recovery trajectories to maintain semi-open conditions for decades (Lee and Boutin 2006, van Rensen et al. 2015). While management decisions often assume that LIS lines recover rapidly because disturbance to the ground substrate is avoided during line construction, few data are available to evaluate actual recovery patterns along LIS lines.

In this study we quantify the accumulation of LIS lines cut to different widths and the recovery patterns along mulched LIS lines in far northeast British Columbia (NE BC). Our intent is to assess whether LIS lines being cut in the region are sufficiently narrow to prevent triggering a behavioural responses of wildlife, and to assess whether mulched LIS lines indeed recover more rapidly than conventional lines. E&P activity has been ongoing in NE BC since the 1970s and the region experienced a marked uptick in the rate and spatial extent of activity in the early 2000s. Currently E&P in NE BC is largely focused around extraction of natural gas from shale in the Horn River and Liard Basins and the Cordova Embayment. Boreal woodland caribou also occur throughout the region in several population units, none of which are considered to be self-sustaining under the current Federal caribou recovery strategy (Environment Canada 2012). To continuously improve caribou management in the region it is critical to understand whether the LIS lines used to support exploration achieve their intended management objectives of mitigating impacts to caribou.

1.1 Background

Historically across western Canada, conventional seismic lines were cut using bull dozers, were up to 8 m wide, and showed limited to no natural recovery after decades (Revel et al. 1984; Lee and Boutin 2006). Significant research has demonstrated that conventional lines impact a variety of wildlife in a variety of ways when lines are open, but those impacts can dissipate for some species with line recovery (e.g., marten (Tigner et al. 2015), wolves (Williamson-Ehlers 2012; Dickie 2015), ovenbirds (Bayne et al. 2005; Lankau et al. 2013), entire passerine communities (Lankau 2014), caribou (Oberg 2001; DeMars and Boutin 2014)). Management and regulatory issues surrounding seismic lines stems from the theory that conventional lines recover slowly and often unpredictably, both within and among regions. Thus, conventional seismic lines are often perceived to exist as permanent or semi-permanent disturbance features with no clear management solutions beyond costly, active reclamation.

To mitigate the direct impacts of seismic lines on wildlife and to expedite line recovery, a series of alternative line construction techniques, collectively referred to as low-impact seismic (LIS), have been widely employed since approximately 2000. In British Columbia (BC), LIS lines are required under the Environmental Protection and Management Regulation in BC (BC Reg 200/2010, Part 3, Division 1, Section 18; BC OGC 2013). While LIS practices focus on narrowing line widths and minimizing disturbance to soil and plant roots, a variety of practices qualify seismic lines as LIS. For example, lines can be prepared by hand or using mulchers, can be constructed to ~4.5 m, and can be cut in the summer or winter. Such variety in practice can confound evaluation of LIS efficacy to mitigate impacts to vegetation response and associated wildlife use, development of management guidance to industry proponents, and bookkeeping for tracking disturbance footprints over time.

Currently, most LIS lines prepared in BC are done so using mulchers which are designed to remove above ground vegetation without disturbing the ground or plant roots. Several works have shown mulched lines can be cut sufficiently narrow to mitigate the direct impacts to marten (Tigner et al. 2015), birds (Bayne et al. 2005), and wolves (Dickie 2015), but LIS lines wider than 2 m are routinely cut. Thus it is likely the primary mitigation benefit of mulchers will be an expedited recovery of LIS lines. Previous research on conventional lines has suggested that minimizing disturbance to the ground and soil root layer should indeed expedite line recovery (Felix et al. 1992; Emers et al. 1995), and it is often assumed LIS lines recover more completely and quickly than conventional lines. Although some anecdotal evidence supports this idea, it has never been tested. Like conventional lines, recovery of LIS may be influenced by surrounding forest type (Kemper and Macdonald 2009, Jorgenson et al. 2010) or line orientation (Lankau 2014, van Rensen et al. 2015). Further, scant attention has been given to the influence of variation in mulcher practices on the recoverability and recovery timing of LIS lines. Previous research on recovery of LIS lines in the Yukon suggests narrower lines may actually recover more slowly than wider ones because of limited sun exposure to disturbed vegetation (Simpson 2008). While LIS practices likely provide functional habitat for wildlife more quickly than conventional practices, there are no empirical data on which to base these claims, and thus no knowledge base with which to develop meaningful regulations on the complex issues of disturbance longevity and recovery timing for the vast majority of LIS lines in Canada.

Potential and existing developments for downstream LNG across BC suggest seismic exploration will dramatically increase to meet downstream demands. The exploration phase for oil and gas development creates a footprint that may be avoided or minimized if proper methods are used to optimize natural recovery during line creation. The high costs of on-site restoration may also be minimized if line preparation techniques that expedite recovery and facilitate reclamation can be integrated directly into operations. Gathering empirical data on the nuanced recovery of LIS lines is imperative to facilitate the development of policies capable of accurately balancing development and wildlife interests with a high likelihood of meeting intended management objectives.

2.0 OBJECTIVES

As caribou habitat restoration initiatives have become more widespread across western Canada in the last decade, key uncertainties have been recognized regarding 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 Explor and Golder Associates Ltd. (Golder) with support from the BC Oil and Gas Research and Innovation Society (BC OGRIS) to monitor the vegetation attributes on LIS lines in NE BC. The following objectives were addressed within this study:

- Assess recovery of mulched lines in a way useful for both developing targeted management recommendations for future seismic programs, as well as bookkeeping needs for recovery timing in land use forecasting.
- To quantify structure and composition of natural recovery of vegetation relevant to caribou, caribou predators, and alternate prey along LIS lines in NE BC.
- To compare the influence of light penetration, soil temperature and moisture, and soil disturbance and compaction on natural recovery of vegetation along LIS lines.

Understanding the rate of recovery of vegetation along LIS, of varying types, 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 on industrial disturbance 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).

This study aimed to provide a prescriptive estimate of recovery success and timing for LIS construction methods in BC that account for landcover type and line width. Such data will assist managers in developing new Best Operating Practices for restoration during the clearing and operational phases of projects and inform current barriers to detailed line recovery estimates and strategic planning in NE BC.

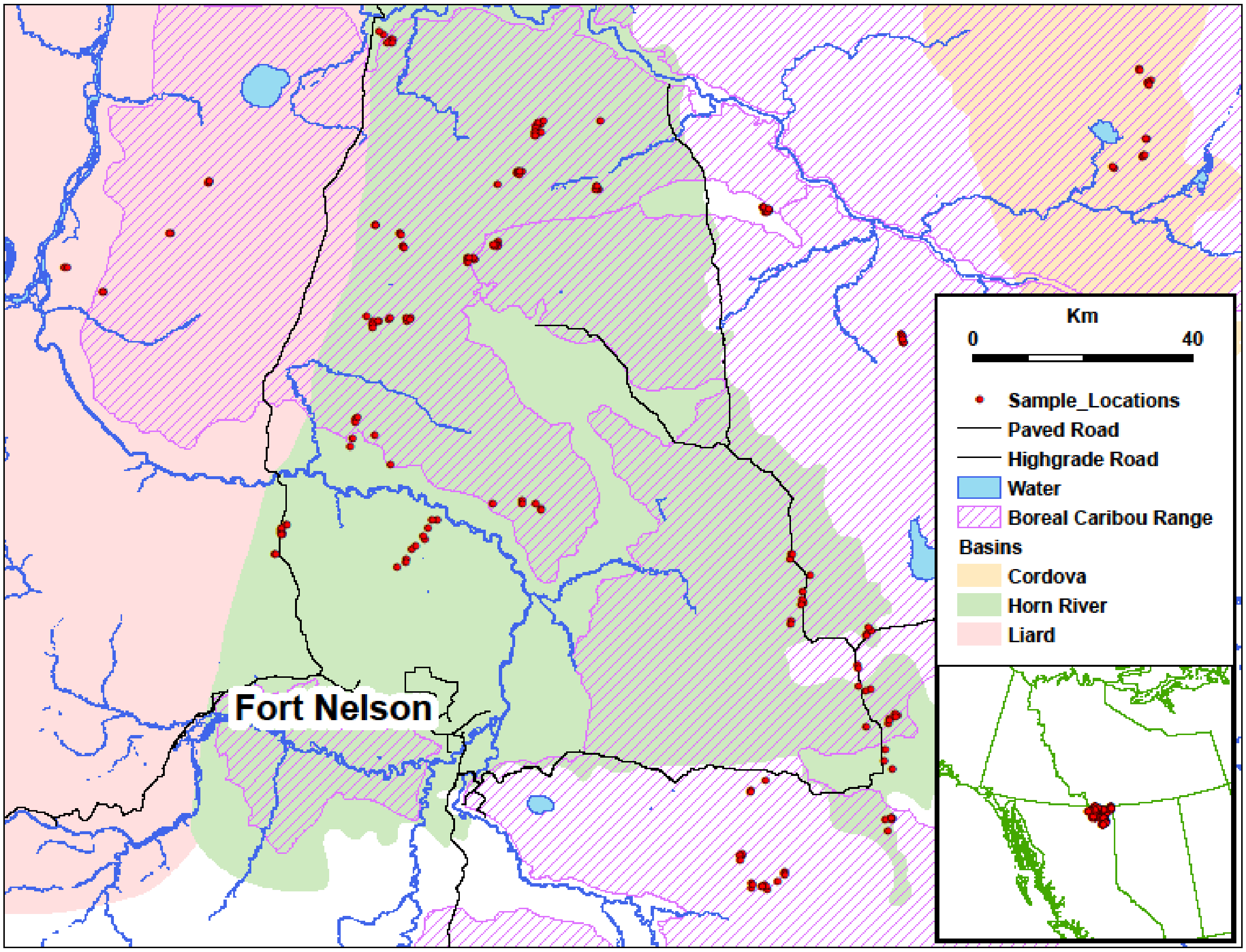
3.0 STUDY AREA

The area selected for this study is represented by the Maxhamish, Calendar, Snake-Sahtaneh, Parker and Prophet boreal caribou ranges in NE BC. The area is also transected by an intensive historical seismic footprint, as well as numerous pipelines, roads and trails (Figure 1). The study area was approximately 30,500 km^2 of northern boreal forest located in the lowlands to the east of the Rocky Mountains in the Taiga Plains Ecoprovince (Demarchi 2011) in Northeast British Columbia (NE BC) (122°4′ 51.5″ W 59° 9′ 38.7″ N) (Figure 1). Terrain was flat to slightly undulating, and was crossed by numerous creek and river tributaries of the Liard River. Climate is continental; long, cold winters are punctuated by short, rainy summers. Vegetation in the study area was characterized by the Moist Cool Boreal White and Black Spruce Biogeoclimatic Zone (BWBSmk; DeLong et al. 2011). Peatlands and wetlands were extensive across the study area and upland forests occurred along fluvial systems and in undulating terrain.

Peatlands and wetlands (collectively lowlands) consisted of treed black spruce (*Picea mariana*) bogs and black spruce – tamarack (*Larix laricina*) fens, and sometimes non-treed expanses dominated by scrub birch (*Betula glandulosa*). Lowlands occurred on fine-grained and organic soils, often deep accumulations of organic material and hummocks at surface, with a shallow water table and many small waterbodies. Occasional ice features including permafrost occurred in lowland soils. Sparse understories included Labrador tea (*Ledum groenlandicum*), leatherleaf (*Chamaedaphne calyculata*), scrub birch, willows (*Salix* spp.), lingonberry (*Vaccinium vitis-idaea*), cloudberry, sedges (*Carex* spp.), sphagnum and fen mosses (*Sphagnum* spp. and *Tomentypnum nitens*, respectively), and reindeer lichens (*Cladonia* and *Cladina* spp.). Uplands consisted mostly of mixed stands of white spruce (*Picea glauca*) and trembling aspen (*Populus tremuoidis)* (though pure conifer and deciduous stands did occur), accompanied by balsam poplar (*P. balsamifera*) in floodplains and paper birch (*Betula papyrifera*) in rich sites. Uplands occurred on mineral soils that were typically well drained, with well-established leaf litter and humus layers. Dense and diverse understories included prickly rose (*Rosa acicularis*), high-bush cranberry (*Viburnum edule*), soopolallie (*Shepherdia Canadensis*), red-osier dogwood (*Cornus stolonifera*), alders (*Alnus* spp.), and numerous herbaceous species.

Energy development was the primary land use in the study area. Both timber harvest and forest fires have occurred in some parts of the study area, but we did not sample in cut blocks or burns.

Figure 1: Study Area and Sample Locations Along Low-Impact Seismic Lines in Northeastern British Columbia



Boreal woodland caribou occurred in five separate mapped ranges in the study area. Recent work estimates the population at 300 animals in the Maxhamish Range, 290 in the Calendar Range, 360 in the Snake-Sahtaneh Range, 54 in the Prophet Range and 25 in the Parker Range (Table 6 in BCMoE 2010). Both wolves and black bears are common throughout the study area, as are alternative prey species including moose and beaver. Other alternative prey including white-tailed deer and elk are found in the southern portions of the study area, close to Fort Nelson.

4.0 METHODOLOGY

4.1 LIS Line Assessment

We used geophysical spatial data (i.e., seismic line footprint) managed by the BC Oil and Gas Commission (OGC) (http://data.bcogc.opendata.arcgis.com/), and seismic line cut summary data used to calculate Timber Damage Assessments (TDA) (unpublished data BC OGC, R. Dunn) to estimate the accumulation of seismic lines, by width and linear kilometer in a Geographic Information System (GIS; ArcGIS 10.4, ESRI, Redlands, California). We reclassified seismic lines by year cut (i.e., seismic survey year), survey program, and line width. Some spatial data managed by the OGC is well attributed and numerous data fields, including line width, are available per seismic line. In cases where data were incompletely attributed, we cross referenced seismic programs in the TDA database to assign line widths where possible or available line descriptions to classify lines of unknown widths as mulched (from which we inferred narrower than standard conventional line widths). Data was included from the year 2000 (1999 – 2000 winter operating season) as this is the firt reported use of mulchers to prepare LIS lines in the region.

4.2 Vegetation Sampling

We used a mensurative approach to estimate LIS line recovery trajectories in NE BC to test a series of hypotheses on recovery of mulched lines. In particular we developed a sampling design to determine the influence of surrounding forest cover on vegetation structural and compositional recovery timing controlling for line preparation year, surrounding forest type, and whether the line was a new or existing disturbance. We tested the following hypotheses:

1) Winter operations recover more quickly than summer operations;

2) Wider mulched lines recover more quickly than narrower mulched lines;

3) Line orientation influences recovery trajectories; and

4) New cut mulched lines recover more quickly than reopening existing lines.

We proposed to collect data across the Maxhamish, Calender, Snake-Sahtaneh, Parker, and Prophet boreal caribou ranges in NE BC to compare recovery between summer and winter operations (2 treatments), in upland and lowland forest types (2 treatments), and along new cut and existing lines (2 treatments). Within each treatment we will evenly sample across a continuum of line preparation years, line widths (approximately 2 m to 4.5 m), and line orientations (N-S, E-W, diagonal) to control for those variables.

4.2.1 Site Selection

In a GIS, we reclassified Vegetation Resources Inventory (VRI), a polygon-based forest inventory dataset managed by BC Ministry of Forests, Lands and Natural Resources Operations (http://geobc.gov.bc.ca/), into upland and lowland forest types, and several non-forested land covers (Appendix A). We also reclassified the BC OGC geophysical spatial data to further separate seismic by lines type, line orientation, and whether they were newly cut or existing, reopened lines (i.e., beyond previous reclassification to year, program, and width).

We generated a set of candidate sites along newly prepared, mulched seismic lines of various width, line type and orientation for each year from 2005 through 2014 (excluding 2013 due to low availability; no seismic programs were shot in 2015) in upland and lowland forest types. A total of 500 preliminary sample locations were selected across the study area in NE BC. We anticipated collecting data at a minimum of 200 plots, selecting from the 500 preliminary sample locations (Table 1). Sites were also selected to sample variation in line recovery along narrow (≤ 1.75 m – 2 m), mid (2.7 m – 3.14 m) and wide (≥ 3.14 m) mulched seismic lines across a variety of forest types. Width classes were selected by frequencies and break points in reported line widths. All sites are located in seismic programs cut from 2000 to 2014. For each year, we located candidate sites in > 1 survey program separated in space to prevent confounding results by operator practice or localized ecotype, respectively. We located all candidate sites within VRI polygons sufficiently large to encompass all survey plots per site. To the extent possible, we sampled only once per seismic line and VRI polygon, though for logistical reasons multiple sites were sometimes located along the same line in different polygons or in the same polygon along different lines. We considered a seismic line segment within a VRI polygon as the sample unit when evaluating line recovery. While reopening existing lines was infrequent on a per-line and per-kilometer basis in our study area relative to the total volume of seismic line cut, we did generate a small number of candidate sites along existing conventional lines reopened by mulchers in 2010.

Access restrictions were taken into consideration when selecting sites, with our field work schedule following the Peace Region boreal caribou least-risk window (critical timing March 15 to July 15). We controlled for human use and line access during study design.

Table 1: Number of Candidate Field Sites Selected Based on LIS Establishment Year

Year Line Treated	Number of Sampling Sites Selected
2014	41
2013	42
2011	40
2010	105
2009	51
2008	32
2007	18
2006	36
2005	72
2000-2004	63

4.2.2 Data Collection Methods

At each sampled site, we established a series of nested plots. First we established a 100 m transect along the LIS line and confirmed cut history by searching for seismic shot point tags, including whether a line was reopened or newly mulched, and we searched for evidence of human maintenance or non-intended use, measured line width to the nearest decimeter, classified the surrounding forest stand to biogeoclimatic (BEC) Site Series (DeLong et al. 2011), estimated the distribution of deposited mulch as continuous (akin to a garden path with little visibility of the ground) or scattered (mulch scattered discontinuously with the ground clearly visible) or none (i.e., mulch absent), and identified animal use of lines to species and whether a worn game trail had been established along the line.

To capture potential variability in recovery along the length of sampled lines, we nested three 2 × 2 m plots (1 × 4 m along lines < 2m) set at metres 1, 50, and 99 along the 100 m transect along the center of the sampled seismic line. In the 2 × 2 m plots we inventoried all woody stems ≥ 50 cm to species (or Salix spp.) and height (cm). We focused on vegetation > 50 cm, as wolf use of seismic lines has been documented to diminish and travel speed slowed once vegetation reaches 50 cm regardless of adjacent forest type or conditions (Dickie 2015). We also inventoried all conifer seedlings to species and height (cm), and counted the number whorls to estimate seedling age. We used a Robel pole to estimate height of "first breaks" of recovering vegetation (i.e., the height at which there was a gap in the visual obstruction in vegetation as measured from the ground up), and to estimate visual obstruction (as percent of Robel pole obstructed by vegetation from 10 m away) for three height strata of shrubs including low (< 0.5 m), medium (0.5 – 1.5 m) and tall (> 1.5 m). For a subset of individual 2 × 2 m plots we also collected these data in paired offline 2 × 2 m plots to compare online to adjacent, undisturbed conditions.

4.3 Statistical Analyses Methods

4.3.1 Overall Vegetation Regrowth and Black Spruce Seedling Regeneration

In order to quantify seismic line vegetation regrowth, we assessed both average Robel pole height, a proxy for overall vegetation regrowth, as well as the occurrence and height of black spruce seedlings. A separate general linear model was run for Robel pole height and black spruce seedling height. Robel pole height measurements at 2 × 2 m plots were averaged within seismic lines, creating one mean vegetation height value per line. For the black spruce seedling analysis, individual seedling height measurements were averaged within 2 × 2 m plots and a mixed effect model was created whereby average seedling height within plots was entered as the response variable and line ID was included as a random effect. Only plots containing black spruce seedlings were included in the seedling height analysis (n = 180).

The models for both Robel pole height and seedling height contained several explanatory variables representing line characteristics (Table 2) and included age of line (i.e., time in years since line was cut) as a covariate. We log-transformed both Robel pole height and black spruce seedling height prior to running models to ensure assumptions of normality were met. Black spruce presence on seismic lines was assessed using a generalized linear model with a logit link function (logistic regression). A binary value for black spruce presence (i.e., black spruce either present or absent) was assigned to each 2 × 2 m plot within the seismic lines sampled. Spruce presence was used as the response variable in the model along with the explanatory variables listed in Table 2. Three variables representing percentage coverage of shrubs at various height strata were also entered into the model to assess the effect of plot-level competition on seedling growth. A separate continuous variable was created for height of shrubs as low shrubs (< 0.5 m in height), medium shrubs (0.5 m – 1.5 m) and tall shrubs (> 1.5 m) and all three were included in the model as fixed effects. Since multiple plots from the same line were analyzed, we included line ID as a random effect.

Table 2: List of Explanatory Variables Included in General Linear Models Assessing the Effects of Seismic Line Characteristics on Vegetation Regrowth

Explanatory Variable	Description	Variable Type	Reference category used in model
Line orientation	Cardinal direction seismic line was running. All plots were grouped into either north-south or east-west orientations.	Categorical	North-south
Line width	The width of the seismic line disturbance (m).	Numeric	-

Explanatory Variable	Description	Variable Type	Reference category used in model
Mulch distribution	Pattern of dispersal for mulched wood present on the line. Categorized in the field as either continuous, scatteredor none present.	Categorical	Continuous
Ecosite	Vegetation and moisture conditions of forest stand adjacent to seismic line. Classified as Lowland, Wetland, Upland Coniferous or Upland Deciduous.	Categorical	Upland Deciduous
Age of line	Time in years since line was treated (either re-cut or newly mulched).	Numeric	-

4.3.2 Shrub Regeneration on Seismic Lines

In addition to overall vegetation regrowth and black spruce seedling regeneration, we examined shrub occurrence, height and abundance along and adjacent to seismic lines. We selected alder and willow species for analysis since they are biologically relevant to ungulate populations locally (Romito et al. 1999; Spythe et al. 2015) and are abundant on the landscape. Average heights and number of stems for both alder and willow were quantified for each 2 × 2 m survey plot on seismic lines as well as those that occurred within adjacent offline plots.

We used logistic regression to analyze the presence of alder and willow in 2 × 2 m plots along seismic lines. Separate logistic models were created with either willow or alder presence (binary variable) included as the response variable. Both models contained the explanatory variables listed in Table 2 and line ID as a random effect. Similar models were created to analyze stem counts and average height for alder and willow within 2 × 2 m plots but instead of a logit-link, a log-link function was used to analyze the stem count data and a standard identity link function was used for the height data.

We ran a paired Wilcoxon signed rank test to compare shrub abundance on seismic lines to abundance in adjacent plots, off of the line. Alder and willow stem count data was analyzed for 77 individual 2x2 m plots with paired adjacent plots.

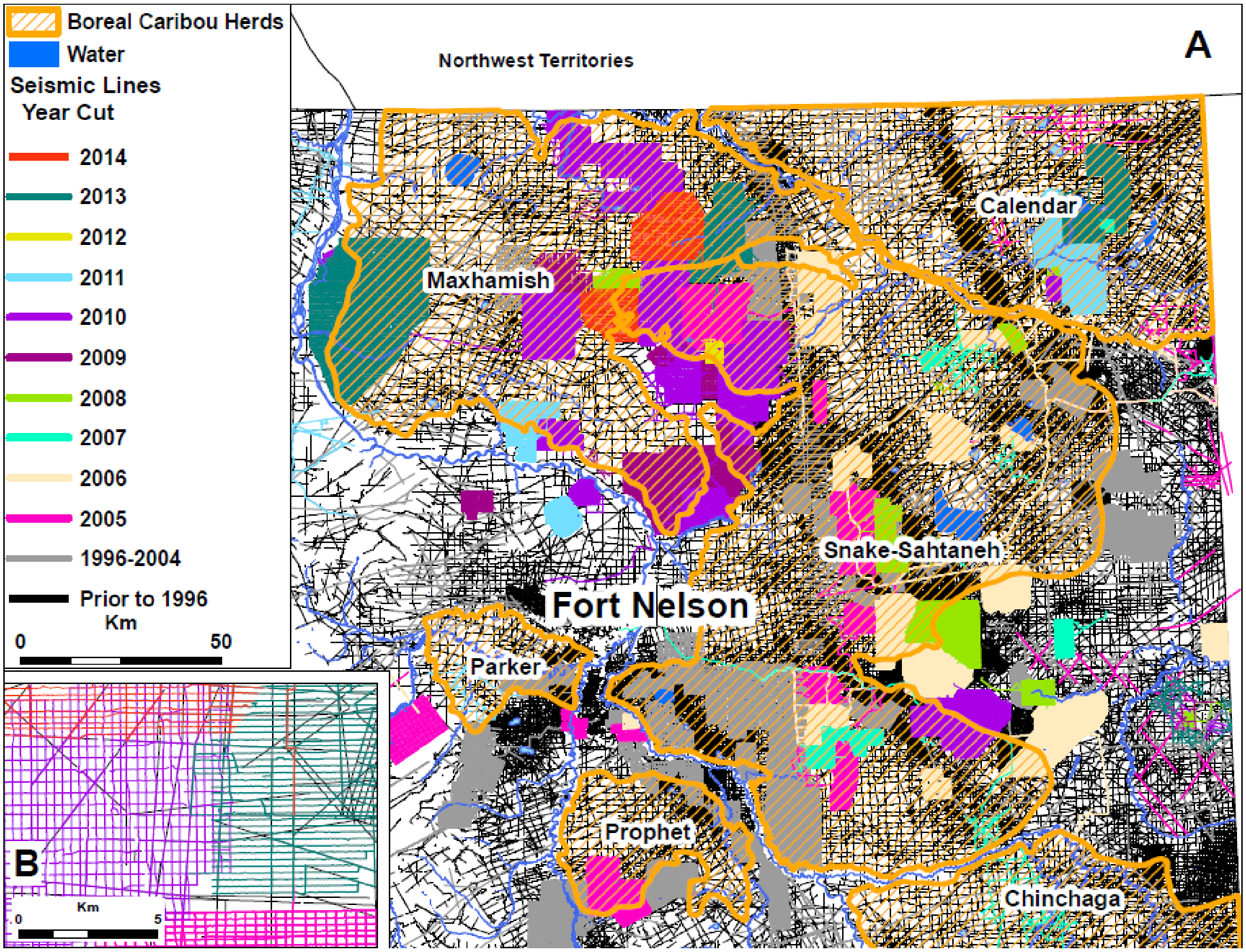
All statistical analyses were performed in program R, version 3.2.3 (The R Foundation for Statistical Computing 2016). To interpret the effect of variables entered into linear models, we assessed p-values when provided by the statistical package, or calculated 95% confidence intervals around parameter estimates when p-values were not provided. A variable was deemed to have a significant effect on the response if the p-value was less than 0.05 or if the 95% confidence interval around the parameter estimate did not overlap 0.

5.0 RESULTS

5.1 LIS Line Assessment

LIS construction practices were first reported in the study area in 1998. Those programs used bulldozers and prepared lines to 5 and 5.5 m wide, but use was infrequent. By 1999 line widths of 3 m (likely mulchers, though reported as bulldozers) were occasionally reported, but lines of 4 and 5 m were common, likely a combination of mulcher and bulldozer cut. By 2000 mulchers were first reported but were not commonly used. In 2003 use of bulldozers was still common across many programs and they were used to cut large portions of some programs to 5 m line widths. By 2005, mulching was common and by 2007 bulldozers were no longer being used (with rare exception). Between 2000 and 2004 when at least some LIS lines were cut by mulchers a total of 28,153 linear km of line was cut across 107 survey programs (all line types). Between 2005 and 2014 when seismic lines were almost exclusively cut by mulchers a total of 67,927 linear km of line was cut across 112 survey programs (Figure 2 inset A), often at very dense line spacing (Figure 2, inset B).

Figure 2: Seismic Line Activity from 2005 – 2014



A significant number of lines were created within mapped boreal caribou ranges (Table 3). Since 2005, the proportion of very wide LIS lines cut decreased while the proportion of narrower lines increased (Figure 3). Some data for years 2005 and 2006 are poorly attributed.

Table 3: Seismic Line Stats for Three Boreal Caribou Herds in Northeast British Columbia

Boreal Caribou Herd	Linear Kilometres of Seismic Lines Cut			No. Seismic Programs	Area of Caribou Range (km²)	Proportion of Range Underlain by Hydrocarbon Basin
	Total[a]	2000 – 2004[b]	2005 – 2014[c]			
Maxhamish	17,928	1,456	16,472	26	7,096	0.96 (0.45 Liard; 0.51 Horn River)
Snake-Sahtaneh	36,768	13,278	23,490	53	12,000	0.33 (0.33 Horn River; 0.003 Cordova)

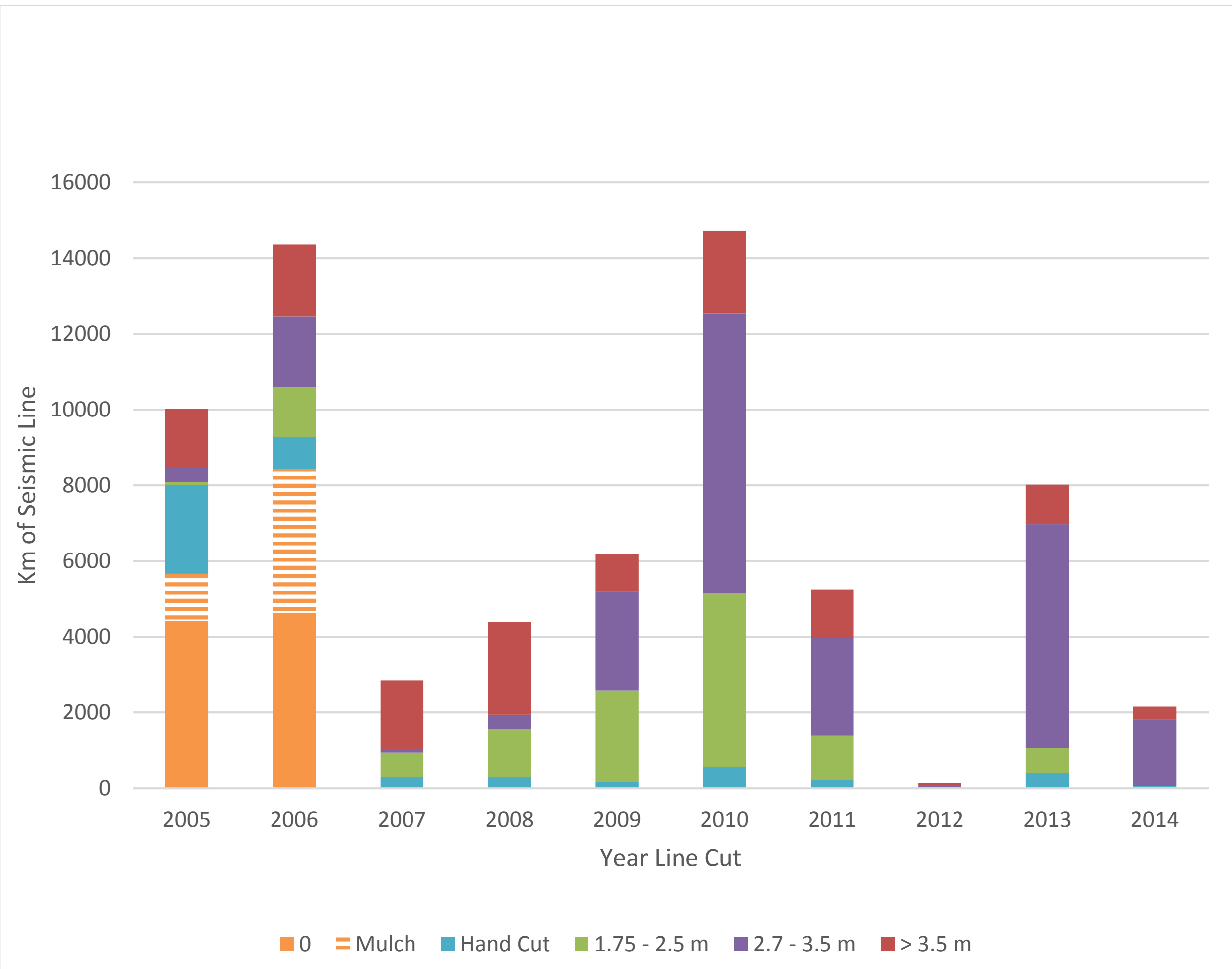
Boreal Caribou Herd	Linear Kilometres of Seismic Lines Cut			No. Seismic Programs	Area of Caribou Range (km^2)	Proportion of Range Underlain by Hydrocarbon Basin
	Total[a]	2000 – 2004[b]	2005 – 2014[c]			
Calendar	5,831	654	5,177	16	4,973	0.49 (0.49 Cordova; 0.008 Horn River)

[a] Includes only those seismic lines cut since the 1999 – 2000 winter operating season.

[b] Years during which at least some low-impact seismic (LIS) line preparation methods were reported.

[c] Years during which lines were exclusively cut using mulching and hand cutting.

Figure 3: The Accumulation and Proportion of Seismic Lines Cut in Northeast British Columbia by Linear Kilometres and Width between 2005 and 2014 (Winter Operating Seasons 2005-6 to 2014-15)



Note: Hand cut lines are ≤ 1.5m

5.2 Vegetation Sampling

A total of 188 LIS lines were sampled during the summer of 2016 (Table 4). Of those, 10 were reopened, previously existing conventional lines. The majority of the lines present on the landscape were new mulch cuts and areas containing existing cut lines were often difficult to access during the summer collection period.

Table 4: Attributes of Low-Impact Seismic Lines Sampled in Northeastern British Columbia, 2016

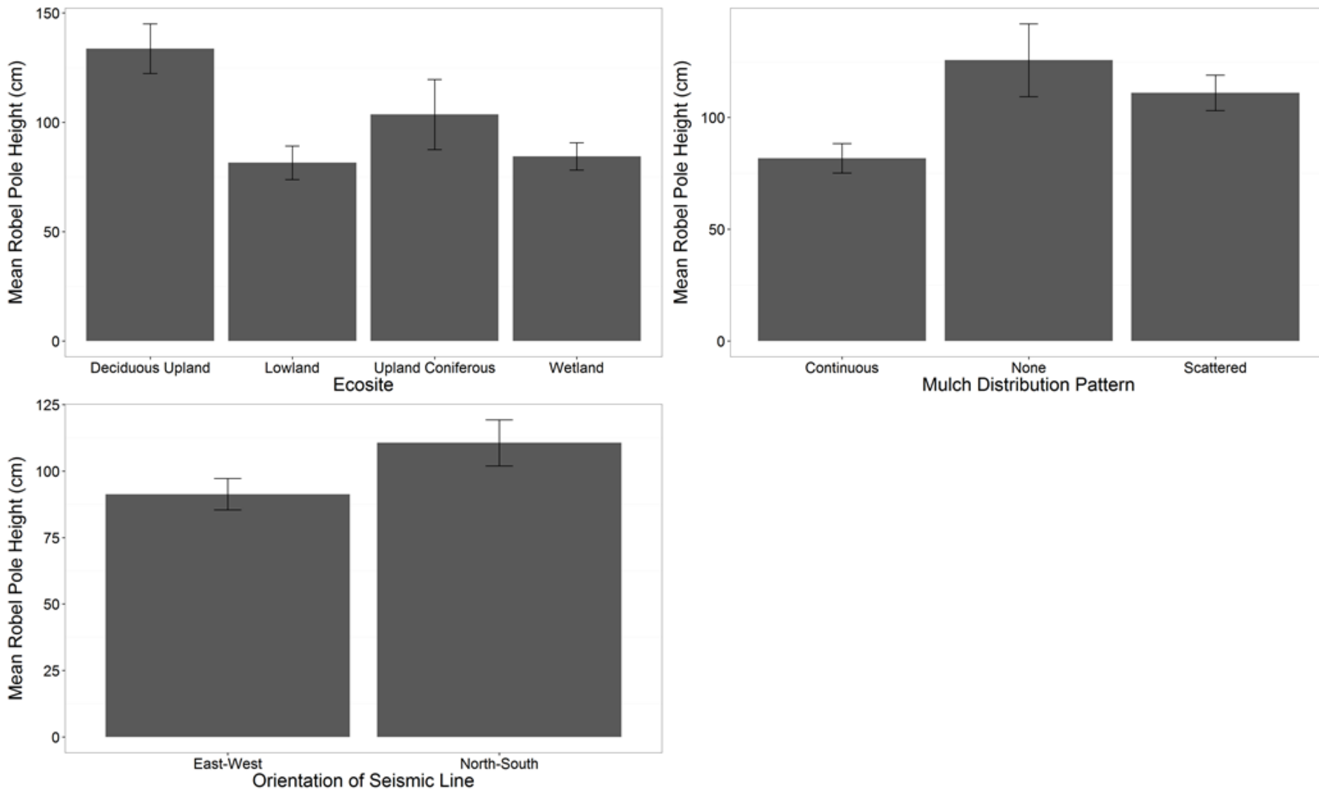
Line Attributes	Attribute Categories	Number of Lines (n)	Average (mean ± SE)	Minimum	Maximum [a]
Width	-	188	3.19 ± 0.08 m	1.27 m	7.70 m
Age	-	188	6.64 ± 0.21 years	2 years	11 years
Orientation	North-South	76	-	-	-
	East-West	112	-	-	-
Ecosite	Wetland	89	-	-	-
	Lowland	25	-	-	-
	Upland Coniferous	28	-	-	-
	Upland Deciduous	46	-	-	-
Mulch distribution	Continuous	83	-	-	-
	Scattered	82	-	-	-
	None	23	-	-	-
Cut Type	Newly Prepared	178	-	-	-
	Re-treated	10	-	-	-

[a] Maximum width includes existing conventional lines.

5.2.1 Overall Vegetation Regrowth and Black Spruce Seedling Regeneration

General linear model results indicated that orientation, mulch distribution pattern, and ecosite type all had a significant effect on the average Robel pole height of vegetation regenerating on LIS lines. Robel pole height was significantly greater on lines with a north-south orientation compared to lines with an east-west orientation ($\beta = 0.102$, $p = 0.039$) (Figure 4). Compared to lines with continuous mulch distribution patterns, lines with scattered mulch ($\beta = 0.174$, $p < 0.001$) or no mulch ($\beta = 0.197$, $p = 0.016$) had significantly higher vegetation regrowth present. Finally, seismic lines that occurred in wetlands ($\beta = -0.217$, $p < 0.001$), lowlands ($\beta = -0.159$, $p = 0.035$) or, upland coniferous ecosites ($\beta = -0.157$, $p = 0.038$) had significantly shorter Robel pole height measurements compared to lines occurring in deciduous upland ecosites (Figure 4). Neither line width nor age had a significant effect on the overall height of vegetation.

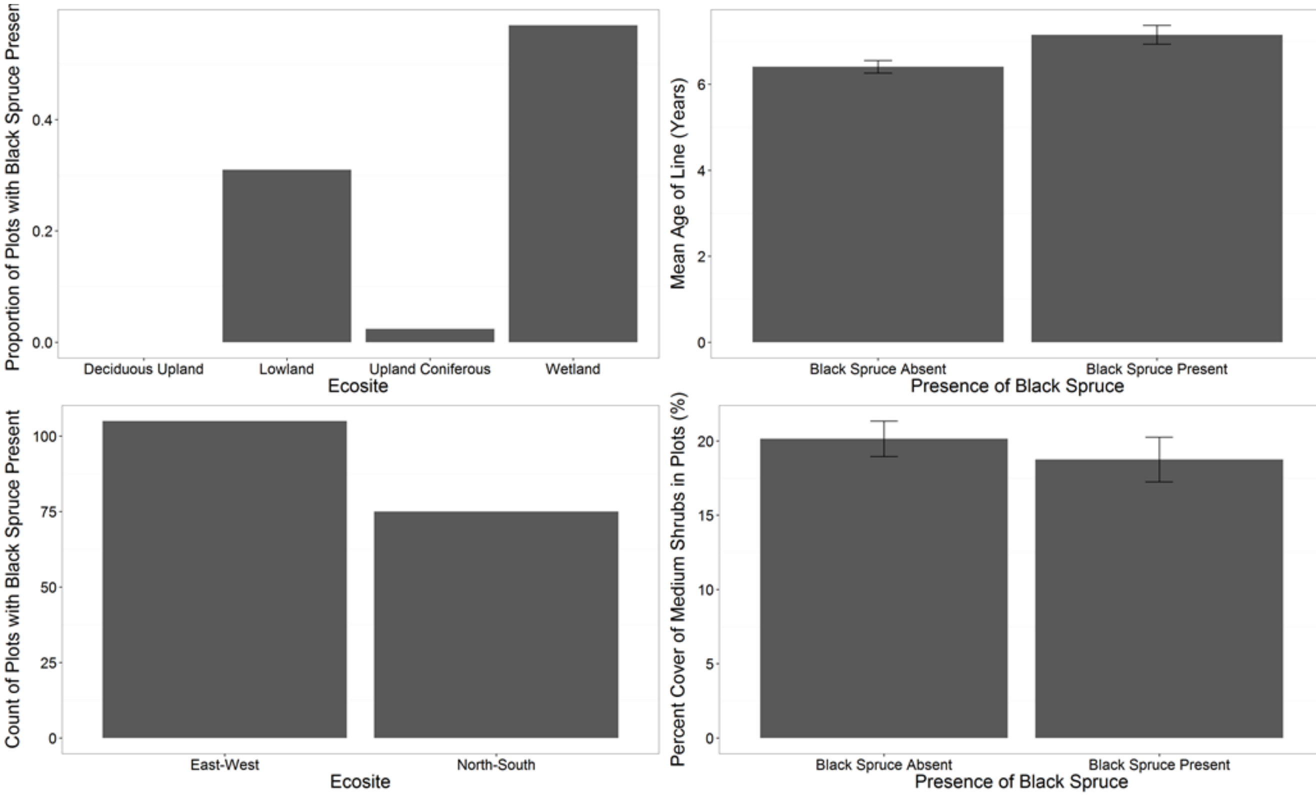
Figure 4: Average Robel Pole Height of Vegetation Measured along Low-Impact Seismic Lines in Northeastern British Columbia



Note: Error bars represent ± 1 SE

Black spruce seedlings were detected on approximately 46% of the LIS lines (n=87) and in 32% (n=180) of the 2 × 2 m plots sampled in the project area. Black spruce presence was significantly impacted by the ecosite, the age of the line and by line orientation. Not surprisingly, plots occurring in wetlands ($\beta = 5.715$, $p < 0.001$), and lowlands ($\beta = 4.416$, $p < 0.001$) were significantly more likely to contain black spruce compared to lines occurring in upland deciduous ecosites (Figure 5). Plots occurring on lines with a north-south orientation ($\beta=-0.899$, $p = 0.041$) were significantly less likely to contain black spruce seedlings than those on lines with an east-west orientation. In general, plots occurring on older lines were more likely to contain black spruce seedlings than younger lines (line age: $\beta = 0.146$, $p = 0.051$) and seedlings were more likely to occur at plots where medium shrub coverage was lower ($\beta = -0.022$, $p = 0.027$) (Figure 5). Neither the width of the line, the dispersal pattern of mulch, nor the percent cover of tall and low shrubs had a significant effect on the occurrence of black spruce seedlings at sample plots.

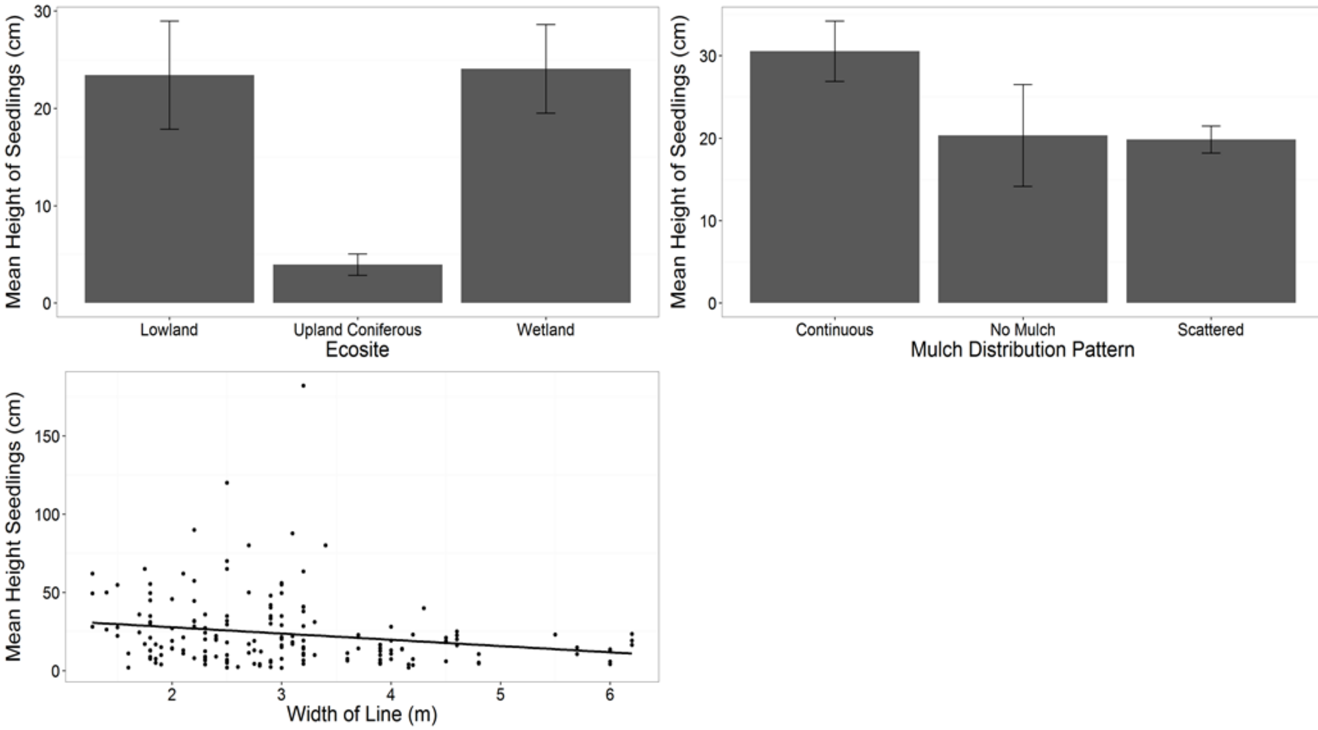
Figure 5: Presence of Black Spruce Seedlings within Sample Plots on Low-Impact Seismic Lines in Northeastern British Columbia



Note: Error bars represent ± 1 SE

Black spruce did not occur in upland deciduous plots so the lowland ecosite was used as the reference category when assessing the effect of ecosite on black spruce height. Results of the general linear model indicated that black spruce height was significantly affected by mulch distribution pattern, ecosite and line width. Seedling height was significantly lower at plots that occurred on wider lines compared to narrower lines (line width: β = -0.098, 95% CI: -0.160 to -0.036) (Figure 6). Seedlings were also significantly shorter at upland coniferous plots compared to lowlands (β = -0.706, 95% CI: -1.295 to -0.127) and significantly shorter at plots with scattered mulch distribution compared to plots with a continuous distribution (β = -0.285, 95% CI: -0.434 to -0.134) (Figure 6).

Figure 6: Average Height of Black Spruce Seedlings Sampled within Plots on Low-Impact Seismic Lines in Northeastern British Columbia



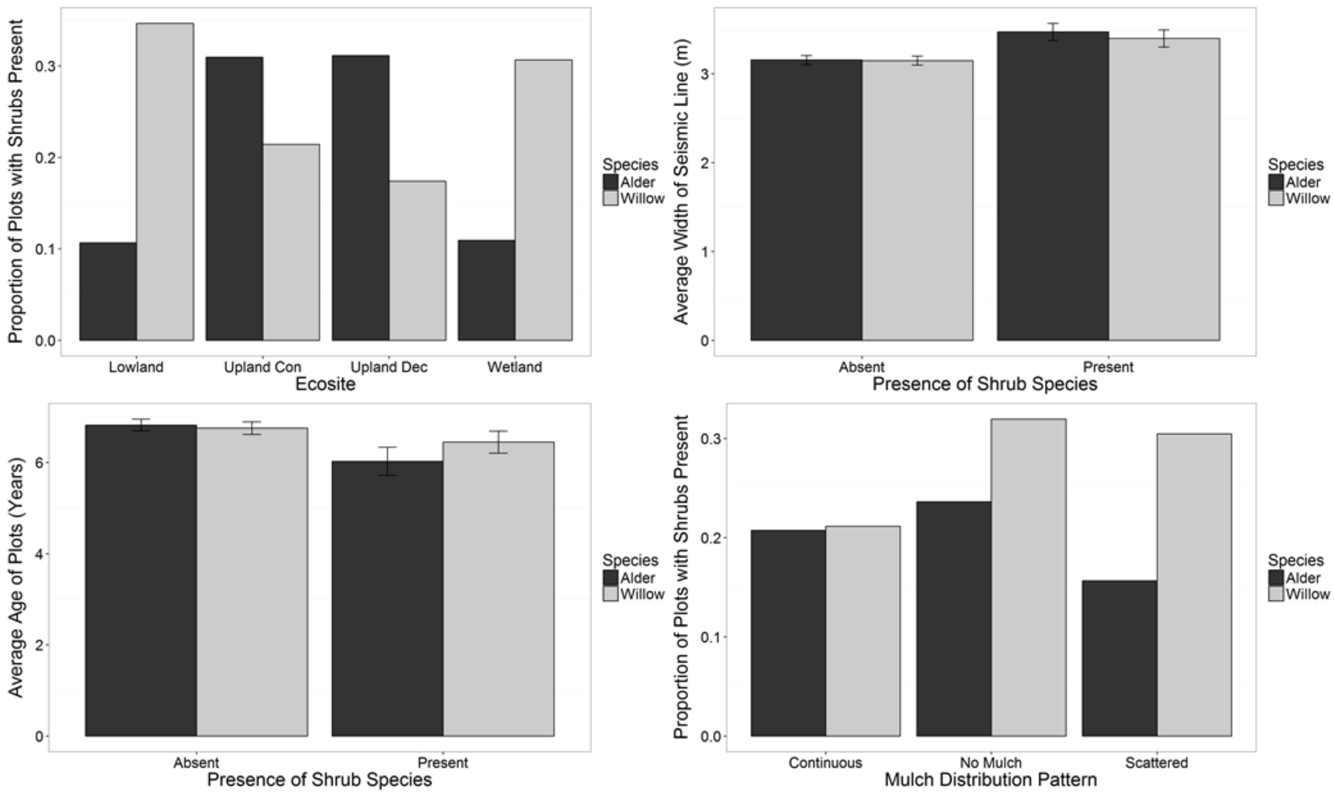
Note: Error bars represent ± 1 SE

5.2.2 Shrub Growth on Seismic Lines

Alder was detected at approximately 19% (n = 106) of 2 × 2 m plots sampled on seismic lines during the summer of 2016 and willow was detected at approximately 27% of plots (n=149). Logistic regression results indicated that willow was significantly more likely to occur in plots on wider lines compared to narrower lines (β = 0.344, $p = 0.027$) (Figure 7). Despite lacking statistical significance at an alpha-level of 0.05, general trends indicated that willow was more likely to occur at plots with a scattered mulch distribution (β = 0.651, $p = 0.065$) compared to a continuous distribution (Figure 7). Willow was also somewhat more likely to occur at plots in wetland ecosites (β = 0.689, $p = 0.085$) compared to plots in upland deciduous ecosites (Figure 7).

Alder was significantly less likely to occur at plots in wetland ecosites compared to upland deciduous ecosites (wetland ecosite: β = -1.269, $p = 0.004$) and significantly less likely to occur at plots sampled on older lines compared to younger lines (line age: β = -0.183, $p = 0.008$) (Figure 7). Alder occurrence was also positively tied to line width; individuals were significantly more likely to occur on wider lines compared to narrower lines (β = 0.448, $p = 0.011$) (Figure 7).

Figure 7: Presence of Willow and Alder Shrubs within Plots along Low-Impact Seismic Lines in Northeastern British Columbia



Note: Error bars represent ± 1 SE

Analysis of shrub stem counts and height measurements at 2 × 2 m plots indicated that stems of both willow and alder were more abundant on wider lines (willow: β = 0.312, p = 0.011; alder: β = 0.577, p = 0.047). Intuitively, more willow stems were present at plots in lowland (β = 1.347, p = 0.030) and wetland (β = 1.275, p = 0.030) ecosites compared to plots in the upland deciduous ecosite, and alder was less abundant in these wetter ecosites (lowland ecosite: β = -2.141, p = 0.028; wetland ecosite: β = -2.355, p = 0.001) compared to drier, upland plots. Mulch distribution had a significant effect on the abundance of willow stems; plots with scattered mulch contained more willow stems than plots with continuous mulch distribution (β = 0.867, p = 0.039).

Line age was the only variable included in linear models that explained a significant amount of variation in either alder or willow height models. For alder, average heights were greater on older lines compared to younger lines (β = 0.015, CI: 0.001 to 0.030). Although a similar relationship was observed for willow, the effect of line age on willow height was not statistically significant (β = 0.010, CI: -0.002 to 0.022). No other explanatory variables have a significant effect on average alder height in sample plots.

A paired Wilcoxon signed rank test was used to compare shrub stem abundance on LIS lines to abundances in adjacent sample plots that occurred in undisturbed habitat. Results indicated that there was not a significant difference in the number of willow stems on LIS lines (mean = 0.179 ± 0.050 stems/m^2 [SE]) compared to adjacent plots (mean = 0.097± 0.034 stems/m^2) (V=88.5, p = 0.220); however, there were significantly more alder stems present on LIS lines (mean = 0.396 ± 0.103 stems/m^2) than in adjacent (mean = 0.162 ± 0.051 stems/m^2), undisturbed habitat (V = 53, p = 0.030).

5.3 Wildlife Use of Seismic Lines

In total, 30 LIS lines sampled in 2016 had established game trails present which represented approximately 16% of the 188 LIS total lines surveyed. In contrast, using a linear disturbance inventory exercise in the Parker Caribou Range in NE British Columbia, conventional seismic lines had established game trails on 64% of conventional seismic lines (Golder 2016) (Table 5).

Table 5: Presence of Established Game Trails Along Conventional and Low-Impact, Mulched Seismic Lines and in Northeast British Columbia

	Conventional Lines in the Parker Caribou Range	LIS Mulched Lines in Northeast BC
Sampled Line Segments	439	188
Line Segments with Established Game Trails	283	30
Percent of Line Segments with Established Game Trails	**64**	**16**

5.4 Vegetation Regrowth in Comparison to Alberta Conventional Lines

Vegetation regrowth (average robel pole height) along low-impact seismic lines in the current study was compared to regrowth along conventional seismic lines located in the Little Smoky Caribou range. The Little Smoky caribou range occurs along the eastern slopes of the Rocky Mountains in west-central Alberta and exists in three subregions: the Upper Foothills Subregion, the Lower Foothills Subregion and the Subalpine Subregion (Natural Regions Committee 2006). The Little Smoky range contains both treated conventional seismic lines and, untreated (naturally-regenerating) conventional seismic lines. Treatments along lines included tree/shrub seedling planting, seeding of tree species, tree/shrub transplanting, mounding, spreading of woody debris, and soil de-compaction.

Vegetation regrowth was assessed on conventional lines in the Little Smoky range in 2015, examining recovery trajectories and the effectiveness of restoration treatments over a 10 year period (Golder 2015). In total, 71 treated conventional lines (original treatments occurred between 2001 and 2005) and 24 untreated conventional lines were assessed for vegetation regrowth (Table 6). Vegetation regrowth along conventional and low-impact lines can be contrasted in association with moisture regime/broad ecosite classification.

Table 6: Vegetation Regrowth Along Conventional (Little Smoky Range) and Low-Impact Seismic Lines in NE BC

Ecosite Classification	Line Type	Number of Lines Sampled	Average Age of Line (Years)[a]	Average Line Width (m)	Average Robel Pole Height (m) ± SE
Lowland	Treated Conventional	15	9.64	6.85	0.75 ± 0.15
	Untreated Conventional	9	22.40	7.00	0.91 ± 0.14
	Low-Impact Seismic	25	6.88	3.14	0.81 ± 0.77
Upland Coniferous	Treated Conventional	35	9.71	6.66	0.41 ± 0.08
	Untreated Conventional	12	29.10	7.40	2.72 ± 0.65
	Low-Impact Seismic	28	6.04	3.19	1.04 ± 0.16
Upland Deciduous	Treated Conventional	1	9.00	6.00	0.35[(b)]
	Untreated Conventional	2	33.50	6.00	1.73 ± 1.07
	Low-Impact Seismic	46	6.96	3.45	1.34 ± 0.11

Ecosite Classification	Line Type	Number of Lines Sampled	Average Age of Line (Years)[a]	Average Line Width (m)	Average Robel Pole Height (m) ± SE
Wetland	Treated Conventional	20	9.84	6.83	0.51 ± 0.04
	Untreated Conventional	1	9.00	7.00	0.30 [(c)]
	Low-Impact Seismic	89	6.61	3.06	0.84 ± 0.06

[a] Age of line refers to the time since line was cut or, as in the case of the treatment conventional lines, the time since treatment was applied to the line.

[b] Only one treated conventional seismic line occurring within upland deciduous has been monitored for regrowth in available data sources.

[c] Only one untreated conventional seismic line occurring within wetland (treed bog or treed fen) has been monitored for regrowth in available data sources.

On average, treated conventional lines in the Little Smoky range of Alberta had lower Robel pole height measurements across all ecosite types compared to low-impact lines in the current study (Table 5). At the time of vegetation regrowth measurement, treated conventional lines were, on average, 2.9 years older (from time of treatment) than low-impact seismic lines.

Even though disturbance along low-impact seismic lines had generally occurred more recently, they had greater vegetation regrowth compared to conventional treated lines occurring in equivalent ecosites. Untreated conventional lines had the greatest vegetation regrowth of the three types of lines assessed (Table 6). The age of untreated conventional lines (the majority of lines were cut between 1960 and 1980) was significantly greater than the ages of the other two types of lines and therefore plant communities had been regenerating along the lines for a much longer period of time compared to conventional treated lines and low-impact seismic lines.

6.0 DISCUSSION

Our results on LIS line recovery mirror the general recovery patterns attributable to ecosite seen along conventional lines wherein upland and deciduous forest types support taller and more recovery of woody biomass compared to lowland forest types. This has been discussed extensively in the literature and is thought to be a function basic ecology around moisture, nutrients, growth rate and successional processes between upland and lowland forest types in boreal ecosystems.

Of greater interest, we clearly show that mulched LIS lines recover more rapidly than conventional lines in two important ways. First, controlling for forest type, we show that most sampled lines support shrubs and the mean height of vegetation, even in lowland stands, is > 0.8 m within 10 years. Thus, for mulched LIS lines between one and ten years old recovery to shrubs is immediate and higher than the 0.5 m threshold required to influence wolf movement (Dickie 2015). Secondly, over half of sampled lines in lowland ecosites supported black spruce seedlings. Many lowland lines supported seedlings > 50 cm tall immediately after they were mulched (i.e., 1 year after being mulched). By mulching, LIS line preparation seems to prevent the catastrophic disturbance that knocks conventional lines back to a state of primary succession. Instead, preservation of the ground substrate seems to protect plant roots to facilitate immediate recovery of woody vegetation, likely by root sprouting for the observed willows and alder. Further, elevation of mulcher cutting drums above the ground surface seems to facilitate retention of some black spruce seedlings growing prior to line construction and maintains the capacity of the O horizon to germinate and support conifer seedlings soon after line construction, thereby also promoting long term recovery trajectories. Rather than showing stalled recovery along unexpected recovery trajectories, mulching LIS lines appears to establish rapid recovery along expected trajectories for boreal ecosystem, even in lowland caribou habitats, with scattered mulch distribution pattern having a greater influence on response of vegetation, with black spruce taller when mulch is continuous.

LIS lines showed greater vegetation regrowth than equivalent conventional lines occurring in Alberta based on age since disturbance, in the same habitat types. The LIS lines sampled in northeastern B.C. received no treatment and were disturbed more recently than the treated conventional lines in Alberta but still had taller average robel pole height measurements than treated conventional lines.

We also show nuanced recovery patterns along mulched LIS lines with respect to both line width and orientation that can be used to better inform planning of line construction in the future. Other research has noted that recovery along conventional lines occurs unevenly between different sides of lines (MacFarlane 2003, Lankau 2014) and that the height of recovering vegetation is influenced by line orientation (van Rensen et al. 2015, Keim et al. 2013). Here we show a clear influence of line orientation on the height of vegetation recovery. Even shortly after line preparation, woody vegetation is higher on north-south orientated lines than on east-west lines. Further, wider lines are more likely to support shrub recovery than narrower lines, with narrower lines supporting more return to conifer cover (black spruce height significantly affected by wider with reduced heights on wider lines > 3 m).

Both phenomena are likely influenced by high latitude gap and light dynamics. Low sun angle at northern latitudes coupled with the architecture of boreal canopies create complex light conditions in gaps. When gaps are small light conditions inside and outside of gaps may be quite similar. When larger, gaps may receive both diffuse and direct sunlight disparately across the gap footprint that can influence the spatial patterning of subsequent plant growth. In the northern hemisphere the north side of canopy gaps typically receive more light than the south side. Wider mulched LIS lines may allow for the penetration of more direct sunlight to the forest floor thereby increasing productivity. Regardless of width, north-south orientated lines are exposed to direct sunlight daily as a result of the sun's arc in the sky. Although seismic lines create comparatively narrow gaps across their width, a north-south line creates a significant amount of "north side" gap surface along their length.

One concern of using mulchers to prepare seismic lines has been that depositing mulch may inhibit subsequent recovery. Indeed, we observed an effect of mulch on line recovery. Specifically, we saw proportionally more lines supporting shrub growth and higher growth of vegetation along lines with no apparent or scattered mulch compared to those with continuous mulch coverage. However, relatively few lines supported continuous mulch coverage. In upland stands trees were large and widely spaced so mulchers could easily meander around much of the live biomass; in lowland stands trees were typically very small and widely spaces so there was little live biomass available to be converted into mulch. Typically, we observed sparse mulch coverage and rapid decomposition of mulch into the soil horizon. Mulch coverage did not affect black spruce seedling occurrence, but somewhat ironically, seedlings were shorter on lines with less mulch. Thus, while less mulch may facilitate fuller recovery of lines initially (i.e. to shrubs), more mulch may help to support eventual recruitment of black spruce required to ultimately convert seismic lines to forested stands. Decomposing mulch likely provides a good growing medium for young seedlings and prevents competition from shrub cover. Anecdotally, we saw numerous seedling rooted in clumps of partially decomposed mulch with properties similar to that of decomposing logs.

Mulch may also act to buffer black spruce seedlings against less hospitable growing conditions. Black spruce seedlings were less likely to occur along north-south lines than east-west ones, and along wider lines than narrower ones. With more exposure to direct sunlight, north-south lines and wider lines may become drier and thus less conducive to fostering microsites conditions required for seedling retention (van Rensen et al. 2015). Similarly, older lines supported fewer seedlings. More and taller seedlings on younger lines suggests that continued improvement of line mulching (smaller and lighter machines that can create narrower lines with continuous mulch) the overall rate of seedling retention and germination is similarly improved.

Despite a general trend toward cutting narrower seismic lines, most mulched LIS lines prepared were likely too wide to prevent use by wildlife based on current, albiet somewhat limited, data. Larger-bodied mammals tend to ignore seismic lines that are ≤ 2 m wide but use lines ≥ 3 similarly regardless of width (Kolowski and Alonso 2010 and 2012, Rabanal et al. 2010, Tigner et al. 2014). Thus, despite widespread adoption of preparing narrower LIS seismic lines, many of those lines prepared to date may not meet one of their primary management objectives. Though we saw evidence of animal use along many of the mulched LIS lines we surveyed, it is promising that few supported established game trails. It is feasible that game trails have not yet established along the lines we surveyed because they were too young. The deep and obvious game trails frequently observed along conventional lines in the Parker Range had far more time to develop. However, many of the LIS lines we surveyed were 10 years old, seemingly sufficient time for trails to develop if lines were consistently used as travel paths.

It is plausible that behavioural decisions to use or not use seismic lines made by wildlife are influenced both by line width and the ground surface along a seismic line. Because older conventional lines were meant to provide a level work surface for field crews they also served as easy travel corridors especially compared to undisturbed ground surfaces adjacent lines. In contrast, the ground surface along mulched LIS lines was largely unchanged from undisturbed conditions. Many of the tracks we encountered, especially in lowland caribou habitats, had sunk deeply into the surface substrate and moss. Thus although many of the mulched LIS lines we sampled were “too wide” to prevent use based on width alone, use was dissuaded to some extent by soft and uneven ground conditions along the lines. Few of the lines visited had thick and continuous mulch mats and almost all deep O Horizons and intact hummocks (in lowlands). There is some indirect support for this idea in the literature that shows differential use of conventional and LIS lines regardless of LIS widths by wolves (Latham et al. 2011, Dickie et al. 2016). Further, rapid natural recovery of woody vegetation along the mulched LIS lines we sampled may have also acted to dissuade movement. Whether wolves and other predators such as bears, travel more or less along open, mulched LIS lines differently than recovered ones is unknown, but could be explored using remote cameras or fine-temporal scale GPS radio collar data.

Preventing consistent use of seismic lines by wildlife that acts to establish game trails along lines is important. While Dickie (2015) clearly shows that wolf use of lines diminishes once minimum vegetation height reaches 0.5 m, other work shows black bears continue to use even heavily recovered lines once game trails are established (Tigner et al. 2014). Further, early reclamation efforts have shown that physically closing lines inconsistently dissuades predator use, and results may be more promising for black bears than for wolves (Neufeld 2006). This disparity may be that patchy and inconsistent recovery along conventional lines does not close open pathways along “every square inch” of line needed to achieve recovery for wolves (Dickie 2015). While newer reclamation efforts seem to be successful in re-growing woody vegetation and fell trees along or otherwise blocking conventional seismic lines (Bentham and Coupal 2015), it is unclear whether those successes change wolf movement decisions. Regardless, it will require an intensive effort to sufficiently reclaim the tens of thousands of kilometers of conventional seismic lines in NE BC.

Understanding the direct wolf response to LIS line preparation methods and how those responses influence wolf caribou relationships is particularly important with the shift in E&P away from development of large conventional reservoirs toward shale and other unconventional resources because there is a concomitant need for higher seismic line density. Lack of clarity in LIS requirements in the current regulatory framework may lead to an increased need to actively restore/reclaim LIS of > 3 m widths where more shrub cover which may act as an attraction to alternative prey species (moose, deer) and reduced height of black spruce were observed. Hydrocarbons are formed by geologic processes acting on source rocks; over time oil and gas tends to migrate or seep from those source rocks. Conventional E&P was focused on producing accumulations of seeped oil and gas trapped in large and obvious geologic architecture. That was typically accomplished by coarse subsurface data acquired with regional 2D seismic surveys along a single or small number of widely spaced lines. In contrast, shale development is focused on developing hydrocarbon directly from their source rocks. This requires detailed, 3-dimensional subsurface data acquired with 3D or megabin surveys that acquire data along a grid of closely spaced and intersecting source and receiver lines or from closely spaced seismic lines orientated parallel to one another, respectively. On 3D surveys receiver lines are typically narrower than source lines, but megabin surveys often use wider lines to facilitate both source and receivers. Regardless, if seismic lines are not cut sufficiently narrow to prevent behavioral responses in wildlife and support conifer growth over shrub growth, such surveys translate to a high density of linear disturbances that can negatively impact habitat, individual fitness, and population size and viability (Sorensen et al. 2008, Festa-Bianchet et al. 2011).

In NE BC mapped caribou ranges already exceed federal disturbance thresholds (Environment Canada 2012), and many of those ranges also significantly overlap shale gas basins subject to continued development. Clearly, a significant effort must be made to further reduce seismic line widths. As our data was determined to be from all winter seismic operations, we could not compare whether winter or summer operations impact vegetation response following treatment. Similarly, our sites sampled lacked variability in recut; so sample size was too low to determine if a conventional line recut to LIS responds differently following treatment.

7.0 MANAGEMENT RECOMMENDATIONS

7.1 Seismic Line Width

Our work shows that despite a gradual reduction in LIS line widths, many of the lines mulched in NE BC are likely too wide to prevent triggering behavioural responses in wildlife, based on our current knowledge.

We strongly recommend requiring very narrow line widths as normal operating procedure, especially within mapped caribou range. With current technology lines can be routinely mulched to < 2 m wide and on occassion receiver lines for entire 3D surveys are hand cut. Further, rapidly advancing technologies in seismic data acquisition, such as used of wireless geophones and alternative source, allow for almost “lineless” seismic surveys. Line width has been captured in neighboring jurisdictions in an effort to manage woodland caribou habitat. In Alberta (Alberta Government 2016) where existing disturbances occur (i.e. clearings and cleared lines with vegetation heights less than 1 meter in height and within 200m of proposed seismic program line), the creation of new lines is prohibited, and the existing lines must be reused. Where existing disturbances are not available, new clearings must adhere to widths of less than 2.75 meters for source lines which are meandering and employ tree avoidance techniques and receiver lines must be undercanopy and hand cut (Alberta Government 2016). Given rapidly changing seismic technology, requiring operators to re-use existing disturbances may not make sense, though it is a reasonable default subject to exemption with a clearly defined need and a clearly defined and scientifically defensible line construction plan to eliminate or mitigate impacts. Our work demonstrates that the new energy requirements around seismic operations are supported, and could be considered by the OGC.

7.2 Long Term Recovery Trajectory

Our work shows short term recovery of vegetation along lines, but can only infer on long term recovery trajectory and ultimate success. While encouraging that mulched LIS lines support conifer seedlings in lowland caribou habitat, in their current states these lines have not reverted back to forested stands, and one example exists where as year since disturbance increases, that mulch and spruce tree success may differ in response (Keim et al. 2013).

We recommend revisiting these study plots in the future to track recovery trajectory over time (e.g. similar to mensurative work conducted in NEBC and the NWT (Lankau 2014) and in west-central Alberta on conventional seismic lines [Golder 2015b], or long term study on the Alaska northslope [Felix and Raynolds 1989, Felix et al. 1992, Emers et al. 1995, Jorgenson et al. 2010]).

7.3 Integration Line Width and Orientation Outcomes into Seismic Survey Planning

Our work shows clear influence of line width and orientation on recovery.

We recommend such outcomes be used to improve seismic survey design during survey planning. For example, in cases where use of very narrow lines is infeasible or inappropriate, wider lines should be orientated north-south to facilitate more rapid recovery to functional habitat. Narrower lines, for which rapid recovery may be less important, should be orientated east-west because recovery is slower but also more conducive to black spurce recovery. Unlike 2D seismic surveys where line orientation and placement is critical for data collection, source and receiver orientation in 3D and megabin surveys is not.

7.4 Management of Mulch

Our work shows that mulch can influence line recovery. While too much mulch may act to slow line recovery, mulch along many lines appears to rapidly decompose and this may foster conifer seedling persistence when in a continuous distribution pattern. In many ecosites insufficient biomass is mulched to produce a thick scattered mulch mat.

We recommend that in stands of extremely dense black spruce it may be important to manually clear or thin mulch after line preparation to facilitate rapid recovery. In contrast, we also recommend that in open lowland stands where little mulch is created, it may be beneficial to collect mulch in piles to create artificial nurse logs to support seedling establishment and recruitment.

7.5 Importance of Ecosite

Our work shows that similar to conventional seismic line response following seismic disturbance, LIS lines occurring within wetlands (fens/bogs) are recovering significantly slower than in mesic or deciduous upland ecosites. Avoiding wetlands and other lowland areas within caribou range during seismic program activity, if feasible, would enhance recovery within a range. If avoidance is not feasible, clear and scientifically defensible mitigation strategies should be required for all lines constructed in lowlands areas.

Within the Alberta Government (2016) draft Little Smoky and A La Peche Caribou Range Plan, the importance of ecosite has been considered within the requirements for the Energy Industry operating within the range plan area. Within the draft range plan, new disturbances should avoid open and treed wetlands throughout the ranges.

7.6 Footprint Minimization

Our work demonstrates, that although recovery of vegetation along LIS lines occurs in less than 10 years, that the LIS lines still contribute to a development footprint within caribou ranges. Although this footprint can impact the threshold of development under the Federal Recovery Strategy, LIS generally do not contribute to disturbed habitat, as line width is often too small to be seen on Landsat imagery (EC 2012). As such, applications for new seismic exploration, even if LIS, should demonstrate that reprocessing existing seismic data cannot be used in its place.

7.7 Bookkeeping of Spatial Data

During this project, we encountered two issues with the metadata attached to seismic line shapefiles obtained from the BC OGC. First, some seismic survey program dates were difficult to ascertain. In some instances dates attached to programs did not match personal knowledge of in-field activity (e.g. lines sampled on previous projects were reported as applied for in later years in the metadata). In other instances, and more commonly, the dates attached to seismic programs in the OGC data were the application dates for survey programs, rather than the dates for which surveys were completed in the field. Often long time lags can occur between program application and completion. From the prospective of understanding line recovery trajectories, and subsequent bookkeeping and management decisions, differentiating between application and completion dates for seismic programs is critical.

The second metadata issue we encountered were inconsistencies between proposed line widths and “as built” or final plan line widths. During program application a proponent applies for a variety of program parameters including line widths. Often those widths change to some extent during actual operations, or fluctuate around an idealized width. Although such variation is often tracked by field operations, if it is not reported in some capacity it is lost from final data. We routinely measured lines wider than application widths. While lines were not typically meters wider, even several decimeters can alter the management implication of whether or not a line is a functional disturbance feature for caribou and wolves. Further, because we show that line width influences recovery timing, even small discrepancies in width may influence our understanding of recovery trajectories for existing lines on the landscape.

While strides are being made to improve data quality, detail and availability, we strongly recommend that the OGC requests a) program status and completion is clearly indicated, and that b) program attributes are reported from as built information rather than proposed information for all available spatial data from the BC OGC. This is readily achievable given modern database and bookkeeping technology (e.g., cascading updates in geodatabases in ESRI), simple QA/QC of program information (e.g., development of and infill of appropriate “Completion Date” columns in program attribute tables), and dissemination of clear, user friendly metadata (e.g., data fields clearly explained and abbreviations clearly defined). These issues persist even in the newest geophysical data available from the BC OGC. By remedying these bookkeeping issues, researchers and managers will have access to better and more accurate data from which that can make clearer and more precise management recommendations and decisions.

8.0 CONCLUSION

Since the release of the Recovery Strategy for the Woodland Caribou, Boreal Population (*Rangifer tarandus caribou*) in Canada (Environment Canada 2012), there has been much emphasis on recovery of industrial footprint, including roads, seismic lines, pipelines and clearings, to meet undisturbed habitat targets contained in the Recovery Strategy. Determining the effect of length of time since disturbance, land cover type and line width on natural recovery rate of low impact seismic lines provides a basis for removing previously disturbed caribou habitat from the disturbance footprint. As such, our study provided results and recommendations around how width, mulch distribution pattern, line orientation, and ecosite type contributes to the vegetation attributes of natural recovery on LIS lines in NE British Columbia

9.0 CLOSURE

This report was prepared by Golder Associates Ltd. (Golder) and Explor for the BC Oil and Gas Research and Innovation Society. The material in this report reflects Golder and Explor's best judgment in light of information available to us at the time of preparation. If BC OGRIS edits, revises, alters or adds to the material in this report in any way, all reference to Golder and Explor, and Golder or Explor's employees must be removed unless BC OGRIS's changes are agreed to by Golder and Explor. Any use which a third party makes of this report or any reliance on or decisions to be made based on it, are the responsibility of such third party. Golder and Explor accept no responsibility for damages, if any, suffered by any third party as a result of decision made or action based on this report.

We trust that this Draft Report meets your current needs. If you have any questions, please contact Christopher Shapka at (780) 930-8670 (office) or (587) 336-4126 (mobile).

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APPENDIX A

VRI Data Interpretation

We used the British Columbia Vegetation Resources Inventory (VRI) dataset to interpret land cover, and identify and select sampling locations for this project. VRI is a forest inventory managed by the BC Ministry of Forests, Lands and Natural Resources Operations that delineates unique land cover types as discrete polygons based on a series of ground cover, vegetation and soil attributes. In a Geographic Information System we used available polygon attributes to reclassify the VRI in our study area to non-forested land covers and upland and lowland forested stands. Our goal was to support an *a priori* sampling design by removing non-forested land covers from sampling consideration and then simplifying remaining forested land covers into lowland and upland stand types. Because VRI data are classified by different individuals using different data in an iterative classification framework, our reclassification required a series of separate attributes and steps. We describe our workflow and rational below.

Separation of non-forested land covers from forested stands

In this step we used 2 VRI attributes to separate non-treed polygons from those dominated by trees.

Water

To identify polygons dominated by water we used information in British Columbia Land Cover Classification Scheme Level 2 (bclcs_level_2, Page 10). This attribute classifies polygons as treed or non-treed and as land or water. We selected the following class representative of water:

- W [Water]

Non-woody vegetation

To identify polygons dominated by non-woody vegetation we used British Columbia Land Cover Classification Scheme Level 4 (bclcs_level_4, Page 14). This attribute classifies polygons by vegetation types and non-vegetated cover types. We selected the following classes representative of non-woody vegetation:

Non-vascular vegetation

- BY [Bryoid]
- BM [Bryoid – Moss]
- BL [Bryoid – Lichens]

Non-woody, vascular vegetation

- HE [Herb]
- HF [Herb – Forbs]
- HG [Herb – Graminoids]

Shrub

To identify polygons dominated by shrubs (woody vegetation, but non-forested polygons) we used Species Composition Code – Leading Species (species_cd_1, Page 214) and British Columbia Land Cover Classification Scheme Level 4. Species Composition Code – Leading Species describes the canopy species within a delineated polygon representing the highest percent composition. We first used this attribute to select the NULL values, thus representative of all non-forested stands. From those selected polygons, we then used bclcs_level_4 to select the following classes representative of shrub dominated vegetation:

- SL [Shrub Low]
- ST [Shrub Tall]

All remaining polygons were considered forested.

Differentiation of forested stands by canopy species composition

In this step we used 5 VRI attributes to differentiate upland from lowland stands based on canopy tree species composition. We used Species Composition Code – Leading Species, Species Composition Code – Second Species, Third Species, and Fourth (species_cd_2 Page 219 and species_cd_3 Page 224, species_cd_4 Page 229 respectively) and Leading Species Percentage (species_pct_1, Page 244). Species Composition Code – Second and Third Species describes the canopy species within a delineated polygon representing the second and third highest percent composition, respectively, and Leading Species Percentage describes the percentage of the canopy comprised by the Leading Species defined above.

Lowlands

To identify polygons dominated by lowland forest types we first used Species Composition Code – Leading Species, and Leading Species Percentage to select the following classes representative of typical lowland tree species occurring in pure stands:

Species Composition Code – Leading Species

- LT [Tamarack]
- SB [Black Spruce]

***and** Leading Species Percentage*

- 100%

We considered these polygons as pure black spruce or tamarack stands.

We then used Species Composition Code – Leading, Second and Third Species, and Leading Species Percentage to select the following classes representative of typical lowland tree species occurring in mixed stands:

Species Composition Code – Leading Species

- LT [Tamarack]
- SB [Black Spruce]

***and** Leading Species Percentage*

- < 100%

Species Composition Code – Second or Third Species

- LT [Tamarack]
- SB [Black Spruce]

We considered these polygons as mixed species lowland stands.

Finally we used Species Composition Code – Leading and Second Species, and Leading Species Percentage to select the following classes representative of tree species typical of lowlands as the lead species but typical of upland species as secondary species (we defined these as lowland shoulders):

Species Composition Code – Leading Species

- LT [Tamarack]
- SB [Black Spruce]

***and** Leading Species Percentage*

- < 100%

Species Composition Code – Second Species

- AC [Balsam Poplar or Cottonwood]
- ACB [Balsam Poplar]
- ACT [Black Cottonwood]
- AT [Trembling Aspen]
- B [True Fir]
- BL [Alpine Fir]
- E [Birch]
- EA [Alaska Paper Birch]
- EP [Common Paper Birch]
- P [Pine]
- PJ [Jake Pine]
- PL [Lodgepole Pine]
- PLI [Lodgepole Pine var. latifolia]

- SW [White Spruce]

We considered these polygons as mixed species stands likely to be drier lowland stands, or lowland shoulders.

Uplands

To identify polygons dominated by upland forest types we first used Species Composition Code – Leading Species to select all polygons led by a possible upland species. We selected the following classes:

- AC [Balsam Poplar or Cottonwood]
- ACB [Balsam Poplar]
- ACT [Black Cottonwood]
- AT [Trembling Aspen]
- B [True Fir]
- BL [Alpine Fir]
- E [Birch]
- EA [Alaska Paper Birch]
- EP [Common Paper Birch]
- P [Pine]
- PJ [Jake Pine]
- PL [Lodgepole Pine]
- PLI [Lodgepole Pine var. latifolia]
- SW [White Spruce]

Because some species may occur as the lead species in wetlands with mineral soil or otherwise atypical lowland sites, we then used Species Composition Code – Leading Species, and Leading Species Percentage to select reselect from those polygons the following classes representative of typical pure upland stands:

Species Composition Code – Leading Species

- AC [Balsam Poplar or Cottonwood]
- ACB [Balsam Poplar]
- ACT [Black Cottonwood]
- AT [Trembling Aspen]
- SW [White Spruce]

***and** Leading Species Percentage*

- 100%

We considered these polygons as pure upland stands.

We then used Species Composition Code – Second Species, and Leading Species Percentage to reselect from the original upland polygons the following classes representative of typical upland tree species occurring in mixed stands:

***and** Leading Species Percentage*

- < 100%
- Species Composition Code – Second Species
- AC [Balsam Poplar or Cottonwood]
- ACB [Balsam Poplar]
- ACT [Black Cottonwood]
- AT [Trembling Aspen]
- SW [White Spruce]

We considered these polygons as mixed species upland stands.

Finally we used Species Composition Code – Second, Third, and Fourth Species, and Leading Species Percentage to reselect from the original upland polygons following classes representative of tree species likely upland species as the lead species and typical of lowland species as secondary species (we defined these as upland shoulders):

***and** Leading Species Percentage*

- < 100%

Species Composition Code – Second, Third, Fourth Species

- LT [Tamarack]
- SB [Black Spruce]

We considered these polygons as mixed species stands likely to be wetter upland stands, or upland shoulders.

Pure and mixed stands were considered core and shoulder stands were considered shoulder for both upland and lowland stand types.

Differentiation of forested stands by soil moisture regime and compilation of final stand types

In this step we used combined wetness classifications from the Soil Moisture Regime 1 (soil_moisture_regime_1, Page 210) with reclassifications based on stand composition to delineate final upland and lowland stand classes. Soil Moisture Regime 1 classifies polygons by the average amount of soil water annually available for evapotranspiration on a 0 (very xeric) to 8 (hydric) ranked scale. We used the SMR and composition reclassifications to delineate stand types as:

- Extreme Wet or Dry
  - Wet
    - Lowland core and shoulder, upland core and shoulder + SMR 7 and 8
  - Dry
    - Lowland core and shoulder + SMR of 0, 1, 2
    - Upland core and shoulder + SMR of 0, 1, 2, 3

Muskeg

  - Lowland core + SMR 4, 5, 6; lowland shoulder + SMR 5 or 6
- Upland
  - Upland core + SMR 4, 5, 6
- Shoulder
  - Dry lowland
    - Lowland core + SMR 3; lowland shoulder + SMR 3, 4
  - Upland shoulder
    - Upland shoulder + SMR 4, 5, 6

APPENDIX B

2016 Survey Site Photos

Figure 1: View of vegetation growth on a continuous mulch mat along a line prepared in 2011 in an upland ecosite.

Figure 2: View of vegetation growth on a scattered mulch line prepared in 2011 in an upland ecosite.

Figure 3: View of north-south orientated line in a wetland approximately 2 m wide cut in 2010.

Figure 4: View of north-south orientated line in a wetland approximately 4 m wide cut in 2010.

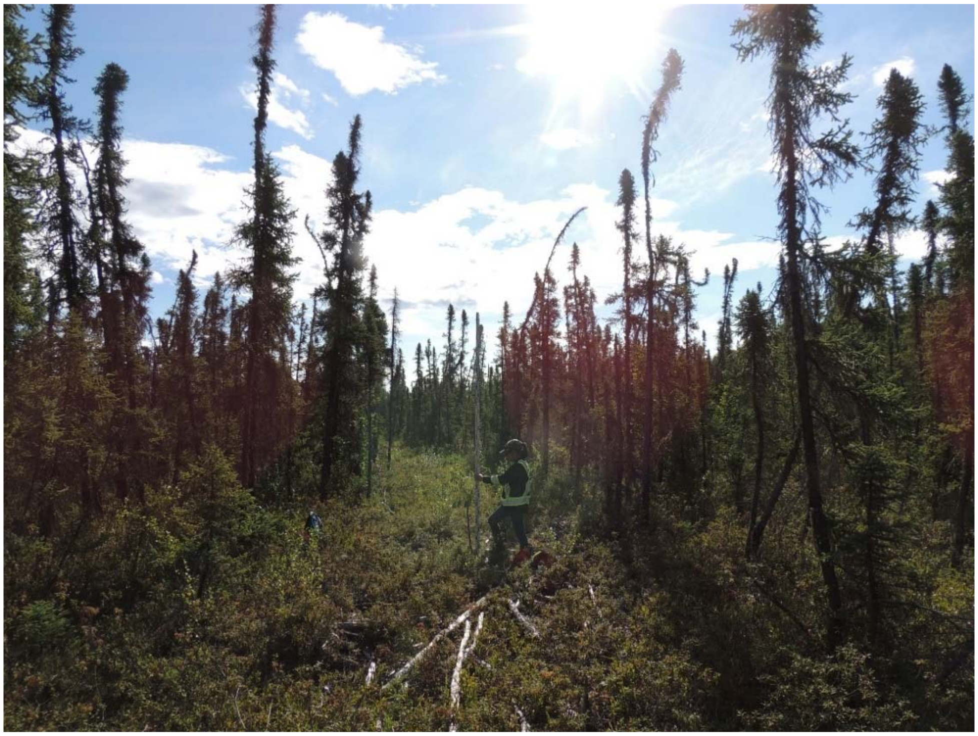

Figure 5: View of re-growth in a wetland along an east to west line that was prepped in the same year and width as Figure 6.

Figure 6: View of re-growth in a wetland along an north to south line that was prepped in the same year and same width as Figure 5.

APPENDIX C

GIS Analusis of Available Seismic Line Data

Despite a shift to low-impact seismic (LIS) practices in northeast British Columbia (NW BC), a significant number of lines have been created in mapped Boreal Caribou Ranges over the last 15 years. To gain a better understanding of the attributes of those lines created in mapped ranges, we completed some additional analyses of available seismic line data in a Geographic Information System ((GIS; ArcGIS 10.4, ESRI, Redlands, California). Here we used the same data described in section 4.1 of the main body of this report. We focused this analysis on LIS line prepared between 2005 and 2014.

Since 2005 (2004 – 2005 winter operating season), a total of 59, 526.74 km of LIS seismic line and 8,414.66 km of access has been cut in NE BC (Table C-1) (Study Area described in Figure 1, Section 3.0 of main body of this report). Most of the lines cut have been new cut, and those lines have been unevenly distributed across mapped boreal caribou ranges (Table C-2).

Table C1: Low-Impact Seismic (LIS) and Access Lines Prepared Between 2005 and 2014 in Northeast British Columbia

Line Type	Line Width (m)	Total Linear Kilometers Cut (km)	Cut Type	Linear Kilometers Cut by Cut Type (km)
Access	0	1075.90	Unknown	138.32
			Existing	8.92
			New	928.66
	Hand Cut	1.22	New	1.22
	1.75 - 2.5	7.22	New	7.22
	2.7 - 3.5	1001.60	Existing	699.70
			New	301.90
	> 3.5	6328.72	Existing	6300.45
			New	28.27
Seismic	0	3719.14	Unknown	656.02
			Existing	791.79
			New	2271.33
	Hand Cut	5469.11	Existing	395.58
			New	5073.53
	1.75 - 2.5	11893.05	Existing	1216.41
			New	10676.63
	2.7 - 3.5	26689.70	Existing	3570.48
			New	23119.22
	> 3.5	11755.74	Existing	6105.19
			New	5650.54

Table C2: Low-Impact Seimic (LIS) and Access Lines in Boreal Caribou Herd Ranges in Northeast British Columbia

Boreal Caribou Herd	**Access Line (km)**		**Seismic Line (km)**				
			Line Width (m)				
			0	*Hand Cut*	*1.75 - 2.5*	*2.7 - 3.5*	*> 3.5*
Maxhamish	*Existing Lines*	2119.01	2.16	25.90	271.39	1006.99	825.61
	New Cut Lines	218.23	-	699.08	2497.62	8582.60	195.04
Snake-Sahtaneh	*Existing Lines*	1920.46	1358.95	116.29	305.08	945.37	2663.29
	New Cut Lines [a]	859.73	2215.70	1623.15	3095.15	6463.65	2607.16
Calender	*Existing Lines*	378.19	-	64.73	415.98	828.68	429.34
	New Cut Lines [b]	67.14	0.74	234.22	1314.57	1192.61	270.49

[a] Of which 652.27 are unknown cut type.
[b] Of which 27.07 are unknown cut type.

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