TECHNICAL REPORT

Effects of Mountain Pine Beetles and Forest Harvesting on Caribou Terrestrial Forage Lichens in the Omineca Area

Annual Report – 2016/17

Project No. PEA-F-17-W-1315

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In memory of

Randy Sulyma (1967-2011)

EXECUTIVE SUMMARY

In north-central British Columbia (BC), caribou (*Rangifer tarandus*) in the Chase, Wolverine, and Scott ranges (Omineca caribou) are part of the Southern Mountain Caribou (SMC) population, which is listed as Threatened under the federal *Species at Risk Act* (Environment Canada 2014). During winter, Omineca caribou use low elevation lodgepole pine (*Pinus contorta*) forests where they forage for terrestrial lichens. The recent mountain pine beetle (*Dendroctonus ponderosae;* MPB) epidemic and increased forest harvesting pressures on Omineca caribou winter ranges have led to concerns about habitat supply and caribou population dynamics. This project assesses response of caribou terrestrial lichens in the Omineca area to six forest harvesting treatments 12-14 years following treatment, and to MPB attack, using previously established permanently marked plots. Information from this project will assist in assessing the effects of habitat alteration due to MPB and forest harvesting on habitat supply and population dynamics for the Wolverine, Scott and Chase caribou populations.

The goal of this project is to better understand terrestrial caribou forage lichen dynamics following habitat alteration in order to develop conservation practices for the sustainable supply of forage for caribou. Specific objectives for 2016-17 include: 1) re-measuring terrestrial lichen abundance, competing vegetation abundance, stand structure, regeneration and coarse woody debris at five sites in MPB-killed stands and post-forest harvest sites in the Omineca area, and 2) assessing changes in forest floor vegetation dynamics, stand structure, and coarse woody debris accumulation since pre-MPB measurements at control plots, and since post-harvesting measurements at harvested plots.

This project aligns with the Fish and Wildlife Compensation Program's Species of Interest Action Plan in that it addresses Action 1b-2 'Implement projects identified through approved recovery strategies, action plans, and management plans' by addressing three recovery approaches in **"**The Recovery Strategy for the Woodland Caribou, Southern Mountain population (*Rangifer tarandus caribou*) in Canada" (Environment Canada 2014): 1) measure and monitor habitat alteration to southern mountain caribou habitat; 2) assess the impact of natural disturbance (e.g. forest fire, mountain pine beetle, pine rusts) on the long-term habitat management of southern mountain caribou ranges; and, 3) monitor habitat and use adaptive management to assess progress and adjust management activities as appropriate. This project evaluates the impact of MPB and six different forest harvesting regimes on caribou terrestrial forage lichens using previously established permanent plots.

The study area is located in north-central BC in the Mackenzie Natural Resource District and includes five sites located in three biogeoclimatic zones (SBSmk1, SBSmk2, BWBSdk1), two of which were characterized as successional sites (98-Mile, South Discovery Creek), and three of which were characterized as pyroclimax sites (Phillip Lakes, Discovery Creek, Upper Osilinka). Two sites (98-Mile, Phillip Lakes) were established as adaptive management trials to assess six different forest harvesting treatments, and three sites (South Discovery Creek, Discovery Creek, Upper Osilinka) were established to assess effects of MPB. Methods for this project follow methods used for previous pre- and post-treatment field sessions and all fieldwork was conducted in July and August 2016. Data collected included vegetation abundance, stand structure, regeneration, and coarse woody debris.

Lodgepole pine was the dominant canopy tree at all MPB monitoring sites. The degree of MPB attack varied across sites, with the lowest level of attack at the site with the smallest diameter trees (Discovery Creek). Lodgepole pine was also the dominant regeneration species at all sites and treatments. Regeneration densities varied across sites with the highest densities at Phillip Lakes and the lowest density at Upper Osilinka. At adaptive management sites, total regeneration was higher at Phillip Lakes than at 98-Mile for all forest harvesting treatments. Density of regeneration at the Phillip Lakes site may have been influenced by treatment location. The four treatments with the highest densities were located on the lower bench on the northwest side of the road that bisects the site, while the two treatments with the lowest densities were located on the slightly higher bench on the southeast side of the road. A high degree of blowdown resulted in a low density of residual live trees at the 98-Mile site. This site was surrounded by a large forest harvest opening, which was likely the primary factor contributing to the high degree of blowdown at the site. The high degree of blowdown at that site has likely resulted in canopy cover conditions that are more similar to post-harvest canopy cover conditions than to post-MPB canopy cover conditions at the other four sites. Volume of coarse woody debris at the other four sites was relatively low.

Overall, caribou terrestrial lichen abundance at adaptive management sites was lower at the 98-Mile site than the Phillip Lakes site, with means and medians of total caribou terrestrial lichen cover at 98-Mile, at all treatments during all sampling sessions, rarely exceeding 1%. Responses of abundance of total caribou terrestrial lichens to the effects of harvesting treatment between 1-year post-harvest and 2016 differed between the two adaptive management sites. At 98-Mile, overall, caribou terrestrial lichen abundances increased between 2003 and 2016, although this effect was small. In particular, caribou terrestrial lichen abundances at both WTr-W-N-Nat (Trt 1) and WTr-S-N-Nat (Trt 6) were significantly higher in 2016 compared with the first post-treatment measurement. At Phillip Lakes, only the CtL-S-S-Nat (Trt 5) showed a significant increase in caribou terrestrial lichen abundance between the year immediately post-treatment (2005), and the second re-measurement in 2016.

Overall, total vascular vegetation increased and red-stemmed feathermoss continued to decline at the 98-Mile site since the 1-year post-harvest assessment. At 98-Mile, vegetation abundance increased at the No Harvest control and at all treatments between 2003 and 2016. Phillip Lakes also showed significant increases in vascular plant abundance among treatments and through time, although the increases through time were similar between the No Harvest controls and all harvest treatments.

At MPB sites, decline in total caribou terrestrial lichen abundance was most evident at the Phillip Lakes and Upper Osilinka sites. Total vascular vegetation increased on all MPB sites while response of red-stemmed feathermoss was variable. Red-stemmed feathermoss declined at the 98-Mile site, but increased slightly at the South Discovery Creek and Phillip Lakes sites. The decrease in cover of red-stemmed feathermoss at the 98-Mile site was likely reflective of high levels of blowdown resulting in canopy cover conditions more similar to harvested sites that to than the other MPB sites. We also found that there was a positive relationship between level of MPB attack and relative change in abundance of vascular plants, and a negative relationship between level of MPB attack and relative change in total caribou terrestrial lichen abundance. Although the relationships were based on only four datapoints and were not significant at $\alpha=0.05$, they were highly suggestive.

Results from the sites assessed in 2016 suggest that post-harvest conditions have succeeded in creating conditions that are unfavourable to red-stemmed feathermoss, as evidenced by the continued decline in abundance, and that stands with lower levels of MPB attack could continue to provide adequate conditions for caribou terrestrial lichen survival. In 2017, we will be assessing three additional sites with a broader range of disturbances, including a prescribed burn site, a MPB monitoring site, and an adaptive management site that includes three forest harvesting treatments that differ from those assessed in 2016. Data collected in 2017 will be combined with data collected in 2016 to provide a more comprehensive assessment of the effects of MPB, forest harvesting and fire on caribou terrestrial lichens in both successional and pyroclimax sites.

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INTRODUCTION

In north-central British Columbia (BC), caribou (*Rangifer tarandus*) in the Chase, Wolverine, and Scott ranges (Omineca caribou) are part of the Southern Mountain Caribou (SMC) population, which is listed as Threatened under the federal *Species at Risk Act* (Environment Canada 2014). During winter, Omineca caribou use low elevation lodgepole pine (*Pinus contorta*) forests where they forage for terrestrial lichens. Preferred terrestrial caribou forage lichens (*Cladina* sp., *Cladonia* sp., *Stereocaulon* sp., *Cetraria* sp.) are slow growing and can take decades to become abundant following disturbance (Ahti 1977). Fire and forest insects are the two main large-scale natural disturbances affecting forests in caribou ranges in north-central BC, while forest harvesting is the primary anthropogenic disturbance (McNay et al. 2008). The recent mountain pine beetle (*Dendroctonus ponderosae;* MPB) epidemic and increased forest harvesting pressures on Omineca caribou winter ranges have led to concerns about habitat supply and caribou population dynamics.

An adaptive management trial was initiated in 2001 to assess the effects of forest harvesting on caribou terrestrial lichens (Sulyma and Sulyma 2006). In the Mackenzie Natural Resource District, permanent plots were established at two sites prior to conducting six different forest harvesting treatments at each site, and were revisited one year following treatment. Short-term effects included an overall decrease in caribou terrestrial lichen and other vegetation abundance in all treatments, with treatments including drag scarification resulting in the greatest decrease (Sulyma and Sulyma 2006).

The level of MPB attack in the Mackenzie Natural Resource District began increasing in the mid 2000s and peaked in 2009 and 2010 (Westfall and Ebata 2008, 2011). Studies conducted on other caribou winter ranges indicated that terrestrial lichen abundance declined following MPB attack, while dwarf shrubs increased (Cichowski et al. 2009, Seip and Jones, 2010, Cichowski and Hauessler 2013). However, observations during recent field activities in the Omineca area suggested that caribou terrestrial lichen abundance in some areas may not have declined to the same extent following MPB attack. In 2008, prior to MPB attack, permanent plots were established at three sites in the Omineca area to monitor long-term effects of MPB on caribou terrestrial lichens (Sulyma and McNay 2009), but had not been re-visited. The three MPB sites were established and combined with controls from the two adaptive management sites to assess effects of MPB on terrestrial lichens in unharvested forests in successional lichen sites and pyroclimax sites (Sulyma and McNay 2009). Successional lichen sites are sites where terrestrial lichens are outcompeted by mosses in later stages of succession, while pyroclimax sites are defined as sites that change very slowly such that terrestrial lichens persist in very old stands and are typically burned before changing to a non-lichen state (Sulyma and McNay 2009).

Results from the initial phase of this study have already contributed to General Wildlife Measures (GWMs) for low elevation Ungulate Winter Ranges (UWRs) for Northern Caribou in the Fort St James and Mackenzie Natural Resource Districts. For UWR 7-007 in the Mackenzie District, the 40% retention target for terrestrial lichens in GWM 3 was based on the percent of shrub lichens retained through the application of treatment combinations associated with this study (Sulyma and Sulyma 2006). For UWR 7-015 in the Fort St James District, GWM 3 restricts forest harvesting in terrestrial lichen habitats to winter periods when snow cover is sufficient, and to processing trees at the roadside to minimize debris on the cut over area, which is also based on results from this study.

This project assesses response of caribou terrestrial lichens in the Omineca area to six forest harvesting treatments 12-14 years following treatment, and to MPB attack. Information from this project will assist in assessing the effects of habitat alteration due to MPB and forest harvesting on habitat supply and population dynamics for the Wolverine, Scott and Chase caribou populations.

GOALS AND OBJECTIVES

The goal of this project is to better understand terrestrial caribou forage lichen dynamics following habitat alteration in order to develop conservation practices for the sustainable supply of forage for caribou. Specific objectives for 2016-17 include 1) re-measuring terrestrial lichen abundance, competing vegetation abundance, stand structure, regeneration and coarse woody debris at five sites in MPB-killed stands and post-forest harvest sites in the Omineca area, and 2) assessing changes in forest floor vegetation dynamics, stand structure, and coarse woody debris accumulation since pre-MPB measurements at control plots, and since post-harvesting measurements at harvested plots.

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STUDY AREA

The study area is located in north-central BC in the Mackenzie Natural Resource District and includes 5 sites (Figure 1).

Sites

All five sampling sites are located in low-elevation forests dominated by lodgepole pine, and are accessible by road. Site 1 (98-Mile) lies within the Williston variant of the moist cool Sub-Boreal Spruce biogeoclimatic subzone (SBSmk2) and Site 3 (Phillip Lakes) lies within the Mossvale variant of the SBSmk (SBSmk1). Sites 12 (South Discovery Creek), 34 (Discovery Creek), and 48 (Upper Osilinka) lie within the Stikine variant of the dry cool Boreal White and Black Spruce biogeoclimatic subzone (BWBSdk1).

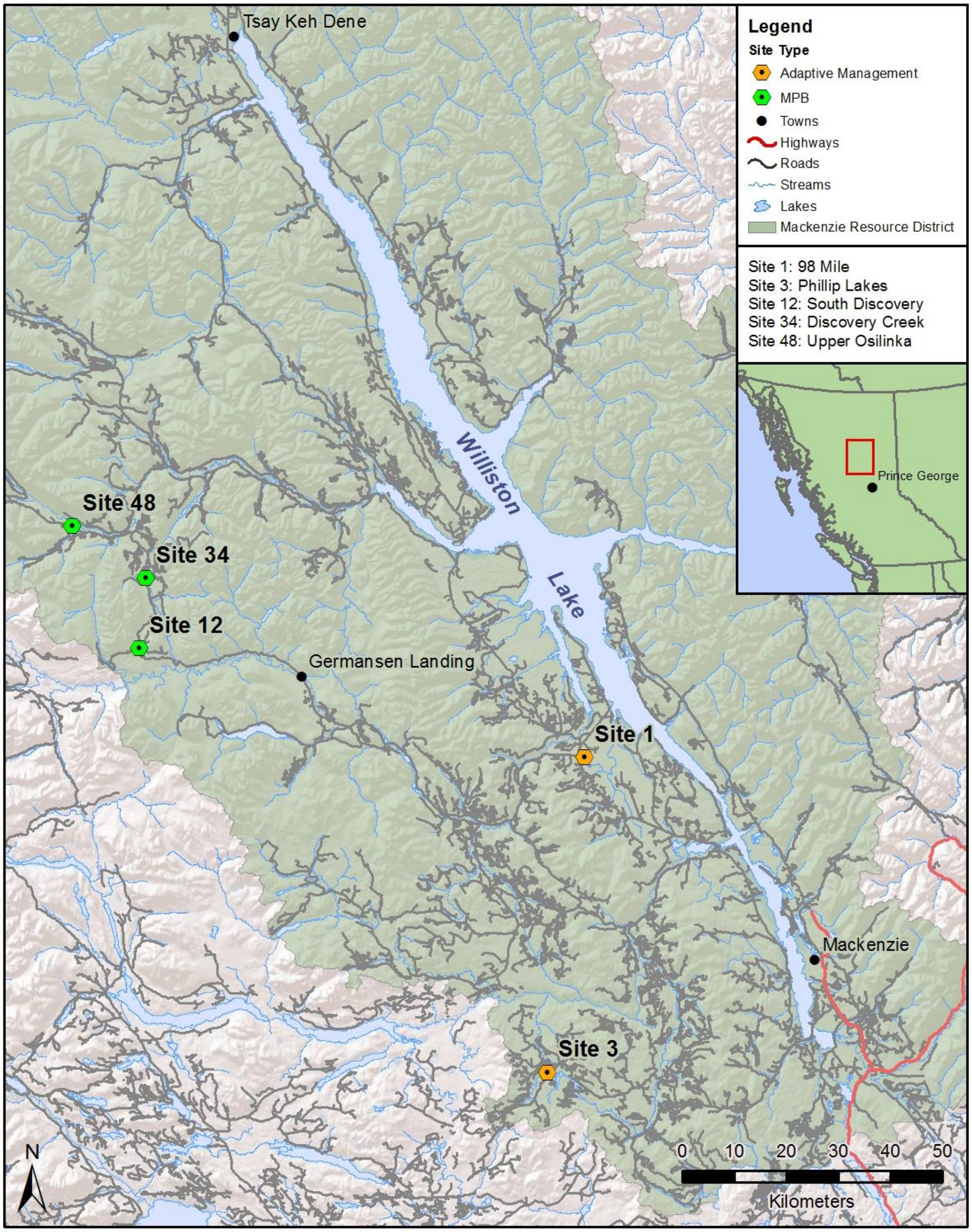


Figure 1. Location of the study area in north-central British Columbia.

The 98-Mile and Phillip Lakes sites were established as adaptive management trials to assess how caribou terrestrial lichens responded to forest harvesting (Sulyma and Sulyma 2006; Table 1). Each site included six different forest harvesting treatments and one No Harvest control (Table 2). The forest harvesting treatments varied in harvesting method (whole-tree vs. cut-to-length), season (winter vs. summer), site preparation method (none vs. drag scarification), and regeneration method (natural vs. planting).

The Discovery Creek, South Discovery Creek and Upper Osilinka sites were established to monitor changes in caribou terrestrial lichen abundance due to MPB attack in unharvested forests (Sulyma and McNay 2009; Table 1). Those three sites were established before MPB attack. The controls at the 2 adaptive management sites were also established before MPB attack and were combined with the other three sites for the MPB portion of the study (Sulyma and McNay 2009).

Of the five sites, two were characterized as successional sites and three were characterized as pyroclimax sites (Sulyma and McNay 2009; Table 1). The MPB monitoring sites were younger than the adaptive management sites, and the Discovery Creek site contained smaller diameter trees than the other sites.

More detailed descriptions of each site can be found in Sulyma and Sulyma (2006) and Sulyma and McNay (2009).

METHODS

Methods for this project follow methods used for previous pre- and post-treatment field sessions (Sulyma and Sulyma 2006, Sulyma and McNay 2009). In 2016, methods had to be adjusted at some sites to standardize data collection across all sites and sampling periods. Table 3 summarizes data available from previous sampling sessions. In 2016, all fieldwork was conducted in July and August 2016.

Vegetation quadrats

Permanently marked vegetation quadrats were previously established along 300 m of linear transect (Sulyma and Sulyma 2006, Sulyma and McNay 2009). Transects in harvesting treatments generally consisted of one straight line, whereas transects in NoHarvest/controls or at MPB sites mostly consisted of two parallel transects totaling 300 m (see Appendix 1). At the point of commencement, point of termination and at every 50 m station along a transect, a wooden stake was permanently set to provide an anchor for an Eslon tape or tight chain and to aid the re-establishment of the quadrats. Half square metre (0.71 m X 0.71 m) quadrats were located randomly along the 300 m transect with an equal proportion of quadrats located in each 100 m segment of the 300 m transect to ensure representation of the vegetation community from across the site. Quadrats were established on the southernmost side of the transects (or the east side if the transect ran north-south) at each randomly selected point. Two corners of each quadrat were marked with either 60 cm long rebar or metal pigtail survey stakes. A numbered plastic tag was secured to one of the permanent stakes. In 2016, plastic tags were replaced with aluminum tags with the original plastic tag numbers inscribed. The corner markers of the quadrat were usually placed along the transect edge of the quadrat as close to the metre mark as possible. During initial setup, rocks and coarse woody debris sometimes made installing the marker at the metre mark impossible. Where procedures deviated, notes were taken for the marker placement of the quadrat. In 2016, the quadrat photo from the previous sampling session was used to re-establish plots if one or both of the marker pins had been pulled up.

Table 1. Summary of characteristics of study sites.

Site	Site name	BEC subzone/ variant	Successional type[1]	Site purpose	Average[1] Age (years)	dbh (cm)	Height (m)	Previous sampling sessions Pre-harvest	Post-harvest	Pre-MPB
1	98-Mile	SBSmk2	Successional	Adaptive management	148	16.7	14.8	2001	2003	2003[2]
3	Phillip Lakes	SBSmk1	Pyroclimax	Adaptive management	195	14.7	12.6	2002	2005	2005[2]
12	South Discovery Creek	BWBSdk1	Successional	MPB	114	15.0	17.8	NA	NA	2008
34	Discovery Creek	BWBSdk1	Pyroclimax	MPB	126	11.5	11.5	NA	NA	2008
48	Upper Osilinka	BWBSdk1	Pyroclimax	MPB	114	14.1	10.9	NA	NA	2008

[1] From Sulyma and McNay (2009)
[2] For adaptive management sites, only unharvested treatments (No harvest) were used for assessing effects of MPB-caused mortality of trees.

Table 2. Forest harvesting treatments used at adaptive management trials at Sites 1 and 3 (from Sulyma and Sulyma 2006).

Trt[1]	Treatment code[2]	Harvesting method	Harvesting season	Site preparation	Regeneration method	Predicted conditions for lichens[3] Overall	Amount of debris	Disturbance to lichens	Regenerating canopy
1	WTr-W-N-Nat	Whole-tree	Winter	None	Natural	Best	Small	Low	More open
2	CtL-W-N-Nat	Cut-to-length	Winter	None	Natural	Good	Large	Low	More open
3	CtL-S-N-Nat	Cut-to-length	Summer	None	Natural	Moderate	Large	Moderate	More open
4	CtL-S-N-Pla	Cut-to-length	Summer	None	Plant	Moderate	Large	Moderate	More closed
5	CtL-S-S-Nat	Cut-to-length	Summer	Drag scarify	Natural	Worst	Large	Very high	More open
6	WTr-S-N-Nat	Whole-tree	Summer	None	Natural	Good	Small	High	More open
99	No Harvest	NA	NA	NA	Natural	NA	NA	NA	NA

[1] Treatment regime number (from Sulyma and Sulyma 2006)
[2] Treatment codes correspond to codes in figures in the Results section: abbreviations denote harvesting method, harvesting season, site preparation method and regeneration method respectively.
[3] From Sulyma and Sulyma (2006); predicted overall condition is based on the premise that no disturbance provides optimal conditions for lichen growth and regeneration.

Table 3. Availability of data from previous sampling sessions.

Trt[1]	Pre-harvest			Post-harvest				Pre-MPB		
	Quadrat veg	Stand/ regen	CWD	Quadrat veg	Stand/ regen	CWD	Soil disturb	Quadrat veg	Stand/ regen	CWD
Site 1 – 98-Mile										
1	2001[2]	2001	2001	2003	NC	2003	2003	-	-	-
2	2001	2001	2001	2003	NC	2003	2003	-	-	-
3	2001	2001	2001	2003	NC	2003	2003	-	-	-
4	2001	2001	2001	2003	NC	2003	2003	-	-	-
5	2001	2001	2001	2003	NC	2003	2003	-	-	-
6	2001	2001	2001	2003	NC	2003	2003	-	-	-
99	2001	2001	2001	2003	NC	2003	2003	2003	2001[3]	2003
Site 3 – Phillip Lakes										
1	2002	2002	2002	2005	NC	2005	2005	-	-	-
2	2002	2002	2002	2005	NC	2005	2005	-	-	-
3	2002	2002	2002	2005	NC	2005	2005	-	-	-
4	2002	2002	2002	2005	NC	2005	2005	-	-	-
5	2002	2002	2002	2005	NC	2005	2005	-	-	-
6	2002	2002	2002	2005	NC	2005	2005	-	-	-
99	2002	2002	2002	2005	NC	2005	2005	2005	2002[3]	2005
Site 12 – South Discovery Creek										
99	-	-	-	-	-	-	-	2008	2008[4]	NC
Site 34 – Discovery Creek										
99	-	-	-	-	-	-	-	2008	2008[4]	NC
Site 48 – Upper Osilinka										
99	-	-	-	-	-	-	-	2008	2008[4]	NC

[1] See Table 2 for descriptions of treatments 1-6. 99 = No harvest.
[2] Year indicates the year that the data were collected. "-" = not applicable. NC = not collected.
[3] Stand and regeneration data were not collected post-harvest so pre-harvest data were used.
[4] Stand and regeneration data were collected during another study at 3 plots that did not appear to match stand plot centres along the vegetation quadrat transects in this study. Stand plots were 5.64 m in radius and regeneration plots were 3.99 m radius.

For each quadrat, a metal frame was positioned over the marker pins (Figure 2), and percent cover of vegetation was visually estimated and representative heights were measured. The percent of each quadrat occupied by soil, rock, litter or coarse woody debris was also estimated. In 2016, quadrat frame placement was sometimes challenging due to regenerating trees that were growing along one of the axes of the square, or due to large accumulations of coarse woody debris. In some cases, the quadrat had to be disassembled and only a portion of the quadrat could be positioned. Also, large accumulations of coarse woody debris at some No Harvest/control sites made it difficult to locate some quadrats.

Figure 2. Positioning the metal frame around quadrat stakes

Photographs of each quadrat were taken looking straight down over the quadrat frame. During previous sampling sessions and for the first 10 days of fieldwork in 2016, photographs were taken using a digital camera mounted on a tripod and boom and positioned approximately 1.2 m directly over the frame (Figure 3). For the remainder of the 2016 fieldwork, photographs were taken using an IPad positioned by hand over the quadrat. A small erasable board with site and quadrat information and date written on it was placed within the field of view. During sunny days, a tarp was used to shade the quadrat when taking the photo to eliminate shadows (Figure 3). In 2016, lower level branches from regeneration both inside and outside the quadrats often obscured the forest floor, so two photographs were taken for those plots: one that included the branches, and one where branches and/or trees were pulled back to expose as much of the forest floor as possible.

All quadrat data were entered into an Excel spreadsheet.

Figure 3. Photographing a vegetation quadrat using a digital camera, tripod and boom

Stand structure and regeneration

Previous sampling sessions

During previous sampling sessions, methods for collecting stand and regeneration data varied slightly between some sites.

For the adaptive management sites, six stand plots were established during the initial phase of this project (prior to harvest) at the 50 m stations along the quadrat transect lines in each treatment (Sulyma and Sulyma 2006). Stand structure and regeneration data were not collected during the post-treatment sampling sessions (Table 3). At the 98-Mile site (Site 1), stand structure and regeneration were measured in 5.64 m or 7.98 m radius plots. At the Phillip Lakes site (Site 3), all stand plots were 7.98 m radius in size. During pre-treatment data collection, stand (large tree) data were collected for trees ≥4 cm dbh and regeneration data were collected for trees <4 cm dbh. Regeneration was further subdivided into >1.3 m or <1.3 m height classes. For stand structure, each tree was individually numbered and tagged, and species, status (alive, dead), dbh and height were recorded. Ages were determined for a subset of live trees. For regeneration, live trees were tallied by species and height class.

For the three MPB monitoring sites (South Discovery Creek, Discovery Creek, Upper Osilinka), stand and regeneration data were collected in 2008, prior to MPB attack, as part of another study (Haughian 2010). For that study, three stand plots were measured at each site, but they did not correspond to the 50 m stations along the quadrat transect lines. Stand data were collected for trees ≥7.5 cm dbh and regeneration data were collected for trees <7.5 cm dbh. Large tree data were collected in 5.64 m radius plots and included species, tree condition (based on the BC Wildlife Tree classification system), height, and dbh. Age was determined for a subset of live trees. Regeneration data were collected in 3.99 m radius plots by species for 3 size classes: >10 cm, 10-130 cm, and >130 cm.

Current sampling session (2016)

In 2016, we standardized stand and regeneration data collection to be consistent across all sites. Stand data were collected for trees ≥7.5 cm dbh and regeneration data were collected for trees <7.5 cm dbh for 2 size classes: <1.3 m and >1.3 m in height.

For the No Harvest (control) plots at the adaptive management sites, we used the same plot sizes that were used for individual plots during the previous sampling sessions. At the Phillip Lakes site, we were able to identify most of the previously tagged trees in the stand plots in the control. Trees were re-tagged with aluminum tags, and status (alive, dead, MPB-Grey, etc.) and whether the tree was down were recorded. For trees that were still alive, we also measured dbh and height. At the 98-Mile control, we were unable to identify previously tagged trees due to excessive blowdown. For those stand plots, we numbered and tagged each tree that was still standing and recorded species, status, dbh and height. For all stand plots in all treatments at the adaptive management sites, we numbered and tagged any new trees that grew into the ≥7.5 cm dbh size class since the previous sampling session and recorded species, status, dbh and height for those trees. We also recorded the bearing from plot centre to the new trees to aid in relocating trees during future sampling sessions.

For harvested treatments, we started by using the same plot sizes for individual plots that were used during the previous sampling sessions. However, all original plots at the Phillip Lakes sites were 7.98 m radius in size. During the 2016 sampling session, for regeneration, we were counting upwards of 300 trees at some plots at the Phillip Lakes site, which often took over 1.5 hours to complete. To reduce the amount of time to complete regeneration plots, we tested whether we could reduce plot sizes to 5.64 m radius (see Appendix 2). Subsequent plots were then reduced to 5.64 m radius for both regeneration and stand (large tree) data. At the 98-Mile site, we started by using 5.64 m radius plots for stand and regeneration data at treatments 3 and 4, however, regeneration densities were much lower at that site so plot sizes at the other four harvesting treatments were increased to 7.98 m radius.

For the three MPB monitoring sites, we established six stand plots at each site at the 50 m stations along the quadrat transect lines. Each stand and regeneration plot was 5.64 m radius in size. Stand and regeneration data were collected as described above for the adaptive management sites in 2016.

Stand and regeneration data were converted to stems/ha and basal area/ha for large trees, and to stems/ha for regeneration.

To standardize all stand and regeneration data across all sites and sampling sessions, we revised previously collected datasets at the adaptive management sites to include only trees ≥7.5 cm dbh in the stand (large tree) datasets, and transferred trees ≥4 cm dbh but <7.5 cm dbh into the regeneration dataset. Stem densities and basal area for previous sampling sessions were recalculated based on the revised datasets.

Coarse woody debris

Coarse woody debris (CWD) measurements followed methods outlined in the Field Manual for Describing Terrestrial Ecosystems (BC MOELP and BC MOF 1998). During earlier sampling sessions, three CWD plots were set up at each treatment with each plot consisting of two transects 24 meters in length. CWD plots were centred at 50 m stations along the quadrat transect line and the locations of the three plots were selected randomly. The first transect was established along a random bearing, and the second transect was established at plus 90° to the first bearing.

For all CWD pieces ≥7.5 cm in diameter, diameter, species, decay class, tilt angle, length (from the widest end to the point where the log is 7.5 cm in diameter), height of lowest end, angle of ground, and the start and finish of where the piece of CWD intersected the transect line were recorded.

In 2016, we re-measured CWD at adaptive management No Harvest plots and at the MPB monitoring sites and installed pigtail stakes at the end of the transects. Initially, we started re-measuring CWD in all treatments, but eventually discontinued measurements in harvested treatments due to time constraints. All harvested sites were clearcut (i.e. no residual standing trees) and for the transects that we did sample, there was generally no or little change in CWD since the post-harvesting sampling session because there were no large diameter standing trees left that could have contributed to increased coarse woody debris on those sites.

CWD data were not collected during the 2008 field sessions at the three MPB monitoring sites (Table 3). Therefore, in 2016, we established and measured CWD plots at three randomly selected 50 m stations along the quadrat transect line.

Data analysis

Where possible, statistical tests used in this analysis are comparable to those used in previous analyses (Sulyma and Sulyma 2006). Tests follow a Generalized Additive Modelling (GAM) framework based on two-way analyses of variance (ANOVA) of the effects of site condition (treatment) and time on responses of vegetation. In particular, we focus on post-treatment patterns of recovery of caribou terrestrial lichen abundance in the harvest treatments, but also analyze responses of other components of vegetation. We conducted both correlational and statistical analyses. For correlations, we considered correlations above ± 0.40 to be of interest (Evans 1996). Separate GAM analyses were conducted for each site. Following Sulyma and Sulyma (2006), Tukey's HSD (honestly significant difference) was the primary post hoc comparison among factors (treatment type or time). Applying either comparison method, variances were considered homoscedastic. Differences that were significant according to HSD were judged significant; differences that were not significant according to HSD were judged to be non-significant. For the ANOVAs, preliminary explorations indicated satisfactory models of variance were specified as poisson (as most measures were counts or percentages) with log link functions. All tests were assessed with an $\alpha=0.05$.

Effect sizes are also calculated for each statistical test. The effect size is a measure to express the strength of the statistical findings. Eta ($\eta 2$) was calculated for *F*-stats where $\eta 2 \approx 0.02$ is considered small, $\eta 2 \approx 0.15$ is medium, and a $\eta 2 \approx .35$ is large (Kirk 1996).

All analyses were conducted in R 3.3.2 (R Core Team 2016) using the gam, multcomp and psych packages, while plots used the ggplot2 package.

RESULTS AND OUTCOMES

Stand structure and regeneration

At MPB monitoring sites, lodgepole pine was the dominant canopy tree species at each site (Table 4). Hybrid white spruce (*Picea glauca x engelmanii*) and subalpine fir (*Abies lasiocarpa*) contributed to the canopy at 98-Mile (Site 1) and Phillip Lakes (Site 3), and hybrid white spruce and willow (*Salix* sp.) made up a minor component of the canopy at South Discovery Creek (Site 12).

Table 4. Average density (stems/ha) and basal area (basal area/ha) of trees ≥7.5 cm dbh for each species/status for MPB monitoring sites in the Omineca area in 2016.

Site[1,2]	Willow	Fir	Hybrid spruce	Pine unk[3]	Pine	Dead-MPB	Dead	Total live	Total live (Range)
Average stems/ha									
1[4]	0	25	92	17	50	217	25	167	0 - 250
3	0	83	42	0	142	533	192	267	100 - 450
12	17	0	17	17	964	489	266	998	564 - 1400
34	0	0	0	0	1633	433	167	1633	1100 - 2100
48	0	0	0	0	300	1100	50	300	0 - 800
Average basal area/ha									
1[4]	0	0.3	1.7	0.1	0.5	6.7	0.2	2.5	0 - 7.1
3	0	0.8	0.3	0	1.7	18.9	3.7	2.8	0.9 - 4.1
12	0.4	0	0.1	0.3	16.6	12.0	2.7	17.0	8.4 - 23.4
34	0	0	0	0	15.7	5.2	1.1	15.7	10.3 - 27.1
48	0	0	0	0	2.8	22.2	0.6	2.8	0 - 8.7

[1] Sites: 1 = 98-Mile; 3 = Phillip Lakes; 12 = South Discovery Creek; 34 = Discovery Creek; 48 = Upper Osilinka
[2] N = 6 plots at each site
[3] Status information (alive or dead or dead-MPB) for three pine trees was not collected
[4] The 98-Mile site (Site 1) suffered a high degree of blowdown

The degree of MPB attack varied across sites (Table 4, Figure 4). By 2016, Discovery Creek (Site 34), which was the site that contained the smallest diameter trees (see Table 1), contained the lowest percent of MPB attack and the highest density of residual live trees. The lowest density of residual live trees was at 98-Mile (Site 1), which was in part due to the high degree of blowdown at the site (see Coarse Woody Debris). Stand

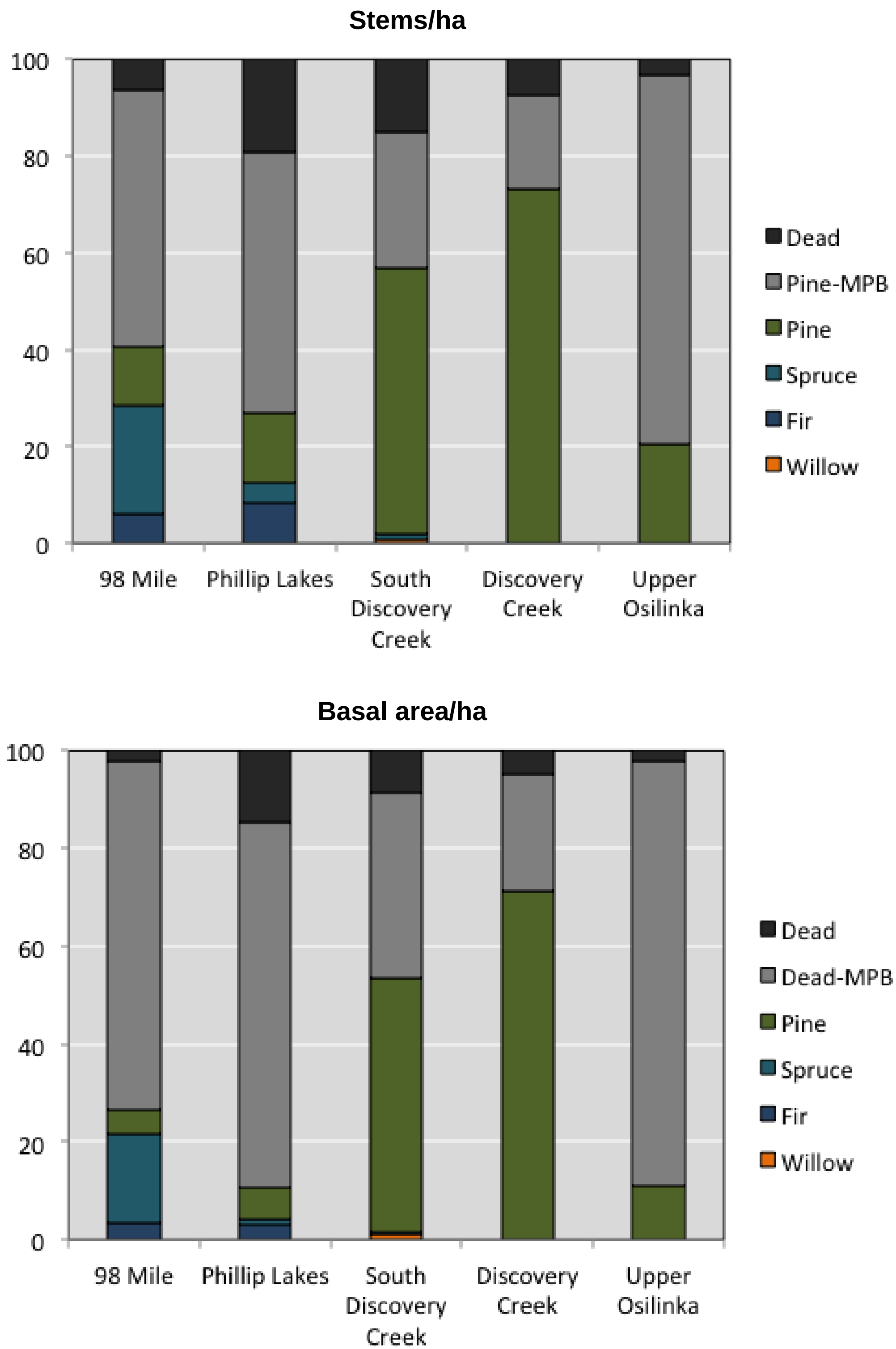


Figure 4. Average percent of trees ≥7.5 cm dbh in each live and dead species class based on stems/ha (top) and basal area/ha (bottom) at MPB monitoring sites in the Omineca area in 2016.

structure observed at 98-Mile (Site 1) in 2016 may not have been representative of original stand structure due to the high degree of blowdown. Residual live tree density was also low at Phillip Lakes (Site 3) and Upper Osilinka (Site 48).

Lodgepole pine was the dominant regeneration species at all sites (Table 5). Hybrid white spruce was present at all sites, and subalpine fir was present at all sites except for harvested treatments at 98-Mile (Site 1). Trembling aspen (*Populus tremuloides*) and willow were present at the two successional sites: 98-Mile (Site 1) and South Discovery Creek (Site 12). Regeneration in the No Harvest treatment at 98-Mile (Site 1), and at South Discovery Creek (Site 12), also included black spruce (*Picea mariana*). Alder (*Alnus* sp.) was only found in the No Harvest treatment at 98-Mile (Table 5).

Regeneration densities varied across sites with the highest densities at Phillip Lakes (Site 3) and the lowest density at Upper Osilinka (Site 48; Table 5). Total regeneration was higher at Phillip Lakes (Site 3) than at 98-Mile (Site 1) for all forest harvesting treatments. At Phillip Lakes (Site 3), the highest regeneration density was in the No Harvest treatment, averaging 14 450 stems/ha. Average densities at treatments 1, 2, 5 and 6 ranged from 8 917 to 11 667 stems/ha, and average density at treatments 3 and 4 were 4 800 to 6 058 stems/ha respectively. Density of regeneration may have been influenced by treatment location. Treatments 1, 2, 5 and 6 were located on the lower bench on the northwest side of the road that bisects the site, while treatments 3 and 4 were located on the slightly higher bench on the southeast side of the road (see Appendix 1). The only treatment that included planting was treatment 4. In 2016, treatment 4 at Phillip Lakes (Site 3) had the second lowest density of regeneration out of the 7 treatments (including No Harvest) at the site.

At 98-Mile (Site 1), the highest regeneration densities were found in the No Harvest treatment and treatment 5, followed by treatment 4. Treatment 5 was the only treatment that included drag scarification and treatment 4 was the only treatment that included planting. None of those 3 treatments were adjacent to each other (see Appendix 1). The 3 treatments that contained the lowest densities of regeneration (treatments 1, 2, 3) were located adjacent to each other.

There did not appear to be any consistent trends in regeneration densities in response to treatment regime across the two adaptive management sites.

Figures 5 to 7 show examples of regeneration and stand structure at each site/treatment.

Vegetation quadrats

Percent cover (all sites)

Trends through time for total caribou lichen abundances are illustrated at the two adaptive management sites: 98-Mile and Phillip Lakes, followed by results for the three MPB monitoring sites: South Discovery Ck., Discovery Ck. and Upper Osilinka (all sites labelled TRT-Monitoring or MPB-Monitoring respectively in the figures below).

Table 5. Average density of regeneration (stems/ha) of trees <7.5 cm dbh at all sites/treatments in the Omineca area in 2016.

Trt[1]	Pine	Hybrid Spruce	Black spruce	Fir	Aspen	Willow	Alder	Total	Total (Range)
98-Mile (Site 1)									
1	575	267	0	0	283	33	0	1158	350-2700
2	442	50	0	0	483	50	0	1025	200-2900
3	900	0	0	0	200	67	0	1167	1000-1400
4	1867	33	0	0	300	0	0	2200	1100-3700
5	2642	17	0	0	0	0	0	2658	1650-4050
6	1292	8	0	0	83	292	0	1675	250-5350
99	1217	283	42	92	167	350	492	2642	1100-5850
Phillip Lakes (Site 3)									
1	9900	92	0	175	0	0	0	10167	7700-14950
2	11517	75	0	75	0	0	0	11667	6600-14150
3	4760	20	0	20	0	0	0	4800	2400-10000
4	5767	42	0	250	0	0	0	6058	3150-8500
5	8183	483	0	250	0	0	0	8917	4400-16400
6	8833	250	0	308	0	0	0	9392	4450-13050
99	12183	142	0	2125	0	0	0	14450	6800-21000
South Discovery Creek (Site 12)									
99	1039	64	16	65	17	297	0	1496	500-2725
Discovery Creek (Site 34)									
99	2017	200	0	33	0	0	0	2250	500-3500
Upper Osilinka (Site 48)									
99	400	50	0	17	0	0	0	467	100-1200

[1]N=6 plots at each site/treatment except Phillip Lakes Treatment 3 where N=5; see Table 2 for treatment codes

We examined Spearman rank correlations (*rho*) between vegetation cover variables (i.e., quadrat samples) to assess the strength of their effects on our primary response variable: total cover of caribou lichens, and to gain insight into possible interactions between these components of vegetation in the study stands. Across all samples (pooling quadrat samples across sites, treatments+controls, and time periods), we found that total caribou lichen abundance was negatively correlated with cover of any other vegetation, including vascular plants and red-stemmed feathermoss (*Pleurozium schreberi*) (Table 6) ($p < 0.001$ for all correlations at $\alpha = 0.025$; two-sided tests). No significant relationship was apparent between caribou lichen abundance and debris on the forest floor(represented either as CWD+litter or as CWD alone). In terms of interactions between these vegetation components, cover of red-stemmed feathermoss was positively correlated with cover of other vascular plants, while cover of accumulated debris negatively impacted cover of all non-lichen plants.

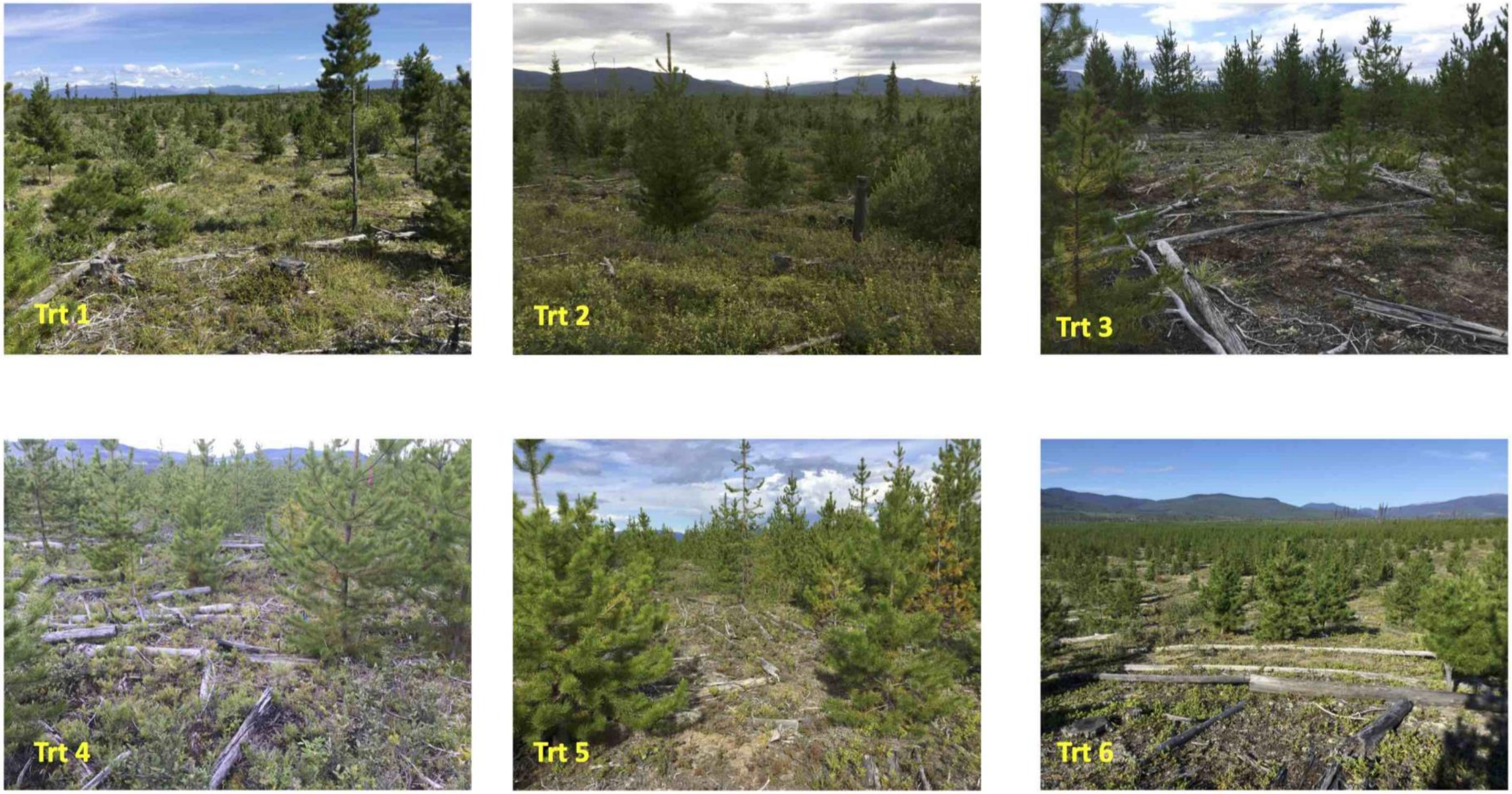


Figure 5. Examples of regeneration at treatments at the 98-Mile site (Site 1), 2016.

Figure 6. Examples of regeneration at treatments at the Phillip Lakes site (Site 3), 2016.

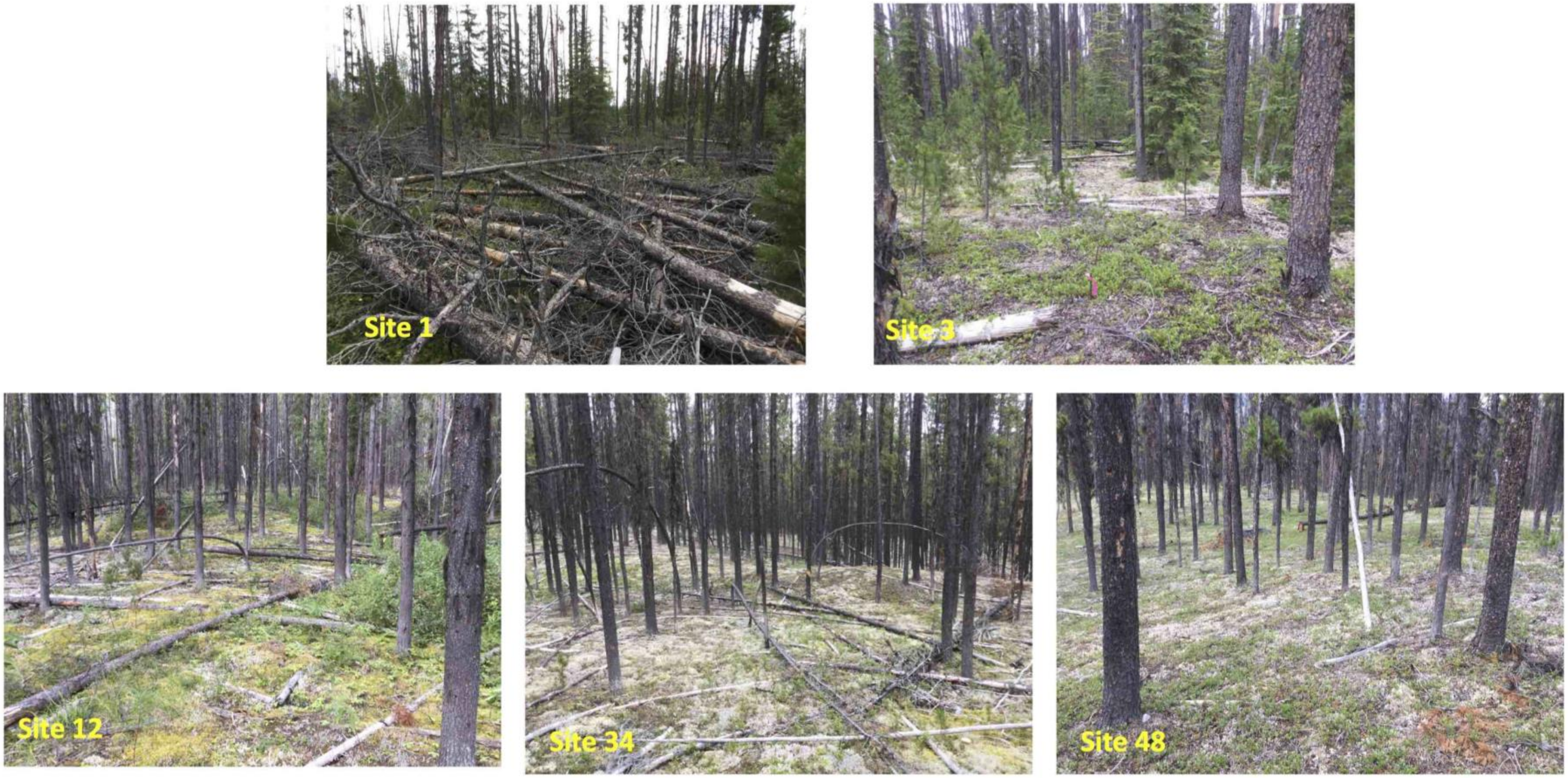


Figure 7. Examples of stand structure and regeneration at the MPB monitoring sites: 98-Mile (Site 1 – No Harvest), Philip Lakes (Site 3 – No Harvest), South Discovery Creek (Site 12), Discovery Creek (Site 34), Upper Osilinka (Site 48), 2016.

Table 6. Correlations (Spearman's rho) between percent cover variables for all sites in all years. Correlation values ≥ |0.4| are shown in bold font.

	Total Caribou Lichens[1]	**Total Vascular Vegetation**[2]	**Total Vascular Vegetation + Mosses**	**Total Vascular Vegetation + Mosses + Debris Accum**[3]	**Debris Accumulation**[3]	**CWD**	**Red-stemmed Feathermoss**
Total Caribou Lichens	1	-0.35	**-0.42**	**-0.64**	-0.02	-0.1	**-0.46**
Total Vascular Vegetation		1	**0.73**	0.34	**-0.41**	-0.03	0.29
Total Vascular Vegetation + Mosses			1	**0.63**	**-0.56**	-0.13	**0.76**
Total Vascular Vegetation + Mosses + Debris Accumulation				1	0.1	0.09	**0.68**
Debris Accumulation					1	0.38	-0.37
CWD						1	-0.09
Red-stemmed feathermoss							1

[1] Total Caribou Lichens = total percent cover of *Cladina* sp. + *Cladonia* sp. + *Cetraria* sp. + *Stereocaulon* sp.
[2] Total Vascular Vegetation = total percent cover of all vascular vegetation in quadrat.
[3] Debris Accumulation = CWD + Litter.

To examine relationships between measures of tree abundance (stems/ha; basal area/ha), measured using plots, with within-stand measure of vegetation cover, measured using quadrats, we computed mean values for all variables for each site x treatment type combination (i.e. a stand-level summary), and assessed relationships between these stand-level mean values using Pearson correlation coefficients *r*. We found that in addition to the relationships identified in Table 6, total caribou lichen abundance was also significantly positively correlated with the density of all trees (stems/ha; Table 7; $p = 0.01$). This relationship may have been influenced by higher tree densities at the Phillip Lakes site (pyroclimax), where caribou terrestrial lichen abundance was higher due to site conditions, and not necessarily a function of tree density. Other positive correlations with total stems of regenerating trees, and with volume of trees are not significant ($p > 0.05$ for both comparisons).

Post-treatment effects on total caribou terrestrial lichen abundance

Overall, caribou terrestrial lichen abundance was lower at the 98-Mile site than the Phillip Lakes site, with means and medians of total caribou terrestrial lichen cover at 98-Mile, at all treatments during all sampling sessions, rarely exceeding 1% (Figure 8).

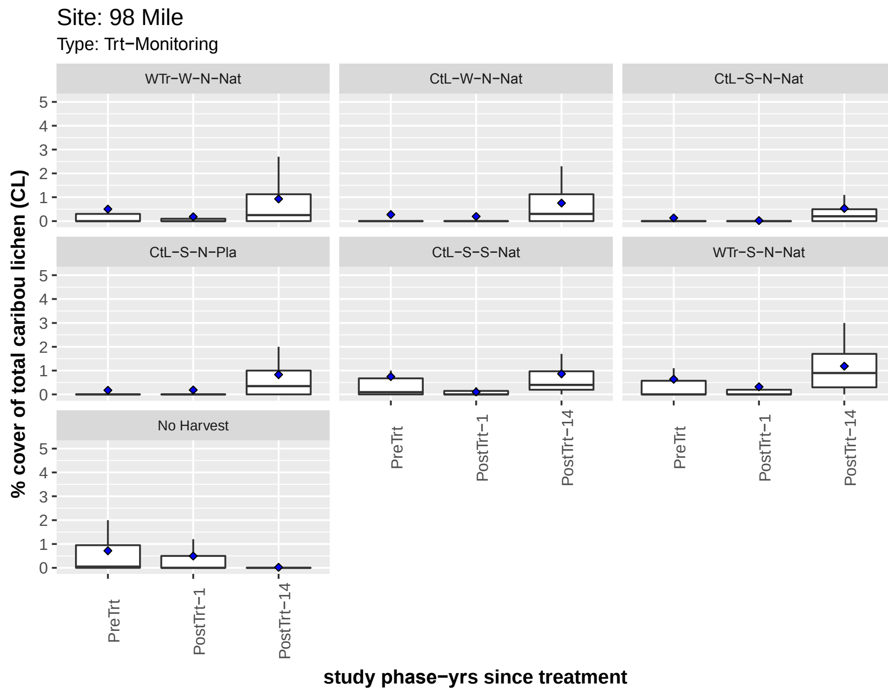
Responses of abundance of total caribou terrestrial lichens to the effects of harvesting treatment over the years since the first post-treatment measurement differed between the two adaptive management sites. At 98-Mile, while the amount of difference in overall total caribou terrestrial lichen abundance among treatments was not significant ($F_{6,564} = 1.8$; $p = 0.096$), and only CtL-S-S-NAT (Trt 5) was significantly higher than the No Harvest treatment (HSD: $p < 0.01$), the only intra-treatment differences in abundance were: WTr-W-N-Nat (Trt 1) was greater than that found either in the CtL-S-N-Nat (Trt 3) and CtL-S-N-Pla (Trt 4) treatments, and WTr-S-N-Nat (Trt 6) > CtL-S-N-Nat (Trt 3) (HSD: $p < 0.01$ in all cases). There were significant interactions between treatments and recovery time ($F_{6,564} = 2.85$; $p = 0.01$, $\eta^2 = 0.5$). Overall, caribou terrestrial lichen abundances increased between 2003 and 2016 ($F_{6,564} = 14.9$; $p < 0.001$) although this effect is small ($\eta^2 = 0.027$). In particular, caribou terrestrial lichen abundances at both WTr-W-N-Nat (Trt 1) and WTr-S-N-Nat (Trt 6) were significantly higher in 2016 compared with the first post-treatment measurement (HSD; $p < 0.01$).

In contrast, total caribou terrestrial lichen abundances at the Phillip Lakes site showed a much greater diversity of responses. There is evidence of overall stronger significant differences in caribou lichen abundances among treatments ($F_{6,567} = 28.9$; $p << 0.001$; $\eta^2 = 0.27$), but less evidence of overall significant recovery between 2005 (immediate post-treatment) and 2016 ($F_{6,567} = 3.3$; $p = 0.07$; $\eta^2 < 0.05$) and little evidence of treatment by recovery time interactions ($F_{6,567} = 0.68$; $p = 0.07$). Caribou terrestrial lichen abundances at some treatments (WTr-W-N-Nat [Trt 1], WTr-S-N-Nat [Trt 6], CtL-S-N-Nat [Trt 3] and CtL-S-N-Pla [Trt 4]) were significantly lower than in the No Harvest control in 2016 (HSD: $p < 0.001$ in these cases). Caribou terrestrial lichen abundance in 2016 in the WTr-W-N-Nat (Trt 1) treatment was significantly greater than in the WTr-S-N-Nat (Trt 6), CtL-S-S-Nat (Trt 5), CtL-S-N-Nat (Trt 3), and CtL-S-N-Pla (Trt 4) treatments (HSD: $p < 0.001$ in all cases). In addition, caribou terrestrial lichen abundance in the WTr-S-N-Nat (Trt 6) treatment was also significantly greater than in any of the cut-to-length treatments (CtL-S-N-Nat, CtL-S-N-Pla, CtL-S-S-Nat, CtL-W-N-Nat; Trts 2-5) (HSD: $p < 0.001$ in all cases). In terms of recovery of abundance between the year immediately post-treatment

Table 7. Pearson correlation coefficients between mean values of vegetation variables at all sites in all years. Correlation values ≥ |0.4| are shown in bold font.

	Total Caribou Lichens[1]	Total Vasc Veg[2]	Total Vasc Veg + Mosses	Total Vasc Veg + Mosses + Debris Accum[3]	Debris Accum	CWD	Red-stemmed Feathermoss	Regen SPH	Trees SPH	% MPB SPH	Trees BAPH	% MPB BAPH
Total Caribou Lichens	1	**-0.46**	**-0.41**	**-0.54**	-0.32	-0.05	-0.34	0.17	**0.46**	-0.06	0.26	-0.05
Total Vascular Vegetation		1	**0.64**	0.37	0.01	**-0.60**	0.35	-0.32	-0.35	0.39	-0.19	0.37
Total Vascular Vegetation + Mosses			1	**0.81**	-0.33	**-0.60**	**0.94**	**-0.47**	**0.40**	0.14	**0.60**	0.14
Total Vascular Vegetation + Mosses + Debris Accumulation				1	-0.06	-0.02	**0.85**	**-0.54**	0.45	0.08	**0.63**	0.08
Debris Accumulation					1	**0.49**	**-0.40**	0.20	-0.69	0.22	**-0.67**	0.21
CWD						1	**-0.44**	0.09	-0.13	-0.27	-0.34	-0.28
Red-stemmed feathermoss							1	**-0.41**	**0.58**	0	**0.75**	0
Regeneration (stems/ha)[4]								1	**-0.42**	0.12	**-0.40**	0.15
Trees (≥7.5) (stems/ha)[4]									1	-0.08	**0.84**	-0.07
% MPB (stems/ha)[4]										1	-0.25	1
Trees (≥7.5) (basal area/ha)[4]											1	-0.25
% MPB (basal area/ha)[4]												1

[1] Total Caribou Lichens = total percent cover of *Cladina* sp. + *Cladonia* sp. + *Cetraria* sp. + *Stereocaulon* sp.
[2] Total Vascular Vegetation = total percent cover of all vascular vegetation in quadrat.
[3] Debris Accumulation = CWD + Litter.
[4] Regeneration (<7.5 cm dbh) based on stems/ha (SPH); Trees (≥7.5 cm dbh) based on stems/ha (SPH) or basal area/ha (BAPH).



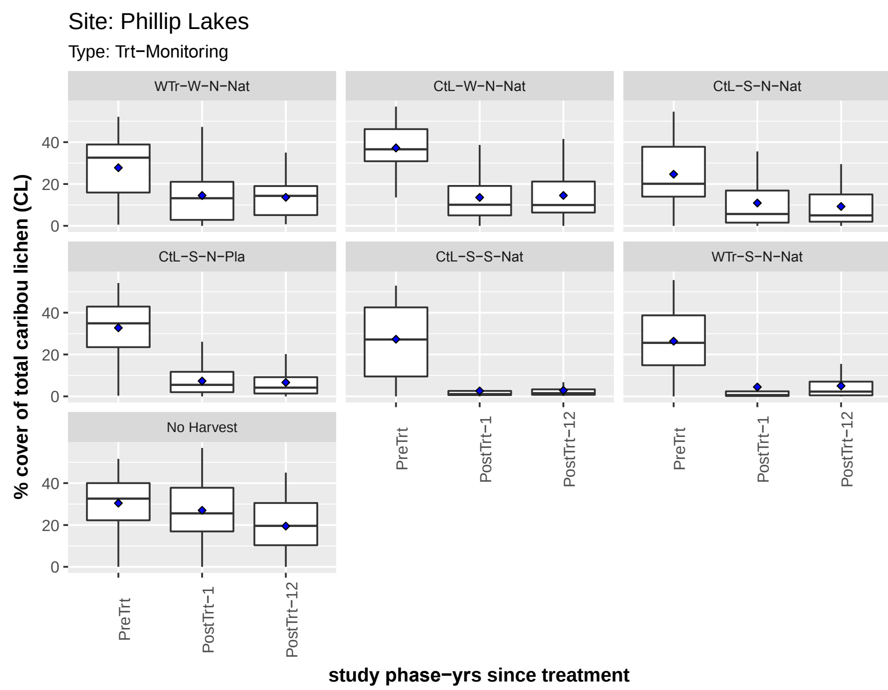


Figure 8. Temporal responses of total cover of caribou terrestrial lichens to harvesting treatments applied at the 98-Mile (top) and Phillip Lakes (bottom) study sites. The x-axis shows study phases; numbers indicate year of measurement post-treatment. The control site is the bottom left-most graph. Data represent untransformed % cover of caribou lichens obtained from sampled quadrats. Boxplots show the mean (blue diamond point), median (central bold line), the 25-75% interquartile distribution of values (white rectangle) and the distribution of values ± 1.5 * the interquartile distance. Outliers beyond the 95% quantile taken at this site were trimmed to improve scaling of the y-axis.

(2005), and this second re-measurement (2016), only one treatment (CtL-S-S-Nat [Trt 5]) showed a significant increase in caribou terrestrial lichen abundance between these periods (HSD: $p < 0.001$).

Post-treatment effects on other vegetation components

Overall, total vascular vegetation increased and red-stemmed feathermoss continued to decline at the 98-Mile site since the post-treatment assessment (Figures 9, 10).

As above for caribou terrestrial lichen abundance, 98-Mile and Phillip Lakes showed differences in their patterns of responses of vascular vegetation among treatments and through time since treatment. In terms of vegetation, overall differences in abundance at 98-Mile among treatments and time periods were significant (treatments: $F_{6,564} = 29.9$; $p << 0.001$; post-harvesting time periods: $F_{6,564} = 350.1$; $p << 0.001$). Vegetation abundance increased at the No Harvest control, and at all treatments between 2003 and 2016 (Figure 9, HSD: $p < 0.001$ for all). There were only a few cases where intra-treatment differences in vascular plant abundance in 2016 were not significant: WTr-W-N-Nat ≈ WTr-S-N-Nat ≈ CtL-W-S-Nat ≈ CtL-S-S-Nat ≈ CtL-S-N-Nat ≈ CtL-W-N-Nat (HSD: $p > 0.05$). Similarly, Phillip Lakes also showed significant increases in vascular plant abundance among treatments ($F_{6,567} = 2.8$; $p = 0.01$; $\eta^2 = 0.03$) and through time ($F_{6,564} = 149.2$; $p << 0.001$; $\eta^2 = 0.2$), although it is important to note that the increases through time were similar between the No Harvest controls and all harvest treatments. Note that the overall effect of these differences is smaller at Phillip Lakes. Intra-treatment differences in vascular plant abundance in 2016 were similar at Phillip Lakes compared with 98-Mile (above): WTr-W-N-Nat ≈ WTr-S-N-Nat ≈ CtL-W-S-Nat ≈ CtL-S-S-Nat ≈ CtL-S-N-Nat ≈ CtL-W-N-Nat (HSD: $p > 0.05$). Most of these also showed no significant difference in 2016 compared with the No Harvest control.

Effects of MPB on total caribou terrestrial lichen abundance

Overall, decline in total caribou terrestrial lichen abundance was most evident at the Phillip Lakes and Upper Osilinka sites (Figure 11). Total vascular vegetation increased on all MPB sites (Figure 12) while response of red-stemmed feathermoss was variable (Figure 13). Red-stemmed feathermoss declined at the 98-Mile site, but increased slightly at the South Discovery Creek and Phillip Lakes sites.

We examined the relationship between the level of MPB attack and change in caribou terrestrial lichen abundance and found that the % of MPB-killed trees had a negative effect on cover of caribou terrestrial lichens on the 4 sites we considered (Phillip Lakes, S. Discovery Ck., Discovery Ck. and Upper Osilinka), although not statistically significant at $\alpha=0.05$ ($F_{1,2}=9.80$; $p = 0.089$, $\eta^2 = 0.83$; Figure 14). The % of MPB-killed trees at the site is also positively but insignificantly affected the growth of vegetation and mosses at these sites ($F_{1,2} = 3.22$; $p = 0.21$, $\eta^2 = 0.62$). Note that our sample size is very small (n = 4), and consequently statistical power of these tests is low. The 98-Mile site was not included in this analysis due to the high level of blowdown in the control, which appeared to be more a function of the small size of the control and location within a large area of harvest than a function of site or MPB conditions., which may have confounded vegetation responses at that site.

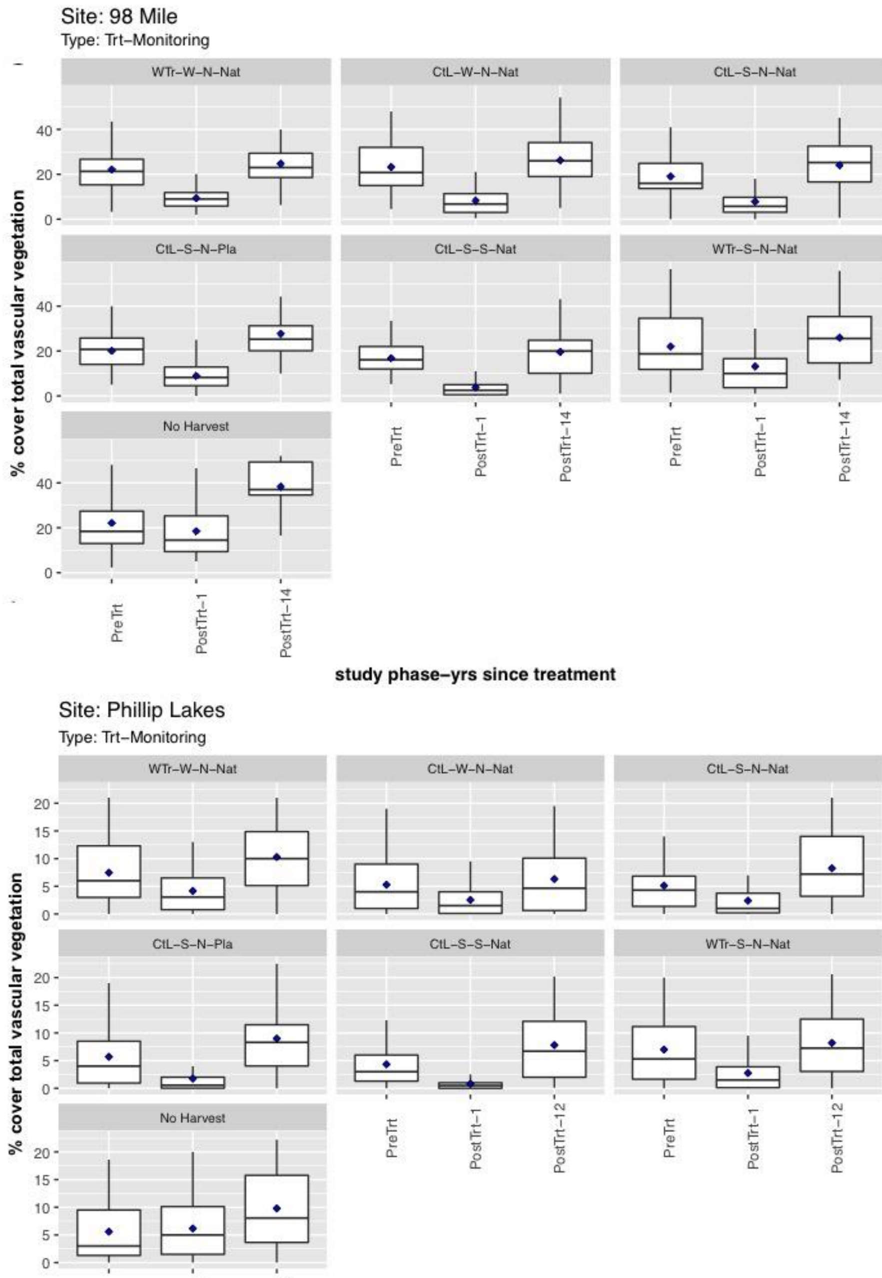


Figure 9. Temporal responses of cover of total vascular vegetation to harvesting treatments applied at the 98-Mile (top) and Phillip Lakes (bottom) study sites. The x-axis shows the study phases; numbers indicate year of measurement post-treatment. The control site is the bottom left-most graph. Data represent untransformed % cover of total vascular vegetation obtained from sampled quadrats. Boxplots show the mean (blue diamond point), median (central bold line), the 25-75% interquartile distribution of values (white rectangle) and the distribution of values ± 1.5 * the interquartile distance. Outliers beyond the 95% quantile taken at this site were trimmed to improve scaling of the y-axis.

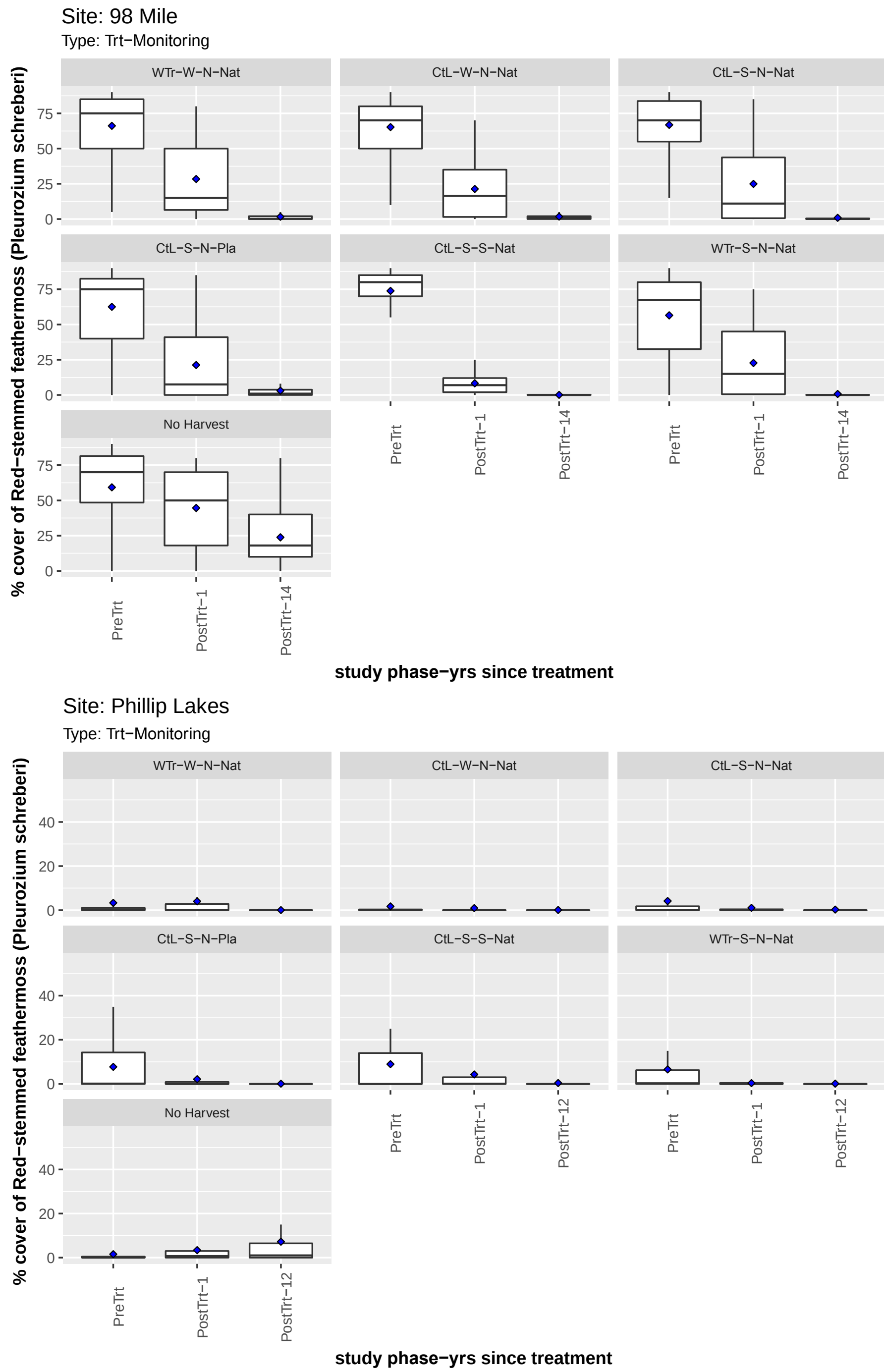


Figure 10. Temporal responses of cover of red-stemmed feathermoss to harvesting treatments applied at the 98-Mile (top) and Phillip Lakes (bottom) study sites. The x-axis shows the study phases; numbers indicate year of measurement post-treatment. The control site is the bottom left-most graph. Data represent untransformed % cover of red-stemmed feathermoss obtained from sampled quadrats. Boxplots show the mean (blue diamond point), median (central bold line), the 25-75% interquartile distribution of values (white rectangle) and the distribution of values ± 1.5 * the interquartile distance. Outliers beyond the 95% quantile taken at this site were trimmed to improve scaling of the y-axis.

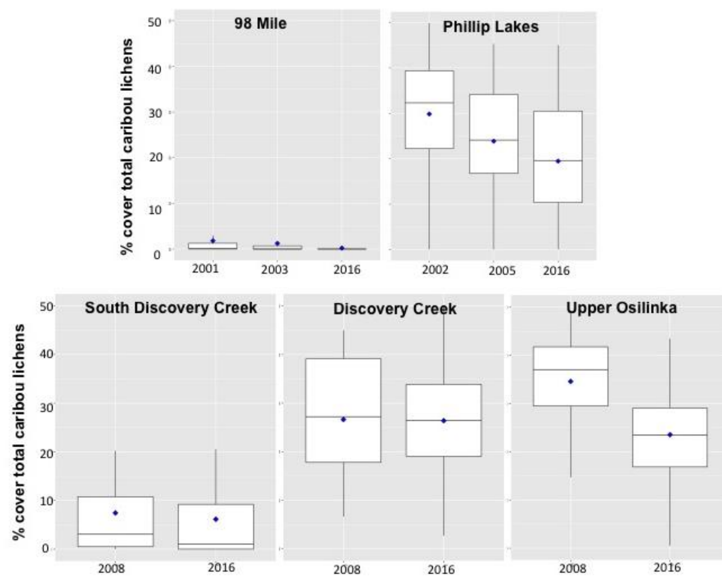


Figure 11. Temporal responses of cover of total caribou lichens to MPB. The x-axis shows the years of data collection. Data represent untransformed % cover of total caribou lichens obtained from sampled quadrats. Boxplots show the mean (blue diamond point), median (central bold line), the 25-75% interquartile distribution of values (white rectangle) and the distribution of values ± 1.5 * the interquartile distance. Outliers beyond the 95% quantile taken at this site were trimmed to improve scaling of the y-axis.

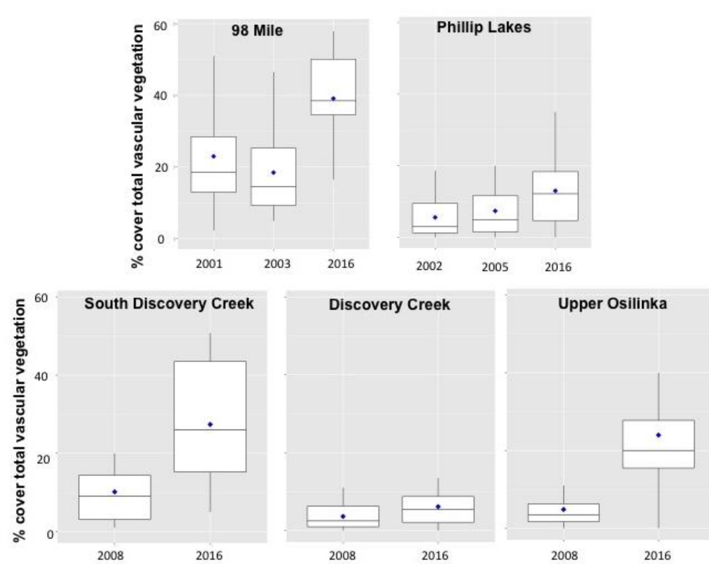


Figure 12. Temporal responses of cover of total vascular vegetation to MPB. The x-axis shows the years of data collection. Data represent untransformed % cover of total vascular vegetation obtained from sampled quadrats. Boxplots show the mean (blue diamond point), median (central bold line), the 25-75% interquartile distribution of values (white rectangle) and the distribution of values ± 1.5 * the interquartile distance. Outliers beyond the 95 quantile were trimmed to improve scaling of the y-axis.

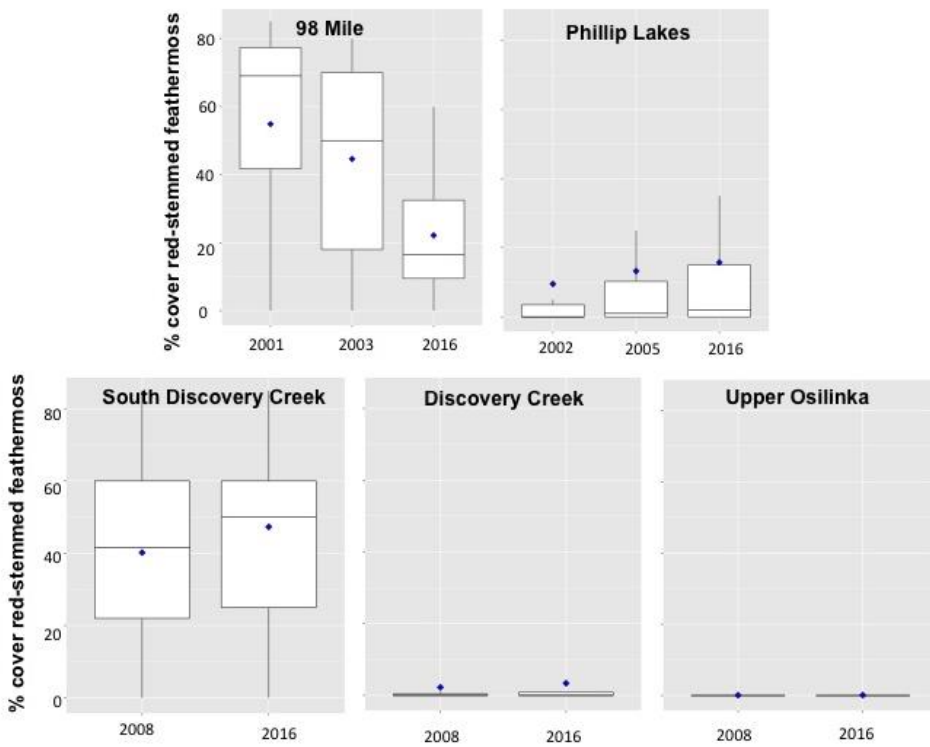


Figure 13. Temporal responses of cover of red-stemmed feathermoss to MPB. The x-axis shows the years of data collection. Data represent untransformed % cover of red-stemmed feathermoss obtained from sampled quadrats. Boxplots show the mean (blue diamond point), median (central bold line), the 25-75% interquartile distribution of values (white rectangle) and the distribution of values ± 1.5 * the interquartile distance. Outliers beyond the 95% quantile taken at this site were trimmed to improve scaling of the y-axis.

Coarse woody debris

Figure 15 shows CWD at MPB monitoring sites prior to and following MPB attack. Levels of CWD were relatively low at the 98-Mile and Phillip Lakes sites prior to MPB attack, and increased following MPB attack with a substantial increase at the 98-Mile site. Post-MPB levels of CWD were low at the 3 MPB monitoring sites (South Discovery Creek, Discovery Creek, Upper Osilinka).

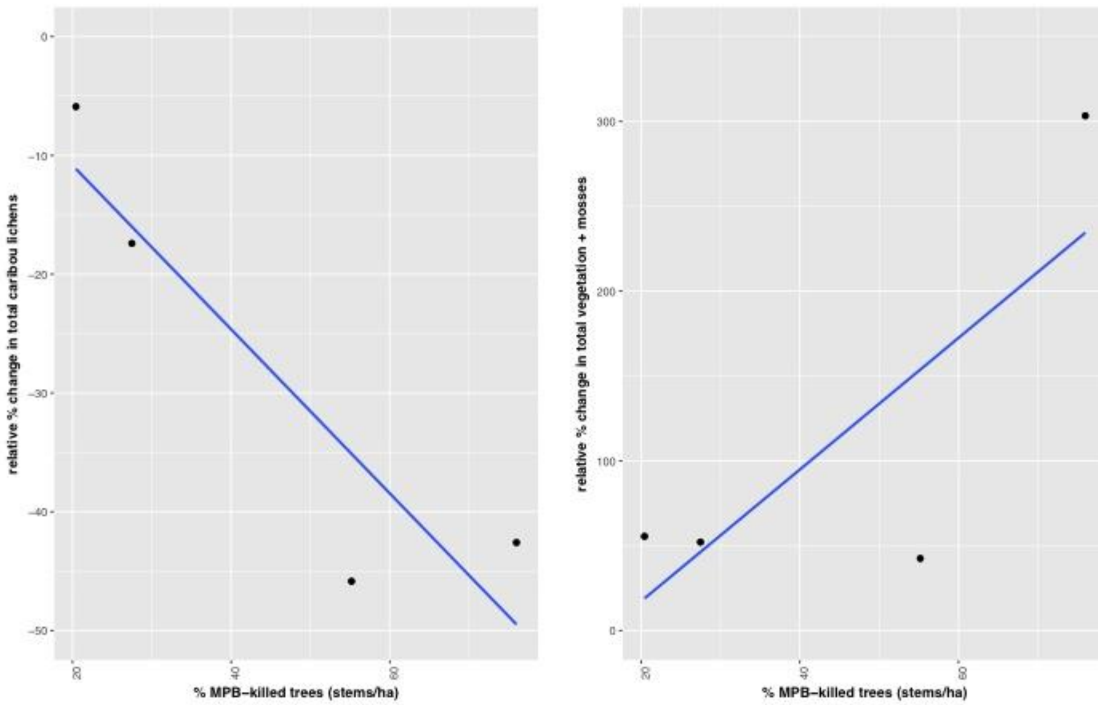


Figure 14. Effect of % MPB-killed trees on the relative change in cover of total caribou lichens (left) and total cover of vegetation + mosses (right) as measured in 2016 compared with the initial measurement. These data were measured in all "no harvest" sites; data from 98-Mile was excluded (see text).

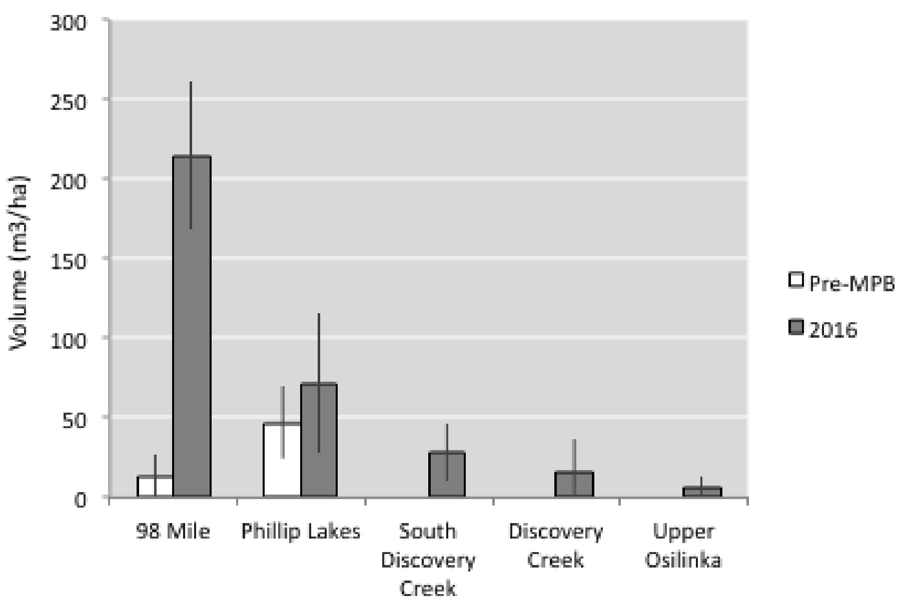


Figure 15. Mean volume (m^3/ha) of coarse woody debris at MPB monitoring sites prior to (pre-MPB) and after (2016) MPB attack. Error bars are ± 1 standard deviation.

DISCUSSION

At the adaptive management sites, there has been relatively little change in caribou terrestrial lichen abundance since the 1-year post-harvest sampling sessions. Overall, current abundance of caribou terrestrial lichens at both adaptive management sites appears higher, or as high, at whole-tree removal treatments compared with other treatments, and there are indications that season of harvest may be important, in that winter harvesting may provide for better response by caribou terrestrial lichens (Figure 8).

Differences among the two adaptive management sites create challenges in interpreting patterns of caribou terrestrial lichen response to the differing harvest treatments applied at both sites. Recovery (in terms of increase in % cover) of caribou terrestrial lichens in the 12-14 years since treatments were applied appears to be small, except at the 98-Mile (successional) site where mean and median lichen abundance at all treatments during all sampling session was at or below 1% cover. Because caribou terrestrial lichen cover is so low at that site, even nominal increases in absolute lichen cover will result in higher relative changes.

One objective of the adaptive management trials was to assess whether various forest harvesting treatments at successional sites like the 98-Mile site where the forest floor is dominated by mosses, could reset conditions to a state that is less favourable to moss and more favourable to terrestrial lichens, thereby fast-tracking recruitment of caribou terrestrial lichen habitats. At 98-Mile, red-stemmed feathermoss abundance declined within 1 year of harvest, and further declined between 1 and 14 years post-harvest at all treatments. However, a substantial increase in caribou terrestrial lichen abundance has not yet been observed 14 years post-harvest, which simply may be due to the slow rate of lichen growth. Increases in vascular vegetation could also be contributing to a potential lag in response by caribou terrestrial lichens.

Variability in stand structure, level of MPB attack and CWD across the five MPB sites contributed to the pattern of responses of caribou terrestrial lichens and other vegetation. Level of mountain pine beetle attack was highest at the Phillip Lakes and Upper Osilinka sites, and also for the residual trees at the 98-Mile site, which suggests that the level of attack in the original stand was also likely high. The lowest level of attack occurred at the Discovery Creek site, which was the site with the smallest diameter trees. By 2016, CWD increased substantially at the 98-Mile site while CWD levels at other sites remained low (South Discovery Creek, Discovery Creek, Upper Osilinka) or increased slightly (Phillip Lakes). Unlike the other 4 sites, which are surrounded by or close to other forest stands, the 98-Mile No Harvest control is a small patch of unharvested forest that is surrounded by a large harvested area. The high degree of blowdown at that site has likely resulted in canopy cover conditions that are more similar to post-harvest canopy cover conditions than to post-MPB canopy cover conditions at the other 4 sites.

Results from the MPB monitoring portion of the project in 2016 are consistent with results from other studies in that caribou terrestrial lichen abundance generally declined following MPB attack while abundance of other vegetation increased (Cichowski et al. 2009, Seip and Jones 2010, Cichowski and Haeussler 2013, McNay et al. 2014). We also found that there was a positive relationship between level of MPB attack and relative change in abundance of vascular plants, and a negative relationship between level of MPB attack and relative change in total caribou terrestrial lichen abundance. Although the relationships were based on only four datapoints and were not significant at α=0.05, they were highly suggestive. In the Quesnel TSA portion of the Itcha-Ilgachuz caribou range, level of MPB attack at the beginning of the study was a strong predictor of terrestrial lichen abundance 3 years following attack (Cichowski et al. 2009). In the Tweedsmuir-Entiako caribou winter range, abundance of other vegetation was a better predictor of terrestrial lichen abundance following MPB attack than level of attack, and the dominant species of vascular vegetation exhibited and consistent increase in abundance on the relatively more humid sites and an increase then a decrease in abundance on the drier sites (Cichowski and Hauessler 2013).

The pattern of change in red-stemmed feathermoss varied across MPB monitoring sites. Initial cover of red-stemmed feathermoss was low at the three pyroclimax sites (Phillip Lakes, Discovery Creek, Upper Osilinka) and higher at the two successional sites (98-Mile, South Discovery Creek). There was little change in red-stemmed feathermoss cover at the Discovery Creek and Upper Osilinka sites, an increase in cover at Phillip Lakes and South Discovery Creek, and a decrease in cover at 98-Mile. The decrease in cover of red-stemmed feathermoss at the 98-Mile site was likely reflective of high levels of blowdown resulting in canopy cover conditions more similar to harvested sites that to than the other MPB sites. In the Tweedsmuir-Entiako caribou range, moss cover increased following MPB attack (Cichowski and Haeussler 2013).

Results from the sites assessed in 2016 suggest that post-harvest conditions have succeeded in creating conditions that are unfavourable to red-stemmed feathermoss, as evidenced by the continued decline in abundance, and that stands with lower levels of MPB attack could continue to provide adequate conditions for caribou terrestrial lichen survival. In 2017, we will be assessing three additional sites with a broader range of disturbances, including a prescribed burn site, a MPB monitoring site, and an adaptive management site that includes three forest harvesting treatments that differ from those assessed in 2016. Data collected in 2017 will be combined with data collected in 2016 to provide a more comprehensive assessment of the effects of MPB, forest harvesting and fire on caribou terrestrial lichens in both successional and pyroclimax sites.

RECOMMENDATIONS

Recommendations will be provided following the final year of the project (Year 2 – 2017/18).

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APPENDIX 1. TREATMENT REGIME MAPS AND VEGETATION QUADRAT TRANSECT LOCATIONS.

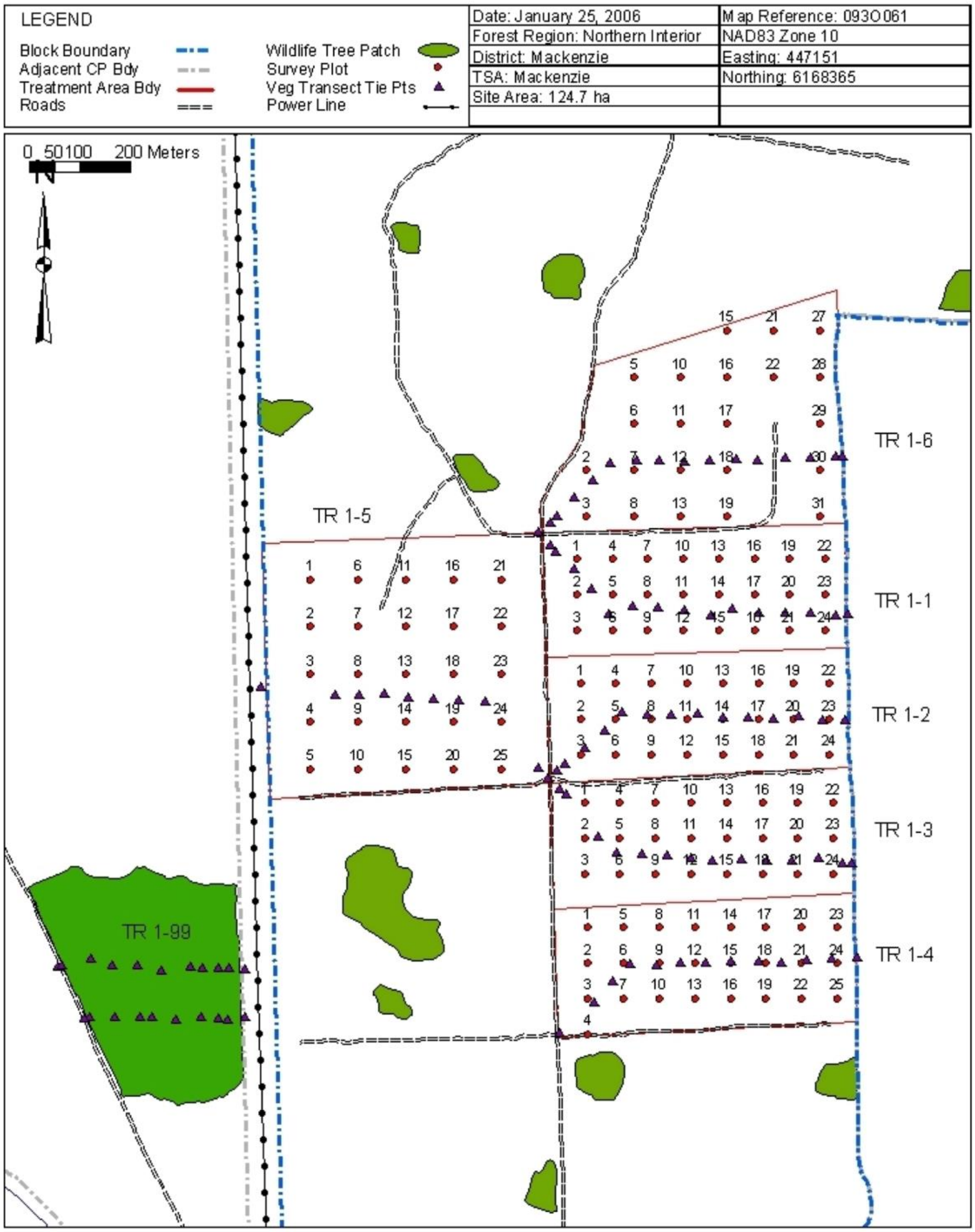

Figure A1-1. Location of forest harvesting treatments and corresponding vegetation quadrat transects (purple triangles) for Site 1 - 98-Mile (from Sulyma and Sulyma 2006).

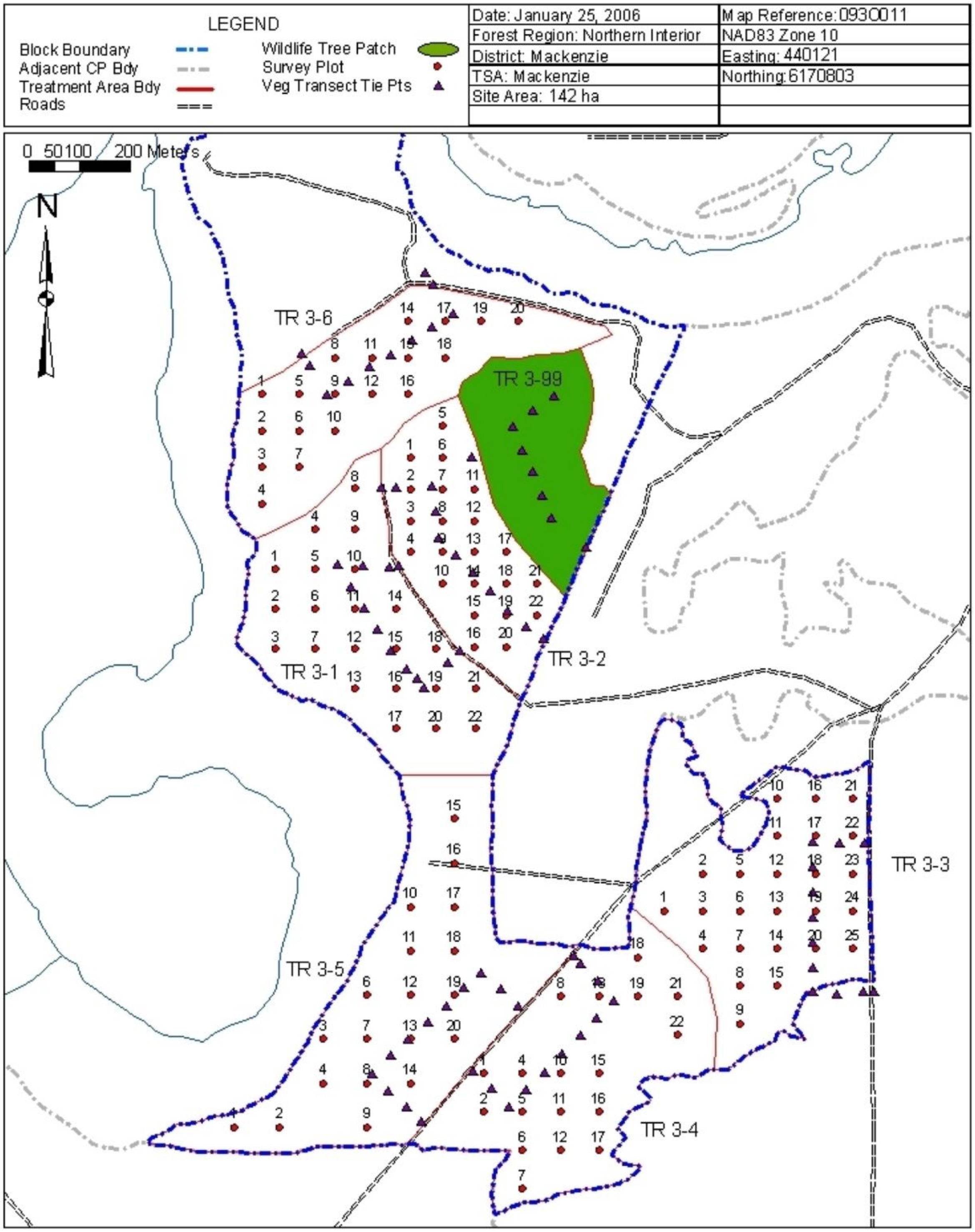

Figure A1-2. Location of forest harvesting treatments and corresponding vegetation quadrat transects (purple triangles) for Site 3 – Phillip Lakes (from Sulyma and Sulyma 2006).

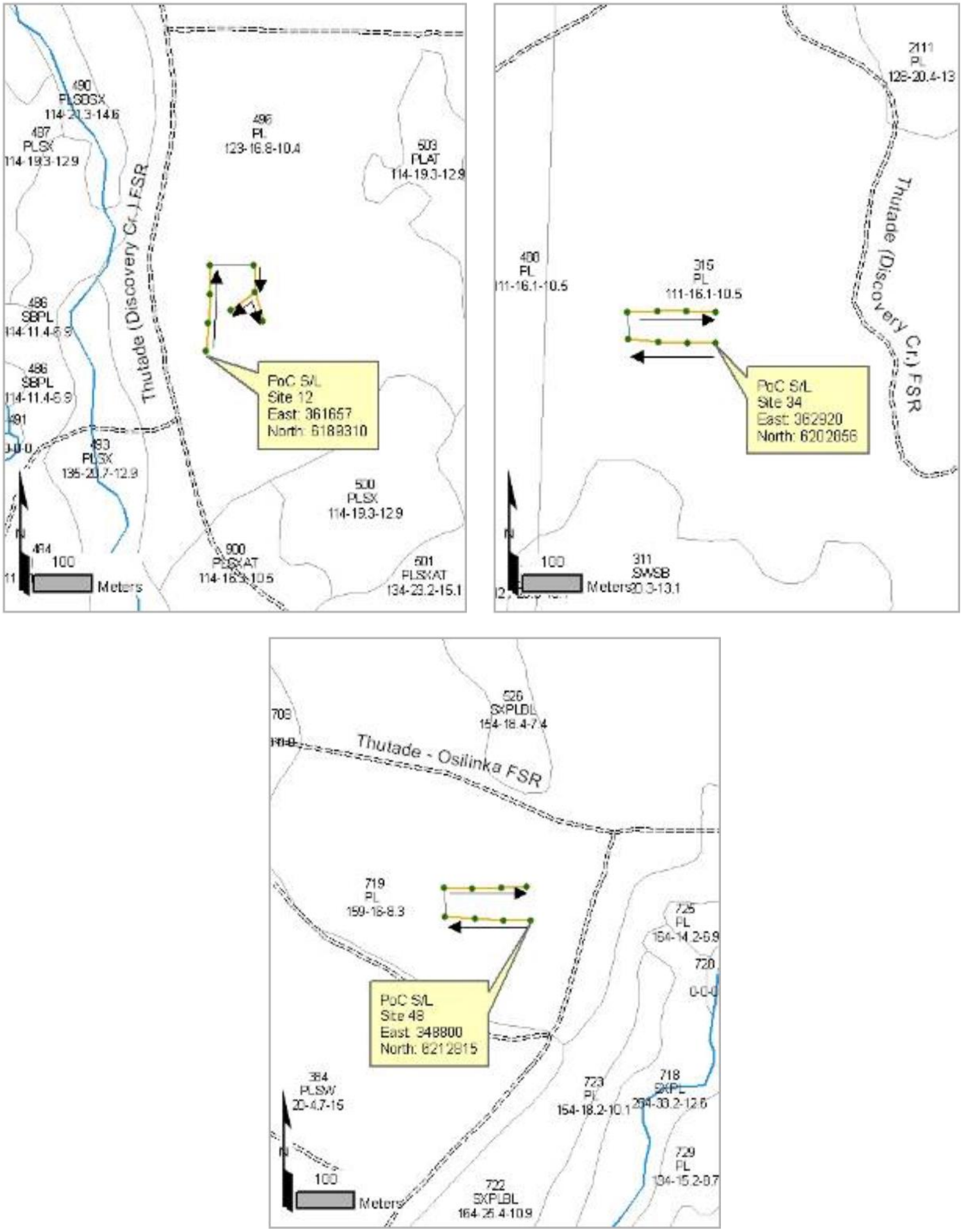

Figure A1-3. Location of vegetation quadrat transects (yellow lines) for Site 12 – South Discovery Creek (top left), Site 34 – Discovery Creek (top right), and Site 48 – Upper Osilinka (bottom) (from Sulyma and McNay 2009).

Note: The Thutade (Discovery Creek) FSR has been realigned in the vicinity of Site 34 since the above map was created. The current alignment is located approximately 1 km to the east. Site 34 should be accessed using the old FSR, which branches off of the current mainline.

APPENDIX 2. EFFECT OF PLOT SIZE ON ESTIMATING DENSITY (STEMS/HA) OF REGENERATING TREES (<7.5 CM DBH)

In 2016, high regeneration densities at the Phillip Lakes site necessitated using smaller plot sizes to reduce the amount of time required to complete the regeneration assessments. All regeneration (<7.5 cm dbh) and stand (≥7.5 cm dbh) plots at Phillip Lakes were initially established as 7.98 m radius plots. We therefore tested whether regeneration densities on smaller plots would provide results consistent with the 7.98 m radius plots. Our intent was to assess the adequacy of 5.64 m radius plots, however, a measuring error resulted in plot sizes of 5.82 m. The number of regenerating trees was counted for both 5.82 m radius plots and 7.98 m radius plots at 7 stand plots, then converted to stems/ha.

We fitted a one-way GAM model to test whether there was a significant effect of plot size on stem density. We found that the estimates of stems/ha of regenerating trees (<7.5 cm dbh) we obtained using the two plot sizes were not significantly different between the plot sizes ($F_{11,1} = 0.015$; p =.90).

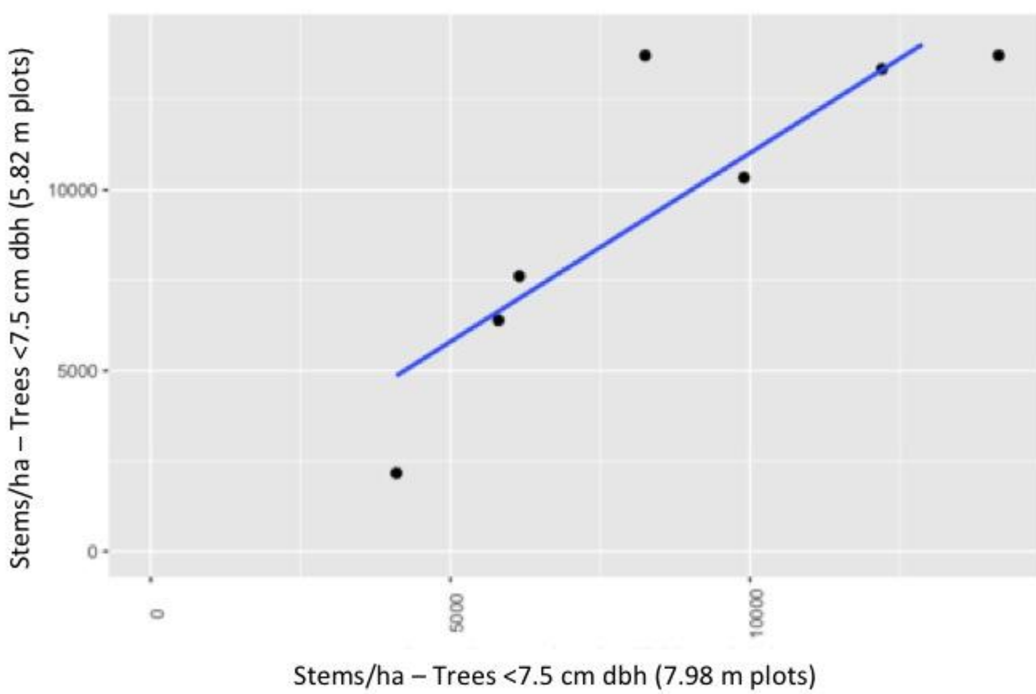

Figure A2-1. Stems/ha of regenerating trees by 7.98 m plots (x-axis) and 5.82 m plots (y-axis).