RED HILLS PRESCRIBED FIRE: EIGHT YEARS POST-BURN VEGETATION MONITORING

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Executive Summary

In 2008 a prescribed burn was carried out to reduce tree encroachment, manly aspen but also pine and spruce, on the red-listed Saskatoon / slender wheatgrass (*Amelanchier alnifolia / Elymus trachycaulus*) shrub/steppe ecosystem in the Red Hills portion of Uncha Mountain Red Hills Provincial Park. Monitoring included transects, quadrats and circular plots to record the condition of the vegetation before the burn (2007), and the subsequent response to the burn (2008 and 2016).

There was a wide range of responses to the burn by different components of the vegetation. Some herb species, notably grasses, increased their cover in response to fire. Some species, notably rose, spirea, peavine and forbs, were resistant to the burn, in that their behaviour paralleled the unburnt vegetation. Other species, notably broad-leaved trees, shrubs, Saskatoon and kinnikinnick, were resistant to the burn, in that their cover initially decreased but has subsequently recovered. Finally some species, mainly conifers and aspen, were not resilient to the burn and their cover has not recovered.

Aspen tree death increased with increasing fire severity. Aspen sucker density initially increased with increasing fire severity; this difference was gone by 2016. The number of aspen suckers had also decreased from approximately 130,000/ha in 2008 to 12,000/ha in 2016. Sucker height also increased to approximately 2 m on low severity sites to 2.7 m on high severity sites.

The reduction on tree cover and the increase in forb and grass cover indicate the project has made progress towards the goal of reducing the woody plant species cover, especially aspen, and increasing the cover of forbs and graminoids. Consistent with the original vegetation prescription, we recommend that the area be reburnt in the next few years to kill the aspen suckers.

Acknowledgements

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1.0 Introduction

Aspen (*Populus tremuloides*) trees have been observed as encroaching on non-forested vegetation types in numerous areas in northwestern BC (Haeussler 1998, Veenstra and McLennan 2002). This commonly occurs in the Saskatoon / slender wheatgrass (*Amelanchier alnifolia / Elymus trachycaulus*) shrub/steppe (SBSdk/81) ecosystem, which is a red-listed ecological community in BC (CDC 2016). Within Uncha Mountain Red Hills Provincial Park the encroachment of aspen on the Saskatoon / slender wheatgrass shrub/steppe ecosystem was recognised as an issue in the Lakes District Land and Resources Management Plan (LRMP) (Government of British Columbia 2000) and the Uncha Mountain Red Hills Management Direction Statement (MDS) (Ministry of Water, Land and Air Protection 2003).

As a result of the direction in the LRMP and MDS, a vegetation management plan for the park was developed (de Groot and Armitage 2007), the grasslands and shrub/steppe ecosystems in the park were described, a restoration and burn plan were written, and pre-burn vegetation conditions were described (Helkenberg and Haeussler 2008, de Groot 2008), and a prescribed fire was completed along with initial monitoring of post-burn vegetation conditions (de Groot and Haeussler 2008). Since 2008 there has not been any monitoring of the burn. The purpose of this project was to revisit the burn site and remeasure the monitoring plots to determine the effectiveness of the prescribed fire.

The objectives of the fire were:

1) To reduce the cover of woody plant species, especially aspen, and increase the cover of forbs and graminoids.
2) To assess the effectiveness of burning as a treatment for controlling aspen encroachment on SBSdk/81 shrub/steppe.

2.0 Methods

2.1 Field Methods

A one half hectare survey area with 5 100 m line intercept vegetation monitoring transects and 50 Daubenmire quadrats (20 cm x 50 cm) was established in 2007 before the burn following standard methods used for grassland vegetation monitoring in BC (Gayton 2003). Pre-burn vegetation was recorded August 14-18, 2007 (de Groot 2008, Helkenberg and Haeussler 2008).

The prescribed fire was carried out on May 9th, 2008 by staff of the Nadina Fire Zone of the B.C. Ministry of Forests and Range Northwest Fire Centre. The burn followed the vegetation management prescription and prescribed fire burn plan for the area (de Groot 2008). The ground layout of the burn closely followed the mapped target area (Figure 1). The fire was contained entirely within the target area as laid out on the ground. The east half of the monitoring plot is within the area targeted for burning and the west half is in the unburnt control. The burn was patchy with unburnt areas creating a mosaic effect over the burn area. Fire intensity was variable, ranging from severely burnt where there was heavier fuel loading to lightly scorched in areas with few fuels.

On May 12th, 2008, three days after the burn, post-fire burn impact monitoring was initiated (Table 1). This consisted of recording fire intensity in each of the Daubenmire quadrats and along the transects established in 2007 and taking photos inward along each of the transects.

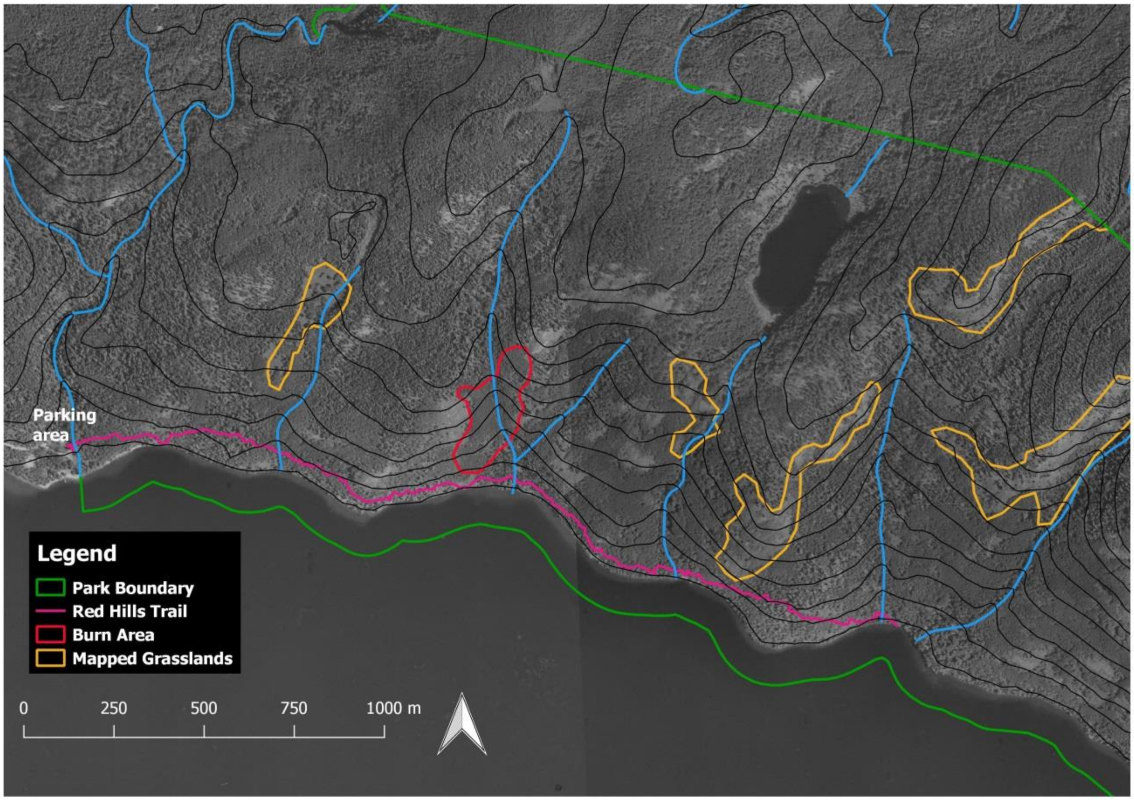

Figure 1. Location of burn within Red Hills[1]

Table 1. Project timeline

Date	Activity
August 14 – 18, 2007	Transects and Daubenmire quadrats established and initial measurements completed
May 9, 2008	Prescribed burn carried out
May 12, 2008	Post-burn fire intensity recorded in Daubenmire quadrats and along transects, and aspen plots established
July 17, 2008	Initial post-burn recording of aspen mortality and sucker density
July 29 – 31, 2008	Initial post-burn remeasurement of Daubenmire quadrats and transects
Sept 1, 2 and 5, 2016	Remeasurement of Daubenmire quadrats, transects and aspen plots

Three classes of fire severity as modified from Wang (2003) were used to describe the impact of fire on the vegetation (depth of burn): Low (litter unburnt or lightly scorched); Medium (litter burnt but without or with very limited duff consumption); and High (forest floor completely consumed and possible consumption of organic matter in the Ah horizon)[2]. This fire classification was relative to conditions found within the burn area. As this was a spring burn, shortly after snowmelt, the duff layers had not dried out. Thus, the High severity class does not imply an extremely hot fire that would cause soil degradation such as might occur in late summer after a prolonged dry period.

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[1] The mapped grasslands were identified as Open Range in the Vegetation Resources Inventory (VRI) (Grassland Conservation Council of BC 2004, de Groot and Armitage 2007)

[2] Wang (2003) and de Groot and Haeussler (2008) referred to the three burn severity classes as Scorched, Light, and Severe. These have been changed to Low, Medium and High to be more intuitive.

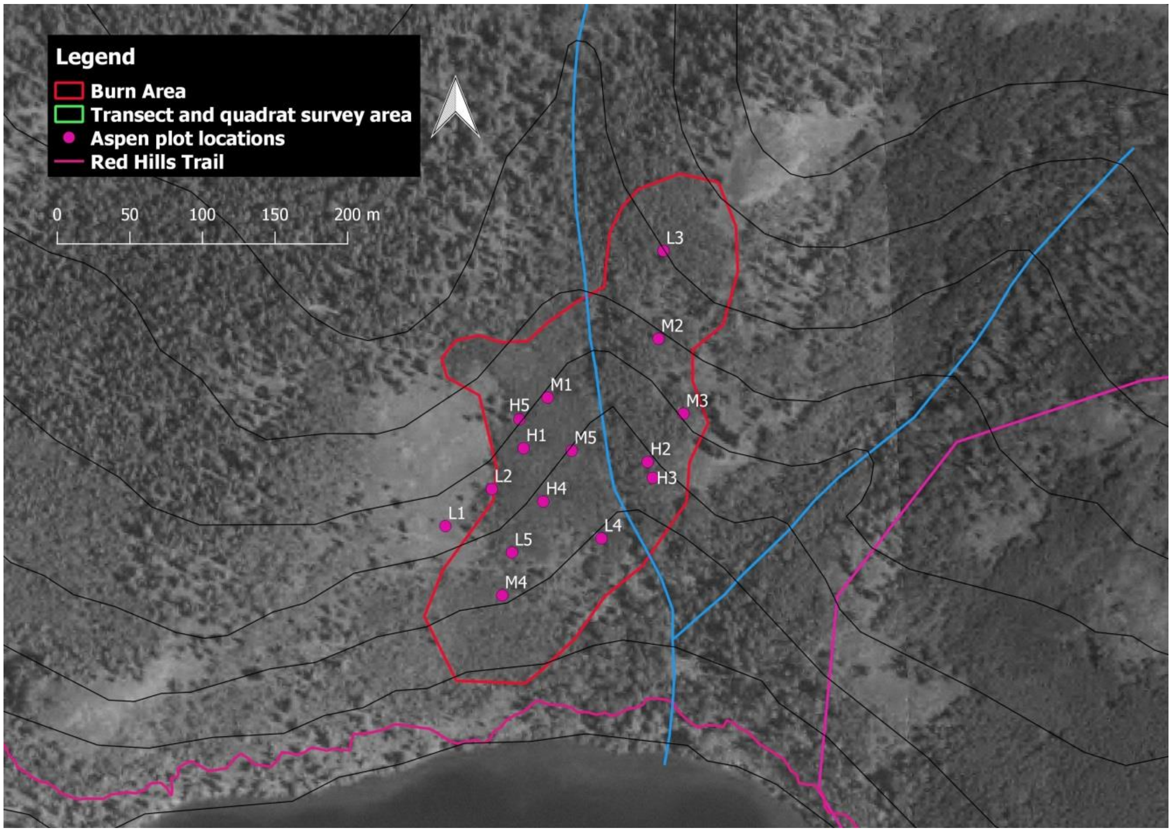

Figure 2. Location of monitoring plots

At this time 15 aspen monitoring plots were also subjectively located (Figure 2, Appendix 1). Five plots were situated in Low, five in Medium and five in High severity burn areas. In each aspen monitoring plot, the ten trees closest to plot centre were marked with numbered aluminium tags and diameter at breast height (DBH) was measured. Live aspen suckers were counted within a 1.78 m radius (1:1000th of a hectare) plot at plot centre. There were no live suckers in any of the plots in May, 2008. These plots were revisited to record aspen tree mortality, sucker production, sucker height and Venturia infection severity (aspen and poplar leaf and shoot blight (*Venturia macularis*)) on July 17, 2008 and Sept 1-5, 2016. Tree and sucker vigour was measured following the classes given in Appendix 1, and the height of the tallest aspen sucker per plot was recorded.

The vegetation along the transects and in the quadrats was remeasured July 29 to 31, 2008 and again Sept 1-5, 2016, following the methods used in de Groot (2008) and Veenstra and Haeussler (2002).

2.2 Data Analysis

Ground cover types and plant species abundances and (mean % cover) were first determined separately for the unburnt and burnt sectors of each line intercept transect and for unburnt and burnt Daubenmire quadrats in each year (2007, 2008, 2016). The mean change in percent cover from 2007 to 2008, from 2008 to 2016 and from 2007 to 2016 (overall) was then calculated for each ground cover type and for each plant species.

For statistical modelling of vegetation layers and major plant species, we pooled the line intercept and Daubenmire data for the unburnt and burnt sectors of each transect (n = 10 observations per year). For trembling aspen, we used line transect data only; for other woody species we took the mean of the transect and Daubenmire plot data.

We used linear mixed effects modelling with maximum likelihood estimation with the lme function in R (Bates 2005; Pinheiro and Bates 2006) to test a set of alternative hypotheses (Ho, Ha) about the response of shrub-steppe vegetation at Red Hills to the prescribed fire. The vegetation response variables included percent cover of 5 vegetation layers or groups (broadleaves trees & shrubs, conifers, herbs, forbs, grasses) and 6 major plant species (trembling aspen, Saskatoon, prickly rose, kinnikinnick, birch-leaved spirea, peavine), and three indices of species diversity (species richness, Shannon's H', Simpson's D). We also used the Axis 1 value from an NMS ordination of the total plant community as a general index of community response. The NMS ordination and calculation of Shannon's and Simpsons indices was done with PC-ORD version 4.25 (McCune and Mefford 1999).

The model framework had 3 components or sets of hypotheses:

A. Site sensitivity: Were unburnt (U) and burnt (B) vegetation communities initially different? Ho: $U_0 = B_0$; Ha: $U_0 \neq B_0$
B. Background trend: Did the unburnt community (control) change from 2007 to 2016? Ho: $U_0 = U_1 = U_9$; Ha_1: directional change (linear); Ha_2: fluctuating (quadratic = 2^{nd} order polynomial)
C. Resilience: Did the burnt community resist, recover or change relative to the unburnt community? Ho (resistant): $B_0 = B_1 = B_9$; Ha_1 (resilient): $B_0 = B_9 \neq B_1$; Ha_2 (not resilient or adaptive): $B_0 \neq B_1 \neq B_9$.

A suite of 18 alternative models (Table 2) incorporated linear combinations of these hypotheses. Parameters a_B, b_B, and c_B were all equal to 0 in unburnt areas. The variable t represented the number of years since disturbance with the pre-burn year, 2007, set at 0. Thus, parameter a, represented the pre-burn condition (i.e., the intercept) for unburnt control areas, and a + a_B represented the pre-burn condition (intercept) for burnt areas. Also, b and ($b+b_B$) represented the slope of the line, c and ($c + c_B$) represented the amount of curvature for unburnt and burnt areas, respectively.

Table 2. Suite of alternative models for Red Hills vegetation response to prescribed fire.

Model #	Description of Model Components	Formula
1	Null model: site insensitive; no background trend; resistant	$Y = a$
2	Site sensitive; no background trend; resistant	$Y = a + a_B$
3	Site insensitive; directional background; resistant	$Y = a + bt$
4	Site insensitive, fluctuating background; resistant	$Y = a + bt + ct^2$
5	Site sensitive, directional background; resistant	$Y = a + a_B + bt$
6	Site sensitive; fluctuating background; resistant	$Y = a + a_B + bt + ct^2$
7	Site insensitive; no background; resilient	$Y = a + b_Bt + c_Bt^2$
8	Site sensitive; no background; resilient	$Y = a + a_B + b_Bt + c_Bt^2$
9	Site insensitive; directional background; resilient	$Y = a + (b + b_B)t + c_Bt^2$
10	Site insensitive; fluctuating background; resilient	$Y = a + (b + b_B)t + (c + c_B)t^2$
11	Site sensitive; directional background; resilient	$Y = a + a_B + (b + b_B)t + c_Bt^2$
12	Site sensitive; fluctuating background; resilient	$Y = a + a_B + (b +b_B)t + c+ c_B)t^2$
13	Site insensitive; no background; not resilient/adaptive[1]	$Y = a + b_Bt$
14	Site sensitive; no background; not resilient/adaptive	$Y = a + b_Bt$
15	Site insensitive; directional background; not resilient/adaptive	$Y = a + (b + b_B)t$
16	Site insensitive; fluctuating background; not resilient/adaptive	$Y = a + (b + b_B)t + ct^2$
17	Site sensitive; directional background; not resilient/adaptive	$Y = a + a_B + (b + b_B)t$
18	Site sensitive; fluctuating background; not resilient/adaptive	$Y = a + a_B + (b + b_B)t + ct^2$

1- the response is considered "not resilient" when $b_B<0$ (decreasing veg. cover) and "adaptive" when $b_B>0$ (increasing veg. cover).

We tested this suite of models on the percent cover of 5 vegetation layers or groups (broadleaved trees & shrubs; conifers, herbs, forbs, graminoids) and 6 major plant species (trembling aspen, Saskatoon, prickly rose, kinnikinnick, birch-leaved spirea, peavine). We used the same suite of models to examine the response of three indices of species diversity: species richness (mean number of species per Daubenmire plot); Shannon's diversity index (*H'*) which measures both richness and evenness; and Simpson's diversity index (*D)* which mainly measures the degree of dominance.

To structure our linear mixed model we nested the repeated observations (2007, 2008, 2016), within the burnt and unburnt sectors in each of 5 transects and varied the fixed effects for each alternative hypothesis, as follows:

Model 1 <- lme (Y ~ 1, random = ~1|transect/sector/year), where 1 = common intercept;

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Model 12 <- lme(Y~*burn* + *time* + b*t* +*t*2 + b*t*2, random = ~1|transect/sector/year), where *burn* is a dummy variable (0 = unburnt; 1 =burnt; *time* = 0, 1, 9, for 2007, 2008, 2016, respectively; b*t* = *burn***time*; *t*2 = *time***time*; b*t*2 = *burn***time***time*;

etc.

We selected the model with the lowest Akike Information Criterion (AIC) except in cases where the residuals were badly skewed and an alternative model could be found with only slightly higher AIC but less skewed residuals and a lower residual mean squared error (RMSE).

We also used mixed effects models with maximum likelihood estimation to test for differences in trembling aspen survival and regrowth on the 15 aspen plots. For aspen vigour, Venturia blight severity, aspen sucker density and height of the tallest aspen sucker per plot, the model structure included three 3 burn severities (low, medium, high; no unburnt control), randomly applied to plots, and two post-burn observations for each plot. The alternative models tested for differences between 2008 and 2016, for linear and non-linear effects of increasing burn severity, and for interactions between burn severity and time. The full model was specified as:

Full model: lme(Y ~ *sev* + *s*2 + *t* + *ts* + *ts*2, random ~1|plot/year), where *sev* = 0, 1, 2, *t* = 0, 1 (for 2008 and 2016), *s*2 = *sev***sev*, *ts* = *t***sev*, and *ts*2 = *time***sev***sev*.

These variables were not transformed prior to analysis.

For % dead and % dead+dying aspen overstory trees we fitted logistic mixed effects models using the glmer function in the lme4 package in R (Bates *et al*. 2016). The logistic model was needed because aspen mortality in 2016 was near 100% and these values could not be normalized. This model used a binomial distribution to predict the probability that each tagged aspen tree was alive (0), dead or dead/dying (1) in each year across the three burn severity classes. The dataset had 150 observations (10 trees x 15 plots in 2008 and 140 observations (10 trees x 14 plots, 1 plot missing) in 2016. The model structure was similar to the other aspen variables except for its random effects:

Full model: glmer(Y ~ *sev* + *s*2 + *t* + *ts* + *ts*2 + (1|plot/tree/year), where *sev* = 0, 1, 2, *t* = 0, 1 (for 2008 and 2016), *s*2 = *sev***sev*, *ts* = *t***sev*, and *ts*2 = *time***sev***sev*.

We tested the complete suite of simple to full models for each aspen variable and selected the model with the lowest AIC. For % dead and % dead + dying, we also tested whether inclusion of the plot soil moisture regime, or splitting burn severity into 2 classes (L+M, H and L, M+H) rather than three, improved the model (neither did).

3.0 Results

3.1 Transect and Quadrat Survey Area (2007 – 2016)

In the Daubenmire quadrats, Saskatoon had the greatest increase in cover in both burnt and unburnt areas (Table 3). Kinnikinnick had the second greatest increase in the burnt quadrats, while yarrow had the second greatest increase in unburnt quadrats. Common juniper and prickly rose had the greatest decrease in cover in the burnt quadrats, while kinnikinnick and spreading dogbane had the great decrease in the unburnt quadrats.

Table 3. Change in % cover in Daubenmire quadrats

Ground cover type		Burnt			Unburnt		
		Average change in % cover of plant species in Daubenmire quadrats					
		2007 to 2008	2008 to 2016	Overall	2007 to 2008	2008 to 2016	Overall
Soil		2.3	-1.4	0.9	2.5	-1.6	0.9
Rock		2.2	-1.7	0.5	2.5	-2.4	0.1
Coarse Woody Debris		-3.6	8.0	4.5	-1.6	1.1	-0.6
Fine Woody Debris		1.9	2.0	4.0	0.4	1.4	1.9
Litter[1]		-2.3			-4.3		
Exposed roots		0.2	-0.2	0.0	0.0	0.0	0.0
1 – litter data was collected differently in 2016 than in in 2007 and 2008 and is not directly comparable so is not shown							
Plant species							
American vetch	*Vicia americana*	1.0	-1.0	0.0	0.1	-0.1	0.0
Arctic aster	*Aster sibiricus*				0.0	0.4	0.4
Bicknell's geranium	*Geranium bicknellii*	0.2	0.3	0.5	0.0	0.1	0.1
birch-leaved spirea	*Spiraea betulifolia*	1.9	-3.8	-1.9	1.0	-1.5	-0.5
blue clematis	*Clematis occidentalis*	-0.4	2.0	1.5			
Canada violet	*Viola canadensis*				0.0	0.0	0.0
choke cherry	*Prunus virginiana*				0.2	-0.2	0.1
Cladonia	*Cladonia* spp.	0.0	0.0	0.0	0.1	-0.2	0.0
common juniper	*Juniperus communis*	-4.3	0.0	-4.3	0.0	0.0	0.0
common red paintbrush	*Castilleja miniata*	0.0	0.3	0.3			
cow-wheat	*Melampyrum lineare*				0.2	-0.2	0.0
creeping juniper	*Juniperus horizontalis*	-1.4	-1.4	-2.9			
cut-leaf anemone	*Anemone multifida*	-0.2	-0.1	-0.4	0.0	0.2	0.2
early blue violet	*Viola adunca*	-0.1	0.0	-0.2	0.1	0.0	0.0
false Solomon's-seal	*Smilacina racemosa*	-0.5	0.0	-0.6			
felt pelt	*Peltigera canina*	-0.2	0.0	-0.2	0.0	-0.1	-0.1
fringed aster	*Aster ciliolatus*	0.6	0.0	0.6	0.0	0.6	0.6
fringed brome	*Bromus ciliatus*	0.1	-0.1	-0.1	0.0	-0.1	0.0

Table 3 con't. Change in % cover in Daubenmire quadrats

Plant species		Burnt			Unburnt		
		Average change in % cover of plant species in Daubenmire quadrats					
		2007 to 2008	2008 to 2016	Overall	2007 to 2008	2008 to 2016	Overall
heart-leaved arnica	*Arnica cordifolia*	-0.1	0.0	-0.1	0.1	-0.1	0.0
Kentucky bluegrass	*Poa pratensis*				0.0	0.0	0.0
kinnikinnick	*Arctostaphylos uva-ursi*	-6.4	14.4	8.0	-5.3	2.4	-2.9
Knight's plume	*Ptilium crista-castrensis*	0.0	0.0	0.0			
mountain arnica	*Arnica latifolia*	-0.2	0.0	-0.3			
narrow-leaved hawkweed	*Hieracium umbellatum*	-0.2	-0.1	-0.3			
northern bedstraw	*Galium boreale*	1.0	-0.1	0.9	0.3	-0.3	0.0
one-sided wintergreen	*Orthilia secunda*	0.0	0.2	0.2			
peavine	*Lathyrus* spp.	7.5	-8.5	-1.0	3.0	-4.2	-1.1
prickly rose	*Rosa acicularis*	-2.8	-0.7	-3.5	-0.5	0.0	-0.4
ragged moss	*Brachythecium* spp.	-0.1	-0.1	-0.3	-0.1	-0.2	-0.4
Rocky mountain fescue	*Festuca saximontana*	0.0	0.0	0.0	0.4	-0.5	0.0
Ross' sedge	*Carex rossii*	0.0	0.0	0.0	0.1	-0.1	0.0
rough-fruited fairybells	*Disporum trachycarpum*	-0.4	0.5	0.1	0.1	0.4	0.5
rough-leaved ricegrass	*Oryzopsis asperifolia*	0.0	0.2	0.2	0.0	0.0	0.1
Saskatoon	*Amelanchier alnifolia*	0.0	18.4	18.4	2.6	5.2	7.8
short-awned ricegrass	*Oryzopsis pungens*	0.3	0.7	1.0	0.1	1.0	1.1
showy aster	*Aster conspicuus*	0.3	2.2	2.5	1.6	-1.6	0.1
slender wheatgrass	*Elymus trachycaulus*	0.1	2.2	2.4	-0.5	0.0	-0.5
snowberry	*Symphoricarpos albus*	0.0	0.8	0.8	0.2	0.2	0.3
spreading dogbane	*Apocynum androsaemifolium*	2.3	n/a	n/a	1.4	-3.9	-2.5
trembling aspen	*Populus tremuloides*	3.8	-0.8	3.0	1.1	-2.7	-1.6
twinflower	*Linnaea borealis*	0.2	0.7	0.9			
western fescue	*Festuca occidentalis*	0.0	0.0	0.0	0.0	0.0	0.0
western meadowrue	*Thalictrum occidentale*	-1.0	-0.6	-1.6	0.0	0.0	-0.1
wild sarsaparilla	*Aralia nudicaulis*				0.3	-0.3	0.0
wild strawberry	*Fragaria virginiana*	-0.2	0.6	0.5	-0.4	0.9	0.4
willow	*Salix* spp.	-1.0	0.0	-1.0			
yarrow	*Achillea millefolium*	0.2	-0.1	0.1	0.4	0.9	1.3
Species Richness per quadrat		-0.9	-0.8	-1.7	0.4	-2.7	-2.2

Along the transects, Saskatoon and kinnikinnick had the greatest increases in cover in both burnt and unburnt areas, while aspen had the greatest decrease in cover in both burnt and unburnt areas. Lodgepole pine had the second greatest decrease in burnt areas, and prickly rose had the second greatest decrease in unburnt areas (Table 4).

Table 4. Change in % cover of plant species along line intercept transects

Plant species		**Burnt**			**Unburnt**		
		Average change in % cover of plant species along transects					
		2007 to 2008	**2008 to 2016**	**Overall**	**2007 to 2008**	**2008 to 2016**	**Overall**
birch-leaved spirea	*Spirea betulifolia*	1.0	-1.5	-0.5	-1.3	0.1	-1.2
black twinberry	*Lonicera involucrata*				0.0	0.2	0.2
blue clematis	*Clematis occidentalis*	0.0	0.1	0.1			
choke cherry	*Prunus virginiana*				0.1	-0.1	0.0
common juniper	*Juniperus communis*	-3.2	0.0	-3.2	0.3	2.4	2.7
creeping juniper	*Juniperus horizontalis*	-0.3	-0.4	-0.7			
Engelmann spruce	*Picea engelmannii*	-0.5	-0.1	-0.7	-1.3	1.8	0.5
kinnikinnick	*Arctostaphylos uva-ursi*	-29.7	45.9	16.2	-50.0	53.6	3.6
lodgepole pine	*Pinus contorta*	-1.3	-8.4	-9.7	-2.2	2.6	0.4
paper birch	*Betula papyrifera*	-0.5	0.6	0.8	0.0	0.0	-0.2
prickly rose	*Rosa acicularis*	-5.2	1.6	-3.5	-2.9	0.5	-2.3
Saskatoon	*Amelanchier alnifolia*	-18.3	39.2	20.9	-6.8	14.5	7.6
snowberry	*Symphoricarpos albus*	-0.5	0.4	0.0	0.0	0.2	0.2
soopolallie	*Shepherdia canadensis*	0.2	-0.3	0.0	-0.1	0.4	0.4
trembling aspen	*Populus tremuloides*	0.0	0.0	-26.5	-5.4	-6.4	-11.8
willow	*Salix* spp.	-3.5	1.3	-2.2			

Figure 3. Overview of burn site before the burn in 2007 (top) and in 2016 (bottom).

Figure 4. View across burn area from the northeast

There were significant pre-burn differences in the vegetation of the unburnt and burnt areas (Table 5: site sensitivity). Unburnt areas had a lower cover of broad-leaved trees and tall shrubs (64% vs 90%, Figure 5a), notably trembling aspen (25% vs 36%, Figure 5f) and rose (4% vs 6%, Figure 5h) and a denser herb layer (Figure 5c), dominated by kinnikinnick (Figure 5i). There were also background changes in the unburnt plant community (Table 5: background trend), including decreases in aspen and spirea (Figure 5f,j), an increase in Saskatoon (Figure 5g) and fluctuations in the cover of forbs, notably peavine (Figure 5d,k). However, many of the key components of the vegetation such as the total cover of broadleaves, conifers, herbs (including grasses and kinnikinnick), did not change significantly over the 9 years of the study in unburnt areas.

Table 5. Best fitting models for response of Red Hills vegetation layers and major plant species to prescribed fire (2007 to 2016)

Layer or species	Scientific names	Best Fit	Site Sensitivity	Background Trend	Response to Fire	Transformation of Y^λ	Equation: (t = years since burn)
Broadleaved trees & shrubs	various	Model #8	yes	none	resilient	λ = 0.5 (square root)	Unburnt: Y = 8.0 Burnt: $Y = 9.5 - 2.2t + 0.24t^2$
Conifers	*Pinus contorta, Picea glauca, Juniperus* spp.	Model #13	no	none	not resilient	λ = 0.25	Unburnt: Y= 1.6 Burnt: $Y = 1.6 - 0.18t$
Herbs[1]	various	Model #14	yes	none	adaptive	λ = 0.5	Unburnt: Y = 7.7 Burnt: $Y = 5.5 + 0.17t$
Forbs	various	Model #4	no	fluctuating	resistant	λ = 0.5	$Y = 3.8 + 0.92t - 0.10t^2$
Grasses	Poaceae, Cyperaceae	Model #13	no	none	adaptive	λ = 0.4	Unburnt Y = 0.7 Burnt: $Y = 0.7 + 0.11t$
Aspen	*Populus tremuloides*	Model #17	yes	decreasing	not resilient	λ = 0.5	Unburnt: $Y = t$ Burnt: $Y = 6.0 - 0.3t$
Saskatoon	*Amelanchier alnifolia*	Model #9	no	increasing	resilient	λ = 0.5	Unburnt : $Y = 5.8 + 0.08t$ Burnt : $Y=5.8-2.5t+0.29t^2$
Rose	*Rosa acicularis*	Model #2	yes	none	resistant	λ = 0.5	Unburnt : Y = 2.06 Burnt : Y= 2.79
Kinnikinnick	*Arctostaphylos uva-ursi*	Model #8	yes	none	resilient	λ = 0.5	Unburnt : Y = 6.5 Burnt : $Y=4.4-2.9t+0.34t^2$
Spirea	*Spiraea betulifolia*	Model #3	no	decreasing	resistant	λ = 0.15	$Y = 1.14 - 0.016t$
Peavine	*Lathyrus* spp.	Model #4	no	fluctuating	resistant	λ = 0.5	$Y = 1.75 + 1.06t - 0.12t^2$

1-Herb layer includes forbs, grasses and dwarf woody species such as kinnikinnick

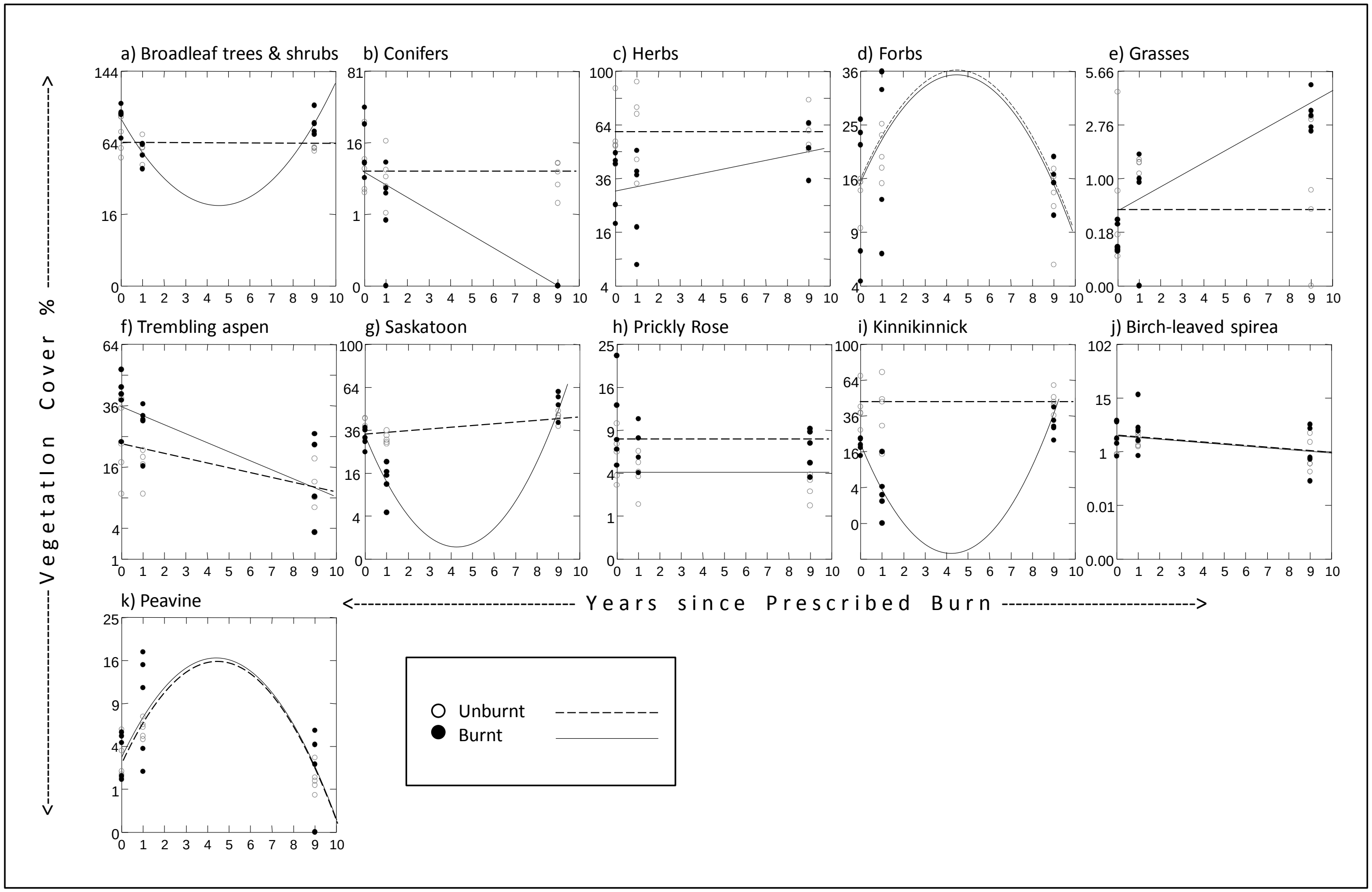

Figure 5. Best fitting models for the cover of vegetation layers and major plant species in unburnt and burnt areas from 2007 (0 = pre-burn) to 2016 (9 yrs post-burn). Refer to Table 1 for model details (n = 5 observations per treatment and year). Note that Y axes are non-linear due to normalizing transformations.

There was a wide range of responses to the prescribed burn by components of the plant community (Table 5: response to fire). Prickly rose, spirea, peavine and forbs, in general, were resistant to the burn (i.e., their behaviour paralleled that of the unburnt community; Figure 5h,d,j,k). Layers and species that were resilient to the burn (i.e., they decreased in 2008 but had recovered to pre-burn/control levels by 2016), included broadleaved trees and shrubs, Saskatoon and kinnikinnick (Figure 5a,g,i). Herbs, notably grasses, displayed a positive or adaptive response to fire (Figure 5c,e), increasing by 19 and 3 percent cover, respectively, from 2007 to 2016. Conifers (pine, spruce and junipers) and aspen were the only major taxa that proved to be not resilient to the burn. Conifers were completely dead on burnt plots by 2016, and aspen declined significantly more in burnt areas (27%) than in unburnt areas (16%).

Likewise, the three measures of species diversity also displayed a varied response to the environmental conditions of the study (Table 7). Simpson's index, which gives more weight to the dominant species, found no difference in diversity between unburnt and burnt areas either before or after the burn and no change in diversity over 9 years (Figure 6c). Species richness was also resistant to burning (Figure 6a). It was slightly higher initially in plots that did not burn (8 species vs. 7 species per plot in 2007) and decreased at approximately the same rate (0.2 species per year) in unburnt and burnt areas. This could well have been due to a sampling bias. Shannon's diversity, which gives more weight to rare species than Simpson's index, suggested that diversity was not resilient to burning. Burnt and unburnt plots had similar diversity initially but the burnt plots decreased in diversity between 2007 and 2016, whereas the unburnt plots did not. These findings suggest that some of the secondary species in the plant community may have diminished in importance as a result of the prescribed burn.

The model based on the first Axis of an NMS ordination of plant community composition (Appendix 2) indicated that overall, the vegetation community was resilient to the prescribed fire (Table 2). This axis accounted for 63% of total variation in species abundances. According to the NMS1 model (Fig. 2d), pre-burn community composition was essentially equivalent in the unburnt and burnt areas and there was a significant change in the unburnt community between 2007 and 2016. The composition of burnt areas changed substantially in 2008, but by 2016 was once again similar to that of the unburnt community.

Table 6. Best fitting models for indices of species diversity (species richness, Shannon's H', Simpson's D) and overall plant community composition (NMS1) at Red Hills (2007 – 2016).

Diversity index	Description	Best Fit	Site Sensitivity	Background Trend	Response to Fire	Transformation of Y	Equation: (*t* = years since burn)
Species Richness	number of species per Daubenmire quadrat	Model #5	yes	decreasing	resistant	none	Unburnt: Y = 8.25 – 0.19*t* Burnt: Y =7.42 – 0.19*t*
Shannon's H'	measures richness & evenness on transects & in Daubenmire quadrats	Model #13	yes	none	not resilient	none	Unburnt: Y = 2.60 Burnt: Y = 2.60 - 0.015*t*
Simpson's D	measures evenness (and richness) on transects & in Daubenmire quadrats	Model #1	no	none	resistant	none	Y = 0.90
NMS1	Position on the first axis of an NMS ordination of the whole plant community	Model #9	no	linear	resilient	none	Unburnt: Y = 0.11 – 0.08*t* Burnt: Y = 0.11 + 1.27*t* – 0.15t^2

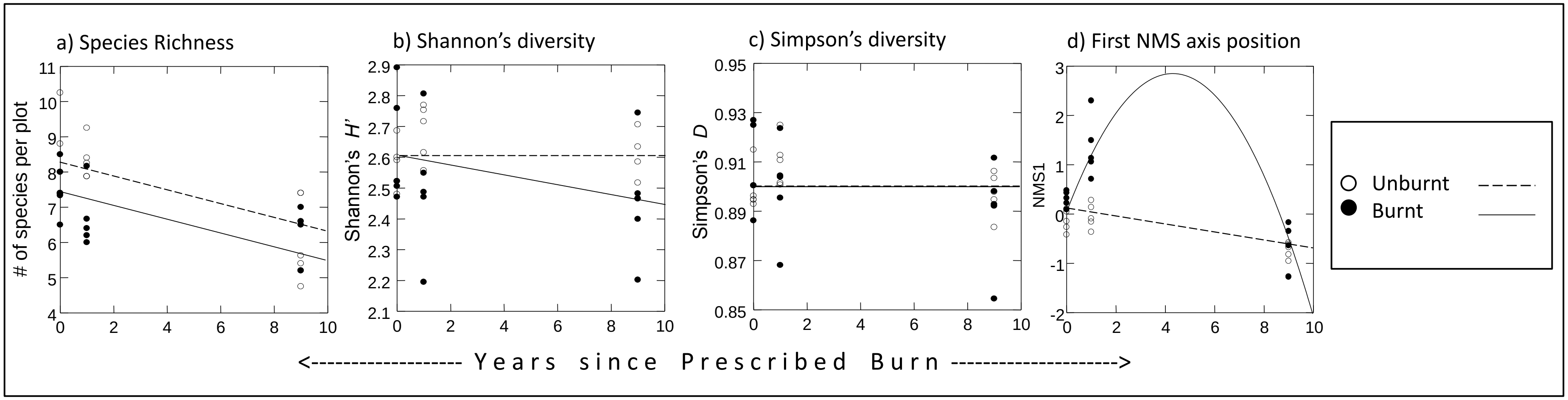

Figure 6. Best fitting models for indices of (a-c) species diversity and (d) total plant community composition (position on Axis 1 of an NMS ordination) at Red Hills from 2007 (0 = pre-burn) to 2016 (9 years post-burn). Refer to Table 4 for model details (n = 5 observations per treatment and year).

3.2 Aspen Plots (2008 – 2016)

In the aspen plots, the number of dead and dying trees increased from approximately 5 per plot in 2008 to 9 per plot in 2016, while the number of suckers declined 10-fold across all burn severities (Figure 4, Table 7). Damage from Venturia was less severe in 2016 than in 2018 and the height of the tallest aspen sucker per plot increased from around 65 cm to over 2 m.

Table 7. Aspen plot data

Plot	# of dead overstory aspen		# of dead or dying overstory aspen		Mean tree Vigour		Venturia class		Suckers per Ha		Height of tallest sucker (m)	
	2008	2016	2008	2016	2008	2016	2008	2016	2008	2016	2008	2016
L1	0	9	7	9	0.92	0.3	1	2	71,000	18,000	0.60	2.07
L2	0	6	1	6	2.05	1.3	2	0	8,000	5,000	0.43	0.88
L3	1	9	4	9	0.9	0.2	6	3	185,000	6,000	0.55	1.06
L4[1]	1	-	1	-	1.65	-	5	3	145,000	15,000	0.57	1.8
L5	0	7	4	7	1.1	0.3	2	2	41,000	14,000	0.90	4.15
Ave	0.4	7.8	3.4	7.8	1.3	1.7	3.2	2	90,000	10,700	0.61	1.99
M1	1	8	2	8	1.35	0.4	4	0	53,000	17,000	0.55	1.5
M2	1	10	3	10	1	0	5	n/a	54,000	0	0.65	0
M3	2	10	5	10	0.9	0	3	2	222,000	3,000	0.85	1.41
M4	1	10	4	10	1.05	0	3	0	161,000	22,000	0.95	2.85
M5	4	10	8	10	0.4	0	3	1	144,000	10,000	0.65	2.3
Ave.	1.8	9.6	4.4	9.6	0.94	0.1	3.6	0.6	126,800	10,400	0.73	1.61
H1	6	10	8	10	0.3	0	2	0	183,000	10,000	0.90	2.8
H2	0	10	1	10	0.95	0	2	2	218,000	19,000	0.60	2.5
H3	4	10	10	10	0.3	0	2	2	235,000	14,000	0.60	2.15
H4	7	10	9	10	0.2	0	1	2	148,000	12,000	0.50	3.07
H5	7	10	7	10	0.3	0	1.5	0	88,000	11,000	0.50	2.8
Ave.	4.8	10	6.8	10	0.4	0	1.7	1.2	174,400	13,200	0.62	2.66

1 – in 2016 plot L4 couldn't be found at the recorded GPS location. Sucker data was recorded at the recorded GPS location

All of the aspen performance variables on the burn plots were significantly different in 2016 than in 2008 (Table 8). Except for vigour, there was a non-linear relationship between burn severity and aspen performance, and the shape of the response curve was quite different in 2008 than in 2016 (Figure 7).

The vigour of residual overstory aspen declined linearly with increasing burn severity in both years (Figure 7c). These aspen had lower vigour in 2016 (mostly dead or dying), compared to fair to poor vigour in 2008. In 2016, approximately 20% of the trees were still alive on lightly scorched plots, two trees were still alive on medium severity plots, and all of the trees were dead on high severity plots (Figure 7a,b).

Venturia blight was worse in 2008 than in 2016, except on high severity burn plots, where levels were similar in both years. Initially, Venturia blight was less severe on high burn plots, but this was no longer the case in 2016 (Figure 7d).

In 2008, aspen sucker density was 90,000 stems per hectare in lightly burnt areas and increased to 174,000 stems per hectare in severely burnt areas. The tallest suckers were approximately 65 cm at that time and did not vary greatly with burn severity. By 2016, the number of suckers had diminished to approximately 12,000 stems per hectare regardless of burn severity; however, the tallest suckers increased from approximately 2 m on low burn severity to 2.7 m on high burn severity (Figure 7e, f).

Table 8. Results of model selection for the aspen burn plots.

Response variable	Are years different?	Effect of burn severity	Best fit model[1]
a) Percent mortality of overstory aspen	Yes, parallel but shifted to right	non-linear	2008: $Y = 100e^{(-3.5547+1.8405s)}/[1 + e^{(-3.5547+1.8405s)}]$ 2016: $Y = 100e^{(1.5093+1.8405s)}/[1 + e^{(1.5093+1.8405s)}]$
b) Percent dead or dying overstory aspen	Yes, non-parallel	~linear in 2008; non-linear in 2016	2008: $Y = 100e^{(-0.945+0.9423s)}/[1 + e^{(-0.945+0.9423s)}]$ 2016: $Y = 100e^{(1.0658+2.8946s)}/[1 + e^{(1.0658+2.8946s)}]$
c) Aspen vigour	Yes, but parallel	linear	2008: $Y = 1.25 – 0.36s$ 2016: $Y = 0.56 – 0.36s$
d) Severity of Venturia blight	Yes, non-parallel	non-linear	2008: $Y = 3.2 + 1.55s – 1.15s^2$ 2016: $Y = 2.0 – 2.1s + 0.85s^2$
e) Number of suckers	Yes , non-parallel	non-linear	2008 : $Y = 90 + 31.4s + 5.4s^2$ 2016: $Y = 11.1 –3.2s +2.0s^2$
f) Height of tallest sucker	Yes, non-parallel	non-linear	2008: $Y = 61 + 23.5s – 11.5s^2$ 2016 : $Y = 199 – 29s + 31.3s^2$

1-Burn severity (s) = 0, 1 and 2, for low, medium and high.

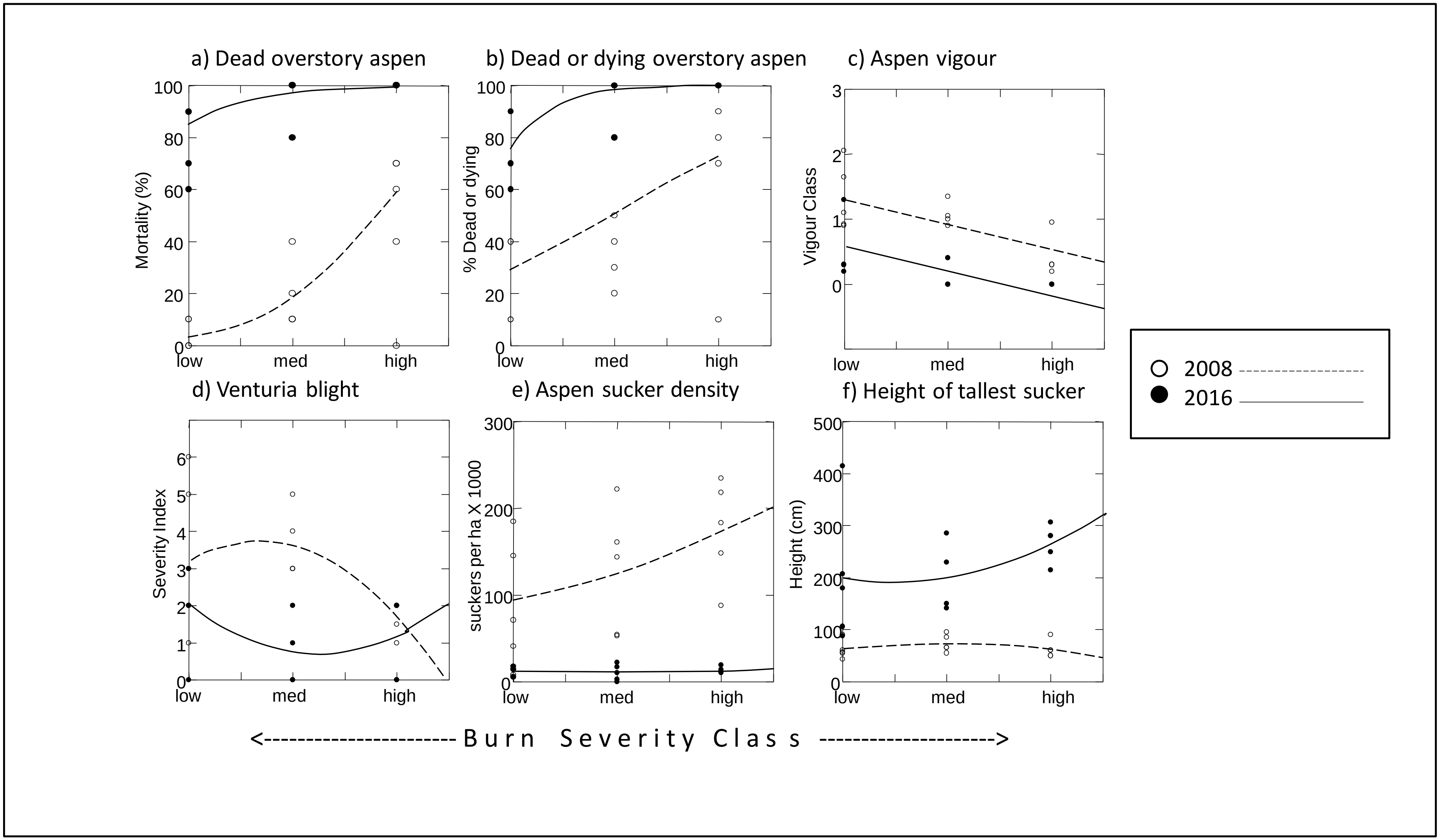

Figure 7. Response curves showing the effect of increasing burn severity on overstory aspen health and understory aspen sucker density and growth in 2008 (open symbols and dashed curve) and 2016 (filled symbols and solid curve). See Table 4 for model details (n = 5 (or 4) observations per plot in each year).

4.0 Discussion

4.1 Current Burn Area

Although the 2008 spring burn at Red Hills was of generally low severity, it appears to have had a lasting effect on the endangered SBSdk/81 scrub-steppe plant community and has met the objectives of reducing tree encroachment by both aspen and conifers and of increasing herb abundance – notably grasses, even though they do remain very sparse at this site. Saskatoon (another characteristic SBSdk/81 plant with important wildlife values) has also increased in cover, apparently in response to the decline in aspen.

Kinnikinnick is the dominant species in the herb layer on this site, and not a preferred species in this site series, as it is typically associated with pine trees, and acidic, nutrient-poor soils with mor humus forms (Pojar *et al*. 1984, Crane 1991). It was thought that the burn would decrease kinnikinnick abundance. Although kinnikinnick was substantially top-killed by the burn, roots and prostrate stems apparently survived the low severity burn, and it has now recovered to pre-burn levels.

Aspen suckers are still present on the site at fairly high, though greatly reduced, densities. This result is similar to other studies (Bartos and Mueggler 1981, Brown and DeByle 1987, Wang 2003). These suckers likely represent a new cohort of aspen trees. The density of suckers is not an unexpected result, as there is an abundance of literature documenting the suckering response of aspen to fire (DeByle and Winokour 1985, Peterson and Peterson 1992, Krasnow and Stephens 2015), and the likelihood of this occurring was noted in the planning stage of this project (de Groot and Armitage 2007, de Groot 2008). Multiple burns will most likely be required to kill these suckers (Buckman and Blankenship 1965) and prevent the return of the area to an aspen stand. The effects of annual burning on aspen suckers is mixed with Svedarsky *et al*. (1986) reporting a decline in suckers after 13 years of annual burning, and Anderson and Bailey (1980) reported that the density and cover of aspen suckers had increased after 24 years of annual burning. How the aspen will respond to intermittent burning is unknown.

Repeated fires are thought to decrease the carbohydrate reserves of the aspen (Perala 1974), which, in turn, are believed to be a major determinants of post-fire sprout density and growth rate (Krasnow and Stephens 2015). Allowing sufficient fuel build-up and curing to carry a fire that is hot enough to kill or damage the aspen are important considerations when planning burns (Perala 1974, Peterson and Peterson 1992). Due to their thin bark, aspen trees and suckers will be damaged by fire if there is enough fuel to carry a fire through the stand (Peterson and Peterson 1992). While the trees and suckers may not be killed outright, the damage to the bark leaves the trees more vulnerable to disease, insect attack or frost damage (Peterson and Peterson 1992). Delayed mortality from secondary causes probably accounts for much of the additional aspen decline observed at Red Hills between 2008 and 2016, and was also reported six years after a 2002 spring burn at Grouse Mountain near Houston (Haeussler and de Groot 2008).

Fire severity is thought to influence the amount of aspen post-fire suckering, though the direction of the influence is not clear with studies showing more suckering with greater fire severity, less suckering with greater fire severity and no relationship between fire severity and suckering (Krasnow and Stephens 2015). In this study there was initially a greater sucker density with greater fire severity, but this difference had disappeared after 8 years.

The average height of tallest sucker in each plot was just 2.24 m after 8 years of growth. Assuming that it took 3 years for the suckers to reach breast height (1.3 m), the site index of the site is approximately 10 m at 50 years (Garcia 2013, http://forestgrowth.unbc.ca/tag/). This is well below the average site index of aspen of 18.3 m of other SBSdk sites where site index is available (Mah 2013), but is very similar to the site index found by Chen *et al*. (1998) for xeric crest position sites in the BWBSmw subzone. There could be several causes of the slow growth, including the dry rocky growing site, Venturia infection, aspen serpentine leaf miner (*Phyllocnistis populiellia*), and the dry summer weather of some recent years.

The Red Hills study area remains remarkably free of invasive non-native plant species compared to other SBSdk/81 shrub/steppe ecosystems in the Lakes District and Bulkley Valley (e.g., Helkenberg and Haeussler 2008). Since the 2008 assessment, non-native hawkweeds belonging to the *Pilosella* subgenus of *Hieracium* have become a major invasive species concern throughout the region, but they were not detected in our samples (*Hieracium umbellatum*, listed in Table 4, is a native hawkweed). There was no evidence that prescribed burning caused an increase in the abundance of invasive non-native species at this site.

Grasslands are very dynamic ecosystems and can experience large fluctuations in plant species abundance within between years in response to weather conditions. Directional changes driven by medium- and longer-term climatic cycles can also occur over a decade. It is thus very important that the monitoring plots include an unburnt control so that vegetation trends that are unrelated to the prescribed burn can be factored into the assessment. Our analysis showed that, unfortunately, there were many pre-burn differences between the burnt and unburnt portions of the transect and quadrat survey area, since the burn treatment could not be randomly applied and replicated and because the fire preferentially spread through areas with more leaf litter. Our modelling approach allowed both pre-burn differences in plant community composition (''site sensitivity"), and changes in the unburnt control ("background trend") to be taken into account, and we feel quite confident that the effects ascribed to the prescribed burn were real effects rather than sampling artefacts

We recommend that the site be reburnt in the next few years to kill the aspen suckers. Our expectation is that the plant species groups that responded positively to the initial burn, (herbs, notably grasses), will continue to show greater cover if continues to decline after a second burn. This would advance the project to meeting goal 1 of reducing the cover of aspen and increasing the cover of forbs and graminoids. Additional burns and post-burn monitoring are required before it can be determined if goal 2 of "assessing the effectiveness of burning as a treatment for controlling aspen encroachment on SBSdk/81 shrub/steppe" can be fully evaluated.

4.2 Proposed Future Burn Area

During our 2008 fieldwork, we identified an area to the east of the initial burn suitable for a larger subsequent burn (Figure 8). This area has terrain and vegetation similar to that of the initial burn. It is located on the lower to middle slopes of Red Hills, and is dominated by young dense aspen forests. The area covers 108 ha and extends east to a ridge coming down from the main Red Hills ridge. Approximately 750 m east of this area there is an area with old Douglas-fir stands that that should not be included in a burn area (de Groot and Armitage 2008).

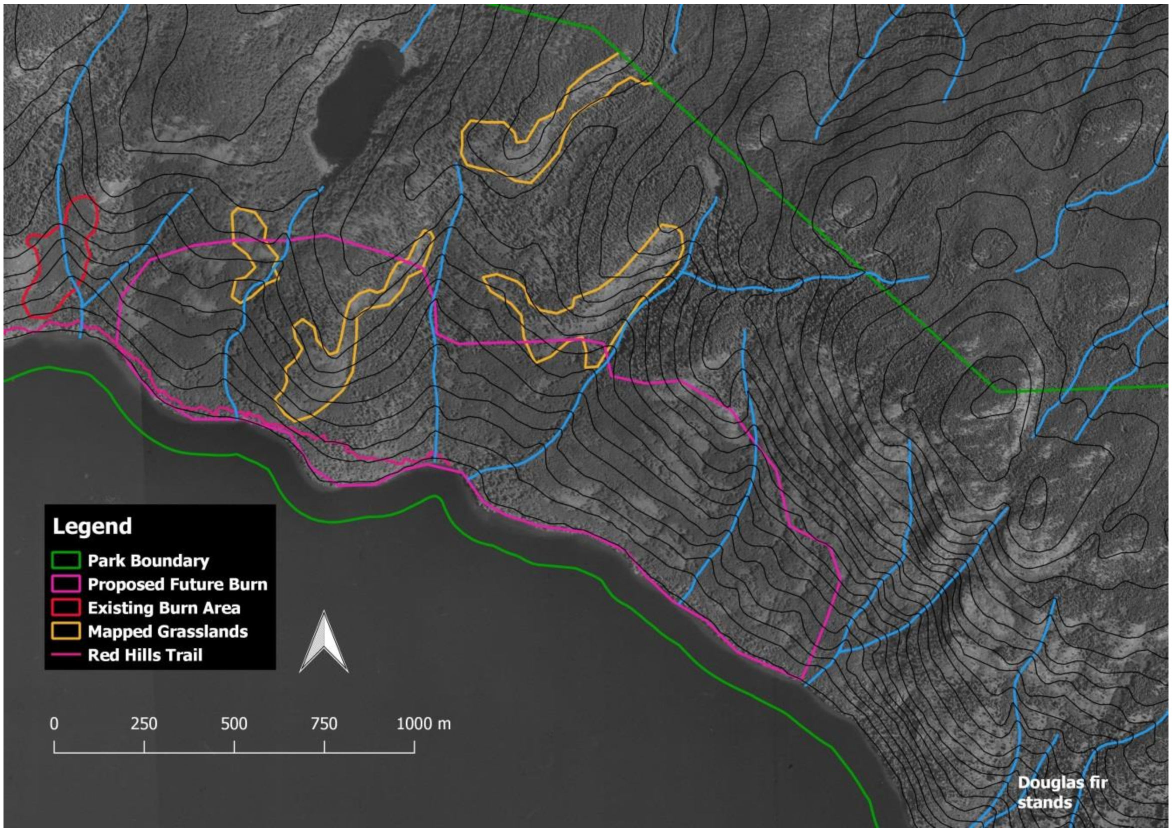

Figure 8. Proposed future burn area

Before a burn is initiated planning would include fieldwork to determine the exact burn area, developing a burn plan and monitoring plan, and conducting pre-burn monitoring. BC Parks, the BC Wildfire Management Branch and local residents should have to be involved throughout the burn process.

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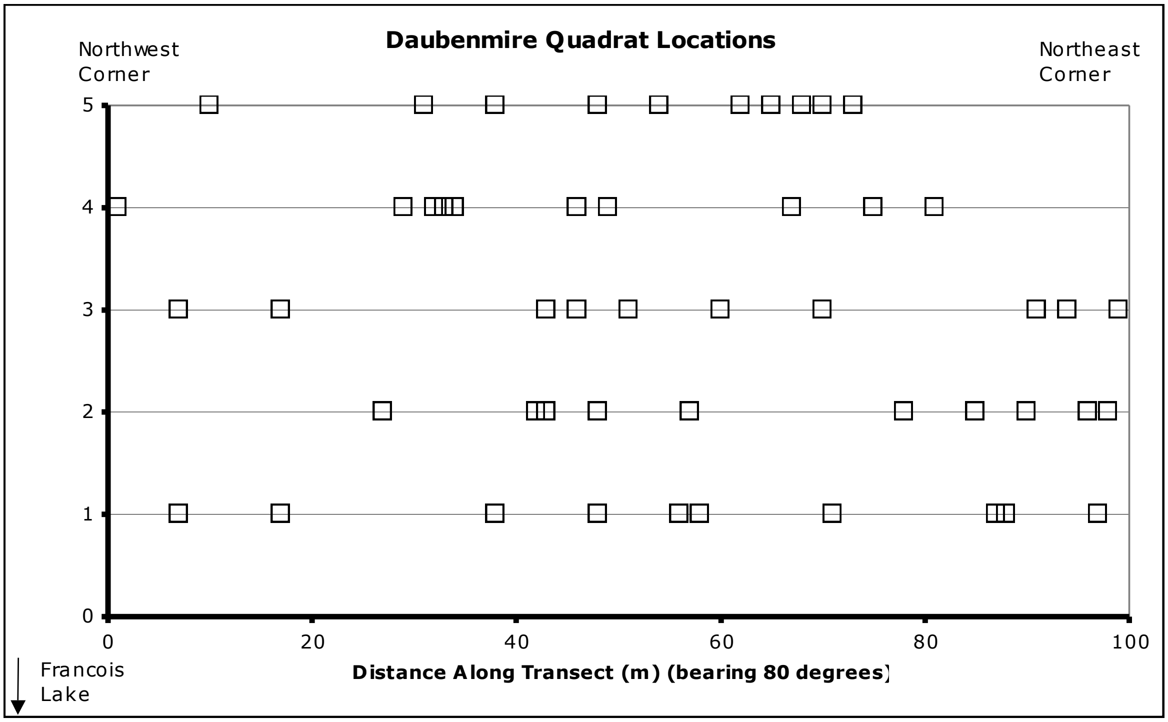
Appendix 1: Detailed Field Methods and Data from previous years



Layout of monitoring plot transects and quadrats

UTM coordinates of corners of vegetation monitoring plot

Location	UTM Zone	Easting	Northing
NW corner	10 U	329650	5991130
SW corner	10 U	329663	5991092
SE corner	10 U	329749	5991100
NE corner	10 U	329733	5991141

Placement of Daubenmire quadrats along transects

Transect #	Metres from Baseline									
1	7	17	38	48	56	58	71	87	88	97
2	27	42	43	48	57	78	85	90	96	98
3	7	17	43	46	51	60	70	91	94	99
4	1	29	32	33	34	46	49	67	75	81
5	10	31	38	48	54	62	65	68	70	73

Along transects, any tree or shrub that intersected the tape was recorded along with the start and stop locations of the interception. In quadrats, all species that occurred in a quadrat were recorded, and the percent cover of each species was visually estimated.

Transects run west to east at a bearing of 80^{o} with the Point of Commencement (POC) on the west end and Point of Termination (POT) of on the east end. Points of Commencement and POT's are 18-inch long rebar stakes painted pink and flagged with pink ribbon. Daubenmires are marked with two six-inch nails along the transect line and flagged with orange ribbon.

Burn severity[3] in Daubenmire quadrats										
Transect	**Quadrat**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0	0	0	0	1	1	1	1	1	2
2	0	0	0	0	1	0	1	3	3	2
3	0	0	0	0	1	1	0	1	2	2
4	0	0	0	0	0	0	0	0	1	2
5	0	0	0	0	0	0	0	2	1	1

0 – unburnt, 1 –Low (scorched) 2 – Medium (lightly burnt), 3 – High (severely burnt)

Summary of burn severity[3] along transects

Severity	Total length (m)	% of total length
Unburnt – 0	293.6	58.7
Low(scorched) – 1	155.4	31.1
Medium (lightly burnt) - 2	33.5	6.7
High (severely burnt) - 3	17.5	3.5

Location of aspen monitoring plots (all were updated in 2016 except L4 and H3)

Severity[3]	Code[3]	Zone	Easting	Northing
Low 1	L1	10U	329691	5991120
Low 2	L2	10U	329724	5991144
Low 3	L3	10U	329849	5991302
Low 4	L4	10U	329798	5991107
Low 5	L5	10U	329736	5991100
Medium 1	M1	10U	329765	5991205
Medium 2	M2	10U	329843	5991242
Medium 3	M3	10U	329858	5991190
Medium 4	M4	10U	329728	5991071
Medium 5	M5	10U	329780	5991168
High 1	H1	10U	329747	5991171
High 2	H2	10U	329832	5991158
High 3	H3	10U	329835	5991147
High 4	H4	10U	329759	5991134
High 5	H5	10U	329745	5991191

[3] Burn severity codes were changed in 2016 to be more intuitive. Codes used by de Groot and Haeussler (2008) codes were Sc = Scorched (now L = Low); L = light (now M = Medium), and S = Severe (now H = High).

Tree vigour (modified from B.C. Ministry of Environment and B.C. Ministry of Forests 1998) and Venturia classes		
Vigour or Venturia Class	**Vigour description**	**Venturia attack level**
0	Dead	No attack
0.5	Moribund (almost dead but a bit of green cambium or a few leaves)	
1	Poor - a few clumps of live leaves but most of crown dead	Very light
2	Fair - crown partly developed but with some dieback	Light
3	Good - healthy crown, tree typically has some stem scarring	Moderate
4	Excellent - full crown and a clear stem	Moderately-heavy
5		Heavy
6		Very Heavy

Mean diameter at breast height (dbh) of aspen trees in monitoring plots	
Burn Severity	**Mean DBH (SD)**
Low (n=50)	11.53 (6.85)
Medium (n=49)	12.44 (4.06)
High (n=50)	11.52 (3.53)
Mean DBH	11.83

Monitoring included recording fire intensity in each of the Daubenmire quadrats and along the transects established in 2007 and taking photos inward along each of the transects. For the photos, a 2 m long graduated pole with 50 cm graduations was placed 5 m from the transect end and a label was placed 2.5 m from the transect end. All photos were taken with the camera held above the transect marking stake at eye height. Photos were taken with a Fujifilm Finepix E550 camera with a focal length of 28.8 mm (35 mm camera equivalent).

Appendix 2. NMS ordination of square root transformed species % cover