Tweedsmuir Lichen Restoration Trial
Year 1 Report

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February 13, 2018
Prepared for L. Grant
Skeena Region, Ministry of Forests, Lands, Natural Resource Operations, and Rural Development
(Contract CS18RSK009)

Acknowledgements

We would like to thank a number of people who have contributed to this project. Anne-Marie Roberts (FLNRORD) was the instigator of the project, sought funding, and made the initial contact with the Cheslatta Carrier Nation. Jocelyn Campbell shared her lichen knowledge with us, and connected us with Darwyn Coxson of UNBC, who loaned us a fluorescence measurement device. James Rakochy, Land and Resource Manager, Cheslatta Carrier Nation, coordinated hiring of field technicians and equipment rentals. Charlene Peters and Rick Edmonds, technicians, Cheslatta Carrier Nation, helped us initiate the study, and put up with our "loads of methods". Agathe Bernard, Stewardship Forester, FLNRORD Nadina, helped to set up transects. Josh Jonker, Operations Manager and Director of Engineering, Western Aerial Applications Ltd, provided his expertise and time to help design the aerial seeding trial. Greg Vissia, Pilot, and Tyler Murray, Pilot in Training, Western Aerial Applications Ltd, travelled to our remote study site with their Hiller helicopter, and ran a smooth aerial seeding operation. Ryan Madley, White River Helicopters, transported us safely to and from the study site, and provided insight into fire conditions at the time of the wildfire.

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1.0 Introduction

The Tweedsmuir-Entiako herd is a subpopulation of southern mountain caribou (*Rangifer tarandus*), which is currently numbered at approx. 150 individuals (Roberts and Grant 2017). This herd is listed as Threatened under the federal Species at Risk Act (SARA; COSEWIC; 2000 and 2002) and at risk in British Columbia. A number of anthropogenic and natural disturbances may influence the trajectory of the Tweedsmuir-Entiako caribou population. In 2014, the Chelaslie River fire burned 140,000 hectares, including 80% of the herd's critical low-elevation winter range (LEWR) and much of the high value caribou migration corridor (CMC) in Entiako Provincial Park. It is hypothesized that food is not a direct limitation, but that loss of spatially distributed lichen sources may leave the herd more vulnerable to predators. Migration and forage availability beyond the fire zone is limited by past forest harvesting and associated seral stage constraints. The ability to move about a large landscape and thus be less predictable to predators is a key survival strategy for caribou (Steventon 2016). Although the Tweedsmuir-Entiako caribou herd is being closely monitored, accelerated recovery of lichen sources may mitigate the effects of the fire on this population.

Lichen mats may take 40 to 70 years to recover after a forest fire, depending on regional climate and the severity of disturbance (Bruelisauer *et al*, 1996, Morneau and Payette 1989, Coxson and Marsh 2001). Landsat imagery interpretation indicates that much of the area within the Chelaslie fire boundary was moderately to severely burned (GeoBC 2016). The fire affected all vegetation layers, and the soil humus layer was incinerated down to mineral soil in many areas. Lichen mats take a long time to regenerate in moderately to severely burned areas because of reproductive strategy and growth rates. Many of the *Cladonia* or reindeer lichens proliferate primarily through fragmentation (Ahti 1977), and initial dispersal distance appears to be limited, with most fragments falling within 1 m of their source (Roturier *et al,* 2007). Birds, mammals, and wind likely contribute to lichen dispersal patterns (Goward 2000, Turner 2009), however, the opportunity for dispersal in a fire of this size is low because of the long distance to source lichens. Growth rates for reindeer lichen podetia are limited to 3-6 mm/year on average and vary by latitude and forest cover (Scotter 1963).

Artificial dispersal of lichen fragments has been studied as a reclamation tool after major disturbances caused by wildfire, mining, and forest harvesting and results are promising (Table 1). Some key findings are:

- The volume of lichen distributed influences the time required for mat development. For example, fragment distribution at 2.25 L m-2 (4500 L/ 2000 m-2) on burnt substrate can establish a new lichen mat within less than a decade. Fragment distribution at 45 L m-2 (900 L / 2000m-2, similar to our treatments) on burnt substrate may be more efficient over a slightly longer timeframe for operational scale applications.
- Moss and twig substrates may improve lichen retention on clear-cuts.
- Acrocarpus mosses, such as firemoss, help to stabilize soil and appear to provide an anchoring substrate, without competing for light or smothering lichens.
- Two years post-treatment is adequate time for soil pH to normalize and for firemoss to establish.

Table 1. Summary of other lichen restoration trials

Project	Ecology/Prep	Variables	Treatments	Results / Discussion
Terrestrial lichen transplants within Mesilinka Fire west of Williston Reservoir Tsay Keh Dene Nation (Rapai 2016, 2017) Initiated in 2015	• Boreal White and Black Spruce cool dry subzone (BWBSdk), Pine - Kinnikinnick - Lingonberry (102) • Lichen was stored in open plastic garbage bags for 2-5 days under shade	• Intense burn and crest slope position • Intense burn and flat • Less intense burn and flat	• Intact lichen mats and lichen fragments • Burned mineral soil and application of a forest floor litter mix	• By June 2017, new podetia had been identified on the lichen fragments and an average growth rate of 3-5 mm/year of lichen structures was observed (pers. com. McColl 2017).
Reindeer lichen transplant feasibility for reclamation of lichen ecosites on Alberta's Athabasca oil sands (Duncan 2011) Initiated in 2009	• Lichen - Jack Pine (Boreal ecosystem phase a1)	• 12 and 24-year-old reclaimed sites, where soil had been disturbed, affecting pH and nutrient regimes.	• Lichen fragments onto different substrates (moss, litter, or bare soil).	• Moss and twig substrates appeared to improve lichen retention on clear-cuts, but had no significant effect in second growth forests. • Acrocarpus moss species appeared to provide stabilization of the soil surface as well as an anchoring substrate for lichens, and they did not compete with the lichens for light or smother them like feathermoss species.
Restoration of reindeer lichen pastures after forest fire in northern Sweden: Seven years of results. (Roturier *et al,* 2017) Initiated in 2008	• Lichen was fragmented using a leaf shredder resulting in strands several mm long to cushions a few cm across. • Viability assessed based on color (bleached strands considered dead; strands with green pigment alive). • Establishment assessed based on growth of podetia or hyphae.	• Site 1 high fire severity, clear-cut after the fire • Site 2 moderate fire severity on lower moist-mesic slope, clear-cut and planted with pine • Site 3 low fire severity, scattered live and dead trees (38% cover) left to natural post-fire dynamics • September and March transplant seasons	• .45 L m^{-2} (900 L / 2000m^2) dose • 2.25 L m^{-2} (4500 L/ 2000 m^2) dose • 8 blocks (20 x 20 m) at each site	• Lichen fragments distributed 2 years after fire can survive on burnt substrate and can establish a new lichen mat within less than a decade. • The lower dose was more efficient and could be more effective for large-scale restoration. • Establishment rate was higher under cover than in clearcuts, but still good in clear-cuts. • New growth was observed from apparently non-viable (bleached) fragments.
Detour Gold Mine reclamation trial Northern Ontario (Rapai and McMullin, unpublished) Initiated in 2015	• Jack Pine – Black Spruce– Feathermoss ecosystems on dry to moist, sandy to coarse loamy soils.	• Locations 1 and 2 typically have 30 cm of overburden spread over cobble sized rock. • Location 3 is an old forest access road with a gravel and coarse sand 'cap'.	• 200 g doses: • Lichen mats, lichen fragments, and controls • mineral soil, moss, wood chips, and erosion blanket	• Results will be available in February 2018. • Rapai is also in the early stages of a 'greenhouse' trial in which viability and growth of different size lichen fragments will be evaluated.
First Coal Corporation Central South Property (Turner and Duncan 2009) Initiated in 2009	• Dry sites in alpine and subalpine parkland, particularly windswept ridges.	• Microsite enhancement, including surface recontouring, and loosening of compacted gravel and rock surfaces • Potential for further compaction of soil	• 4 treatments, 10 plots/treatment • 0%, 5%, 10%, and 25% cover of lichen fragments	• By 2012, fragments on bare mineral soil were scoured by blowing sand or coated in soil during rain events. • Fragments on Acrocarpus mosses had good survival and showed signs of anchoring. • Transplanted patches expanding on leeward sites. • Windblown fragments becoming established where "caught" by alpine grasses.

In 2017, a terrestrial lichen restoration trial was initiated within the burned portion of the home range of the Tweedsmuir-Entiako caribou herd in west-central British Columbia. The study site is on the traditional territory of the Cheslatta Carrier Nation (Figure 1). Lichen fragments were dispersed by ground and aerial application onto logged and unlogged areas of pine-lichen woodland in the Chelaslie River burn (2014). The purpose was to test whether lichen fragment distribution could be an effective means of accelerating lichen recovery on favorable sites, and to explore means of implementation at the operational scale.

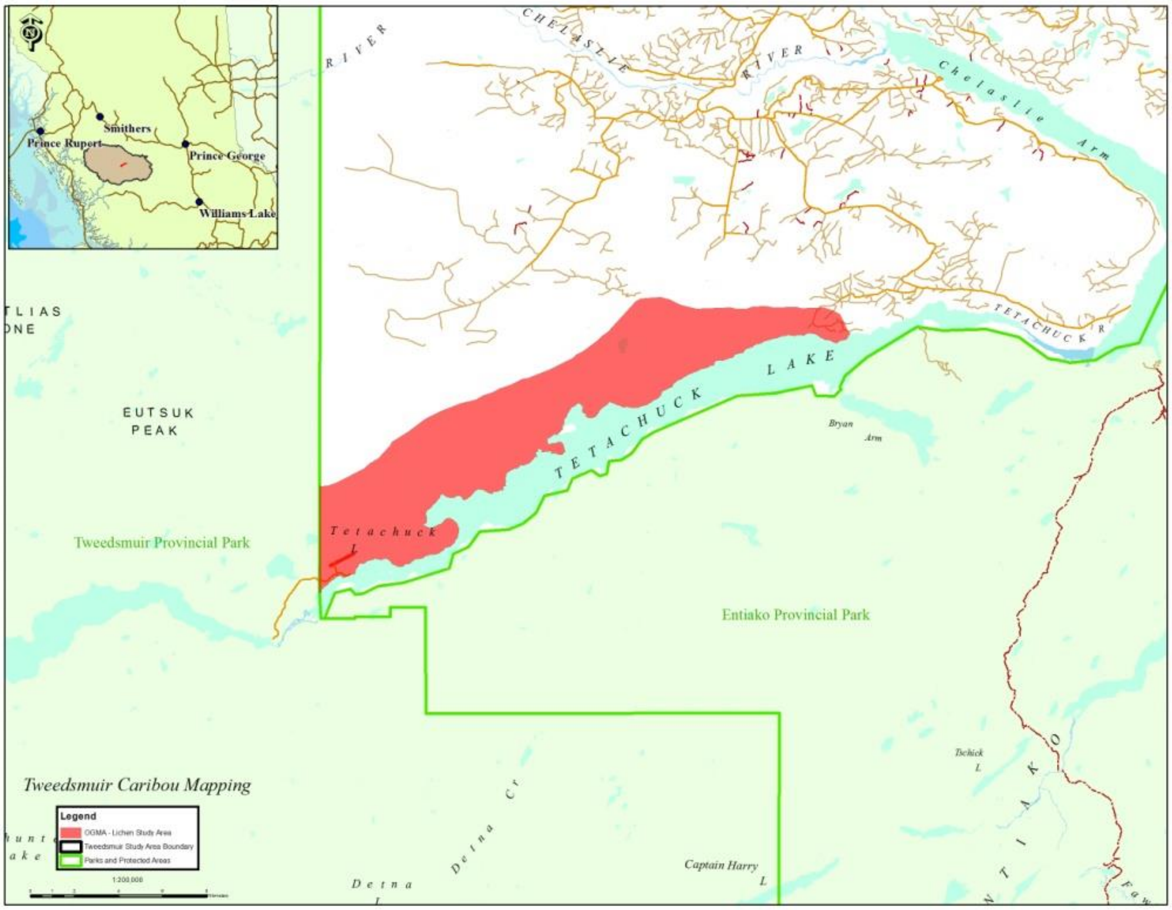

Figure 1. Location of lichen restoration trial in the burned area of the Tetachuck Old Growth Management Area.

Collaboration with the Cheslatta is a key aspect of this project.[1] In this first field season, FLNRORD hired two Cheslatta field technicians to help with trial installation, and rented field equipment from the Cheslatta Band office. Charlene Peters, Lichen Field Technician, from the Cheslatta Carrier Nation comments that:

*"As a member of the Cheslatta Carrier Nation, I am honored to be involved in this project to begin restoring the presence of lichen in the caribou habitat within our territory. In my language, I call this exercise "**nastl'oo**", which means repairing by trying. We are involved in a rare chance*

[1] In September 2016, the Cheslatta Carrier Nation signed a reconciliation and settlement framework with the B.C. government to advance reconciliation between the Parties and to redress any impacts related to the Nechako reservoir on Cheslatta's cultural, social, environmental, and economic well-being (2016).

to help reseed and grow the primary food source for our caribou, which is on the brink of gone. Our territory has undergone substantial impacts over the last few decades with flooding, huge fires, and clearcut logging. This is my chance to do my part in an important project to sustain and enhance the caribou which historically were an important source of food and sustenance for my ancestors."

2.0 Methods

2.1 Overview

Two sites were selected for the lichen restoration trial within the Chelaslie River wildfire boundary and the Tweedsmuir-Entiako caribou herd range. At each site, transects were laid out for both treatment and control purposes. An ecosystem plot (FS882) was also established in association with each transect. Lichen was collected north of Fort St. James, BC and was stored for a maximum of 7 days. Prior to dispersal, the lichen was either torn up manually or using a weed wacker. Restoration treatments varied based on the method of fragment dispersal (manual, leaf blower, and aerial), the volume of lichen distributed, and the season of fragment distribution (summer or fall). Following treatment, monitoring data was collected from each transect and plot in order to track success of lichen establishment.

2.2 Study area

The study area is located within the Tetachuck Lake Old Growth Management Area (OGMA), which is 8,434 ha in size and is characterized by the low-lying, flat to gently rolling terrain of the Nechako Plateau. Eskers and melt water channels are aligned in a southwest to northeast direction within a predominantly morainal landscape (Holland 1967). Lodgepole pine and mixed lodgepole pine/white spruce (*Picea glauca*) stands were the dominant forest type prior to the Chelaslie River wildlife. Deciduous stands of trembling aspen (*Populus tremuloides*) were found on the south-facing slopes above Tetachuck Lake. The rapidly drained eskers supported open stands of poor-growing lodgepole pine with an abundance of reindeer (*Cladonia*) lichens on the forest floor (Banner *et al*, 1986). Roughly half of the OGMA was logged prior to 2000, before old growth forest management objectives were established.

The study area has a continental climate, with relatively dry, warm summers and, cold, relatively dry winters with a snowpack of less than 50 cm. Wistaria weather station data, used to characterize the Sub-Boreal Spruce zone, indicates a mean annual temperature of 2.2^{o}C and mean annual precipitation of 441 mm, with less than half of that falling as snow (Banner *et al*, 1993).

The trial focused on the xeric and sub-xeric biogeoclimatic site units (SBSdk 02 and 03) that are thought to support Pine-Lichen woodlands throughout forest succession (i.e., they do not transition to Spruce - Feathermoss communities) (Banner *et al*, 1993).

2.3 Site Selection

Two study sites were chosen within the OGMA and close to Tetachuck Lake. Both sites were located about 1 km from any long-term stand and lichen development monitoring plots established by Cichowski and Haeussler (2013). At Site 1, esker and terrace formations occur next to coarse-textured glacial tills so that the rapidly drained Lodgepole pine - Feathermoss - Cladina (SBSdk 03) biogeoclimatic site series is the common site type. Most of the area is mapped as moderate burn severity (Regional GeoBC 2016)[2,3]. Prior to the fire parts of this site were clear-cut, and parts were logged for MPB salvage, with young residual lodgepole pine and occasional hybrid white spruce left standing.

Site 2 is a complex of more pronounced eskers and terraces, where Lodgepole pine - Juniper - Ricegrass (SBSdk 02) and Lodgepole pine - Feathermoss - Cladina ecosystems occur adjacent to old melt water channels occupied by wetland complexes and seepage forest. This site includes areas of high fire severity and moderate fire severity. Prior to the fire, these stands were characterized as mature MPB-killed lodgepole pine.

HOBO weather stations, for monitoring daily air temperature and precipitation, were placed at the two study sites in July 2017.

2.4 Transect Layout

Control and treatment transects were established at each site. Transects were selected such that they would be relatively uniform in site conditions including site series (SBSdk 02 and 03), stand condition prior to burn (mature MPB-killed forest, logged), and burn severity (moderate and severe). Table 2 provides a summary of transect characteristics including ecosystem, condition prior to fire, fire severity, and treatment.

Each transect was laid out by establishing a start point and running a 100-m tape along a bearing (i.e. centre line) that would satisfy the conditions described above. The corner points were located by measuring 10 m from the start and end of the transect at a 90-degree angle. Transect start, midpoint, endpoint, and corners were marked with pigtails, labeled metal tags, and orange flagging. These points were recorded in GIS Kit on an iPad (http://garafa.com/wordpress/all-apps/gis-pro).

2.5 Plot Layout and Ecosystem Data Collection

One 100 m^2 (5.64 m radius) ecosystem plot was established within 100 m of the start point of each transect. The distance and bearing from the transect start point was recorded and plot centre was marked with a pigtail, labeled metal tag, and blue flagging. Blue flagging was tied along the perimeter of the plot to facilitate cover estimates and for treatment application. Two additional plots were laid out adjacent to transects 1 and 2 in order to test two different treatment doses (40 L and 80 L per 100m^2).

Full ecosystem, coarse woody debris (CWD), stand structure and caribou mobility data was collected within the 100 m^2 plots using protocols set out in LMH 25 Describing Ecosystems in the Field (2010). Stand structure (live or dead) was recorded by counting the number and status of trees > 7.5 cm, < 7.5 cm DBH, the number of live saplings 7.5 cm to 1.3 m tall, and, the number of seedlings < 7.5 cm tall within each plot.

CWD data was collected according to LMH 25, using transects 30 m in length. Caribou mobility class was recorded for each log that intersected the CWD transect based on the criteria developed by Cichowski *et al*. (2011):

[2] Burn severity mapping is an imagery-derived dataset based on Burned Area Reflectance Calculation (BARC) and has a resolution of 30 m.

[3] Areas of high fire severity have a dead forest canopy with only the trunk and large branches remaining, the litter is completely consumed, duff layer is mostly consumed, and mineral soil exposure is greater than 40%. In areas of moderate fire severity, the trunk, large branches, as well as smaller branches remain, twigs and cones are blackened but remaining, litter is mostly consumed, duff is spottily consumed, and mineral soil exposure is 5 - 40% (Hope et al 2015).

Caribou mobility classes:
0: top side of log <10 cm above ground and log mostly part of forest floor;
1: top side of log 10-40 cm above ground and log mostly branch free;
2: top side of log or branches 40-100 cm above ground with scattered branches;
3: top side of log or branches 40-100 cm above ground with dense branches, or top side of log >100 cm above ground (log mostly branch free); and,
4: top side of log or branches > 100 cm above ground with dense branches reaching down to the ground if log is raised off the ground.

A caribou mobility index was calculated for each log by multiplying its CWD length class by its mobility class. These mobility indices provide the relative contribution of each log to mobility obstructions on the plot. The mobility index for the plot was calculated as the sum of mobility indices for all logs on the CWD plot.

2.6 Lichen collection, storage and preparation

Lichen was collected 80 km north of Fort St. James from an area with extensive glaciofluvial outwash deposits supporting SBSmk1 /03 forest ecosystems (DeLong *et al*. 1993). Lichen biomass in these systems can reach in excess of 1700 kg/ha (Coxson and Marsh 2011). Collection sites were outside of designated caribou winter range and were planned for harvest through BC Timber Sales (Joanne Vinnedge, pers com, 2017). Less than 20% of the lichen mats within a given area were collected (Kauppi 1979). *Cladonia mitis* was the most common species collected, followed by *Cladonia uncialis, Cladonia rangiferina, Stereocaulon* species and minor amounts of foot-lichens and club-lichens.

Two separate lichen collection trips were carried out (spring and fall of 2017) to avoid storing lichen for any length of time and compromising viability. The lichen mats were lifted from the forest floor with an effort to leave the humus layer intact and to obtain a "clean", humus-free product. Debris such as humus, soil, and pinecones can affect lichen viability and distribution.

If storing lichen for any length of time, it is important to ensure maximum air ventilation to avoid rot (Honneger 2003). As a precaution, burlap bags were used for collecting lichen in June, and woven nylon bags were used to store the lichen in September. The burlap provides excellent ventilation, while the woven nylon is more water resistant yet still breathable.

Lichen (23 x 100 L burlap bags) was collected for the manual and leaf blower seeding trial on June 21, 2017. At that time, the forest floor was quite dry, with less than 40 mm of precipitation within the previous 20 days. Air temperature reached a high of 15^{o}C and a low of 5^{o}C that day.

Lichen (30 x 100 L woven nylon bags) was collected for the aerial seeding trial on September 24, 2017. Air temperature reached a high of 15^{o}C and a low of 10^{o}C that day, with a mix of overcast skies and light rain.

Lichen mats were broken into fragments manually and by weed wacker. The manual approach, which was used in the spring seeding trial, involved pulling the lichen mats apart into individual strands (4-6 cm long) and small cushions (4-8 cm across) immediately prior to distribution. Following a study by Roturier (2017), we used a mechanized approach to lichen fragmentation in the fall. This involved loading a 200 L garbage can with roughly 40 L of lichen and applying a Stihl FS 40 trimmer. The trimmer wire spun and cut the lichen into fragment sizes ranging from 2 cm long strands to 4 cm cushions. The prepared fragments sat in nylon bags overnight and were distributed the following morning.

2.7 Ground and aerial lichen distribution

Lichen fragments were distributed using three methods: manual, leaf blower, and helicopter distribution. Transects was treated using one of the three methods, while corresponding ecosystem plots were manually treated only. All transects and plots were treated at a rate of 40 L of lichen fragments/ m^2. Two additional small plots (at transects 1 and 2) were seeded at a rate of 80 L/ m^2. Ground distribution of lichen took place on June 28 and 29, and aerial distribution was conducted on September 27.

To our knowledge, aerial distribution of lichen had not been attempted prior to our study. As a result, a substantial amount of time was invested in exploring the mechanics of aerial distribution. It was necessary to find a hopper system that could overcome the propensity of lichen branches to stick to each other and avoid jamming the device. The use of slurries and tackifiers was explored and the results are documented in Appendix II. The 1000 L cone-shaped fertilizer bucket available at Canadian Helicopters Ltd. in Smithers, was considered, but the cone shape would cause the "Velcro-like" lichen branches to jam as they flowed downward and on-board controls were limited. Western Aerial Applications Ltd (WA), a company specializing in precision aerial applications, was willing to work with us in designing a trial system that they could learn from and scale up in the future. After numerous tests at their hangar in Chilliwack, WA was able to design a functional trial approach. They used a small easily transportable Hiller helicopter equipped with a bucket that had a hydraulic aperture, rotary disc, and blower. Swath width and length of each distribution flight was precisely tracked using on board GPS. They transported the Hiller to the study site to perform the aerial operational trial, and will use the results to inform their operational design.

2.8 Monitoring plots

Monitoring plots were established in both transects and ecosystem plots in order to track changes in lichen cover relative to substrate and vegetation cover over time. In each transect, ten 1 x 1 m relevé monitoring plots were established. One plot was randomly placed within each 10-m increment of the transect by: 1) drawing from a table of random numbers to determine the distance from the beginning of each increment, 2) drawing a second random number to determine the distance of plot placement from the transect centre line, and 3) placing the plot right (R) or left (L) of the centre line, based on the best lichen coverage. The 1 x 1 m plot was always placed on the side of the line closest to the start of the transect. Plot corners were marked with flagging and pigtails, and a metal disc with the plot number was placed at the corner nearest to the centre line. The location of each plot (i.e. the distance along the centre line and the distance from the centre line) was recorded in an Excel spreadsheet.

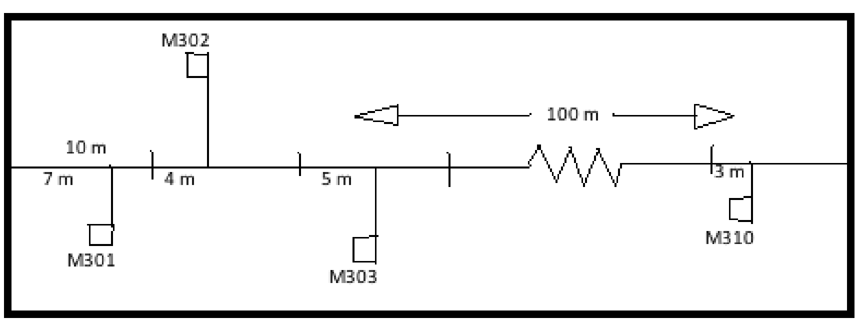

Figure 2. Illustration of 20 x 100 m transect with nested 1 x 1m monitoring plots.

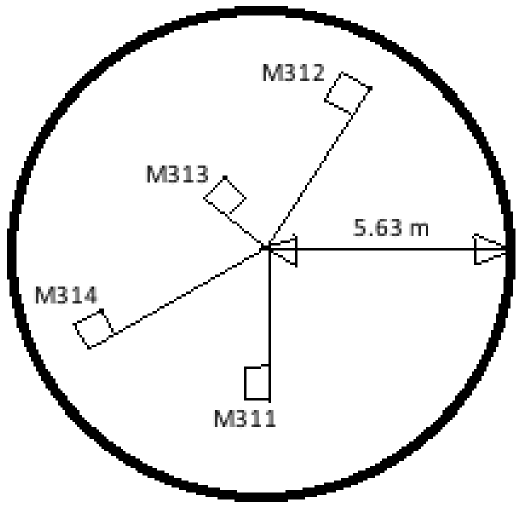

Figure 3. Illustration of 100 m^2 ecosystem plot with nested 1 x 1 m monitoring plots.

Four - 1 m x 1 m monitoring plots were established within each of the 100 m^2 ecosystem plots associated with each transect. Bearing from plot centre was chosen randomly by spinning a compass wheel. Distance from plot centre was randomly selected from a random numbers table. The 1 m x 1 m plots were placed in a counter-clockwise direction and the leading edge of the plot frame was aligned with the compass bearing. Plots corners were marked with flagging and pigtails, and a metal disc with the plot number was placed at the corner nearest to plot centre. The location of each plot was recorded in an Excel spreadsheet.

Substrate and vegetation cover was recorded for each monitoring plot. A 20 x 20 cm square[4] (representing 4 % of plot area) was used to facilitate precise measurement of cover values. Substrate categories were: organic matter and fine-woody debris (FWD) (includes decaying wood < 10 cm thick, large animal droppings, mats of bunchgrasses), decaying wood and CWD (> 10 cm thick), bedrock, rock (cobbles and stones > 7.5 cm), litter (mostly recent pine needle fall < 1 cm thick), and mineral soil.

[4] A Ridgid(c) measuring stick was folded to form the 20 x 20 cm square, so that cm and mm increments were used to calculate smaller cover values.

Table 2. Transects and ecological plots summary

Transect #	Ecosystem	Stand structure prior to fire	Fire severity	Treatment	Timing of treatment	Dimensions	Small (manual) plot #	Ecoplot #	Treatment	Comments
1	SBSdk/03	Harvested, with young forest residuals	M	800 L manual	June 28	20 m x 100 m	101	09770	40 L / 100 m^2 manual	Live trees were scorched by fire and died later - explains presence of pine needle litter.
							102	N/A	80 L / 100 m^2 manual	
2	SBSdk/03	Clearcut	M	800 L leaf blower	June 29	20 m x 100 m	201	09771	40 L / 100 m^2 manual	
							202	N/A	80 L / 100 m^2 manual	
3	SBSdk/03	Clearcut	M	control	N/A	20 m x 100 m	301	09772	N/A	
4	SBSdk/03	Harvested, with young forest residuals	M - L	control	N/A	20 m x 100 m	401	09773	N/A	Live trees were scorched by fire and died later - explains presence of pine needle litter.
5	SBSdk/03	Clearcut	M	800 L aerial	Sept 27	40 m x 50 m	501	09774	40 L / 100 m^2 manual	
6	SBSdk/03	Harvested, with young forest residuals	M - L	800 L aerial	Sept 27	40 m x 50 m	601	09775	40 L / 100 m^2 manual	Live trees were scorched by fire and died later - explains presence of pine needle litter.
7	SBSdk/02	Mature with MPB-killed Pl	H	800 L aerial	Sept 27	20 m x 100 m	701	09776	40 L / 100 m^2 manual	Some SBSdk/03 in concave lower portions of transect.
8	SBSdk/03	Mature with MPB-killed Pl	M	Untreated		20 m x 100 m	801	09777	0	Heli access. Could be treated Spring 2018.

Two plot photos were taken within each 1 m x 1 m monitoring plot using a Nikon Coolpix AW100 digital camera on a tripod and extender arm at 4608 x 3456 resolution. One photo of the entire plot was taken from approximately 1.3 m above ground with the camera attached to a tripod and extender arm. One 50 cm x 50 cm photo was taken of quadrat 1 (closest to centre line/plot centre) using the tripod to steady the camera approximately 50 cm above the ground. These photos provide a digital image record that can be used to analyze changes in lichen cover over time using software such as ImageJ version 1.46r plant image analysis (Ferreira and Rasband 2012).

3.0 Results: Year 1

Overall, there were 8 – 0.1 ha transects established in 2017. Three transects were aerially treated with lichen and 2 were manually treated (Figure 4 and 5, Table 2). The remaining three transects acted as controls. There was a total of 10 corresponding ecosystem plots established; 2 were manually seeded with 80 L/ha, 5 were manually seeded with 40 L/ha, and 3 acted as controls. Data describing site, soil, and vegetation characteristics, stand structure, coarse woody debris and caribou mobility indices were collected for 8 of the 10 ecosystem plots. Within both transects and ecosystem plots, 98 1 x 1 m monitoring plots were established and baseline monitoring data was collected.

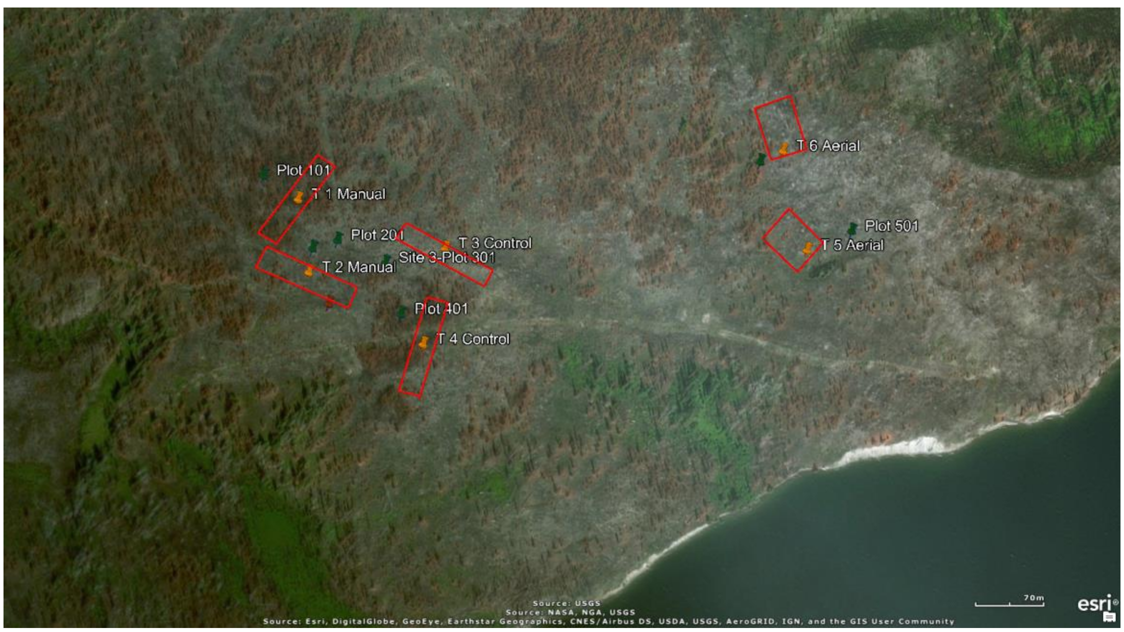

Figure 4. Transects 1-6 and associated ecosystem plots at Site 1.

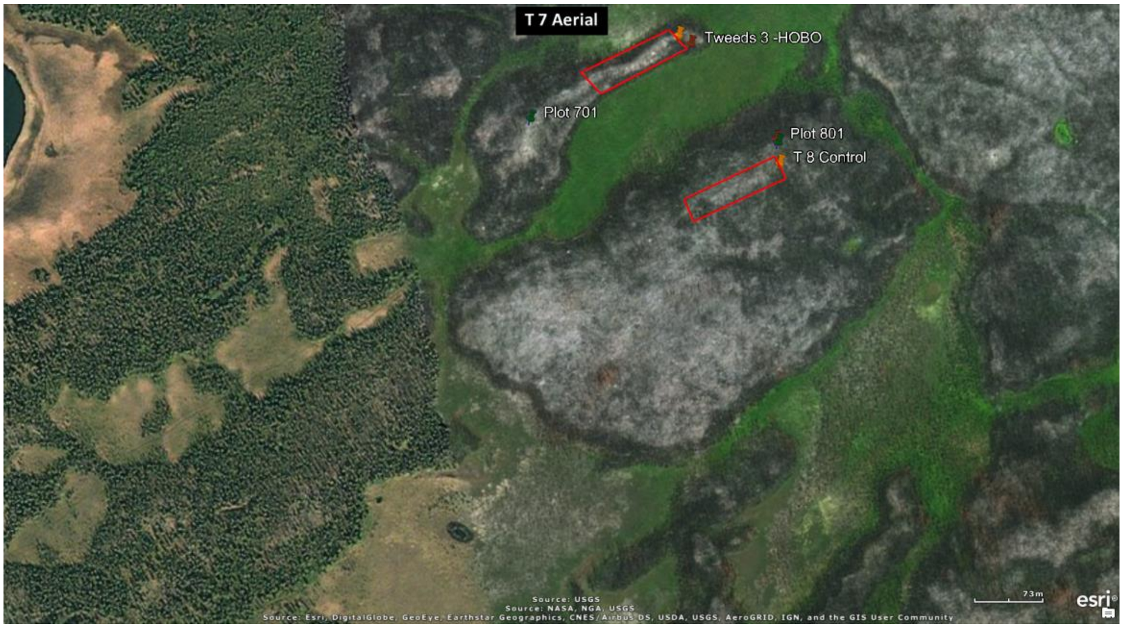

Figure 5. Transects 7-8 and associated ecosystem plots at Site 2.

3.1 Site Characteristics

Structure of standing dead snags and presence of lodgepole pine seedling and sapling regeneration was surveyed in the 5.43 m radius ecological plots corresponding to each transect (Table 3). Stand structure and extent of regeneration varied considerably across transects. The volume of CWD also varied across the study area, yet, the associated caribou mobility indices did not (Table 4).

Table 3. Transects and stand structure summary

Plot Reference			**Stand Structure (standing dead trees)**		**Regeneration**	
Transect	Ecoplot	Condition prior to fire	DBH > 7.5 cm	DBH < 7.5 cm	Seedling < 7.5 cm	Saplings 7.5 cm - 1.3 m
1	09770	Harvested, with young forest residuals	6	8	0	2
2	09771	Logged	0	13	0	4
3	09772	Logged	1	2	0	15
4	09773	Harvested, with young forest residuals	12	20	2	0
5	09774	Logged	0	1	0	0
6	09775	Harvested, with young forest residuals	10	19	2	10
7	09776	Mature MPB-killed Pl	4	3	0	2
8	09777	Mature MPB-killed Pl	3	0	32	10

Table 4. CWD and caribou mobility indices

Plot #	Site Condition Prior to Fire	Mobility Class Average	Decay Class Average	CWD Volume (m3/ha)
101	Harvested, with young forest residuals	1	4	90.4
201	Logged	1	3	17.4
301	Logged	1	3	479.1
401	Harvested, with young forest residuals	1	4	483.8
501	Logged	1	5	222.2
601	Harvested, with young forest residuals	1	2	11.6
701	Mature MPB-killed Pl	1	4	125.3
801	Mature MPB-killed Pl	1	3	87.0

There was no significant difference in mineral soil exposure among sites with various pre-fire stand conditions (Figure 6). Exposure appeared lower in transects that had young residual forest remaining after logging, however, this is likely a product of the litterfall in the form of pine needles that dropped as the trees died following the fire.

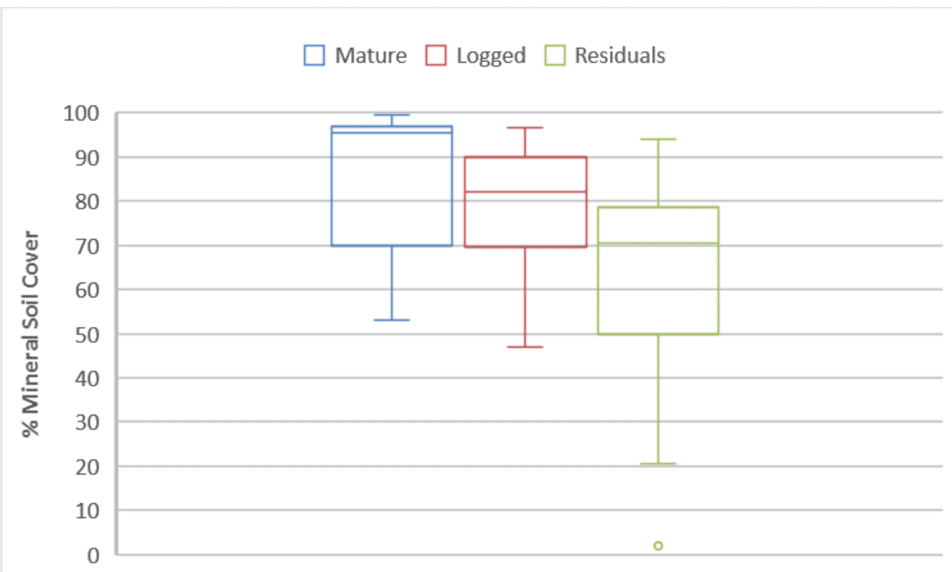

Figure 6. Mineral soil cover (%) by stand condition prior to fire.

Shrubs such as soopolalie (*Shepherdia canadensis*), prickly rose (Rosa *acicularis*), and birch-leaved spirea (*Spiraea betulifolia*) were thoroughly burned, and are regenerating from stems and roots that survived the fire. A similar pattern is found in the dwarf shrubs such as twinflower (*Linnaea borealis*), kinnikinnick (*Arctostaphylos uva-ursi*), and dwarf blueberry (*Vaccinium caespitosum*). Firemoss (*Ceratodon purpureus*) is common, especially over areas where decaying wood remained in the soil humus layer.

Plants that produce abundant seeds, including Ross' sedge (*Carex Rossii*), rough-leaved ricegrass (*Oryzopsis asperifolia*), purple reedgrass (*Calamagrostis purpurea*), and fireweed (*Epilobium angustifolium*), are present at modest cover values. The only invasive species recorded was common dandelion (*Taraxacum officinale*), which occurred in 5 plots at low cover.

3.3 Post-Treatment Lichen Distribution

There was no significant difference in lichen cover between aerial and manual distribution methods, however, average lichen cover was higher in manually distributed transects/plots (Figure 7). Manual treatments also yielded greater variability in lichen cover compared to aerial application. At manual treatment sites, lichen cover ranged from 1% to 4% cover, with an average of 2.4%. On the aerial treatment transects, lichen cover ranged from 1% to 1.7%, with an average cover of 1.2 %. There was no lichen found in control transects/plots. Small patches of naturally regenerating *Cladina* lichen were observed on our walk into Site 1 and in proximity to transects 5 and 6. Incidental examination of lichen thalli on transects 1 and 2 by Jocelyn Campbell during her site visit Sept 28 were positive with respect to lichen viability.

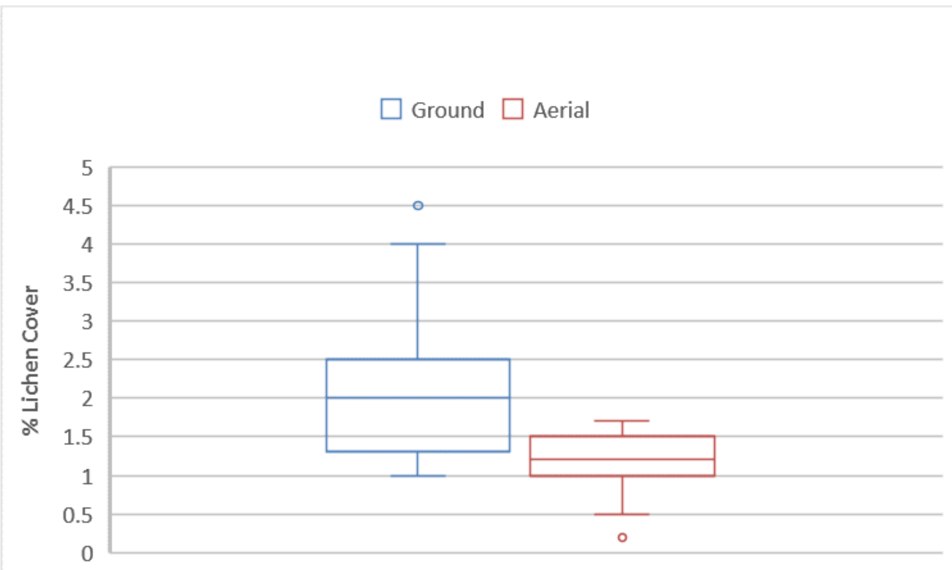

Figure 7. Lichen cover (%) by distribution method.

4.0 Discussion

4.1 Lichen Restoration Trial

The lichen restoration trial provided information that will allow for more efficient collection, treatment, and distribution of lichen at an operation scale. Collection of lichen north of Fort St. James was a success. Large expanses of mature Pine - Lichen woodlands occur within close proximity of the North Road for over 50 km, from Kalder Lake to Nation River. This made for easy access to extensive mats of lichen, where collection had a minimal impact.

It became apparent that it is necessary to collect clean lichen, free of humus, soil, or pinecones. Although this lengthens the time required for lichen collection, dirty lichen clogged the mechanical hoppers and decreased the efficiency of aerial distribution. Additionally, soil can affect the viability of the lichen as the mycorrhizae may be harmful to the lichen photobiont.

Precise measurement of lichen by unit volume was problematic because fragment density varied with water content. The same volume of moist lichen weighed significantly more than dry lichen because it held more water and the thalli fit together more densely. There was therefore some uncertainty in the volume of lichen being distributed, which should be considered when interpreting results.

The project was designed so that storage time of lichen was minimized and lichen viability was maximized. The maximum amount of time lichen was stored was 10 days. Storing the lichen in burlap bags in the shade appeared to work well. The lichen bags did dry out, losing up to 5 lbs of moisture and rot was avoided. Prior to distribution, the burlap bags of dry lichen were immersed in the lake, which was very effective for rehydrating the lichen. The lichen that was stored in woven nylon bags appeared to hold moisture; however, this may have been in part due to the environment being moist during collection. It was not necessary to rehydrate prior to distribution, however, there were concerns about whether the moisture affected lichen viability. There are therefore a number of factors to consider when storing lichen including environmental conditions during collection, length of storage, and rehydration requirements.

Manual fragmentation of the lichen mats was time consuming. The challenge was to find a mechanical method of breaking up the lichen mats that would not cause too much damage to the thalli, yet had some operational potential. Overall, we found the Stihl weed wacker worked best at fragmenting the lichen. Campbell checked the chopped lichen fragments prior to dispersal and observed that they were viable (pers. com, 2017). It should be noted that once the lichen was chopped, the density roughly doubled. Accurate measurement of lichen quantities may require a combination of volume and weight measurements.

Distribution of lichen fragments by leaf blower was problematic. The leaf blower was able to launch the lichen fragments up to 5 m horizontally, however, each fist full of lichen had to be pushed through the intake tube by hand or risk getting clogged. Lichen would also flow from the idling leaf blower before depressing the throttle, so that it was challenging to aim and distribute the lichen evenly. It quickly became evident that distributing the lichen fragments by hand was more efficient than using a leaf blower.

The aerial application of lichen fragments was successful. Western Aerial's approach was to test and learn from a scaled down, easily transportable Hiller helicopter and bucket system. The only time the bucket jammed during distribution was with the final 2 bags of lichen on transect 7, both of which contained humus and mineral soil. Western Aerial will be able to take what they learned from this trial to engineer a larger scale, pressurized, cylinder bucket for operational application. From an operational perspective, working with “dirty” lichen would be simpler and may be worth further exploration and testing.

The average lichen cover in manually seeded areas was higher than in aerially seeded transects, perhaps due the method of fragment preparation (Figure 7). Furthermore, there was substantial variability in lichen cover values in both manually and aerially seeded areas. This highlights that it is difficult to have consistent distribution of lichen within transects/plots, regardless of treatment type. Nevertheless, it is unlikely that this has a significant influence on the success of lichen restoration.

4.2 Future monitoring and analysis

Lichen viability and establishment will be monitored in the spring of 2018 on all plots. Lichen cover will be assessed using the methods described in section 2.8 and compared to cover values recorded immediately post-treatment (i.e. from this year). This will allow us to assess whether or not growth has occurred and lichens have established over time.

Lichen establishment will be confirmed by the presence of new growth of podetia or hyphae (Roturier *et al,* 2017). Lichen viability will be assessed by examining the colour of the thallus fragments (the thallus of dead lichen is bleached white). Viability and establishment will be assessed for lichen fragments occurring in quadrant 1 within each monitoring plot. Samples will be collected for further lab examination, to assess lichen fluorescence when fully hydrated.

Lichen viability and establishment will be compared across treatments and ecosystem variables as presented in Table 3 (page 11). Substrate and plant cover values will be re-measured at this time. This ecological relevé approach to restoration monitoring will help to track lichen recovery relative to vegetation community dynamics; and, may help identify potential changes in plant community assemblages in a changing climate. Plots should be monitored annually for the first 2 years, and every other year until year 10.

4.3 Future restoration on an operational scale

With a fire as large as the Chelaslie, areas for lichen restoration will have to be prioritized. Modeling of fire skips (fire refugia), spatial analysis of pine-lichen ecosystems, and knowledge of optimal foraging theory will be important factors in prioritizing areas for restoration. Proximity of target ecosystems to a road accessible staging area will be important to minimize flying costs. Caribou winter habitat capability mapping and fire severity mapping is available (FLNRORD 2016) and models are being developed to identify fire refugia based on topographic complexity and fire weather condition (Krawchuck *et al*, 2016).

Once areas have been prioritized, it will be necessary to decide on the spatial extent of restoration. This decision will be influenced by the amount of lichen required and cost. For example, 4 m^3 or 200 kg (40 bags) of lichen fragments would be required per hectare[5] of treatment, assuming that the same application rate of lichen fragments was applied at the landscape level. Therefore, 4000 bags of lichen would be required for 100 ha of lichen restoration. During the trial it took about 1 hour to collect 100 L (5 kg dry weight) of lichen, so it could take up to 4000-person hours to collect 4000 bags of lichen. The preferred approach would be to collect the lichen over as short a time-frame as possible.

Large quantities of terrestrial lichen could be collected in the Pine – Lichen woodlands north of Fort St. James, as they are extensive and cover over 100 km^2. Any large-scale collecting should be carried out under the advisement of the Nak'aszdli Whut'en Carrier Nation. The FLNRORD District Office can provide BCTS mapping to identify sites that are planned for logging.

[5] Based on the weight of lichen collected June 21 weighed an average of 5 kg / 100 L bag.

Collected lichen could be stored in a large cargo trailer. A 14.6 m trailer typically holds 92 m^3 of cargo. Delivery and pick up of the trailer to the Ootsa Lake barge site would cost roughly \$1000. Daily rental of the trailer is about \$150.[6]

Lichen fragmentation should occur on site as close as possible to the distribution date, in order to minimize impacts on lichen. The use of an industrial chipper / shredder for fragmenting lichen would be more efficient than a weed wacker. The optimal size of lichen fragment for restoration is unknown, but would also influence the spatial extent of lichen restoration. Smaller lichen fragments spread over a larger area could be more cost effective than larger fragments, but we do not know what the tradeoff is in terms of viability. Rapai has just initiated a study that will attempt to answer this question. Roturier appears to have the data to address this question as well.

A linear pattern of fragment distribution may be more effective than a hectare-by-hectare approach. Seeding rate may also affect restoration success. The best adaptive management approach may be to try a few different seeding patterns and seeding rates, based on expert information.

Manual seeding would require physically fit field crews, and camp support similar to remote tree planting camps. As a reference, the average price for hiring a tree planter for reforestation is roughly \$350/ hectare[7]. One would expect manual lichen seeding to be quicker and therefore cheaper per hectare than tree planting, however, helicopter costs for moving crew and bags of lichen could be significant. Additional costs would include food and accommodation for crew members.

The aerial trial conducted by Western Aerial was successful. Even in the small trial, actual distribution time for 2400 L of lichen, once air borne, was less than 5 minutes. Additional time was required for orientation, loading the lichen into the bucket (1 bag at a time), lift off, and landing. Chief Engineer, Josh Jonker, is confident his company can design a cylinder-shaped bucket equipped with a blower and spinning disc for operational scale lichen seeding. The bucket would hold up to 1.5 m^3 of lichen, or the equivalent of 30 bags of processed lichen. Although the Hiller aircraft has a range of 160 km, future aerial trials should be located so that flying time is minimized to the extent possible.

Western Aerial was asked to provide a ball-park estimate of cost for distributing lichen over 100 hectares of targeted restoration sites based on the following hypothetical criteria:

- 200 kg dry weight of lichen per hectare (equivalent to restoration trial).
- 4000 bags[8] of lichen slung to 10 distribution sites.
- Distribution sites are within 50 km of vehicle access (staging area).
- Target restoration sites must be within 2 km of distribution sites.
- 1500 L[9] of lichen loaded per drop.

Western Aerial's cost estimate for aircraft and crew mobilization, crew food/ accommodation, application flight cost, lichen slinging cost, and associated aircraft fuel

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6 Mike Andrews, Mike Andrews Trucking, Smithers BC.

7 Jason Kruger, General Manager, Summit Reforestation, Smithers BC.

8 Each bag is 100 L before processing, 50 L after processing.

9 1500 L lichen processed into fragments equals roughly 30 100 L bags of lichen.

is $125,000. If distribution sites can be located within 25 km of the staging area this figure could be reduced to $95,000. They anticipate the work to require 7 to 10 days, not including bad weather days. In their view, it would be most efficient for the same crew to sling the lichen to the load sites, as they are already on site, and their air craft is cheaper. There are likely more slinging hours involved than lichen spreading. If the slinging is excluded from the estimate the estimate for application will likely be higher.

Some combination of ground and aerial restoration may be the best approach going forward. Manual lichen restoration has the benefit of employing more local Cheslatta over a longer time period. Aerial restoration could be applied in more remote areas, and for sensitive sites within Tweedsmuir park, as well as where ground application is too dangerous due to the potential for falling snags. Availability of services from specialized application companies like Western Aerial is good in April and May, but more difficult throughout the fall.

4.4 Training and working with Cheslatta technicians

The Cheslatta technicians indicated that they were genuinely pleased to be working on a habitat stewardship project within their territory. The work was physically and mentally challenging at times, and camp living conditions were primitive and remote. Each field day required the technicians to learn and carry out new tasks. Setting up the lichen transects required problem solving under relatively tight time lines. Lichen collection and preparation required physical labour and attention to detail. Monitoring required careful recording of data. Despite these challenges, each field week ended on a positive note. We look forward to collaborating again next spring for survivorship monitored.

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Appendix I Summary of the tasks and time required

Task	Details	Time	Comments
Establish transects	8 transects	4 people, 1.5 hours	Time required to walk sites and locate representative transects
CWD, caribou mobility data	8 plots	2 people, 2 hours	Good tasks for Charlene and Rick
Monitoring plot set up	98 plots	10 monitoring plots = 2 people, 1 hours	Teams of 2 work well
Collect lichen	50 x 100L bags	1 - 1.5 bags / person hour	Check that lichen is free of humus, pine cones, and soil
Prepare lichen by hand	Pull mats apart by hand	1 bag / person hour	Good task for group
Prepare lichen mechanically	Stihl snipper and garbage can	30 bags / 4 people, 3 hours	1 person to operate Stihl, one person to move lichen
Distribute lichen	leaf blower	1 2000 m^2 transect - 800 L/ 2 people, 2 hours	Inefficient, requires manual pushing to avoid clogging
Distribute lichen	by hand	1 2000 m^2 transect - 800 L/ 2 people, 2 hours	Slow, still requires helicopter assist to move people and lichen
Distribute lichen	aerial	1 2000 m^2 transects/ 15 minutes for pilot and 1 ground crew	Actual aerial spray time is much less
Monitoring plots	98 plots	Substrate, veg and lichen covers for 10 plots/ 2 people, 1 hour	Data recording a good task for Charlene
Photoplots		10 plots/ 2 people, 1 hour	Requires person to set up shade, plus camera person
Other tasks			
Travel South Side Francois Lake to barge		1.5 hours	
Drive camp headquarters to end of drivable road (35 km)		1.2 hours	
ATV from gate to Site 1 parking (6 km)		1 hour	
Walk into site 1		.5 hour	

Appendix II Other Lichen Distribution Approaches Explored

Method	Description	Comments
Local bucket seeder slung beneath helicopter.	Initially we wanted to use the local seeder available at Canadian Helicopters. However, the lichen fragments would jam in this shape of hopper and the mechanical parts are 1970's technology. Sand, feed pellets, wood chips, and peat moss, were considered as carrier agents to help the lichen flow from the hopper.	• All options would introduce foreign substances to the ecosystem. • Substances could negatively interact with the lichen. • The bucket system could never be operationalized.
Various slurries: Psyllium tackifier; Guar powder and peat moss mixed with lichen fragments; polyacrylamide tackifier	Mix with water to form a slurry, which holds the lichen fragments in suspension in the seeder bucket, and assures good soil contact.	• Not practical due to weight and need for a water source. • Potential negative impacts on lichen viability. • No operational potential.