TECHNICAL REPORT

Rehabilitation of Caribou Winter Range Following Attack by Mountain Pine Beetle: 2017 Post-treatment Site Monitoring UWR U-7-012

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EXECUTIVE SUMMARY

The purpose of the Laidman Lake prescribed burn project is to investigate the use of fire for rejuvenating lichen site types that become dominated by mosses, and for rejuvenating sites affected by the recent mountain pine beetle epidemic (*Dendroctonus ponderosae*) for enhanced rates of lichen recovery. The study area is located approximately 120 km southwest of Vanderhoof in Ungulate Winter Range (UWR) U-7-012 in the Tweedsmuir-Entiako caribou (*Rangifer tarandus*) winter range.

Permanent sample plots were established in 2008 in the area within the proposed burn, and in an adjacent control area. The area had been attacked by mountain pine beetles in the early 2000s and was in the grey attack stage when the study began. Preparation for the prescribed burn began in March 2009 with the knockdown of trees in the treatment area. The prescribed burn was conducted September 24, 2009 and post-burn sampling was conducted in September 2010. Plots were sampled again in 2017 to assess conditions eight years after the prescribed burn.

Abundance of most vegetation types was reduced immediately following prescribed burning, including *Cladina mitis*, *Cladina rangiferina* and red-stemmed feathermoss (*Pleurozium schreberi*). By 2017, foliose lichens were observed in two of the 36 vegetation quadrats, but no caribou forage lichens were found. Kinnikinnick (*Arctostaphylos uva-ursi*) abundance was lower eight years following the burn than prior to the burn, while twinflower (*Linnaea borealis*) abundance was slightly but not significantly lower (p<0.001, p=0.11 respectively). Several species initially decreased following the burn, but then increased to pre-burn or higher levels by 2017 including willow (*Salix* sp.), soopollalie (*Shepherdia canadensis*), spikelike goldenrod (*Solidago spathulata*), bunchberry (*Cornus canadensis*) and dwarf blueberry (*Vaccinium caespitosum*). Although grasses and sedges were not abundant before the prescribed burn, two additional species (*Calamagrostis canadensis, Carex spp*) invaded following the burn, and all species increased immediately after the fire and continued to increase until 2017. Fireweed (*Epilobium angustifolium*) also increased following the prescribed burn (p=0.002). The prescribed burn also resulted in an increase in exposed soil immediately after the burn, which continued into 2017. Although litter was similar before and immediately after the burn, by 2017, litter had decreased below pre-burn levels (p<0.001).

On the control (MPB), percent cover of both *Cladina* sp. and *Cladonia* sp. decreased from 2008 to 2017 but not significantly (p=0.442, p=0.059 respectively), while red-stemmed feathermoss increased slightly, but not significantly (p=0.410). Also, neither twinflower abundance nor kinnikinnick abundance changed significantly between 2008 and 2017 (p=0.11, p=1.0, respectively).

On the control (MPB), an average of 21% of all trees and 29% of MPB-killed trees fell between 2008 and 2017 resulting in average fall-down rates of 2.4 and 3.2 trees/year respectively, and volume of coarse woody debris increased from an average of 18.4 m^3/ha in 2008 to 50.2 m^3/ha in 2017.

Lodgepole pine (*Pinus contorta*) comprised over 90% of regeneration on control and prescribed burn plots in 2008 prior to the burn, and on control plots in 2017. Trembling aspen (*Populus tremuloides*) was the dominant regenerating species on prescribed burn plots in 2017 (73% of regeneration), with lodgepole pine making up the bulk of the remaining trees (25%).

In the short term, the Laidman Lake prescribed burn was successful in increasing the amount of exposed soil for lichen recolonization, reducing the abundance of kinnikinnick and twinflower (two main dwarf shrub competitors that increase following mountain pine beetle disturbance), and eliminating red-stemmed feathermoss, which outcompetes terrestrial lichens in later stages of succession. The lack of colonization by caribou forage lichens soon after fire is consistent with the general pattern of lichen colonization and succession in boreal forests, where *Cladonia* species start becoming abundant 10-30 years following fire and *Cladina* species start becoming abundant 30-50 years following fire.

We recommend conducting the next sampling session in five years (2022) to assess vegetation and regeneration conditions.

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INTRODUCTION

The winter range of the Tweedsmuir-Entiako caribou (*Rangifer tarandus*) population is located in the area in and around Entiako Provincial Park, including the area to the southeast of the park in the Vanderhoof Resource District (Cichowski 1993). During winter, Tweedsmuir-Entiako caribou forage on terrestrial lichens in mature lodgepole pine (*Pinus contorta*) forests. The recent mountain pine beetle (*Dendroctonus ponderosae*, MPB) epidemic in the Omineca region has affected most of the winter range, including the designated Ungulate Winter Range UWR U-7-012, which was established in low elevation pine winter range in the Laidman Lake area (BC Ministry of Environment 2005). Recent studies have shown that abundance of dwarf shrubs increases following mountain pine beetle attack, while terrestrial lichen abundance decreases (Seip and Jones 2010, Cichowski et al. 2009, Cichowski 2011, Waterhouse 2011, Cichowski and Haeussler 2013). Disturbances such as fire may help to mitigate the post-MPB increase in dwarf shrubs by re-establishing site conditions that are favourable for terrestrial forage lichen recolonization. Therefore, prescribed fire could be used as a potential tool for restoring site conditions that would encourage lichen growth.

The Laidman Lake prescribed burn project was initiated in 2008 as part of a broader project to strengthen the understanding of caribou winter range ecology and to improve management policy for UWRs in the Omineca region (Sulyma and McNay 2009). The purpose of the project was to investigate the use of fire for rejuvenating lichen site types that become dominated by mosses, and for rejuvenating sites affected by the recent mountain pine beetle epidemic for enhanced rates of lichen recovery.

The objectives of the prescribed burn were to reduce the duff layer to reduce the seedbed and existing vegetation, to reduce coarse woody debris, and to expose mineral soil to facilitate lichen recolonization (Sulyma and McNay 2009). Plots were established in 2008 in the area within the proposed burn, and in an adjacent control area (Sulyma 2009). The burn was conducted in September 2009 and the burn plots were revisited in September 2010 (Cichowski et al. 2011).

In 2017, the Laidman Lake prescribed burn was revisited as part of a broader project to re-assess conditions at adaptive management trials for terrestrial lichens throughout the Omineca region (Cichowski et al. 2017). The objective for the Laidman Lake portion of the project was to document vegetation response in the prescribed burn and in the control area. Both the prescribed burn and the control area were attacked by mountain pine beetles in the early 2000s, prior to the initiation of the study. In this report, we summarize conditions at the Laidman Lake prescribed burn site eight years following the prescribed burn, and compare them to conditions currently found in mountain pine beetle killed forests in the control.

STUDY AREA

The study area is located approximately 120 kilometres southwest of Vanderhoof and two kilometres south of Laidman Lake in the Vanderhoof Forest District (Figure 1). It lies within the Nazko Upland ecosection of the Central Interior ecoprovince (Demarchi 1996)

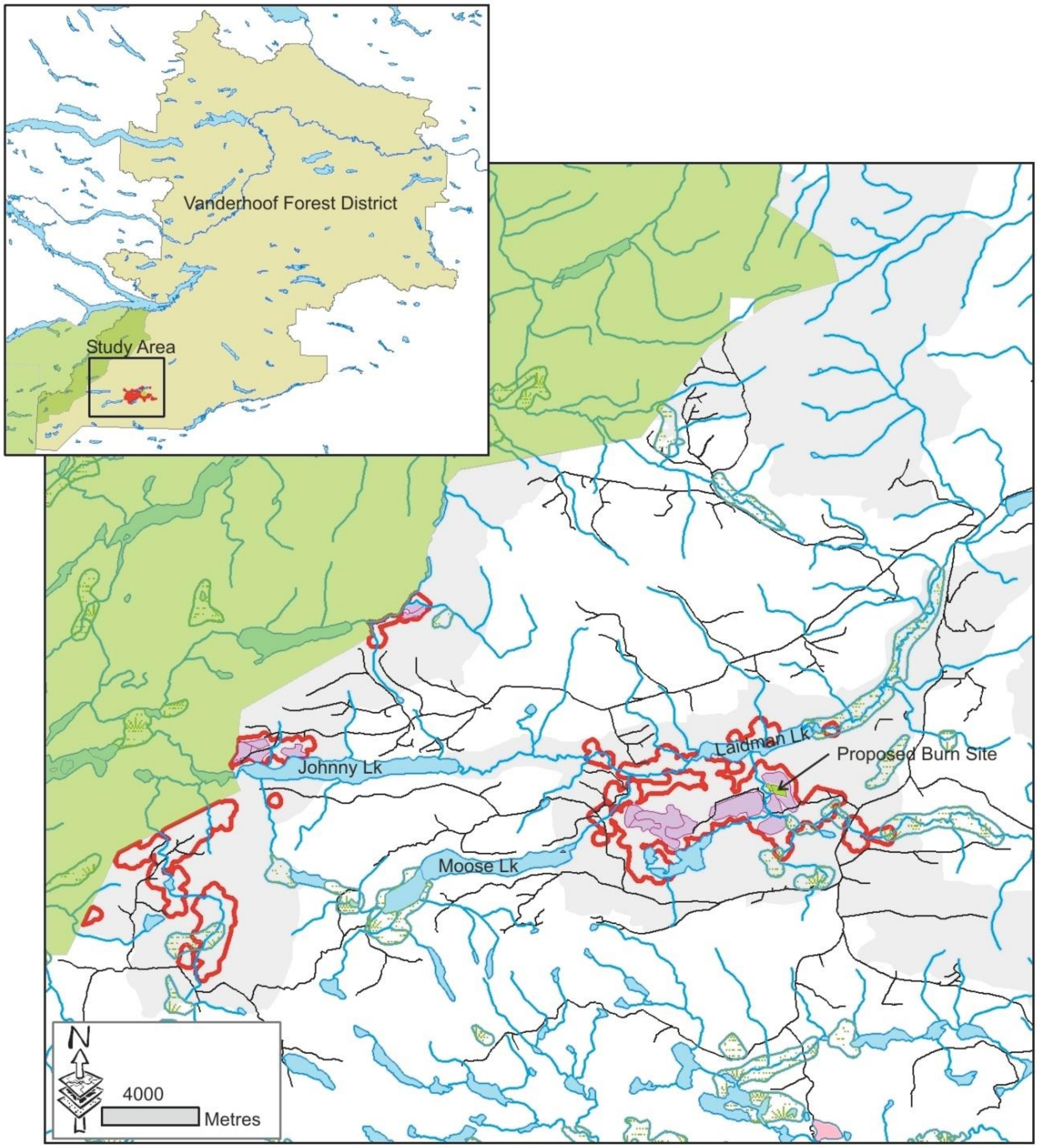


Figure 1. Location of the Laidman Lake prescribed burn site in the Vanderhoof Forest District in north-central British Columbia. The red polygons show terrestrial lichen habitat (TLH) areas within woodland caribou ungulate winter range U-7-012 (grey shaded area). The green shaded area is Entiako Park and the purple shaded areas represent the polygons assessed by the reconnaissance work (Sulyma and McNay 2008).

and in the moist cold subzone of the Sub-Boreal Pine-Spruce biogeoclimatic zone (SBPSmc) (Meidinger and Pojar 1991). The climate in the SBPSmc is characterized by warm dry summers and cold winters (Meidinger and Pojar 1991). Forest cover is dominated by a 103-year old lodgepole pine stand that has a moderately well-developed understory of lodgepole pine regeneration (Sulyma 2009). Mountain pine beetle attack resulted in the mortality of 66% of the tree layer, leaving a live tree density of approximately 300 stems per hectare. Much of the mountain pine beetle attack occurred between 1998 and 2000 (Sulyma *unpublished data*) and the stands were already in the post-attack grey stage when the study began in 2008. Understory vegetation is typical of the SBPSmc 01b site series (submesic phase of the Pine -Feathermoss - *Cladina* plant association) (Banner et al. 1993). Access to the study area is by an all season two-wheel-drive road that ends less than 400 m from the southwest corner. An unmaintained airstrip is located 550 m west of the study site, and a small camp on Laidman Lake is situated 1.8 km north of the site.

METHODS

Pre-2017 Methods

Fieldwork was conducted September 10-12, 2008 prior to the burn, and September 23-25, 2010, following the burn. In 2008, a systematic grid was established in each sampling unit to provide plot centres to anchor surveys (Sulyma 2009). Five permanently-marked plot centres were established in the control area (7.5 ha) spaced 75 m apart, and 9 permanently-marked plot centres were established in the proposed prescribed burn area (37.4 ha) spaced 125 m apart (Figure 2). Originally, the proposed prescribed burn area was stratified into two strata. However, site characteristics were uniform across both strata (Sulyma 2009), so the two strata were combined.

Data were collected at each plot centre to characterize biophysical site characteristics, vegetation, and coarse woody debris/fuel loading. Site attributes such as terrain and soil characteristics were recorded on Ground Inspection Forms in 2008 and followed procedures outlined in a Field Manual for Describing Terrestrial Ecosystems (Province of BC 1998).

In 2008, a 5.64 m radius plot was established at each plot centre to tally all trees larger than 12.5 cm diameter at breast height (dbh). Tree dbh, height, index of beetle attack and wildlife tree class were recorded. An estimate of the crown closure was made using a concave densiometer following procedures outlined by Trelenberg and Hodder (2006). Regeneration was assessed within a 3.99 m radius regeneration plot; the number of stems were recorded by species and health (i.e. live or dead) for the following classes: <1.3 m tall, >1.3 m tall to 7.4 cm dbh, and 7.5 to 12.4 cm dbh.

Ocular estimates of the percent cover of shrubs within the 5.64 m radius tree plot were recorded. The shrub layer included all woody plants less than 10 m tall, except dwarf or creeping shrubs that were generally less than 15 cm tall, which were counted in the herb layer. The percent cover of dwarf shrubs, herbaceous plants, grasses, mosses, and lichens were recorded using a modified cluster survey design where 0.5 m^2 (0.71 m X 0.71 m) quadrats were established around each plot centre (Figure 3). The target was to establish 30 to 40 quadrats in each treatment unit to provide acceptable representation of the vegetation community (McCune and Lesica 1992). The number of quadrats per plot centre was a function of the target divided by the number of plot centres within the treatment unit, resulting in six quadrats per plot centre in the control area and four per plot centres in the prescribed burn treatment area. Quadrats were located at random bearings and random distances (<20 m) relative to the plot centre (Appendix 1).

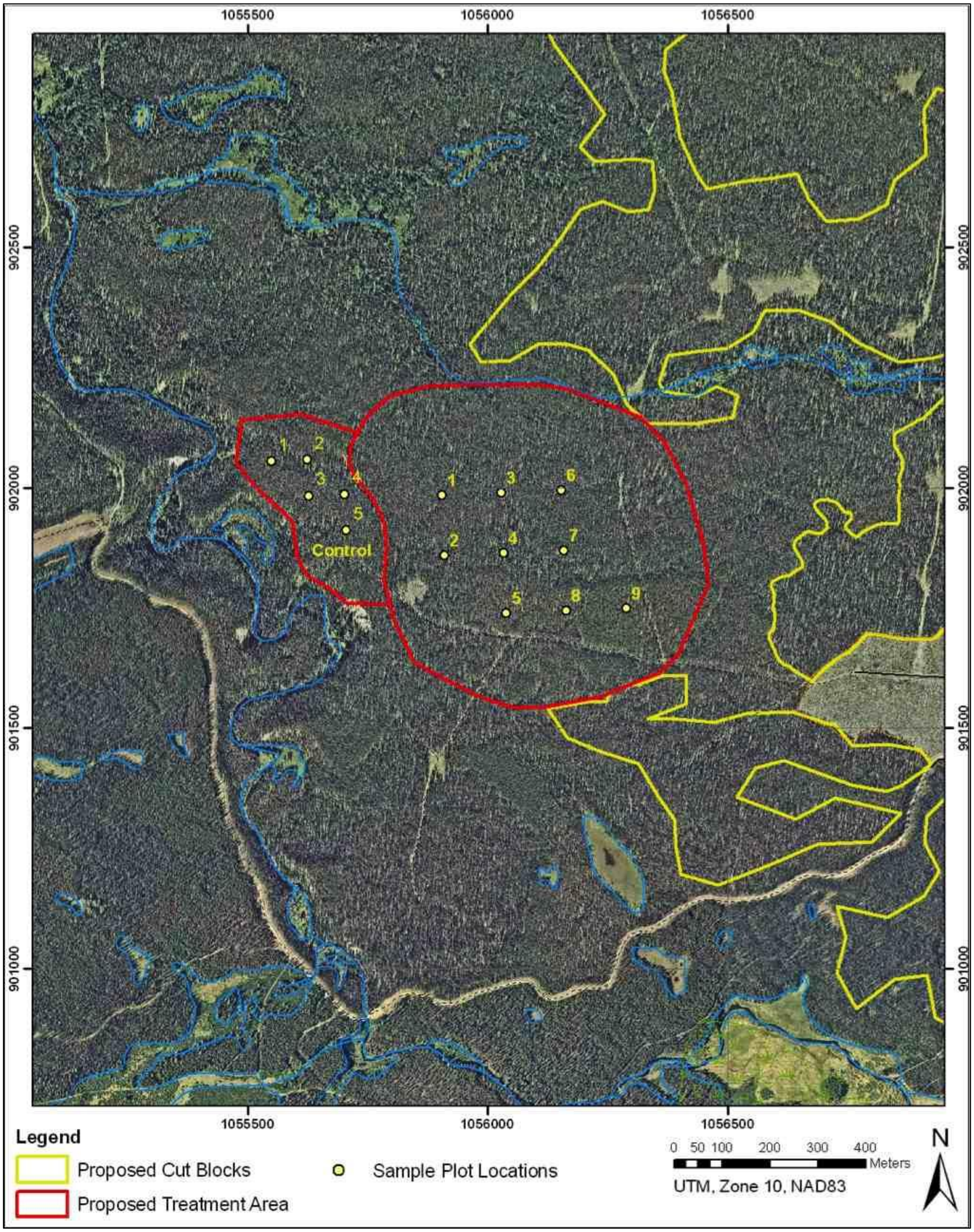
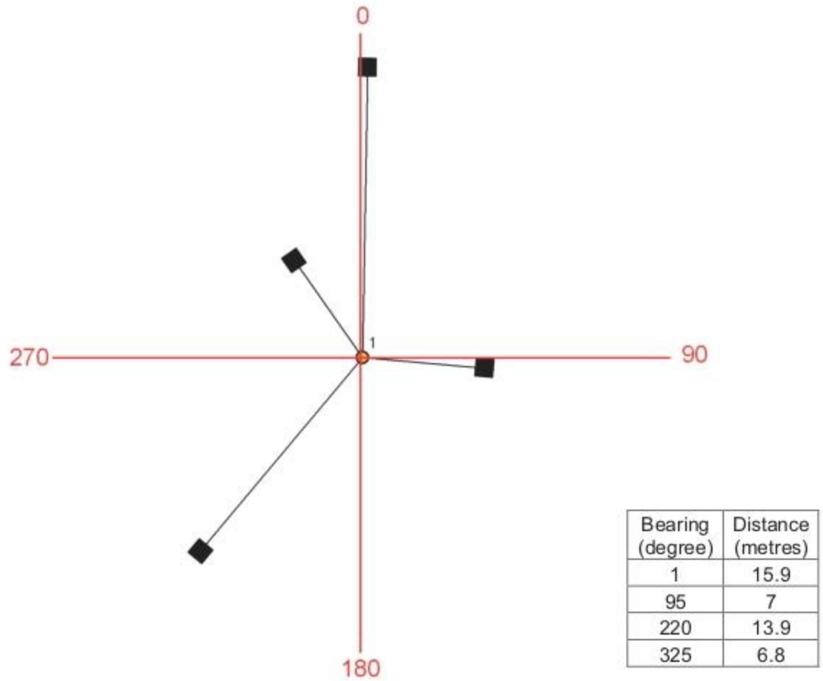


Figure 2. Laidman Lake prescribed burn area and control.



Bearing (degree)	Distance (metres)
1	15.9
95	7
220	13.9
325	6.8

Figure 3. Example of the modified cluster approach for establishing quadrats at each plot centre. The example is based on plot centre 1 in the prescribed burn treatment area.

To ensure equal distribution around a plot centre, the azimuth was divided into identical sized sections equivalent to the number of quadrats that were to be established at the plot, and a random bearing was selected for each section. For example, where four quadrats were established, the azimuth was divided into four sections ranging from 1 to 90 degrees, 91 to 180 degrees, 181 to 270 degrees, and 271 to 360 degrees, and a random number was picked within the range of each section. Random distances, ranging between 0 and 20 m from the plot centre were also selected. To improve the distribution of the quadrats and to avoid the potential for quadrats to overlap, only one quadrat per plot was permitted within a one-metre radius ring around plot centre, and only two quadrats were permitted within a three-metre radius ring. Quadrats were permanently marked with two pigtail stakes and were given individually numbered tags. After the prescribed burn, pigtail stakes were replaced with rebar and old quadrat tags were replaced with new tags (see Appendix 1). Percent cover and height of vegetation were re-measured for all quadrats in the prescribed burn treatment area in 2010, 1 year following treatment. Percent cover of vegetation on five quadrats in the control area (one quadrat from each plot; 143, 152, 156, 164, 174) was also re-measured in 2010.

Two 30-m transects were established at each plot centre to evaluate fuel loading. Measurements along each transect were based on the procedures outlined by Trowbridge et al. (1989). The total number of intersections of debris less than seven cm in diameter were recorded in specified transect segments relative to the diameter class (Figure 4). For pieces greater than seven cm in diameter, species and diameter for each piece were recorded and pieces were marked with a nail at the intersection with the transect line. Pieces greater than seven centimeters in diameter were also recorded post-treatment in 2010 in the prescribed burn treatment area.

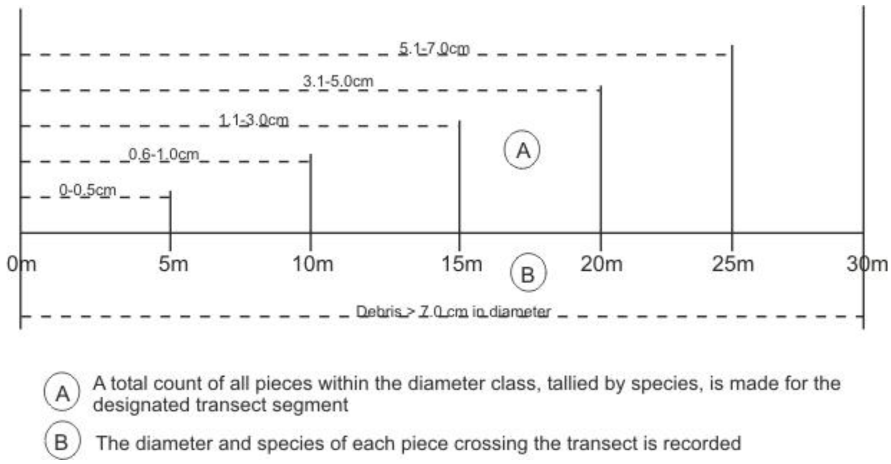


Figure 4. Transect layout for measuring fuel loading indicating the tally by diameter class for designated transect segments (from Trowbridge et al. 1989).

2017 Methods

In 2017, methods were adjusted at the Laidman Lake site to standardize data collection across all sites and sampling periods for the broader project on re-assessing conditions at adaptive management trials for terrestrial lichens throughout the Omineca region.

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. We were able to identify most of the previously tagged trees (≥12.5 cm dbh) in the stand plots in the control. Previously tagged 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. We numbered and tagged any new trees that grew into the ≥7.5 cm dbh size class since the 2008 sampling session, and also trees that were in the 7.5 to 12.49 cm dbh size class in 2008 (because those trees were only tallied during the previous sampling session). For all newly tagged trees, we recorded species, status, dbh and height, and also recorded the bearing from plot centre to the new trees to aid in relocating trees during future sampling sessions. For the prescribed burn, we collected tree and regeneration data in 5.64 m radius plots. For the control, we collected tree data in 7.98 m radius plots and regeneration data in 3.99 m radius plots, except in stand plot #3 where the regeneration plot was 7.98 m due to the low density of regeneration in that plot. Stand and regeneration data were converted to stems/ha and basal area/ha for large trees, and to stems/ha for regeneration. We calculated fall-down rates of standing trees between 2008 and 2017 for trees ≥12.5 cm dbh only because trees in the 7.5 to 12.49 cm dbh size class were not individually marked in 2008 and therefore we could not track their fates.

In 2017, coarse woody debris (CWD) measurements followed methods outlined in the Field Manual for Describing Terrestrial Ecosystems (Province of BC 1998). We used the original transect bearings established in 2008, but revised transect length to 24 m, and measured pieces ≥7.5 cm in diameter. For each log, we recorded 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. To compare CWD between 2008 and 2017, we calculated volume/ha in 2008 using only pieces that were ≥ 7.5 cm in diameter. In 2017, we did not measure CWD in the prescribed burn because after the burn there were no large diameter trees left standing on the plots that could have contributed to increased coarse woody debris on those sites.

Statistical Analyses

We conducted statistical comparisons between pre-treatment measurements (2008) and the most recent post-treatment re-sample measurements (2017) of percent cover in vegetation quadrats in both control and prescribed burn plots. Exploratory plots of data revealed considerable non-normality in distributions of percent cover values. Therefore, we used the non-parametric Wilcoxon signed ranks test to evaluate the significance of per-quadrat changes in percent cover of each species or species group between sampling periods. All tests and graphs were conducted in R 3.4.3 (R Core Team 2017) using the stats and ggplot2 library packages respectively.

Prescribed burn

Preparation for the prescribed burn began in March 2009 with the knockdown of trees in the treatment area. Trees were knocked down with a cable strung between two bulldozers (Figure 5) to create a differential in fuel types between the burn area and the adjacent forests, which permitted ignition of a prescribed burn when fire hazard for the adjacent stands was low. The knockdown was conducted during winter when the ground was frozen to minimize site level mineral soil disturbance and to promote snapping of the boles near the ground.

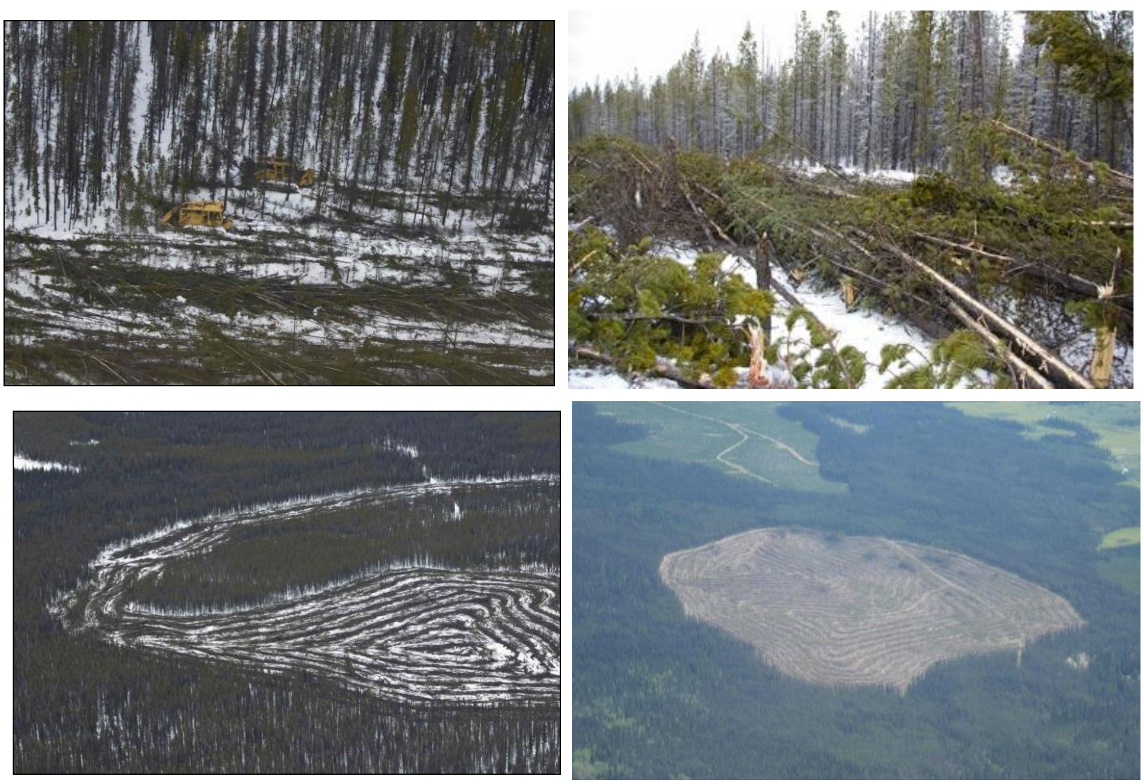


Figure 5. Tree knockdown conducted March 2009 (photos by R. Sulyma).

The prescribed burn was conducted in September 24, 2009, using a heli-torch, and hand-held drip torches to ignite fuel along the perimeter of the treatment area (Figure 6). Most of the forest floor was consumed during the fire (Figure 7; A. Batho, pers. comm.) and depth of burn averaged 4.0 cm in moss and 5.4 cm in lichen (Cichowski et al. 2011).

Figure 6. Prescribed burn conducted September 24, 2009 using heli-torch and hand held drip torch (photos by B. Nelless).

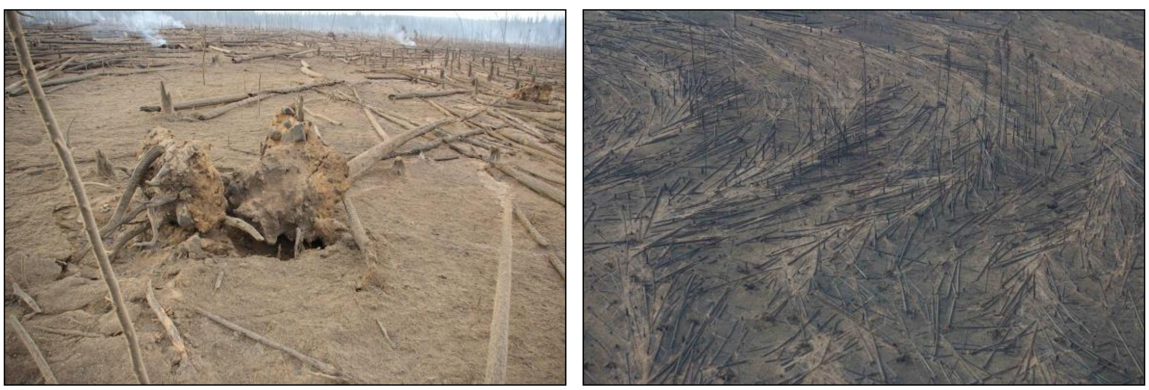


Figure 7. Laidman Lake prescribed burn treatment area, one day following treatment, September 25, 2009 (photos by R. Sulyma).

RESULTS AND DISCUSSION

Stand structure and regeneration

By 2017, average stand density on the control plot had decreased from 1700 stems/ha to 1330 stems/ha on the control, with live trees, primarily lodgepole pine, comprising 46% of the stand (Table 1). As of 2017, no trees have reached 7.5 cm dbh in the prescribed burn (Table 1). From 2008 to 2017, between 0 and 42% of all standing trees, and between 0 and 67% of MPB-attacked trees had fallen over in individual control plots. An average of 21% of all trees and 29% of MPB trees fell between 2008 and 2017 resulting in an average fall-down rate of 2.4 and 3.2 trees/year respectively (Table 2). MPB-attacked trees were already in the grey-attack stage when the plots were established; therefore, we are unable to assess the fall-down rate since trees were attacked because we were unable to determine the year of attack, and whether any trees fell prior to plot establishment.

Table 1. Average density (stems/ha) of trees ≥7.5 cm dbh for each species/status for the Laidman Lake control and prescribed burn treatments, prior to (2008) and eight years following treatment (2017).

Treatment	Year	Hybrid spruce	Pine	Dead-MPB	Dead	Total Standing	Total live	Total live (Range)
Control	2008	40	780	690	190	1700	820	0 - 2400
	2017	60	550	610	110	1330	610	250 - 1300
Prescribed burn	2008	6	1911	494	322	2733	1917	450 - 3100
	2017	0	0	0	0	0	0	-

Table 2. Number of standing trees ≥12.5 cm dbh in control plots at the Laidman Lake prescribed burn site in 2008 and 2017.

	All Standing Trees >12.5 cm dbh			MPB Standing Trees Only >12.5 cm dbh		
Plot	**2008**	**2017**	**% Fall-down 2008-2017**	**2008**	**2017**	**% Fall-down 2008-2017**
1	15	10	33	11	6	45
2	19	11	42	12	4	67
3	21	21	0	12	12	0
4	24	21	13	17	15	12
5	20	15	25	17	12	29
Total	**99**	**78**	**21**	**69**	**49**	**29**

Lodgepole pine comprised over 90% of regeneration on control and prescribed burn plots in 2008 prior to the burn, and on control plots in 2017 (Table 3). Trembling aspen (*Populus tremuloides*) was the dominant regenerating species on prescribed burn plots in 2017 (73% of regeneration), with lodgepole pine making up the bulk of the remaining trees (25%). All regeneration on prescribed burn plots was less than 1.3 m in height.

Regeneration was highly variable in control plots and ranged from 600 to 27,200 stems/ha in 2008, and 950 to 57,800 stems/ha in 2017 (Table 3, Figure 8). Regeneration increased slightly in four of the five plots, and doubled in density in Plot 4. The general understory structure across the control site consisted of generally low to moderate regeneration densities throughout the site, with patches of dense or moderately dense regeneration in places. Plot 4 was located in one of the dense patches.

Table 3. Density (stems/ha) of regeneration at Laidman Lake control and prescribed burn plots prior to (2008) and eight years following treatment (2017).

	Plot	<1.3 m high Pl	Sx	At	Total	1.3 m to 7.49 cm dbh Pl	Sx	Total	Total <7.5 cm dbh Pl	Sx	At	Total
Control												
2017	1	3400	600	0	4000	1000	200	1200	4400	800	0	5200
	2	3200	200	0	3400	5400	400	5800	8600	600	0	9200
	3	600	50	0	650	250	50	300	850	100	0	950
	4	33000	200	0	33200	24200	400	24600	57200	600	0	57800
	5	10000	0	0	10000	7000	200	7200	17000	200	0	17200
	Total	10040	210	0	10250	7570	250	7820	17610	460	0	18070
2008	1	3600	500	0	4100	0	1100	1100	3600	1600	0	5200
	2	4600	200	0	4800	3000	300	3300	7600	500	0	8100
	3	400	100	0	500	0	100	100	400	200	0	600
	4	19200	0	0	19200	8000	0	8000	27200	0	0	27200
	5	15100	100	0	15200	0	0	0	15100	100	0	15200
	Total	8580	180	0	8760	2200	300	2500	10780	480	0	11260
Prescribed burn												
2017	1	100	200	2700	3000	0	0	0	100	200	2700	3000
	2	500	100	5800	6400	0	0	0	500	100	5800	6400
	3	100	200	1100	1400	0	0	0	100	200	1100	1400
	4	700	0	1300	2000	0	0	0	700	0	1300	2000
	5	300	0	400	700	0	0	0	300	0	400	700
	6	100	0	300	400	0	0	0	100	0	300	400
	7	300	100	1900	2300	0	0	0	300	100	1900	2300
	8	500	0	1300	1800	0	0	0	500	0	1300	1800
	9	3800	0	3700	7500	0	0	0	3800	0	3700	7500
	Total	711	67	2056	2833	0	0	0	711	67	2056	2833
2008	1	5100	100	0	5200	100	0	100	5200	100	0	5300
	2	17600	0	0	17600	7400	0	7400	25000	0	0	25000
	3	5700	0	0	5700	500	0	500	6200	0	0	6200
	4	3700	200	0	3900	1300	0	1300	5000	200	0	5200
	5	4300	0	0	4300	2300	0	2300	6600	0	0	6600
	6	0	0	0	0	4900	200	5100	4900	200	0	5100
	7	3800	100	0	3900	400	0	400	4200	100	0	4300
	8	3900	100	0	4000	900	0	900	4800	100	0	4900
	9	1100	100	0	1200	2600	100	2700	3700	200	0	3900
	Total	5022	67	0	5089	2267	33	2300	7289	100	0	7389

Figure 8. Stand structure at Laidman Lake control plots (Plots 1 to 5) and in the prescribed burn (Burn) in 2017.

Coarse woody debris

Volume of CWD increased from an average of 18.4 m^3/ha in 2008 to 50.2 m^3/ha in 2017 in the control (Table 4). The increase in CWD is consistent with the levels of tree-fall recorded at the site.

Table 4. Volume (m^3/ha) of coarse woody debris ≥7.5 cm diameter at Laidman Lake control plots in 2008 and 2017.

	Coarse Woody Debris (≥7.5 cm dbh) Volume (m^3/ha)	
Plot	**2008**	**2017**
C3-1	0	5.7
C3-2	8.3	44.3
C4-1	4.5	63.2
C4-2	56.3	113.6
C5-1	28.6	18.0
C5-2	12.5	56.6
Average	**18.4**	**50.2**

Vegetation quadrats

Dominant species on both the control and prescribed burn plots in 2008 included dwarf shrubs (kinnikinnick [*Arctostaphylos uva-ursi]*, twinflower [*Linnaea borealis*], dwarf blueberry [*Vaccinium caespitosum*]), soopollalie (*Shepherdia canadensis*), terrestrial forage lichens (*Cladina mitis*, *Cladina rangiferina*); *Peltigera* lichens (*Peltigera* sp.), bunchberry (*Cornus canadensis*), and, red-stemmed feathermoss (*Pleurozium schreberi;* Table 5).

Abundance of most vegetation types was reduced immediately following prescribed burning (Figure 9). In 2010, some small patches of *Cladina mitis*, *Cladina rangiferina* and red-stemmed feathermoss survived the fire, but had disappeared by 2017 (Table 5, Figures 10&11). In the control (MPB), percent cover of both *Cladina* sp. and *Cladonia* sp. decreased over that period, but not significantly (p=0.442, p=0.059, respectively). Red-stemmed feathermoss increased slightly, but not significantly (p=0.410). Fire moss (*Ceratodon purpureus*) increased following the prescribed burn and remained absent in the control (MPB) in 2017 (Figure 11).

Although no caribou forage lichens were observed in prescribed burn quadrats in 2017, foliose lichens were observed in two of the 36 quadrats (Figure 12). Prior to the prescribed burn, *Peltigera aphthosa* covered 1% of one of the two quadrats and 0.1% of the other. The successful removal of the competitor red-stemmed feathermoss from the site will aid in providing conditions that will allow for the re-establishment of terrestrial caribou forage lichens on the site.

Table 5. Mean percent cover of plants, mosses and lichens tallied in vegetation quadrats prior to (2008) and following (2010) the prescribed burn. Values are presented as the mean ± the standard error.

	Control				Prescribed burn					
	% Cover		Change in % mean cover		% Cover			Change in % mean cover		
Species	2008	2017	2008 to 2017	Wilcoxon statistic V	Pre-burn (2008)	Post-burn (2010)	2017	2008 to 2017	2017 to 2010	Wilcoxon statistic V 2008 to 2017
Achillea millefolium	0.47±0.12	0.3±0.11	-0.17	105	0.26±0.08	0.20±0.15	0.60±0.12	0.34	0.40	112**
Arctostaphylos uva-ursi	3.47±0.91	3.55±.1.12	0.08	116	7.56±1.77	0.11±0.09	0.92±0.52	-6.64	0.81	359***
Arnica cordifolia	0.03±0.03	0.90±.0.38	0.87	2*	-	-	-	-	-	-
Aster spp.	0.03±0.02	0.02±.0.02	-0.01	4	-	-	0.05±0.02	0.05	0.05	0*
Calamagrostis canadensis	-	-	-	-	-	0.19±0.15	0.22±0.16	0.22	0.03	0
Carex spp	-	-	-	-	-	0.20±0.10	1.66±0.62	1.66	1.46	0***
Cornus canadensis	5.90±0.76	5.13±0.59	-0.77	206	1.68±0.32	0.31±0.08	1.27±0.26	-0.41	0.96	321
Empetrum nigrum	0.83±0.59	0.94±0.71	0.11	7	0.22±0.15	-	-	-0.22	-	3
Epilobium angustifolium	1.15±0.37	1.03±0.34	-0.12	113	0.25±0.15	0.35±0.21	0.93±0.16	0.68	0.58	71**
Fragaria virginiana	0.15±0.09	0.09±0.05	-0.06	20	0.11±0.04	-	-	-0.11	-	35*
Geocaulon lividum	0.2±0.17	0.18±0.17	-0.02	6	-	-	-	-	-	
Juniperus communis	0.18±0.17	0.34±0.33	0.16	5	-	-	-	-	-	
Linnaea borealis	6.13±1.34	3.02±0.78	-3.11	274	4.11±1.16	0.34±0.10	1.64±0.45	-2.47	1.30	331
Lycopodium complanatum	0.8±0.54	0.35±0.19	-0.45	20	0.44±0.29	-	-	-0.44	-	6
Oryzopsis asperfolia	0.05±0.04	0.02±0.01	-0.03	7	0.03±0.03	0.12±0.04	0.01±0.01	-0.02	-0.11	2
Oryzopsis pungens	0.27±0.07	0.07±0.03	-0.20	139*	0.17±0.05	0.04±0.03	0.37±0.20	0.20	0.33	63
Pyrola secunda	0.1±0.1	-	-0.10	6	-	-	-	-	-	
Rosa acicularis	1.02±0.27	1.03±0.21	0.01	65	0.07±0.06	0.08±0.06	0.19±0.12	0.12	0.11	4
Salix spp	-	-	-	-	0.06±0.06	0.01±0.01	0.44±0.19	0.38	0.43	0*
Shepherdia canadensis	2.97±0.92	4.63±1.19	1.66	55	2.75±0.71	0.14±0.06	4.22±1.69	1.47	4.08	131
Solidago spathulata	0.02±0.02	-	-0.02	1	0.20±0.11	0.16±0.08	1.25±0.25	1.05	1.09	49***
Vaccinium caespitosum	6.3±1.07	6.03±0.82	-0.27	202	3.45±0.78	0.63±0.14	3.49±0.71	0.04	2.86	268
Grass spp	-	0.01±0.01	0.01	0	-		0.36±0.13	0.36	0.36	0***
Cetraria ericetorum	0.17±0.06	0.03±0.02	-0.14	62*	0.18±0.04	-	-	-0.18	-	120***
Cladonia ecmocyna	0.87±0.31	0.32±0.10	-0.55	100	1.01±0.30	-	-	-1.01	-	378***
Cladina mitis	1.68±0.4	1.02±0.30	-0.66	208	2.49±0.51	<0.01	-	-2.49	-	465***
Cladina rangiferina	1.01±0.36	0.91±0.39	-0.10	153	2.06±0.43	<0.01	-	-2.06	-	378***
Peltigera apthosa	2.27±0.61	3.06±1.03	0.79	173	2.96±0.51	-	-	-2.96	-	496***
Peltigera malacea	-	-			0.04±0.02	-	-	-0.04	-	6

	Control				Prescribed burn					
	% Cover		Change in % mean cover		% Cover			Change in % mean cover		
Species	**2008**	**2017**	**2008 to 2017**	**Wilcoxon statistic V**	**Pre-burn (2008)**	**Post-burn (2010)**	**2017**	**2008 to 2017**	**2017 to 2010**	**Wilcoxon statistic V 2008 to 2017**
Stereocaulon alpinum	0.05±0.04	-	-0.05	3	0.22±0.10	-	-	-0.22	-	21*
Pleurozium schreberi	35.3±4.18	41.03±4.12	5.73	192	31.32±5.12	0.02±0.01	-	-31.32	-0.02	406***
Polytrichum juniperinum	0.1±0.05		-0.1	10	0.17±0.07	0.07±0.03	0.68±0.20	0.51	0.61	46**
Ceratodon purpureus							8.31±1.40	8.31	8.31	-
Peltigera Total	2.27±0.62	3.06±1.03	0.79	173	3.00±0.51		0.04±0.03	-2.96	0.04	561***
Cladina Total	2.69±0.72	1.93±0.64	-0.76	222	4.56±0.86			-4.56		561***
Cladonia Total	1.34±0.42	0.48±0.14	-0.86	156	2.24±0.44			-2.24	-	435***
Total Caribou Lichens	4.25±1.06	2.43±0.73	-1.82	272	7.20±1.07	<0.01	-	-7.20	-	561***
Mosses	37.08±4.05	42.39±3.91	5.31	195	32.7±5.04	0.09±0.04	9.03±1.42	-23.67	8.94	543***
Forbs	8.06±1.07	7.93±0.94	-0.13	188	2.50±0.46	1.01±0.32	4.22±0.40	1.72	3.21	174*
Grasses and sedges	0.32±0.09	0.10±0.04	-0.22	145*	0.20±0.06	0.57±0.23	2.63±0.68	2.43	2.06	16***
Dwarf Shrubs[2]	16.73±1.89	14.04±1.62	-2.69	285	15.34±1.91	1.09±0.23	6.05±0.83	-9.29	4.96	556***
Tall Shrubs[3]	4.17±0.9	6.04±1.19	1.87	138	2.88±0.72	0.24±0.09	4.85±1.70	1.97	4.61	161

[1] Significance (*p*-value) of Wilcoxon signed rank test with continuity correction: * = $0.01<p<0.05$; ** = $0.001<p<0.01$; *** = $p<0.001$; For each cover variable, paired samples compare values measured in each quadrat between time periods. Note that small values of V generally indicate a small magnitude in the differences between observed values among periods, which provides additional information beyond the calculated *p*-value.

[2] Dwarf shrubs included: *Arctostaphylos uva-ursi, Empetrum nigrum, Linnaea borealis* and *Vaccinium caespitosum*

[3] Tall shrubs included: *Juniperus communis, Rosa acicularis, Salix spp, and Shepherdia canadensis*

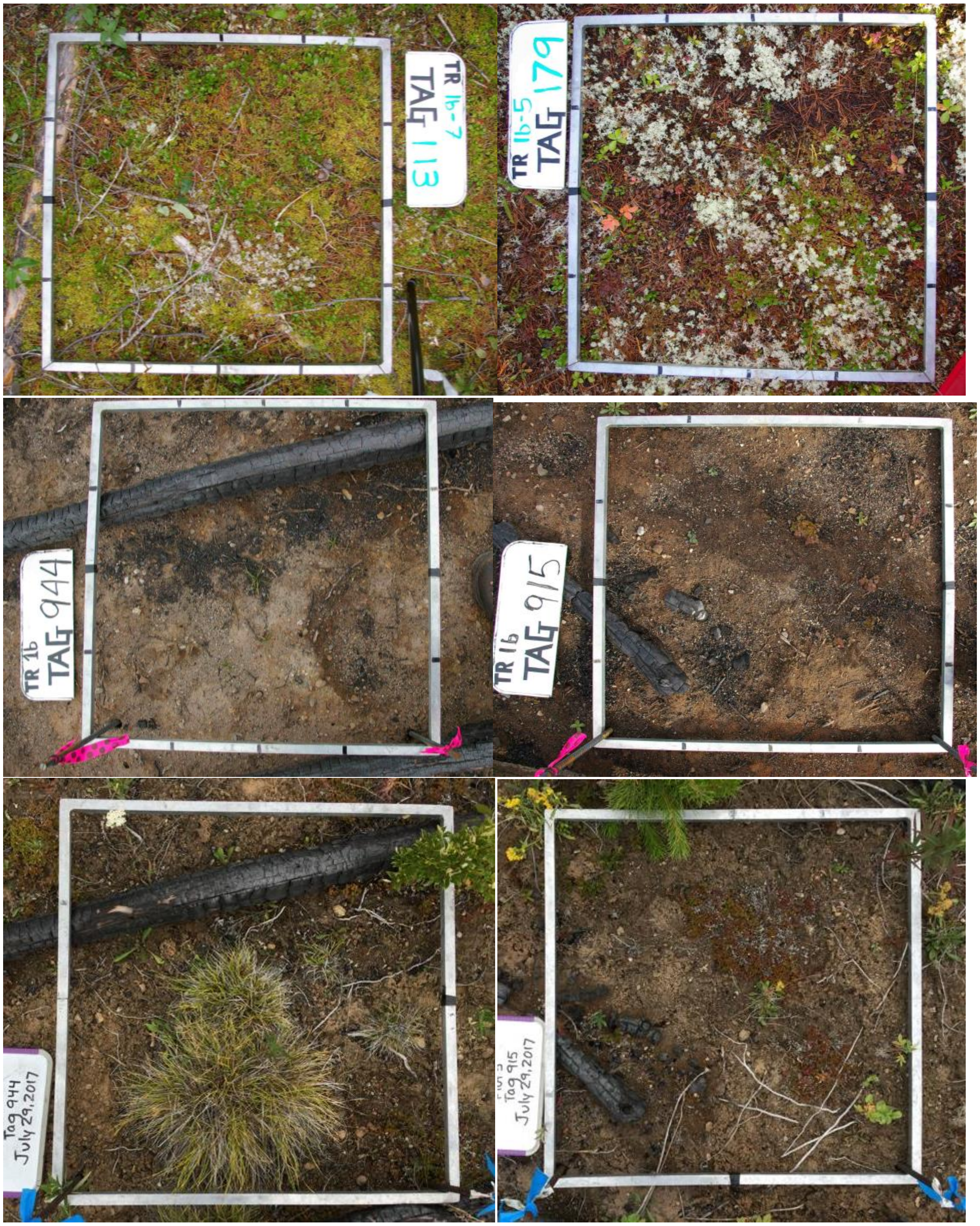


Figure 9. Examples of the effects of the prescribed burn on two quadrats in the Laidman Lake prescribed burn (top-2008; middle-2010; bottom-2017). Note: Tag numbers were replaced following the fire; photos on the left show quadrat 944 and photos on the right show quadrat 915. Also, pre-burn photos were taken prior to the tree knockdown so they do not show the amount of coarse woody debris on the site prior to the burn.

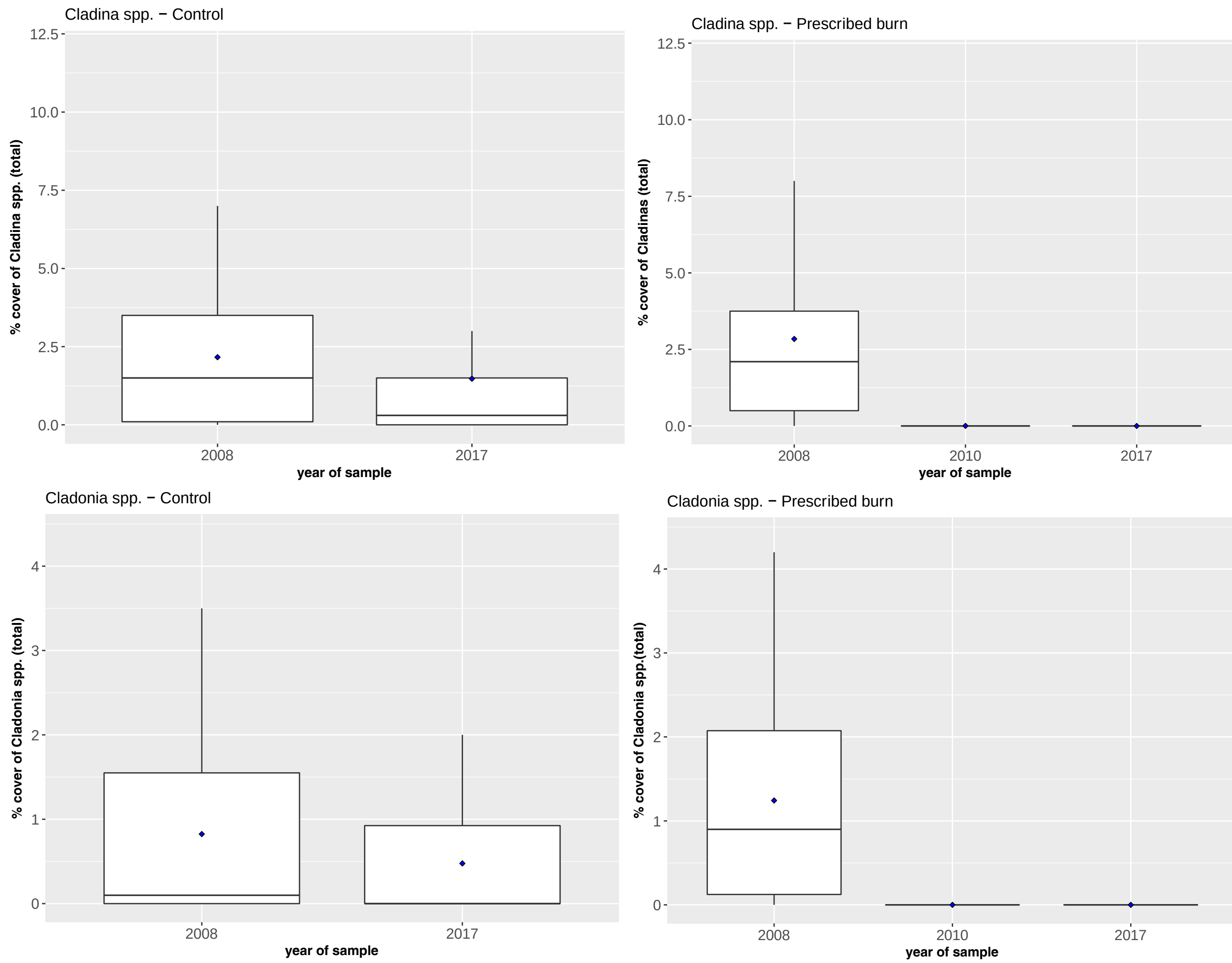


Figure 10. Responses of *Cladina* spp (top) and *Cladonia* spp. (bottom) at the Laidman Lake site in control & prescribed burn plots. The x-axis shows the year of data collection. Data are untransformed % cover values obtained from sampled quadrats. Boxplots show the mean (blue diamond), median (central bold line), the 25-75% interquartile distribution of values (white rectangle) and the distribution of values ± 1.5 * the interquartile distance (vertical black lines). Outliers beyond the 95% quantile taken at this site were trimmed to improve scaling of the y-axis.

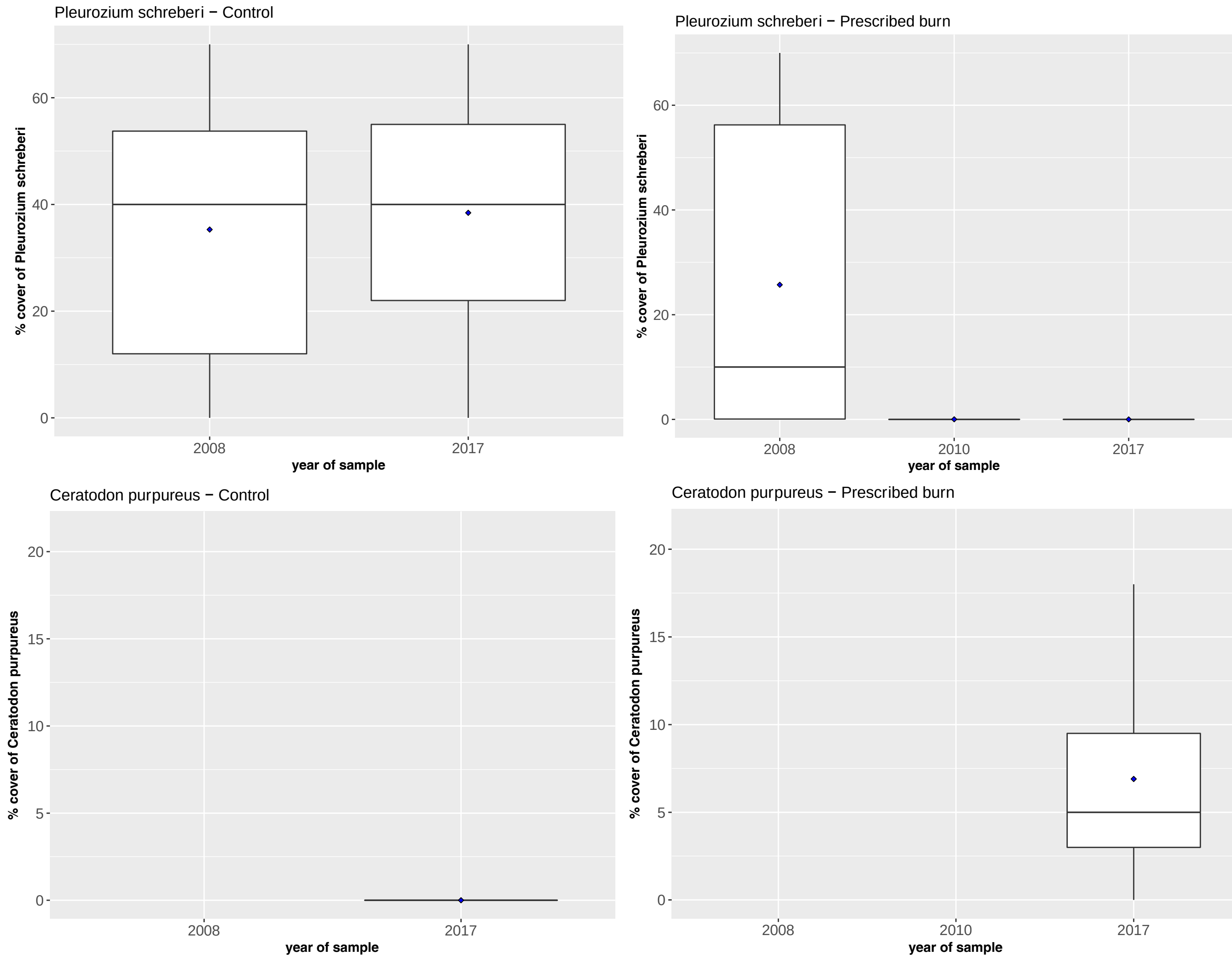


Figure 11. Responses of *Pleurozium schreberi* (top) and *Ceratodon purpureus* (bottom) at the Laidman Lake site in control & prescribed burn plots. The x-axis shows the year of data collection. See caption for Figure 10 for details on interpreting the boxplots and symbols.

Figure 12. Foliose lichens re-establishing in plot 920 in the Laidman Lake prescribed burn, July 2017.

Kinnikinnick abundance was lower eight years following the burn than prior to the burn, while twinflower abundance was slightly but not significantly lower ($p<0.001$, $p=0.11$ respectively; Table 5, Figure 13). On control (MPB) plots, neither twinflower abundance nor kinnikinnick abundance changed significantly between 2008 and 2017 ($p=0.11$, $p=1.0$ respectively). Kinnikinnick and twinflower initially increased following MPB attack in the northern portion of the Tweedsmuir-Entiako caribou winter range, and have been correlated with decreases in terrestrial caribou forage lichen abundance following attack (Cichowski and Haeussler 2013). The apparent disparity in responses to both fire and MPB between the two study sites may be due to differences in the timing of sampling sessions. In the northern portion of the Tweedsmuir-Entiako caribou winter range, kinnikinnick abundance peaked about 7 years following MPB attack and twinflower abundance peaked about 11 years following MPB attack (Cichowski and Hauessler, *in prep*.a). At the Laidman Lake control (MPB), we may not have observed a change in kinnikinnick abundance if the first sampling session was conducted prior to the peak of abundance and the current sampling session (2017) was conducted after the peak, or if the first sampling session (2008) was conducted after the peak of abundance. Similarly, we may have observed a decline in twinflower abundance if the initial sampling session was conducted close to the peak of abundance and the current sampling session was conducted after.

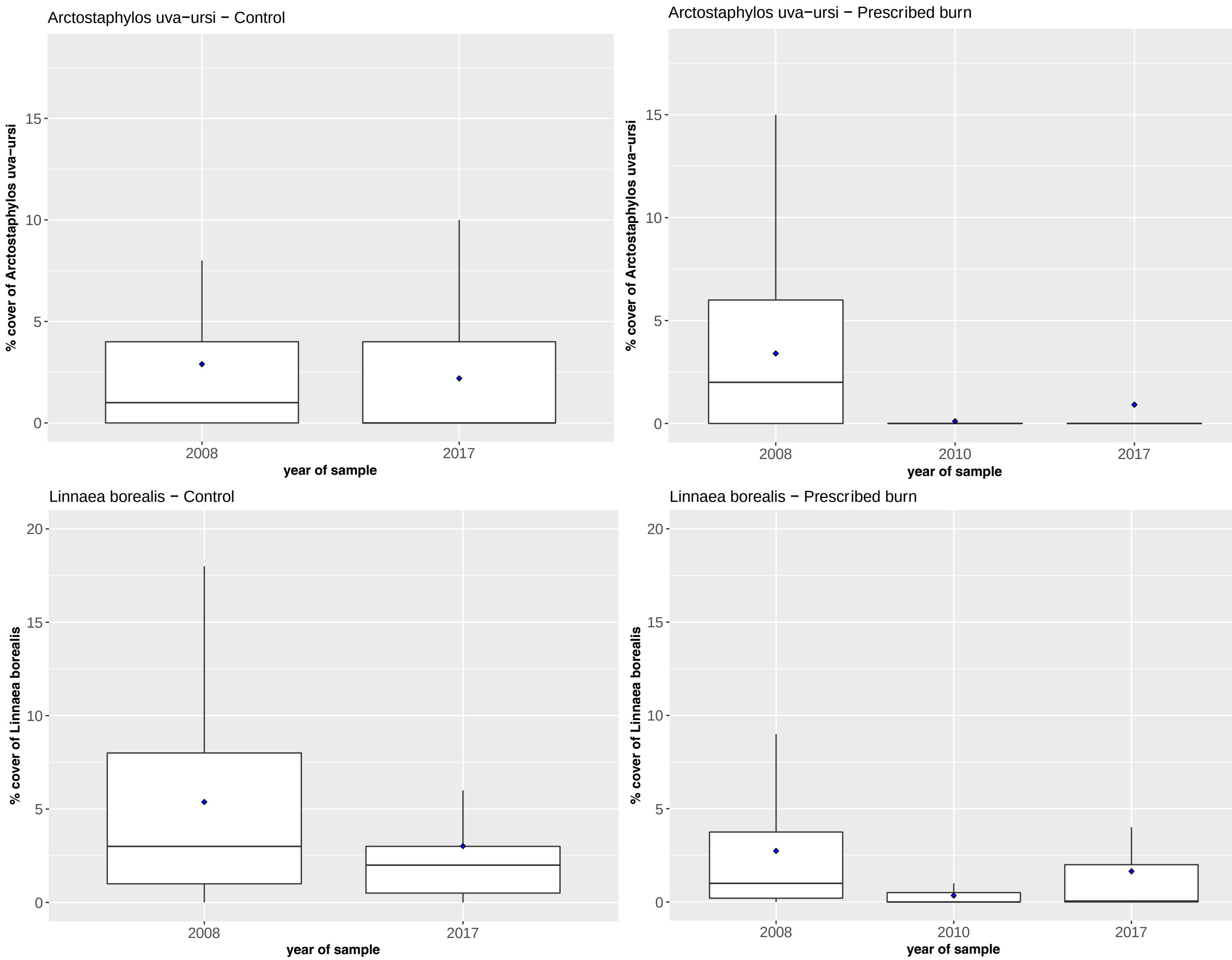


Figure 13. Responses of *Arctostaphylos uva-ursi* (top) and *Linnaea borealis* (bottom) at the Laidman Lake site in control & prescribed burn plots. The x-axis shows the year of data collection. See caption for Figure 10 for details on interpreting the boxplots and symbols.

The decline in kinnikinnick cover following the prescribed burn is consistent with a decline in kinnikinnick cover following the 2004 Blanchet wildfire in the northern portion of the winter range (Cichowski and Haeussler, *in prep*.b). However, the response of twinflower at the Laidman Lake prescribed burn differs from that observed in the Blanchet fire where twinflower cover increased initially then decreased, with an overall effect of an increase in cover by 13 years post-fire, compared to cover before fire (Cichowski and Haeussler, *in prep*.b). Tree knockdown prior to the Laidman Lake prescribed fire may have contributed to a higher intensity burn than at the Blanchet fire, which may have resulted in a greater impact on twinflower.

Several species initially decreased following the burn, but then increased to pre-burn or higher levels by 2017 including willow (*Salix* sp.), soopollalie, spikelike goldenrod (*Solidago spathulata*), bunchberry (*Cornus canadensis*) and dwarf blueberry (Table 5, Figures 14 &15).

Although grasses and sedges were not abundant before the prescribed burn, two additional species (*Calamagrostis canadensis, Carex* spp) invaded following the burn, and all species of graminoids increased immediately after the fire and continued to increase until 2017 (Table 5, Figure 15). Fireweed (*Epilobium angustifolium*) also increased following the prescribed burn (p=0.002).

The prescribed burn resulted in an increase in exposed soil immediately after the burn, which continued into 2017 (Table 6). The increase in CWD in quadrats after the prescribed burn was due to the tree knockdown since quadrats were assessed before tree knockdown. Although litter was similar before and immediately after the burn, by 2017, litter had decreased below pre-burn levels (p<0.001). The combination of increased soil exposure and reduced litter provides good conditions for lichen recolonization.

Table 6. Amount of substrate type in quadrats prior to and following prescribed fire at prescribed fire and control plots at the Laidman Lake prescribed burn site. Values are presented as the mean ± the standard error.

	Percent cover		
Substrate type	**Pre-burn (2008)**	**Post-burn (2010)**	**Post-burn (2017)**
Prescribed burn			
Soil	0	48.58±4.62	34.14±3.82
Rock	0.08±0.08	0.86±0.56	1.81±0.56
Coarse Woody Debris	0.69±0.34	9.64±1.70	10.19±1.66
Litter	31.53±2.92	36.89±4.54	19.25±1.48
Control			
Soil	0	-	0.1±0.1
Rock	0	-	0
Coarse Woody Debris	1.63±0.71	-	4.90±2.14
Litter	24.13±2.55	-	20.43±2.13

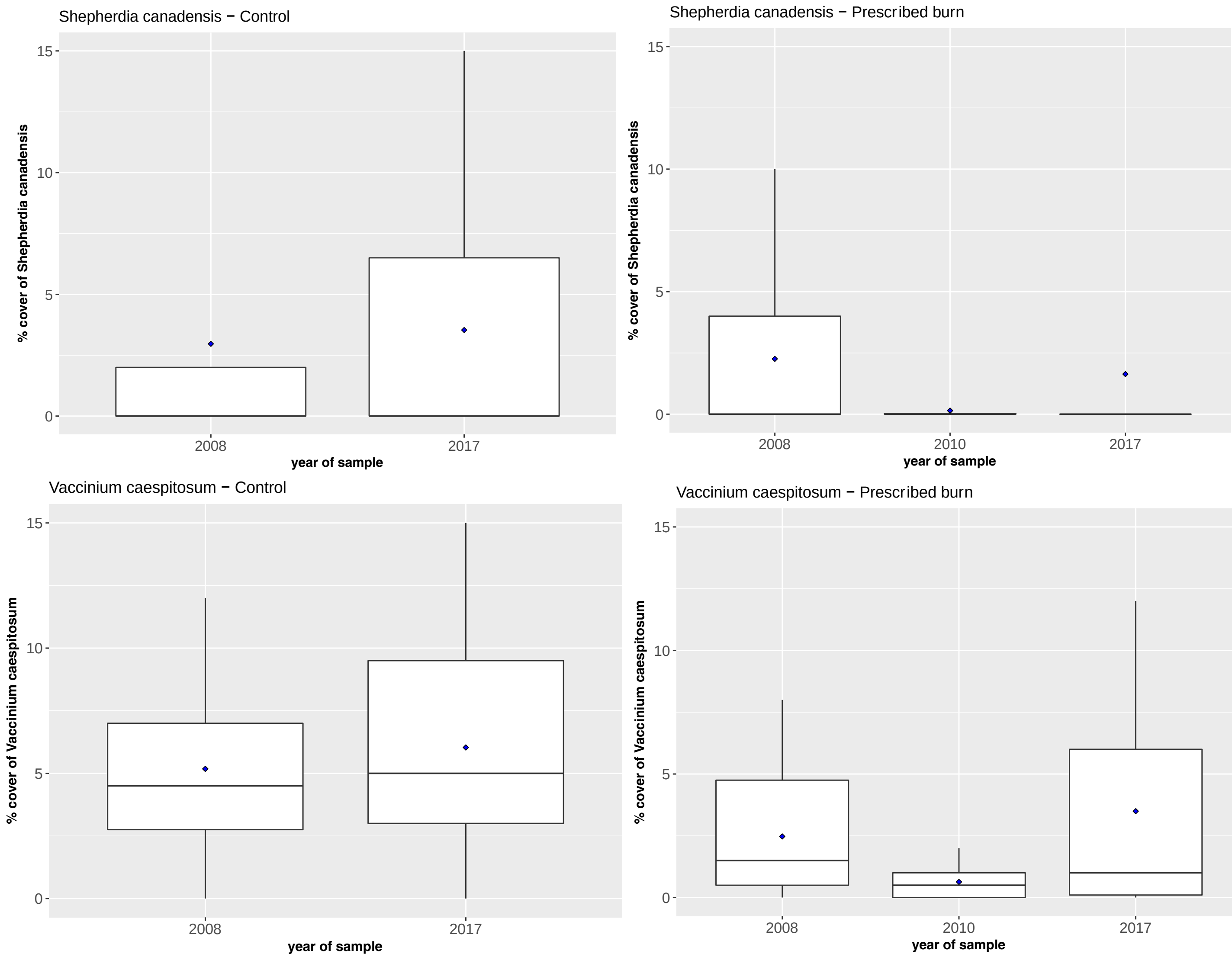


Figure 14. Responses of *Shepherdia canadensis* (top) and *Vaccinium caespitosum* (bottom) at the Laidman Lake site in control & prescribed burn plots. The x-axis shows the year of data collection. See caption for Figure 10 for details on interpreting the boxplots and symbols.

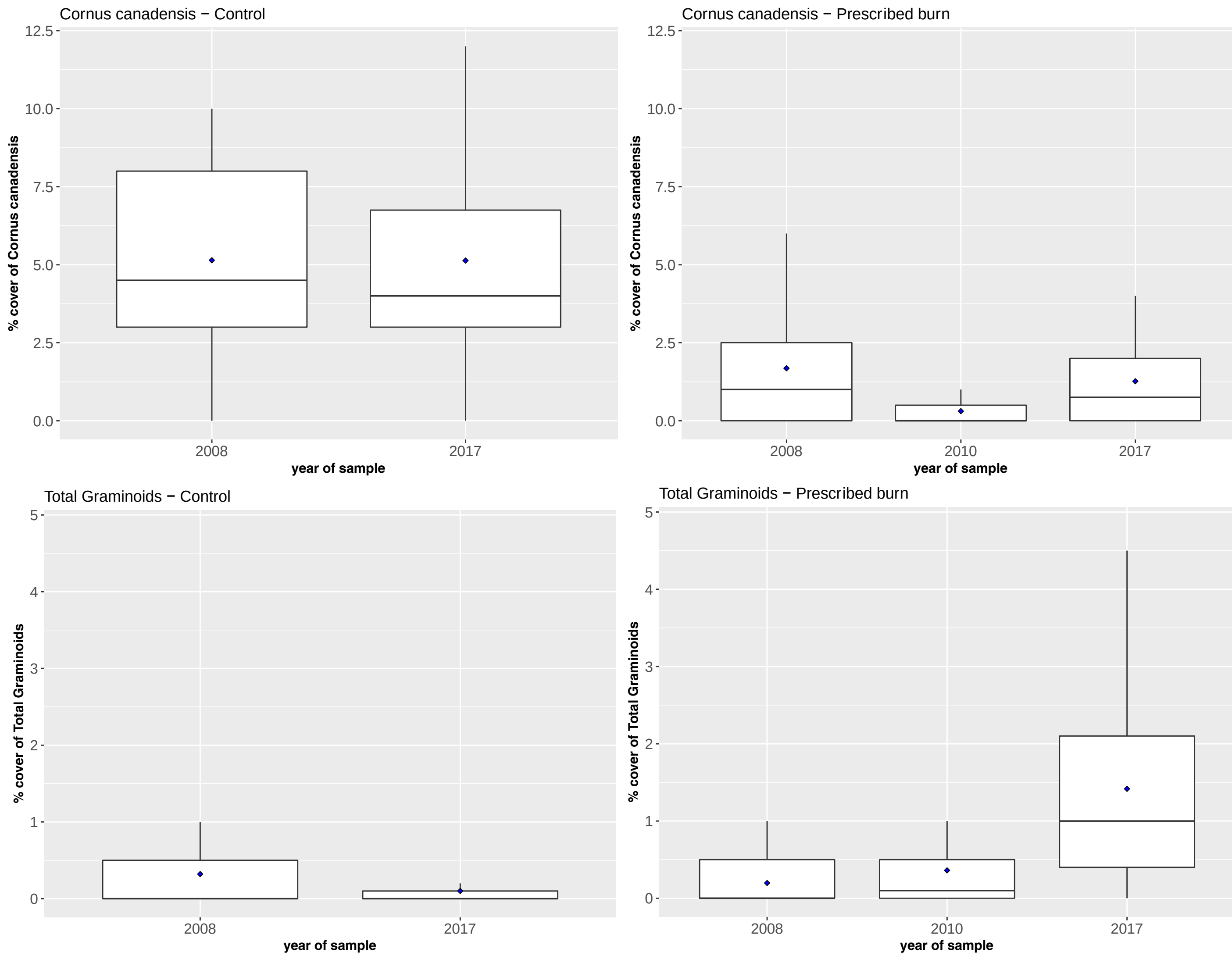


Figure 15. Responses of *Cornus canadensis* (top) and total graminoids (bottom) at the Laidman Lake site in control & prescribed burn plots. The x-axis shows the year of data collection. See caption for Figure 10 for details on interpreting the boxplots and symbols.

SUMMARY - EFFECTS OF PRESCRIBED FIRE ON CARIBOU WINTER RANGE

The Laidman Lake prescribed burn was successful in increasing the amount of exposed soil for lichen recolonization, reducing the abundance of kinnikinnick and twinflower (two main dwarf shrub competitors that increase following mountain pine beetle disturbance), and eliminating red-stemmed feathermoss, which outcompetes terrestrial lichens in later stages of succession. Eight years following the prescribed burn, we are starting to see some re-colonization of the site by foliose lichens, but have not yet detected any of the primary forage lichens from the *Cladina* or *Cladonia* genera. The lack of colonization by caribou forage lichens soon after fire is consistent with the general pattern of lichen colonization and succession in boreal forests, where *Cladonia* species start becoming abundant 10-30 years following fire and *Cladina* species start becoming abundant 30-50 years following fire (Ahti 1977).

Results from the Laidman Lake prescribed burn suggest that the combination of tree knockdown and subsequent prescribed burning is an effective tool in the short term for reducing dwarf shrubs and mosses that can outcompete terrestrial forage lichens on some site types, and in post-mountain pine beetle-killed forests. Tree knockdown prior to the prescribed burn ensures a high intensity fire that kills vegetation and exposes soils, and that reduces potential future impediments to caribou movement caused by fallen dead trees.

The current size and density of regeneration on the prescribed burn site also likely provides favourable conditions for terrestrial lichen colonization and growth. However, the dominant regenerating species, trembling aspen, is a winter forage species for moose (*Alces americanus*), which is the primary prey species for wolves (*Canis lupus*) in this area. Increasing winter habitat potential for moose could result in increased numbers of moose, which could support higher wolf numbers, which in turn results in increased predation risk for caribou (Festa-Bianchet et al. 2011). It is unknown whether the aspen-dominated regeneration is a response to fire, or whether there is a broader ecosystem-level response to disturbance in the area since high levels of aspen regeneration were also observed in some of the plots in the adaptive management forest harvesting trials at the nearby Malaput site (Cichowski et al., *in prep*.). Aspen regeneration was not present in the Blanchet fire by 13 years post-fire, but was present in the Van Tine fire within 11 years post-fire (Cichowski and Haeussler, *in prep*.b). In the Van Tine fire, lodgepole pine was the dominant regeneration species in most plots, except in four plots in one area of the burn where aspen was dominant (Cichowski and Haeussler *in prep*.b).

We recommend conducting the next sampling session in five years (2022) to assess vegetation and regeneration conditions.

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APPENDIX 1. RANDOM BEARINGS AND DISTANCES, AND TAG NUMBERS FOR QUADRATS

Treatment	Stratum	Plot	Original Centre Tag	Original Quadrat tag	Post-burn Centre Tag	Post-burn Quadrat tag	Bearing	Distance (m)
Control	1	1	147	141	-	-	26	15.4
				142		-	91	8.9
				143		-	164	4
				144		-	189	12.7
				145		-	272	2
				146		-	337	6.7
Control	1	2	154	148	-	-	21	11.1
				149		-	111	8.3
				150		-	173	11.3
				151		-	188	16.8
				152		-	258	2.3
				153		-	355	8.5
Control	1	3	161	155	-	-	17	12.4
				156		-	90	11.7
				157		-	149	17.5
				158		-	219	11.1
				159		-	279	6.7
				160		-	340	13.5
Control	1	4	168	162	-	-	23	8.5
				163		-	92	19.9
				164		-	164	11.1
				165		-	205	13
				166		-	274	15.4
				167		-	348	11.6
Control	1	5	175	169	-	-	44	14.9
				170		-	115	13
				171		-	140	8.4
				172		-	185	2
				173		-	295	18.8
				174		-	337	5.2
Prescribed burn	2	1	130	126	926	928	95	7
				127		929	220	13.9
				128		930	325	6.8
				129		927	1	15.9
Prescribed burn	2	2	135	131	921	922	89	4.9
				132		923	144	16.7
				133		924	246	6.4
				134		925	337	1.2
Prescribed burn	2	3	125	121	931	932	33	11.1
				122		933	92	7.5
				123		934	215	13.6

Treatment	Stratum	Plot	Original Centre Tag	Original Quadrat tag	Post-burn Centre Tag	Post-burn Quadrat tag	Bearing	Distance (m)
				124		935	324	16.7
Prescribed burn	2	4	140	136	916	917	74	19.3
				137		918	106	2.8
				138		919	190	19.9
				139		920	300	13.4
Prescribed burn	3	5	180	176	911	912	33	11.1
				177		913	92	7.5
				178		914	263	3.8
				179		915	283	9.7
Prescribed burn	2	6	120	116	936	937	12	17.5
				117		938	141	7.7
				118		939	195	7.9
				119		940	335	19.5
Prescribed burn	2	7	115	111	941	942	32	4.4
				112		943	142	11.9
				113		944	183	3.7
				114		945	320	6.8
Prescribed burn	3	8	110	106	906	907	37	17
				107		908	156	17.2
				108		909	223	4
				109		910	325	7.2
Prescribed burn	3	9	105	101	901	902	1	15.9
				102		903	91	13
				103		904	246	6.4
				104		905	336	12.6