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Fire Effects and Post-burn Vegetation Development in the Sub-Boreal Spruce Zone: Mackenzie (Windy Point) Site

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British Columbia
Ministry of Forests and Range
Forest Science Program

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ABSTRACT

The purpose of this study was to document fire effects and subsequent changes in vascular species composition and structure after a slashburn. Survival and growth of planted hybrid spruce seedlings were also monitored.

The study site is a clearcut at Windy Point in the Mackenzie Forest District in the Sub-Boreal Spruce zone in northern British Columbia. Six permanent plots were established prior to burning and monitored for 10 years after the fire. Fire weather codes and indices were calculated, fuel loading and consumption were determined, and burn severity was measured at three fuel assessment triangles and in the vegetation plots.

The slashburn was of low to moderate severity and consumed 22% of the forest floor. Impacts were considerably less than those forecasted using the Prescribed Fire Predictor in conjunction with the Canadian Forest Fire Weather Index System, likely because the cutblock forest floor was wetter than predicted.

Ten years after burning, the site was dominated by young planted hybrid white spruce, shrubs, and herbs. Most of the original shrub and herb species are well adapted to burning and re-established after the fire by resprouting. Some shrubs (i.e., *Rubus parviflorus, Rubus idaeus, Ribes laxiflorum, Ribes lacustre,* and *Sambucus racemosa*) and herbs (i.e., *Geranium bicknellii* and *Corydalis sempervirens*) established by germination from long-lived seed banks immediately after the fire. A few of the original herb and bryophyte species, including *Rubus pedatus*, had not reappeared by year 10. New species, such as *Salix* sp. and *Epilobium angustifolium*, established by seeding-in from off-site sources. Species including *Ribes laxiflorum* and *Rubus idaeus* increased in cover and frequency and then declined; others such as *Alnus tenuifolia* and *Gymnocarpium dryopteris* gradually increased in abundance over time and others decreased steadily. Establishment of new species continued for many years after the site was burned.

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1 INTRODUCTION

1.1 Background and Rationale

Development of sustainable forest management practices requires an understanding of the short- and long-term effects of harvesting and site preparation on all forest vegetation. Although clearcutting and slashburning have been widely practiced in British Columbia, little is known about subsequent patterns of vegetation development or how management activities, particularly slashburn severity, influence these patterns. FRDA Report 018 (Hamilton and Yearsley 1988) featured predictive models of forest vegetation succession and also contributed to the development of a seral classification within the biogeoclimatic ecosystem classification (BEC). Managers indicated that this kind of information was essential in developing forest management prescriptions to meet integrated resource use objectives, such as regenerating forests, providing wildlife habitat, and maintaining biodiversity.

This technical report presents 10-year results for E.P. 1093.10. The study site described here is one of several in the Sub-Boreal Spruce (SBS) biogeoclimatic zone where vegetation and planted conifer growth is being monitored after clearcutting and slashburning. This study is among very few in British Columbia to record slashburning severity, planted conifer growth, and both pre-burn (in some cases pre-harvest) and several years of post-burn data on all vegetation species in permanent plots (Hamilton and Peterson 2003, 2006; Hamilton and Haeussler 2006).

1.2 Objectives

The objectives of this study are:

1. to quantify and describe changes in percent cover, height, species composition, and diversity of vegetation over time;
2. to quantify the growth and mortality of planted hybrid white spruce (*Picea glauca* × *engelmannii*) seedlings over time;
3. to document the fire weather conditions, forest floor moisture content, and fire effects, and to compare actual and predicted fire effects; and
4. to assess the interactions among burn severity, vegetation development, and planted spruce growth.

2 METHODS

2.1 Study Area

The study site known as Mackenzie (Windy Point) is located in the Mackenzie Forest District of the Northern Interior Forest Region and accessed by a road that heads east from Highway 97 approximately 0.6 km south of the Windy Point Lodge (Figures 1 and 2). The cutblock, which was part of Finlay Forest Industries Ltd. Cutting Permit No. 170, is situated at a 770 m elevation in the Finlay-Peace variant of the Sub-Boreal Spruce Wet Cool subzone (SBSwk2). Before logging, the site supported a Hybrid white spruce – Devil's club site series (05). The site is located near the boundary between the SBSwk2, SBSwk1, and SBSmk1 subzone variants. Plots are located on a moderate slope that faces north.

The site was clearcut in the winter of 1987/88 when snow cover was deep enough to prevent disturbance of the forest floor or destruction of understorey vegetation on most of the site. The block was burned on 3 September 1988 (Figure 3) and planted in 1989.

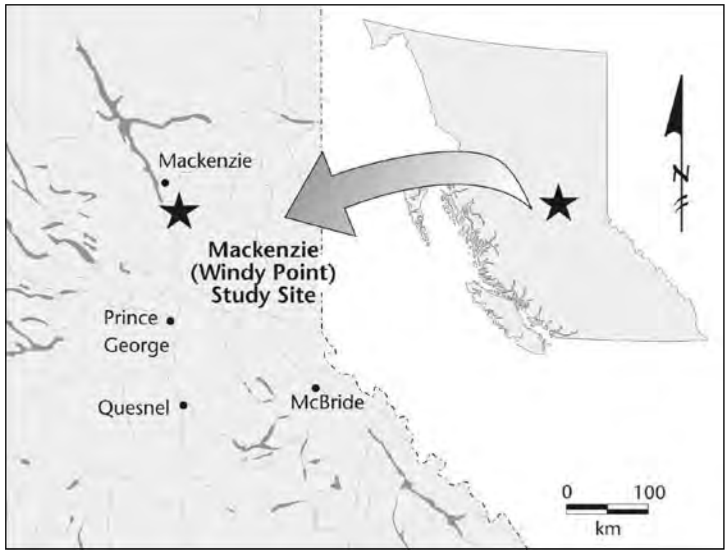

FIGURE 1 *Location of the Mackenzie (Windy Point) study site.*

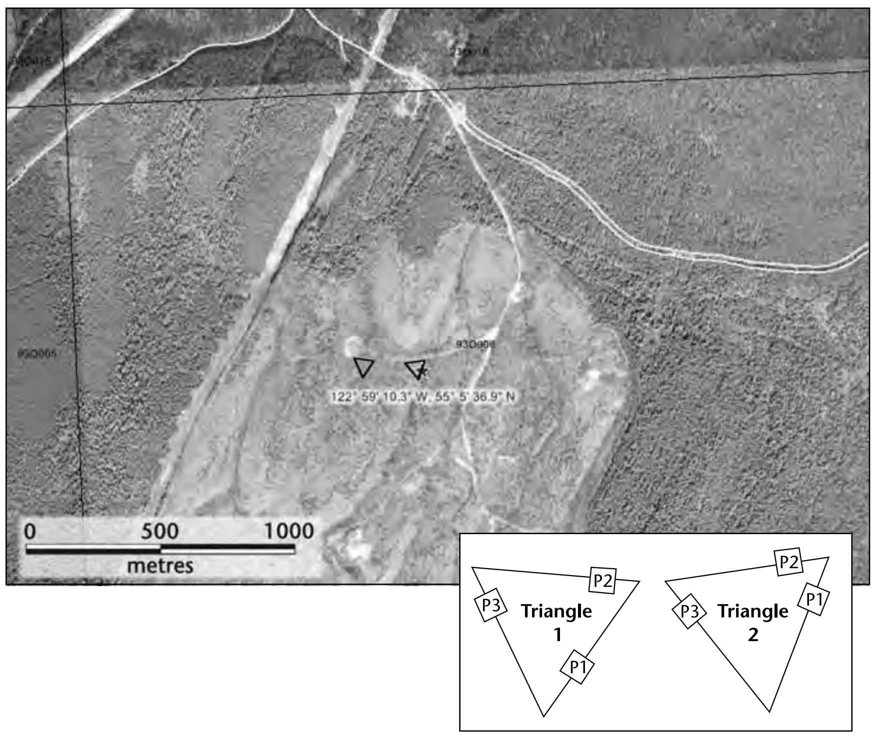

FIGURE 2 *Location of the fuel measurement triangles at the Mackenzie (Windy Point) study site. Inset shows the relative positions of the three vegetation monitoring plots within each of the fuel measurement triangles.*

FIGURE 3 *Aerial view of the site at the time of slashburning (3 September 1988).*

2.2 Data Collection

A fire weather station (known as the Windy Point station in the Canadian Forest Service fire weather database) was established on-site following the standard protocol (Canadian Forest Service 1987). Monitoring continued until immediately before the site was burned on 3 September 1988.

Canadian Forest Fire Weather Index System (CFFWIS) codes and indices at the time of burning (van Wagner 1987) were calculated using on-site weather station data; in cases where gaps occurred in on-site data, information from the weather station at the Mackenzie town site was used to obtain the missing values. The following CFFWIS codes and indices were calculated: Fine Fuel Moisture Content (FFMC), Duff Moisture Code (DMC), Drought Code (DC), and Fire Weather Index (FWI). Wind speed, relative humidity, and air temperature were also monitored.

Samples of the 0–5 cm and 5–10 cm layers of the forest floor in subhygric and mesic microsites in the clearcut and comparable adjacent forest stands were collected using gravimetric sampling tins. Moisture content was determined by weighing samples of a known volume before and after drying. Samples were dried at 70°C for 24 hours in a convection oven following standard procedures. Subhygric cutblock samples were taken on 26 June, 8 August, 12 August, and 3 September 1988, and the mesic cutblock samples were taken on 3 September 1988. These measured forest floor moisture content (MC) values were then used to determine the equivalent Duff Moisture Codes (eDMCs), using the Lawson et al. (1997) equation for the Southern Interior of British Columbia (i.e., $MC = \exp[(DMC-223.9)/-41.7]+20$).

Two fuel assessment triangles were installed on the site in June 1988 after the site was logged, following the methods outlined by Trowbridge et al. (1987). Six 5 × 5 m permanent vegetation monitoring plots were superimposed on the fuel triangles (Figure 2). Ninety-three depth-of-burn pins were established in the six vegetation plots, with three rows of five pins per row in each plot (plus three extra in one plot). Eighty-four depth-of-burn pins were relocated after burning and used to determine pre-burn forest floor depth, litter depth, and forest floor consumption.

Pre-burn vegetation data were collected in late June and mid-July of 1988. Post-burn data were collected in July or August of 1989, 1990, 1991, 1993, and 1998 (1, 2, 3, 5, and 10 years after burning). Estimated percent cover of each plant species in each plot was recorded in all sampling years. Mean height was collected for the dominant herb and shrub species only, except in 1998 when height was recorded for all vascular plant species. In 1989, the mode of establishment (i.e., from seed or resprouting from surviving plant parts) was recorded for selected species. Mode of establishment was determined by gently excavating around the root of the seedling or sprout to determine whether the plant originated from a seed or a rhizome. All vascular plant species were recorded along with the more common species of bryophytes.

Percent cover is an estimate of the actual area covered by projecting the leaves of the species onto the ground, not the area defined by the outline of the plants. Percent cover and height were also recorded in the field for all species combined (total), starting in 1989, and again in 1993 for the shrubs (excluding shrubby deciduous tree species) and herbs. Bryophytes were included in the estimates of total percent cover. Only vascular plants were included in the total height values. The cover of planted spruce was calculated as the percentage of the plot covered by the sum of crown areas of trees in the plots.

Height is considered as the average height of a species in the plot, taking into account the proportion of the cover of individual plants with different heights. This is done by taking several measurements where obvious variation occurs, and then estimating the mean. For example, if 5% of the species cover is 150 cm tall, but the rest is only 90 cm tall, then the estimated height is much closer to 90 cm than to 150 cm. In most years, flowering parts were included in the estimates of vegetation height; however, in 1993, flowering parts were not included in height measurements of two tall herbs (*Carex* sp. and *Epilobium angustifolium*).

Thirty hybrid white spruce seedlings, planted in and around the vegetation plots (five trees per plot) in 1989, were numbered with plastic tags to identify the trees for measurement. Seedlings were measured immediately after planting and then again in 1990, 1991, 1993, and 1998 at the same time as vegetation was sampled. Height, root collar diameter, and two perpendicular diameters of the crown (measured from tip to tip of branches at the widest part of the crown) were recorded for the planted spruce. The crown measurements were used to calculate crown area with the formula πr^2 (where r [radius] is the mean of the two crown measurements divided by two). In 1998, diameter at breast height (1.3 m) was also recorded.

2.3 Data Analysis

To confirm the site series classification, pre-burn vegetation data were compared to the appropriate units in the provincial BEC database and to a draft version of the field guide update for the (former) Prince George Forest Region, now known as the Northern Interior Region (DeLong 2000). Graphs and descriptive statistics were used to present and assess the fire effects, forest floor moisture content, changes in vegetation, and planted spruce growth.

To provide a measure of abundance over the whole site, mean percent cover was calculated as the sum of the cover values for a given species, divided by the total number of sample plots. Mean height was calculated as the sum of the heights recorded for a species, divided by the number of plots in which the species was recorded. Percent presence, an expression of frequency, was determined by the number of plots in which each species occurred, multiplied by 100, and divided by the total number of sample plots.

In 1993, overall heights for all shrubs and all herbs were estimated in the field. Since heights were recorded for all shrub and herb species in 1998, an overall height for these life forms was calculated as:

$$\frac{\Sigma(\%\text{cover} \times \text{height of each shrub or herb species})}{\Sigma\%\text{cover of all shrub or herb species}}$$

Heights for total species were calculated as a weighted average of herbs and shrubs for both 1993 and 1998. In earlier years, an estimate of overall height was made in the field. Trees were not included in the calculations for shrub height or for total height. The mean height of the planted seedlings presented with the vegetation data is based on trees that were in the plots.

3 RESULTS AND DISCUSSION

3.1 Fire Weather and Fire Effects

At the time of ignition on 3 September 1988, the CFFWIS codes and indices on-site were: FFMC = 91.4, DMC = 43, DC = 460, and FWI = 23.9. Wind speed was 10 km/hour, relative humidity was 36%, and air temperature was 25.5°C.

In the subhygric forested site, moisture content (MC) was 98% for the 0–5 cm sample depth and 99% for the 5–10 cm layer. In the subhygric clearcut, MC was 153% for the 0–5 cm layer and 194% for the 5–10 cm layer (Table 1). No significant difference was evident between MC in 0–5 cm and 5–10 cm layers in subhygric site, in either the forest or clearcut; however, the forest floor moisture content in the subhygric clearcut was higher than in the analogous forest for a similar forest floor depth ($p = .05$).

In the mesic forest site, the MC was 61% for the 0–5 cm layer and 63% for the 5–10 cm layer. In the clearcut, the MC was 134% for the 0–5 cm layer and 178% for the 5–10 cm layer (Table 1). No significant difference was evident between MC in 0–5 cm and 5–10 cm layers in mesic sites, in either the forest or clearcut. Again, the forest floor moisture content in the mesic clearcuts was higher than in the analogous forest for a similar forest floor depth ($p = .05$).

To derive an equivalent DMC (eDMC), the MC of the 5–10 cm sample depth in the subhygric site was used with the Lawson et al.'s (1997) equation for the Southern Interior of British Columbia. The calculated eDMC was 9 in the subhygric clearcut and 42 in the forest. When the MC of the 5–10 cm layer in the mesic site is used, the derived eDMC was 13 in the clearcut and 67 in the forest (Table 1) ($p = .05$).

The DMC based on on-site weather station (Windy Point) data was 43. This value is close to the eDMC calculated for the subhygric forest (42), indicating that in this situation the fire weather station accurately predicted the moisture content of the forest floor in a subhygric forest site. The measured DMC (43) was lower than the eDMC calculated for the mesic forest (67), indicating that the weather station did not predict conditions in the mesic forest as well as it did in the subhygric forest.

Although the CFFWIS predicted the DMC on the subhygric forest under the observed conditions, it did not predict the DMC in the mesic forest or in the subhygric or mesic cutblocks very accurately. This is not unexpected, as the

TABLE 1 *Moisture content and equivalent Duff Moisture Codes for subhygric and mesic forested and clearcut sites at the time of ignition on 3 September 1988*

Site type (mean and 95% confidence limits)	Equivalent Duff Moisture Codes	Measured moisture content (%)	Seral stage	Forest floor sample depth (cm)
Subhygric site				
Mean (n = 20)	**42**	**98**	Forest	0–5
Lower 95% c.l.	49	86		
Upper 95% c.l.	36	110		
Mean (n = 16)	**42**	**99**	Forest	5–10
Lower 95% c.l.	55	78		
Upper 95% c.l.	32	120		
Mean (n = 20)	**20**	**153**	Clearcut	0–5
Lower 95% c.l.	30	124		
Upper 95% c.l.	12	182		
Mean (n = 20)	**9**	**194**	Clearcut	5–10
Lower 95% c.l.	14	173		
Upper 95% c.l.	4	215		
Mesic site				
Mean (n = 20)	**69**	**61**	Forest	0–5
Lower 95% c.l.	76	55		
Upper 95% c.l.	63	67		
Mean (n = 19)	**67**	**63**	Forest	5–10
Lower 95% c.l.	74	56		
Upper 95% c.l.	60	71		
Mean (n = 18)	**26**	**134**	Clearcut	0–5
Lower 95% c.l.	41	100		
Upper 95% c.l.	16	168		
Mean (n = 21)	**13**	**178**	Clearcut	5–10
Lower 95% c.l.	21	149		
Upper 95% c.l.	6	207		

CFFWIS was developed to predict forest floor moisture conditions for forested sites and not for cutblocks.

The higher MC in the treeless cutblocks is likely a result of greater interception of precipitation in the cutblocks (because of a lack of forest canopy interception) and reduced transpirational water loss. The magnitude of the difference between the moisture content, of forest and cutblock forest floors suggests that modifications are needed to the CFFWIS to accurately predict forest floor moisture content, and therefore fire effects, in cutblocks.

The initial forest floor depth was 14.4 cm (SD = 5.1) and initial litter depth was 1.7 cm (SD = 0.9). The average depth of burn was 3.1 cm (SD = 2.4, SE = 0.26) or 22% with n = 84. No significant difference was evident in the depth of burn in the six different vegetation plots (p = .05) (Table 2).

The Prescribed Fire Predictor (PFP) (Muraro 1975) forecasted an impact rank 6 burn, with 60% duff consumption under the observed conditions (i.e., when the DMC is 43, DC is 460, forest floor is 10–15 cm thick, and site slope is less than 21–35%). Actual duff consumption was 22%, or impact rank 2. If the EDMC corresponding to the actual moisture content of the subhygric parts of clearcut is used, the PFP predicts a 25% reduction of the forest floor (impact rank 2), which is very close to the observed value of 22%. The predicted impacts based on moisture content of the mesic part of the clearcut are also rank 2.

When using the DMC that corresponded to the actual moisture content of clearcut forest floor as an input, the PFP worked well at predicting forest floor consumption on this site. It did not work as well when the DMC based on the on-site weather station was used. This suggests that it is very important to accurately predict forest floor moisture content in clearcuts before burning to ensure reliable estimates of fire impacts.

TABLE 2 *Depth of burn statistics for the Mackenzie (Windy Point) site*

Plot no.	N[a]	Sum	Mean	Max	Min	Standard deviation	Standard error	Variance
MK4-1	11	40.7	3.7	8.5	2.0	1.734	0.523	3.008
MK4-2	12	41.7	3.5	11.0	1.3	2.606	0.752	6.793
MK4-3	15	40.6	2.7	7.0	0.8	1.861	0.480	3.462
MK5-1	15	57.6	3.8	8.0	0.8	1.808	0.467	3.270
MK5-2	18	35.8	2.0	6.5	0.0	1.852	0.436	3.429
MK5-3	13	44.6	3.4	15.0	0.0	3.806	1.056	14.487
Total	84	261.0	3.1	15.0	0.0	2.382	0.260	5.675

a Note that 15 pins per plot were installed for all but Plot MK5-2, which had 15 plus an additional three pins installed. N represents the number of pins for which data were successfully collected and that were used in the calculation of the statistics.

3.2 Vegetation

3.2.1 Species diversity and autecology The total number of plant species decreased immediately after burning, then increased as species re-established or invaded (Table 3). The initial decrease in species numbers was due largely to a loss of bryophyte species, which were burned off by the fire. The subsequent increase in species numbers was primarily due to an influx of new herb species. Of the 38 species noted before burning, 68% (26) were present in year 10. Seventy percent of the initial herb species and 14% of the original bryophyte species were evident 10 years after burning. The species present pre-burn accounted for 53% of the 49 species present in year 10 (1998). This suggests that these species are relatively well adapted to fire.

TABLE 3 *Number of species or taxa by life form and sample year*

	Life form				
Year	Trees	Shrubs	Herbs	Bryophytes	No. species per year
1988	2	9	20	7	38
1989	1	9	20	1	31
1990	1	10	18	0	29
1991	1	10	18	3	32
1993	1	9	17	2	29
1998	4	11	31	3	49

Deciduous trees (i.e., *Betula papyrifera* and *Populus balsamifera*) were evident by year 10 and contributed to enhancing the structural diversity of the stand (Table 4). All of the original nine shrub species re-established after the fire and were still present in year 10. *Ribes laxiflorum, Ribes lacustre, Rubus idaeus, Rubus parviflorus,* and *Sambucus racemosa* increased greatly in frequency and cover after burning. These species established through germination of buried seeds and resprouted. *Sorbus scopulina* and *Salix* sp. were new shrub species that established, apparently from off-site seed sources, after burning (Table 4).

Of the original 20 herb taxa (including specimens identified only to family or genus as well as species subdivided into varieties), 14 were still present in some plots in year 10. Five new taxa appeared after burning, but only survived for a few years and disappeared by year 5. Two of these, *Corydalis sempervirens* and *Geranium bicknellii*, are early successional species that establish from buried seeds (USDA 2006). Six of the original 20 herbs were not evident in year 10. Of the 31 taxa present in 1998, 17 (55%) appeared only after burning. Of these, 12 were recorded for the first time during the year-10 sampling. Most of the new taxa that established after burning were fairly weedy species that appeared to have established from seed brought onto the site (Table 4).

The original forest mosses had not re-established in any abundance by year 10. Bryophytes typical of burned sites, such as *Polytrichum* and *Ceratodon purpureus,* were common by year 5 (Table 4).

3.2.2 Changes in abundance, composition, and structure Total vegetation cover before burning was about 100%. The first year after burning, total vegetation cover was reduced to about 48% but it had increased to 100% by year 2 (Table 4; Figures 4 and 5).

Both herb and shrub cover exceeded pre-burn levels by year 2, but while herb cover remained high for some time, total shrub cover began to drop soon after year 2. By year 10, shrub cover was slightly less than herb cover (Figure 5). Planted spruce tree cover increased over time, and by year 10 accounted for a substantial proportion of the overall vegetation cover in the plots. Competition between trees and non-tree understorey species likely accounted for the decrease in herb and shrub cover over time (Table 4; Figures 4 and 5).

Herbs increased in abundance primarily because of the influx and expansion of new off-site source colonizers (mainly *Epilobium angustifolium*), although the surviving herbs recovered to some extent (Table 4; Figures 6 and 7). Post-burn shrub cover increased initially because of the rapid expansion of some pre-existing species (e.g., *Rubus idaeus*), by resprouting and seed-bank germination. Shrubs species that colonized the plots later (e.g., *Salix* sp.) did not account for much shrub abundance by year 10, but would likely become significant in time.

Before burning, *Gymnocarpium dryopteris* was by far the most abundant herb species (13% vs. less than 3% cover for other species), and had almost regained pre-burn levels by year 10 (Figure 6). Most herb species that survived the fire were reduced to less than 25% of their former cover, and few had recovered or exceeded their pre-burn values after 10 years. *Cornus canadensis* and *Mitella nuda* are the only forest species that exceeded pre-burn levels at year 10, but their cover was still relatively low (Table 4). *Epilobium angustifolium* established and expanded rapidly, which increased the overall herb cover and continued to keep it elevated beyond pre-burn levels; however, this species appeared to be in decline by year 10 (Figure 7).

TABLE 4 *Mean cover and presence of vegetation on the Mackenzie (Windy Point) site before slashburning and 1, 2, 3, 5, and 10 years after burning*

	Mean cover (%)						Presence (%)					
	Pre-burn	Post-burn					Pre-burn	Post-burn				
Life Form/Species[a]	**1988**	**1989**	**1990**	**1991**	**1993**	**1998**	**1988**	**1989**	**1990**	**1991**	**1993**	**1998**
Trees												
Abies lasiocarpa	1.02					0.03	33					33
Picea glauca × *engelmannii*	0.02	0.44	0.89	1.61	3.65	20.59	17	100	100	100	100	100
Betula papyrifera						1.27						83
Populus balsamifera						0.35						33
Tree total[b]	1.04	0.44	0.89	1.61	3.65	22.12						
Shrubs												
Oplopanax horridus	11.33	0.75	3.33	2.33	1.02	0.22	100	83	83	100	100	83
Alnus tenuifolia	4.67	0.33	1.08	1.58	3.67	8.85	50	50	50	50	50	67
Acer glabrum	3.17	0.67	3.00	3.00	4.17	4.33	50	33	33	33	33	50
Rubus parviflorus	1.00	**8.75**[c]	19.00	16.17	21.67	13.83	50	**83**	100	100	100	100
Rubus idaeus	0.02	**7.33**	25.00	27.50	23.33	0.95	17	**100**	100	100	100	100
Sambucus racemosa	0.50	**7.17**	16.33	3.17	0.78	0.38	17	**100**	100	100	83	100
Ribes laxiflorum	0.02	**4.17**	1.45	0.63	0.02	0.22	17	**100**	100	100	17	67
Ribes lacustre	0.77	**0.37**	1.75	1.17	2.42	2.33	83	**100**	100	100	100	100
Cornus stolonifera	1.83	0.08	0.33	0.50	0.67	0.77	33	17	17	17	17	67
Sorbus scopulina			0.08	0.03		0.08			17	17		17
Salix sp.						0.10						33
Shrub total[a]	23.3	29.6	71.4	56	58	32						
Herbs												
Galium boreale	0.02						17					
Lycopodium annotinum	0.02						17					
Ranunculus sp.	0.02						17					
Rubus pedatus	0.68						83					
Asteraceae	0.02	0.03	0.08				17	33	17			
Streptopus lanceolatus	0.50	0.12		0.08	0.10		33	50		17	33	
Gymnocarpium dryopteris	13.00	0.15	0.60	1.25	3.25	10.17	100	83	83	100	100	100
Athyrium filix-femina	2.33	0.35	0.75	0.67	1.35	0.50	100	33	33	33	83	50
Dryopteris expansa	1.67	0.25	0.93	1.42	0.78	0.33	100	33	67	83	83	33
Galium triflorum	0.68	0.02	0.70	1.52	0.62	0.15	67	17	100	100	83	83
Streptopus amplexifolius	1.67	0.43	0.42	0.20	0.25	0.78	67	83	67	50	33	100
Tiarella trifoliata var. *trifoliata*	2.50	0.18	0.60	1.08	1.58	1.05	100	50	100	100	100	100
Tiarella trifoliata var. *unifoliata*	1.83	0.37	0.60	1.00	0.52	0.20	100	67	100	100	83	50
Clintonia uniflora	0.68	0.02		0.03	0.08	0.20	67	17		17	17	50
Cornus canadensis	0.17	0.02		0.17	0.08	1.00	17	17		17	17	33
Actaea rubra	0.50	0.25			0.05	0.18	33	33			50	50
Mitella nuda	0.50		0.03		0.02	0.83	33		17		17	17
Viola sp.	0.17	0.17	0.02	0.08		0.03	17	17	17	17		33
Thalictrum occidentale	0.18	0.17	0.33	0.50		0.17	33	17	17	17		17
Orthilia secunda	0.02					0.02	17					17
Unidentified dicot		0.08						17				

TABLE 4 *Continued*

	Mean cover (%)						Presence (%)					
	Pre-burn	Post-burn					Pre-burn	Post-burn				
Life Form/Species[a]	**1988**	**1989**	**1990**	**1991**	**1993**	**1998**	**1988**	**1989**	**1990**	**1991**	**1993**	**1998**
Corydalis sempervirens		**0.43**	0.08					**67**	17			
Geranium bicknellii		**4.75**	0.03	0.03				**100**	17	33		
Epilobium ciliatum		**2.58**	0.40	0.10				**100**	83	33		
Epilobium sp.			0.22	0.13					83	83		
Epilobium angustifolium		7.50	30.00	27.50	40.83	27.50		100	100	100	100	100
Carex sp.		**0.02**	0.03	0.03	0.22	0.02		**17**	17	17	83	17
Smilacina racemosa			0.05		0.02	0.10			17		17	33
Anaphalis margaritacea				0.12	0.18	0.38				33	33	100
Prosartes hookeri					0.50	0.33					17	17
Rhinanthus minor						0.83						17
Hieracium albiflorum						0.12						50
Taraxacum officinale						0.08						83
Poaceae						0.03						33
Poaceae sp. 1						0.03						33
Poaceae sp. 2						0.03						33
Achillea millefolium						0.02						17
Equisetum arvense						0.02						17
Goodyera oblongifolia						0.02						17
Hieracium sp. 1						0.02						17
Hieracium sp. 2						0.02						17
Petasites frigidus var. *palmatus*						0.02						17
Herb total[a]	27.2	17.9	35.9	35.9	50.4	45.2						
Bryophytes												
Barbilophozia lycopodioides	3.83						50					
Dicranum sp.	0.33						17					
Mnium sp.	3.67						50					
Pleurozium schreberi	2.85						50					
Ptilium crista-castrensis	1.17						33					
Rhytidiadelphus triquetrus	0.02						17					
Brachythecium sp.	1.17					0.02	33					17
Conocephalum conicum		0.35		0.33				50		50		
Bryum sp.				1.25						50		
Polytrichum sp.				0.67	6.50	6.18				67	100	100
Ceratodon purpureus					38.33	15.00					100	100
Bryophyte total[a]	13	0.4	0	2.25	44.8	21.2						
TOTAL	65	48	100+	100	100+	100+						

a Scientific names follow the British Columbia provincial species list (Meidinger et al. 2004); MacKinnon et al. (1992) was used for species not named on this list.
b Totals for each life form are based on the sum of values for each species. Where the total was greater than 100%, 100 is used.
c Bold numbers for individual species cover and percent presence indicate that plants of seed-bank origin of that species were observed in that year.

FIGURE 4 *Photos of the site* Ⓐ *before burning and* Ⓑ *1 year,* Ⓒ *2 years,* Ⓓ *3 years,* Ⓔ *5 years, and* Ⓕ *10 years after burning.*

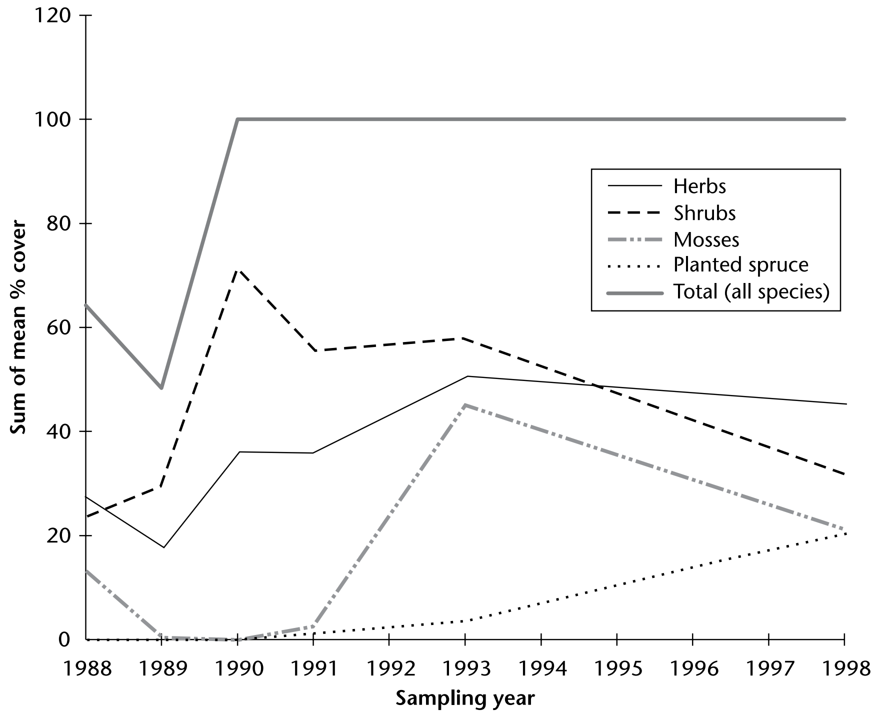

FIGURE 5 *Sum of percent cover of vegetation by life form.*

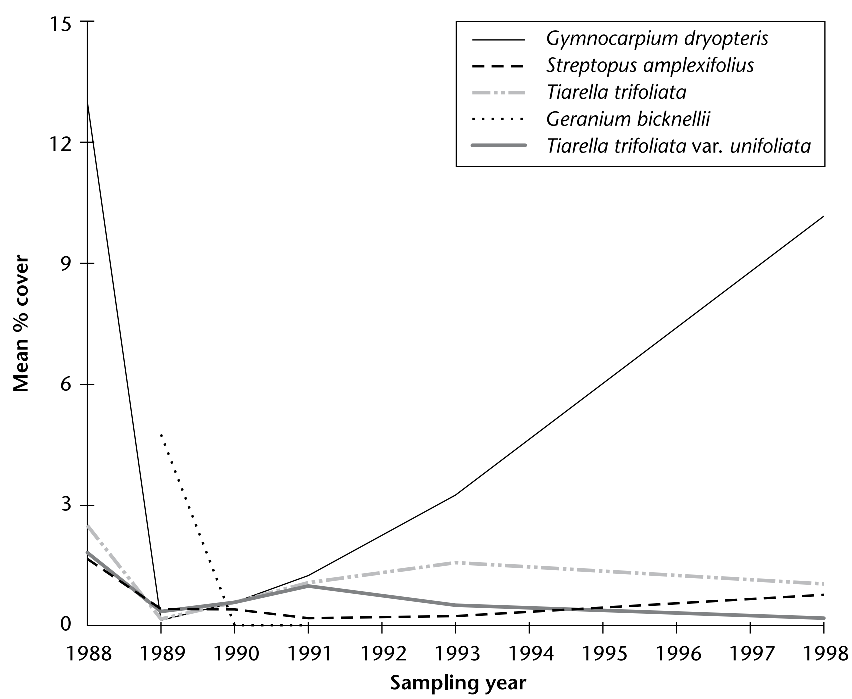

FIGURE 6 *Percent cover of selected small herb species.*

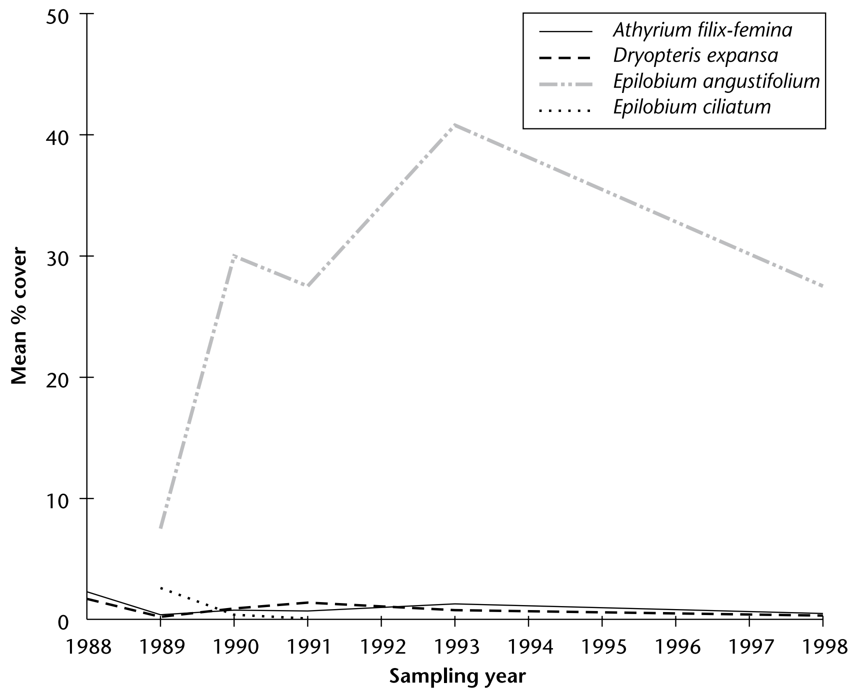

FIGURE 7 *Percent cover of selected tall herb species.*

The herb species that did not persist after fire, such as *Lycopodium annotinum* and *Rubus pedatus,* tended to be relatively uncommon and/or small plants with shallow delicate root systems that were readily consumed by fire. These species generally lacked adaptations to fire such as seed banking or deep-rooted fire-resistant rhizomes (USDA 2006).

One year after the burn, the new seed bank origin colonizers *Epilobium ciliatum, Geranium bicknellii,* and *Corydalis sempervirens* accounted for about one-third of the herb cover, but these species soon decreased and had disappeared altogether by year 5. The herb species that established between years 5 and 10 accounted for very little cover by year 10 (Table 4).

Oplopanax horridus was the dominant shrub species before burning, along with *Alnus tenuifolia* and *Acer glabrum*. Although *Oplopanax horridus* rallied after the burn, its cover appeared to drop off, while the other two pre-burn dominants recovered and exceeded pre-burn levels by year 10. At year 10, *Rubus parviflorus* was still the most abundant shrub species, although in decline. *Rubus idaeus, Sambucus racemosa,* and *Ribes laxiflorum* had all decreased to less than 1% cover by year 10. These species had been major components of the shrub layer between year 1 and year 5 as a result of the germination of buried seed. Although some developed into mature plants, most of the germinants died within a few years and consequently the cover of the species declined thereafter (Table 4; Figure 8).

Total vegetation (i.e., shrubs and herbs) height increased sharply from year 1 to year 2, then decreased (Figure 9). This decrease reflected the fact that total shrub height declined but also the anomaly that measurements of total herb height made in 1993 did not include the flower heads of fireweed, which would have added 10–20 cm. If adjusted for this discrepancy, the decline in total height would be reduced.

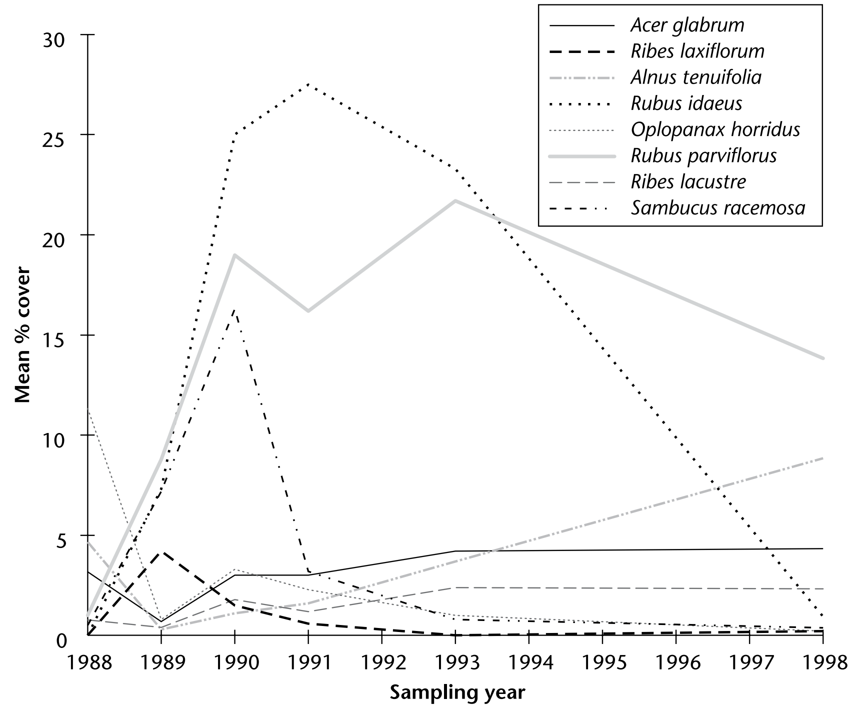

FIGURE 8 *Percent cover of selected shrub species.*

Overall shrub height was greater before than after the burn because of the abundance of *Alnus tenuifolia* and *Acer glabrum,* which were relatively abundant and tall (Figure 10). Shorter species, *Rubus parviflorus* and *Rubus idaeus,* dominated the shrub cover after burning (Figure 10). The pre-burn herb layer was dominated by short herbs (e.g., *Gymnocarpium dryopteris* and *Tiarella* spp.), although some taller fern species were evident (Figure 11). After burning, *Epilobium angustifolium*, which is fairly tall, dominated, which increased the total herb height considerably. By year 10 the understorey plants were showing signs of a reversion back to the original community structure, with the recovery of *Alnus tenuifolia* and *Acer glabrum* and the decline of *Epilobium angustifolium* and some of the early successional shrub dominants. In addition, the establishment of other deciduous broadleaved trees and the growth of the planted spruce contributed to development of a more multi-layered structure at year 10.

Most shrub species found pre-burn were observed in more plots in year 10 than before burning. All of the seed bank origin shrub species, except *Ribes lacustre*, appear to have increased in cover after burning and then declined. *Oplopanax horridus* is the only forest shrub species that declined steadily in both abundance and frequency (Table 4).

Most of the herbs that colonized the site from off-site seed persisted in the plots in which they first appeared. The fluctuations witnessed in some herb species may be attributable to incorrect identification, difficulty in finding some small plants with low cover, or variation in the longevity of the species.

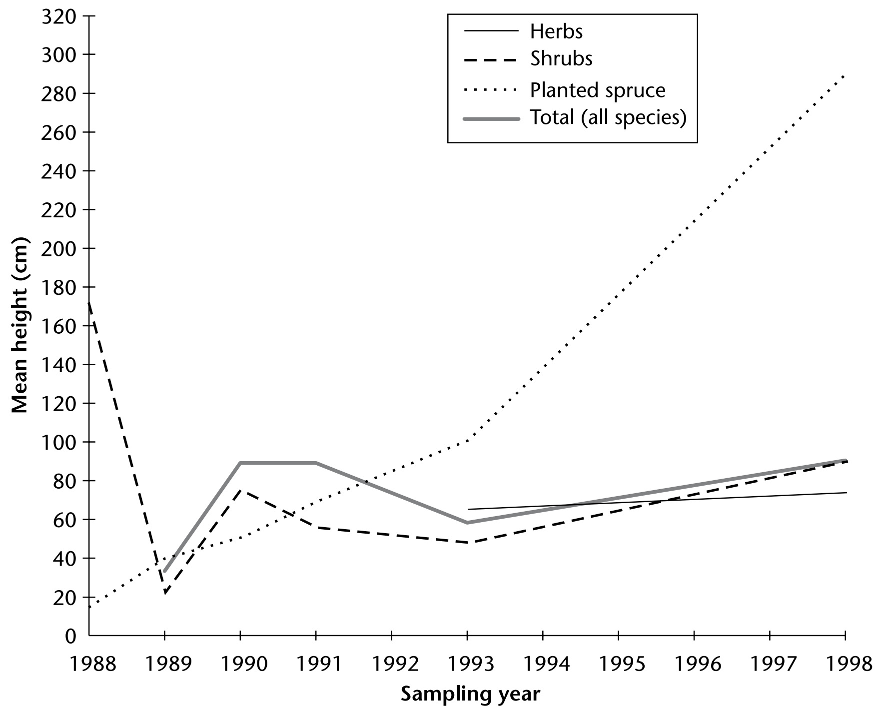

FIGURE 9 *Mean height of vegetation by life form.*

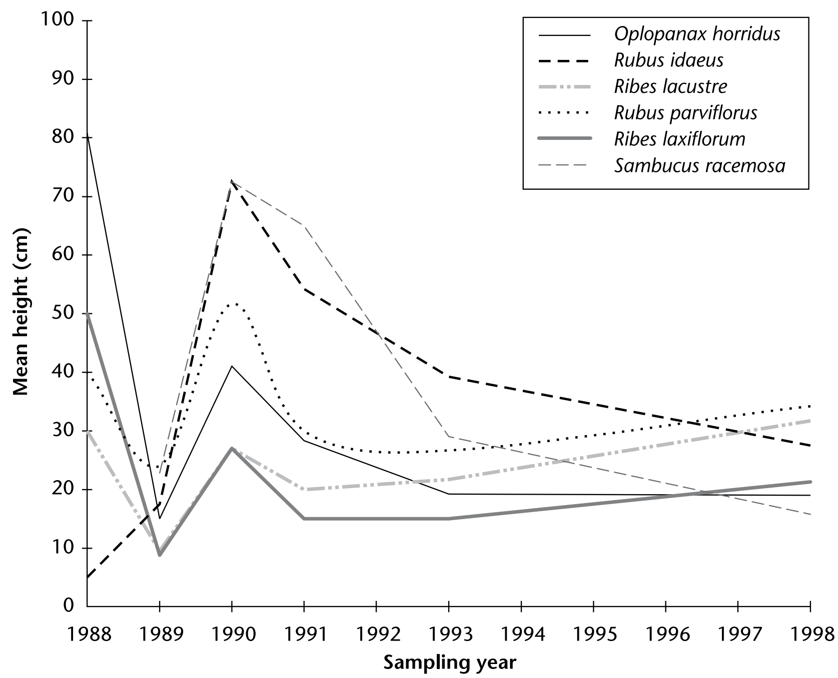

FIGURE 10 *Mean height of selected shrub species.*

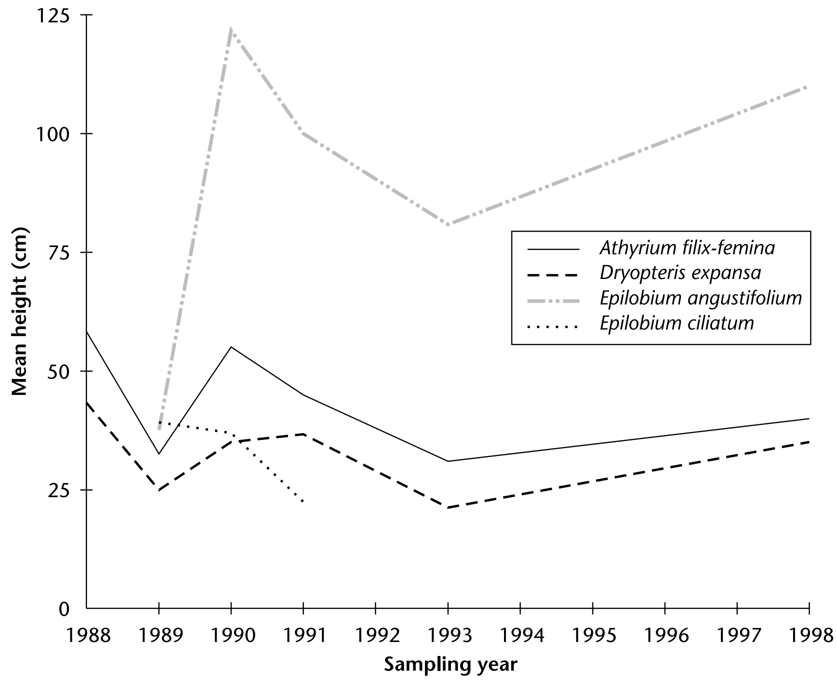

FIGURE 11 *Mean height of selected tall herb species.*

3.3 Planted Conifers

Only one of the 30 tagged conifer seedlings died over the 10 years of sampling (3% mortality). Planted spruce seedlings were about 67 cm tall by year 3 (1991), which was taller than most of the shrubs (Table 5; Figure 9). The other vegetation did not appear to have a significant impact on seedling survival or growth. According to the B.C. Ministry of Forests and Range silviculture history records, the site was declared regenerated in 1993 (year 5) and free growing in 2001.

TABLE 5 *Planted spruce seedling height, diameter, and canopy area over time*

Years after burning	Height (cm)	Diameter (cm)	Canopy area (cm^2)
1 (1989)	38.9	0.9	314
2 (1990)	51.5	1.2	668
3 (1991)	67.4	1.7	1 182
5 (1993)	94.1	2.1	2 781
10 (1998)	279.2	5.9	16 040

4 SUMMARY AND MANAGEMENT IMPLICATIONS

4.1 Summary: Fire Effects and Post-burn Vegetation Development

- The burn was a low- to moderate-severity burn.
- No significant difference was evident between the moisture content for the 0–5 cm and 5–10 cm forest floor sample depths on similar site types in either the forest or clearcut. However, the forest floor moisture content in the clearcuts was higher than in the analogous forest for a similar forest floor depth.
- The CFFWIS derived from on-site weather station data accurately predicted DMC on the subhygric forest under the observed conditions; it did not, however, predict DMC in the mesic forest or in the subhygric or mesic cutblocks.
- Duff consumption was accurately predicted using the PFP, when a DMC value corresponding to the actual moisture content of the forest floor in the clearcut was used as the input.
- These ecosystems are quite adapted to fire, with most of the original understorey vascular species re-establishing quite readily after the burn.
- Conifers, deciduous trees, shrubs, and herbs dominated the site 10 years after it was burned. An increase and then a decrease were observed in the cover and height of shrubs and herbs as the planted spruce seedlings occupied the site.
- The number of vascular plants species increased over time, partially due to an increase in the number of weedy invasive species. Most of the species originally present on the site re-established by resprouting. Some of the small species with delicate root systems were not observed again after the fire.
- The germination of long-lived buried seeds of some shrub and herb species was evident. Although all shrubs of seed-bank origin were perennials, seed bank origin herbs were short-lived annuals or biennials (e.g., *Corydalis sempervirens* and *Geranium bicknellii*) and perennials (e.g., *Carex* sp.)

4.2 Management Implications

- The CFFWIS, which was developed to predict forest floor moisture conditions in forests, would require modification to accurately predict fire effects in cutblocks of the type sampled in this study. When accurate DMCs were used as inputs, the PFP worked well to predict forest floor consumption.
- Burns of this severity (22% duff consumption) on this type of site (Hybrid white spruce – Devil's club) will control understorey vegetation sufficiently to allow for successful reforestation if the sites are planted immediately.
- Burning can promote biodiversity by stimulating the germination of long-lived, seed-bank species (which may be lost from sites if not burned) and by providing substrates for new species.
- Severe burns should be avoided, however, as they can promote the establishment of invasive weedy species.

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