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Succession after Slashburning in an Engelmann Spruce–Subalpine Fir Subzone Variant: West Twin Site

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Forest Science Program

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ABSTRACT

This study was undertaken to determine the successional development after a slashburn of known severity on an Engelmann Spruce–Subalpine Fir (ESSF) biogeoclimatic zone site. Herbaceous and shrubby vegetation composition, cover, and height were monitored along with the growth of planted spruce seedlings for 11 years in 30 permanent sample plots. Fire effects were determined using depth-of-burn pins to measure forest floor consumption and fuel assessment triangles to measure fuel loading and consumption following a microplot approach. Fire weather conditions were determined using standard methods outlined in the Canadian Forest Fire Weather Index System.

The fire on this site was quite severe and consumed 52% of the organic layer. The consumption of such a high percentage of the forest floor favoured establishment of invasive species. Regrowth of some native forest species was quite slow. This may be attributable to the severity of the conditions on the site after burning (e.g., poorer in nutrients, more extreme temperature fluctuations). Planted conifer establishment was quite successful and growth fairly rapid; this may have restricted the growth of understorey species.

Eleven years after burning, the site was dominated by small spruce trees, aspen, *Vaccinium membranaceum, Menziesia ferruginea, Epilobium angustifolium, Cornus canadensis, Calamagrostis canadensis,* and *Polytrichum* sp. Burning increased the number of native species on the site by stimulating the germination of buried seeds of shade-intolerant plants. Fire favoured species such as *Vaccinium membranaceum* over other shrubs such as *Menziesia ferruginea*. Most of the native vascular plants on this site were sufficiently adapted to survive burning so that at least some individuals survived and resprouted. Species of open forests such as *Cornus canadensis*, which are well adapted to open, dry environments with high levels of sunlight, proliferated in the open cutblock, whereas *Gymnocarpium dryopteris*, a shade-adapted fern, declined in cover. For many years, *Epilobium angustifolium* was the dominant herb. Fire also led to the loss of some shallowly rooted species such as *Lycopodium annotinum* and establishment by new species, including *Salix* and *Populus*, which are important for wildlife. Most of the forest mosses did not survive burning and had not re-established by year 11.

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1 INTRODUCTION

1.1 Background

Sustainable forest management relies on an understanding of the short- and long-term effects of harvesting and site preparation on forest vegetation. Clearcutting and slashburning have been widely practised in British Columbia, and are known to facilitate planter access, seedling growth, and vegetation control on some sites (Hamilton and Yearsley 1988).

Post-fire vegetation succession has been described in numerous western coniferous forests (Cattelino et al. 1979; Kercher and Axelrod 1984). Many of the early studies and the more geographically extensive studies assessed succession indirectly through a chronosequence approach (Dix and Swan 1971; Foote 1983), whereas studies that documented succession on permanent quadrats (e.g., Dyrness 1973; Eis 1981; Halpern 1988, 1989) have tended to focus on only a few study sites.

Generalized successonal patterns in subalpine forests have been outlined (Arno et al. 1985). Post-fire development in the Engelmann Spruce–Subalpine Fir (ESSF) biogeoclimatic zone has been described for some individual sites (Parminter 1983; Dawson 1985; Ketcheson et al. 1985; Hamilton and Peterson 2003). Limited synthesis has been done for British Columbia.

Predictive models of forest vegetation succession are needed that will facilitate the integration of forest regeneration with wildlife habitat and biodiversity. Information on succession will also assist in the development of a seral classification within the biogeoclimatic ecosystem classification.

The study site described in this technical report is one of several in the ESSF where vegetation and planted conifer growth were monitored after clearcutting and slashburning. This study, however, is among very few in British Columbia to record slashburning severity, planted conifer growth, and both pre-burn and post-burn data for all vascular plant species in permanent plots over an 11-year period.

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 following prescribed burning;
2. to quantify and describe the growth and mortality of planted hybrid white spruce (*Picea engelmannii* × *glauca*) seedlings after prescribed burning; and
3. to quantify site conditions, including fire weather and forest floor moisture content, and fire effects, such as forest floor and slash consumption, at the time of burning.

1.3 Study Area

The West Twin study site is located in the Headwaters Forest District of the Southern Interior Forest Region in British Columbia, Canada, 10 km up the West Twin Forest Service road (Figure 1). The study area is situated at 1300 m elevation, on a south-facing, 37% slope, at 53°24′58″N, 120°34′18″W. The land encompasses Ziedler Forest Industries Ltd.'s cutting permit A15429, opening 93H 048 034 (also known as CP19-1).

The site is classified as a zonal site series (Subalpine fir – Oak fern – Brachythecium) within the Cariboo variant of the ESSF Wet Cool subzone (wk1) (DeLong 1996). Before logging, the forest was dominated by Engelmann spruce *(Picea engelmannii)* and subalpine fir *(Abies lasiocarpa)*. The dominant understorey species included *Menziesia ferruginea, Vaccinium* *membranaceum, Gymnocarpium dryopteris, Cornus canadensis, Streptopus lanceolatus,* and forest mosses, such as *Barbilophozia lycopodioides, Pleurozium schreberi,* and *Ptilium crista-castrensis.*

Parent material is colluvial with shale fragments. The site is mesic and mesotrophic, on a mid-slope position with some seepage areas. Soils are clay loams to sandy clay loams with 15–20% coarse fragment content. Soil type ranges from Orthic Ferro-Humic Podzols to Eluviated Dystric Brunisols, and the LFH layer is 3–8 cm thick.

The site was logged in the winter of 1987–1988 and burned on September 15, 1989 using helicopter drip torch ignition.

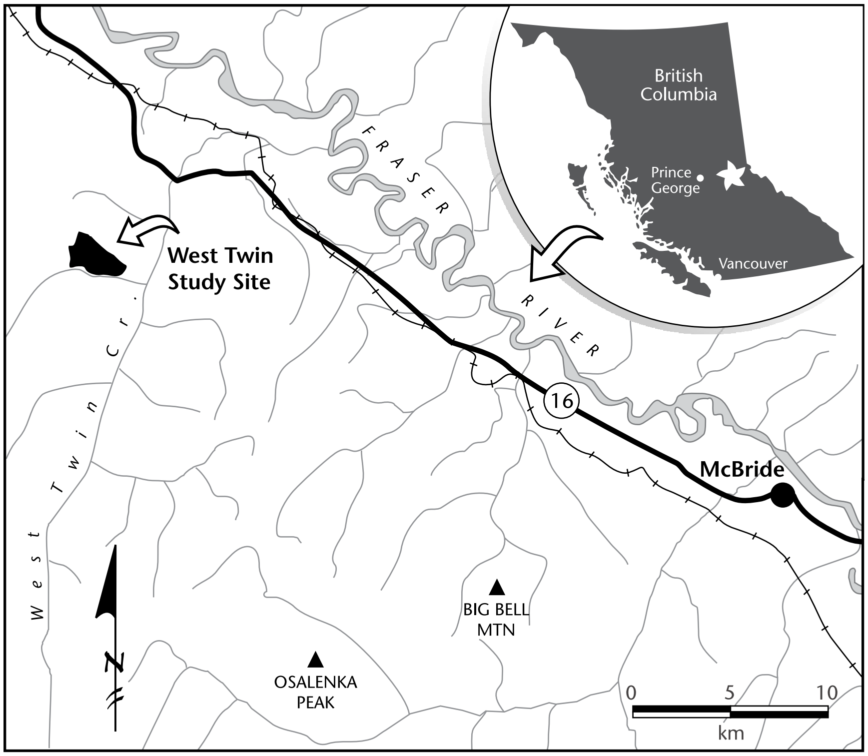

FIGURE 1 *Location of West Twin study site.*

2 METHODS

2.1 Fire Weather, Fuels, and Fire Effects

A standard fire weather station was established on the site on May 27, 1989. Weather information was used to calculate Canadian Forest Fire Weather Index System (CFFWIS) codes and indices (Van Wagner 1987). These included fire weather index (FWI), duff moisture code (DMC), drought code (DC), fine fuel moisture content (FFMC), and build up index (BUI).

Twenty 5 × 5 × 5 cm samples of the forest floor were collected from 0–5 and 5–10 cm depths in both the cutblock and adjacent forest immediately before burning on September 15, 1989. In the cutblocks, four samples were taken from each of the corners of five randomly selected plots. In the forest, samples were taken at regular intervals along a transect. Moss and litter were excluded from the samples. The thickness of the forest floor was recorded at each sample point. Samples were sealed in tin containers and weighed before and after drying to determine their moisture content and to compare predicted DMC to actual moisture content.

To determine fuel loading and consumption and forest floor thickness and consumption, three large fuel triangles were installed on the site following the standard methods described in the *Field Handbook for Prescribed Fire Assessments in British Columbia: Logging Slash Fuels* (Trowbridge et al. 1987). The diameter of fuels greater than 7 cm in diameter and the size class of fuels less than 7 cm in diameter (< 1, 1–3, 3–5, and 5–7 cm) were recorded where these fuels intersected the sides of the triangles. To monitor forest floor consumption, 10 depth-of-burn pins were installed along each side of each triangle (total of 90 pins in the large triangles) (Figure 2).

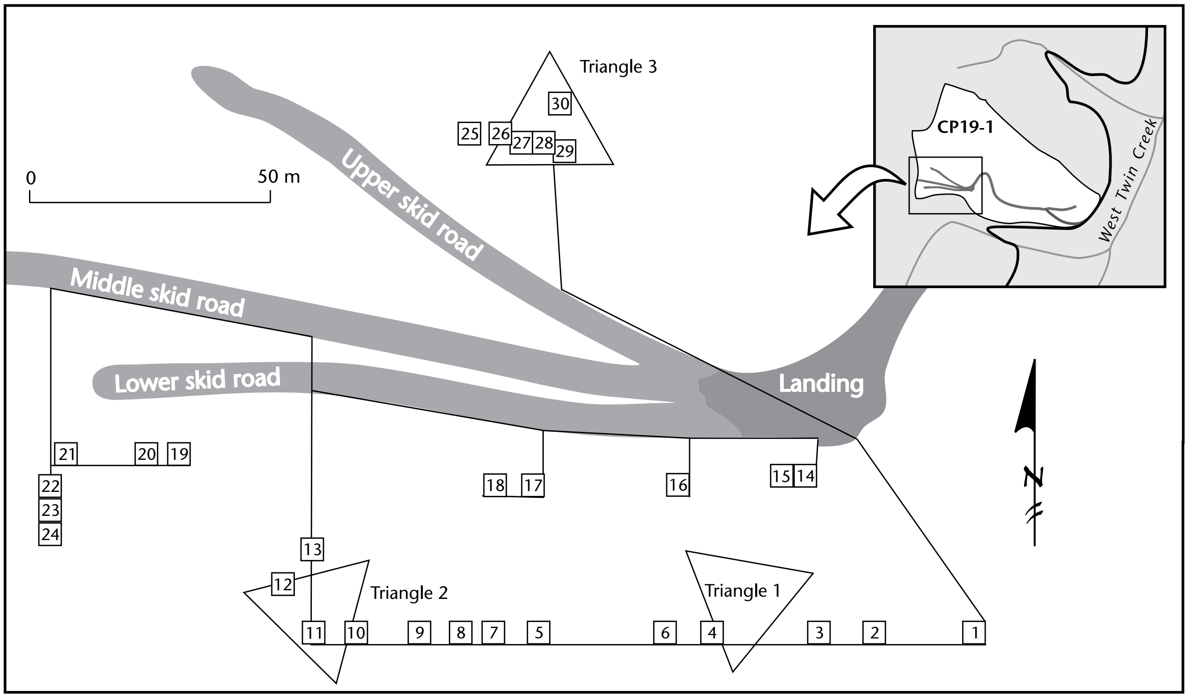

FIGURE 2 *Approximate layout of plots (squares) and fuel triangles (triangles) at the West Twin study site.*

Fuel loading, consumption, and depth of burn were also measured in the 30 vegetation monitoring plots (Hawkes 1986). Four line transects were established running upslope in each plot. The size class of fuels less than 7 cm in diameter and diameters of fuels greater than 7 cm were recorded following the standard method (Trowbridge et al. 1987). Six 50 × 100 cm samples of fine fuels (< 1 cm in diameter) were taken just before burning, with one sample collected from each plot corner and one from the plot centre. Samples were weighed and dried to determine moisture content.

Twenty depth-of-burn pins were used to determine duff thickness (i.e., forest floor minus litter layer) and consumption in each of the 30 plots for a total of 600 pins. Pins were established at 1 m grid points in the plots, except where the presence of stumps or rocks made this impossible. Litter depths were recorded and the forest floor depth was measured in two places.

Just before burning, four 25 × 25 cm samples of the total forest floor (down to mineral soil) were collected, one from each corner of five plots. Collected samples were weighed, dried, and reweighed to determine moisture content.

2.2 Vegetation

Thirty 5 × 5 m plots were established before burning (Figure 2). These plots were located subjectively along transects to encompass a range of fuel loadings. The use of transects aided in the re-location of plots. Cover and height of each vascular plant species were recorded in each plot in 1988 before burning, and after burning in 1990, 1991, 1992, 1994, and 2000 (years 1, 2, 3, 5, and 11). The mode of establishment (e.g., from buried seeds or resprouting) was recorded the year after burning. The origin of plants was determined by very gently excavating down around the plant to determine whether it originated from a buried seed or was a sprout from a pre-existing plant. Twenty-three of the 30 plots were remeasured in 2000. The remaining seven plots were not re-located.

2.3 Planted Conifers

From June 15 to 18, 1990, the 104 ha area below the lower skid road was planted at regular operational spacing (1000 stems per hectare, or 2.7-m spacing) with hybrid spruce (Sx) 2+0 PSB 313A (sowing request seedlot 8583). From July 14 to 21, 1990, the 145 ha area above the lower skid road was planted with Sx 1+0 PSB 313A (seedlot 8583). Drought conditions began after the July 1990 planting. In June 1994, 118 ha were fill-planted; in June 1995, 56.4 ha were replanted; and in June 1996, 5.4 ha were replanted. No brushing or weeding was done.

In June 1990, 200 seedlings (Sx 1+0 PSB 313A seedlot 8583) were planted directly into 10 monitoring plots that spanned the range of burn severities. The trees were planted at 1 × 1 m spacing in five rows, or 20 trees per plot. At the time of planting in 1990, seedling height and root collar diameter were recorded. These measurements were recorded again in 1991, 1992, and 1995. Crown length and breadth were measured in 1991, 1992, and 1995. In 2000, seedling cover and height were estimated in eight vegetation plots (Figure 2).

2.4 Data Analysis

Mean cover and height, and percent presence were determined for individual species and for growth forms (i.e., herbs, shrubs, conifers, and deciduous trees) for all sample plots. Standard error of the mean cover and height was calculated using least-squares estimates (see Appendix 1). Graphs were used to illustrate the changes in vegetation cover and height. Mean and standard error were calculated for seedling height and root collar diameter increment using Microsoft Excel® functions.

Averages, standard deviations, and standard errors were calculated for pre-burn litter depth, initial duff depth, and depth of burn in the plots and triangles using Excel functions. Weighted averages for these values were calculated by pooling data from triangles and plots. Values were weighted according to sample size (i.e., number of pins, or metres of line-intersect transect). Average forest floor moisture content and standard error of the mean were also calculated using Excel functions.

3 RESULTS

3.1 Fire Weather, Fuels, and Fire Effects

When the site was burned on September 15, 1989, the CFFWIS fire weather codes and indices according to the weather station based calculations were: FWI = 10, DMC = 17.6, DC = 222, FFMC = 89.9, and BUI = 29. At the time of ignition, the relative humidity was 40%, the air temperature was 12.6°C, and the wind speed was 4 m/s.

The moisture content of the 0–5 cm depth forest floor (duff layer) determined by gravimetric samples was 176.8% in the clearcut and 138.7% in the adjacent forest (Table 1). Using Lawson et al.'s (1997) DMC to duff moisture content conversion equations for Southern Interior British Columbia, this would correspond to a DMC of 12 in the clearcut and a DMC of 25 in the forest. The DMC indicated by fire weather station monitoring was 17.6, which translates to 161% moisture content using the Lawson et al. (1997) DMC to duff moisture content conversion equation. Although the forest floor in the cutblock and in the forest was slightly wetter than predicted by the fire weather station DMC, the difference was not significant ($p = 0.05$). The measured moisture content of the forest floor on this site corresponded fairly well to that predicted by the DMC (Table 1).

TABLE 1 *Duff moisture code (DMC) and corresponding duff moisture content, based on weather station values and gravimetric sampling of the clearcut and adjacent forest floor*

Method	**DMC**[a]	**Duff moisture content**
Fire weather station values	**17.6**[b]	161%
Gravimetric sampling of clearcut forest floor (0–5 cm layer) *n* = 20	12 (1.6–29)[c]	**176.8%** **SE[d] = 25.4** **95% cl[e] = 126.5–227.1%**
Gravimetric sampling of adjacent forest floor (0–5 cm layer) *n* = 20	25 (12–42)[c]	**138.7%** **SE = 20.6** **95% cl = 97.9–179.5%**

a The relationship between duff moisture content (MC) and DMC, based on the Lawson et al. 1997 equation derived for Southern Interior British Columbia, is
$MC = \exp[(DMC-223.9)/-41.7] + 20$

b Values in **bold** were measured; others are predicted values.

c Numbers in brackets are the range of DMCs that correspond to the 95% confidence limits around the measured forest floor moisture content.

d SE = standard error of the mean.

e 95% confidence limits around MC.

TABLE 2 *Pre-burn litter depth, initial duff depth, depth of burn, and percent duff consumption, and pre-burn woody fuel loading, consumption, and percent consumption*

	Forest floor (duff)				Woody fuels[a]		
Method	**Pre-burn litter depth (cm)**	**Initial duff depth (cm)**	**Depth of burn (cm)**	**Duff consumption (%)**	**Pre-burn fuel load (kg/m^2)**	**Woody fuel consumption (kg/m^2)**	**Woody fuel consumption (%)**
Triangles[b] and plots (weighted average)	1.1[b]	5.7[b]	3.07[b] SE = 0.02	54[b]	15.2[c]	8.0[c]	53[c]
Triangles (average)		5.5[d]	2.9[d] SE = 0.158	52.7[d]	11.72[e]	5.6[e]	48[e]
Plots (average)	SE = 0.0137	5.8[f]	3.1[f] SE = 2.7	53.5[f] SE = 1.5	17.0[g] SE = 4.13	9.3[f]	54.7[f]
Plots (range)		3.5–24.5	1.7–7.5	19.8–100	1.8–120.6	1.7–68.4	

[a] Source: M.C. Feller, unpublished report.
[b] Based on weighted average of triangles and plots (n = 571 pins).
[c] Based on weighted average of triangles and plots (n = 870 m line-intersect transect).
[d] Sample size (n) = 90 pins.
[e] Sample size (n) = 270 m line-intersect transect.
[f] Sample size (n) = 481 pins.
[g] Sample size (n) = 25 plots each with 20 m of line-intersect transect, for a total of 600 m of sample line.

The average initial duff depth was 5.7 cm and pre-burn litter depth was 1.1 cm. The site was completely burned. The average depth of burn calculated from the small plots was 3.07 cm and remaining duff depth was 2.6 cm (Table 2).

Average pre-burn woody fuel loading was 15.2 kg/m^2 and consumption was 53%. Woody fuel loading in the large triangles was 11.7 kg/m^2 and average fuel consumption was 5.6 kg/m^2, or 48%. The average woody fuel loading in the 30 vegetation plots was 17.0 kg/m^2 and average fuel consumption was 9.3 kg/m^2, or 54.7%. Total fuel loading in plots ranged from 1.8 to 120.6 kg/m^2 and fuel consumption ranged from 1.7 to 68.4 kg/m^2 (M.C. Feller, unpublished data).

Actual duff consumption (54%) was only slightly higher than that predicted by the Prescribed Fire Predictor (PFP) (45–50%) for a site with 5–10 cm duff layer on a 36–45% slope when the DC = 222. The PFP uses the CFFWIS to predict fire effects. Total woody fuel consumption (53%) was higher than that predicted by the PFP (25–30%) (Muraro 1975) (Table 3). The under-prediction of woody fuel consumption could be because the fuels were actually drier than predicted by the CFFWIS. Fuel loads were also very high on this site and this may have contributed to the high consumption observed here.

TABLE 3 *Actual and predicted duff and woody fuel consumption, and predicted mineral soil exposure using weather station and gravimetric data with the Prescribed Fire Predictor (Muraro 1975)*

	Duff consumption (%)		Mineral soil exposure (%)		Woody fuel consumption (%)	
Method	Predicted[a]	Actual	Predicted[a]	Actual[b]	Predicted[a,c]	Actual[d]
Based on weather station DMC (DMC = 17.6) DC = 222 duff = 5–10 cm	50	54 SE = 0.0017; n = 571; range = 19–100%[d]	30	N/A	25	53 (48[e]–67[f])
Based on equivalent DMC (eDMC) derived from gravimetric sampling in clearcut		54				53 (48[e]–67[f])
Mean eDMC = 42	50	54	40	N/A	30	53 (48[e]–67[f])
Lower 95% confidence limit, or eDMC = 36	50	54	40	N/A	30	53 (48[e]–67[f])
Upper 95% confidence limit, or eDMC = 48	50	54	40	N/A	30	53 (48[e]–67[f])

a Based on Prescribed Fire Predictor (PFP) (Muraro 1975).
b Not available: mineral soil exposure was not measured.
c Predicted consumption of fuels < 22 cm in diameter.
d Actual consumption of all woody fuels.
e Based on fuel sampling along large triangles.
f Based on fuel sampling in vegetation monitoring plots.

3.2 Vegetation Response

3.2.1 Changes in species abundance and vegetation structure Before burning, 6 shrub, 13 herb, and 8 bryophyte species were present on the site. By 2000 (year 11), 10 shrub, 30 herb (including plants identified only to family or genus), and 3 bryophyte species were present; however, post-burn bryophyte sampling was not done in a sufficiently rigorous manner to be conclusive and, therefore, more species may have been present on site by year 11.

All above-ground components of the existing vegetation were consumed by the fire. The shrub and herb species that were originally present on the site re-established and new shrub and herb species colonized the site. Initially, herbs dominated the site after burning. Bryophytes established gradually. Shrubs, herbs, planted spruce trees, and invading deciduous species increased in cover and height over time. Herb cover appeared to decline after 1994 as deciduous and conifer tree cover increased. Deciduous trees grew taller faster than the planted conifers (Table 4; Figures 3 and 4).

Eleven years after burning, the site was dominated by small spruce trees, aspen, *Vaccinium membranaceum*, *Menziesia ferruginea*, *Epilobium angustifolium, Cornus canadensis*, and grasses, including *Calamagrostis canadensis* and *Polytrichum* sp. (Figures 5, 6, and 7). Although present before burning, most

TABLE 4 *Vegetation cover and occurrence, pre-burn and 1, 2, 3, 5, and 11 years post-burn (original number of plots = 30)*

	Mean cover (%)						Percent presence					
Species	**1988**	**1990**	**1991**	**1992**	**1994**	**2000**	**1988**	**1990**	**1991**	**1992**	**1994**	**2000**
Trees												
Picea engelmannii × *glauca*	0.107				0.823	5.110	17				57	87
Abies lasiocarpa	0.240					0.030	17					26.1
Populus tremuloides			0.093	0.080	0.303	1.750			20	23	33	47.8
Populus balsamifera		T				T						4.35
Total trees	0.347		0.093	0.080	1.126	1.780						
Shrubs												
Menziesia ferruginea	9.100	0.067	0.207	0.147	0.323	1.270	93	33	30	47	53	65.2
Vaccinium membranaceum	3.280	0.517	0.880	0.340	0.757	3.260	93	83	87	87	80	91.3
Ribes lacustre	0.607	**0.047**	**0.283**	0.143	0.183	0.490	30	**43**	**43**	40	37	39.1
Rubus parviflorus	0.400	1.117	**1.523**	1.930	1.740	0.810	7	13	**27**	43	33	52.2
Lonicera involucrata	0.367	0.103	0.200	0.333	0.117	0.240	10	7	3	3	7	8.7
Ribes laxiflorum	0.003	**0.013**	**0.727**	0.160	0.237	0.220	3	**13**	**57**	50	60	56.5
Rubus idaeus		**0.080**	**0.490**	0.490	0.687	0.710		**40**	**33**	37	47	56.5
Sambucus racemosa		**0.163**	**1.670**	0.720	0.863	0.550		**77**	**83**	73	70	60.9
Sorbus scopulina		0.017	0.033	0.020	0.020	0.170		3	3	7	7	8.7
Vaccinium ovalifolium		0.003			0.003			3			3	
Ribes sp.		**0.013**						**13**				
Salix sp.			0.067	0.040	0.167	1.740			10	13	13	21.7
Total shrubs	13.757	2.140	6.080	4.323	5.097	9.460						
Herbs												
Gymnocarpium dryopteris	16.067	0.157	0.687	0.810	0.680	1.530	100	77	80	77	80	95.7
Cornus canadensis	6.067	4.690	11.000	9.900	20.533	27.910	100	100	100	100	100	95.7
Streptopus lanceolatus	3.677	0.800	0.623	1.023	0.950	0.670	100	100	47	40	90	91.3
Rubus pedatus	1.320	0.093	0.297	0.140	0.103	0.170	93	50	43	30	30	34.8
Clintonia uniflora	1.267	0.160	0.233	0.200	0.423	1.160	97	83	60	40	70	73.9
Epilobium angustifolium	0.043	8.020	30.033	32.333	31.500	9.040	13	97	100	100	100	95.7
Tiarella unifoliata ssp. *trifoliata*	0.070	0.067	0.397	0.247	0.047	0.030	40	23	33	37	33	26.1
Tiarella unifoliata ssp. *unifoliata*	0.063	0.143	0.270	0.103	0.047	0.060	33	43	40	33	33	26.1
Veratrum viride	0.170	0.150	0.183	0.367	0.133	0.110	7	7	7	7	7	13
Dryopteris expansa	0.143		0.017	0.003	0.037		20		3	3	10	
Galium triflorum	0.007		0.020	0.020	0.003		7		7	7	3	
Lycopodium annotinum	0.007						7					
Equisetum arvense	0.003	0.333	0.333	1.000	0.567	0.740	3	3	3	3	7	8.7
Equisetum scirpoides		0.100	1.700	2.003	1.350	0.020		3	10	10	10	4.35
Carex sp.		0.003	0.217	0.103	0.063	0.040		3	13	17	23	21.7
Athyrium filix-femina	0.003	0.050	0.050	0.040	0.030		3	7	7	10	13	
Epilobium ciliatum		0.007	0.040	0.117	0.047	T		7	10	20	17	4.35
Poaceae		1.667	2.167	3.000	1.337	1.830		3	3	3	7	8.7
Streptopus amplexifolius		0.003		0.003				3		3		
Anaphalis margaritacea			0.033	0.050	0.097	0.940			3	7	30	82.6
Castilleja sp.			0.033						3			
Aster conspicuus			0.007						3			
Asteraceae			0.017						3			
Viola sp.			0.007	0.003					3	3		
Unknown				0.007	0.003					7	3	
Calamagrostis canadensis				0.033	0.020	2.200				3	7	13
Hieracium albiflorum					0.017	0.250					17	82.6
Hieracium sp.					0.007	0.030					7	13
Arnica latifolia					0.010	0.020					7	4.35

TABLE 4 *(Continued)*

	Mean cover (%)						**Percent presence**					
Species	**1988**	**1990**	**1991**	**1992**	**1994**	**2000**	**1988**	**1990**	**1991**	**1992**	**1994**	**2000**
Herbs *(continued)*												
Senecio triangularis					0.017	0.050					3	8.7
Taraxacum officinale					0.023	0.010					10	8.7
Cirsium sp.					0.010	T					10	4.35
Juncus sp.					0.003	T					3	4.35
Phleum sp.					0.003	T					3	4.35
Calamagrostis rubra						0.150						8.7
Caltha leptosepala						T						4.35
Actaea rubra						T						4.35
Onopordum sp.						T						4.35
Orthilia secunda						T						4.35
Total herbs	28.904	16.396	48.364	51.515	58.070	46.990						
Bryophytes												
Barbilophozia lycopodioides	10.693						93					
Pleurozium schreberi	8.737	0.003					100	3				
Ptilium crista-castrensis	7.420						100					
Dicranum sp.	1.977	0.007					93	7				
Hylocomium splendens	0.333						10					
Brachythecium hylotapetum	0.003						3					
Rhytidiadelphus triquetrus	0.020						20					
Polytrichum commune	0.003					0.430	3					4.35
Marchantia polymorpha		0.043	0.187	0.240	0.033	0.040		30	33	33	3	4.35
Racomitrium sp.		0.003	0.003					3	3			
Polytrichum sp.			0.007		0.733	3.700			3		7	17.4
Total bryophytes	29.186	0.056	0.197	0.240	0.766	4.170						

of the original forest mosses and *Lycopodium annotinum* were burned off. *Dryopteris expansa* and *Galium triflorum* were present before burning and reappeared after burning, but were not observed in year 11.

Most of the species that established or re-established on the site increased in cover and frequency of occurrence over time. *Rubus pedatus, Tiarella unifoliata*, *Gymnocarpium dryopteris,* and *Streptopus lanceolatus* declined in cover after burning and had not recovered to pre-burn levels by year 11. A few species (e.g., *Vaccinium ovalifolium, Castilleja* sp., *Viola* sp., and *Aster conspicuus*) were recorded only in one or two plots after the site was burned. It is not clear whether these species were truly ephemeral or whether they were missed during subsequent sampling (Table 4).

3.2.2 Individual species response

Planted spruce seedlings Tree seedling survival in the plots was 85.5% (172 of 200 seedlings survived) in 1995. At the time of planting, average seedling height was 17.9 cm, with an average root collar diameter of 2.34 mm. By 1995, average height was 43.7 cm and average root collar diameter was 11.5 mm (Table 5.) Figure 6 illustrates the size of planted tree seedlings on the site in 2000.

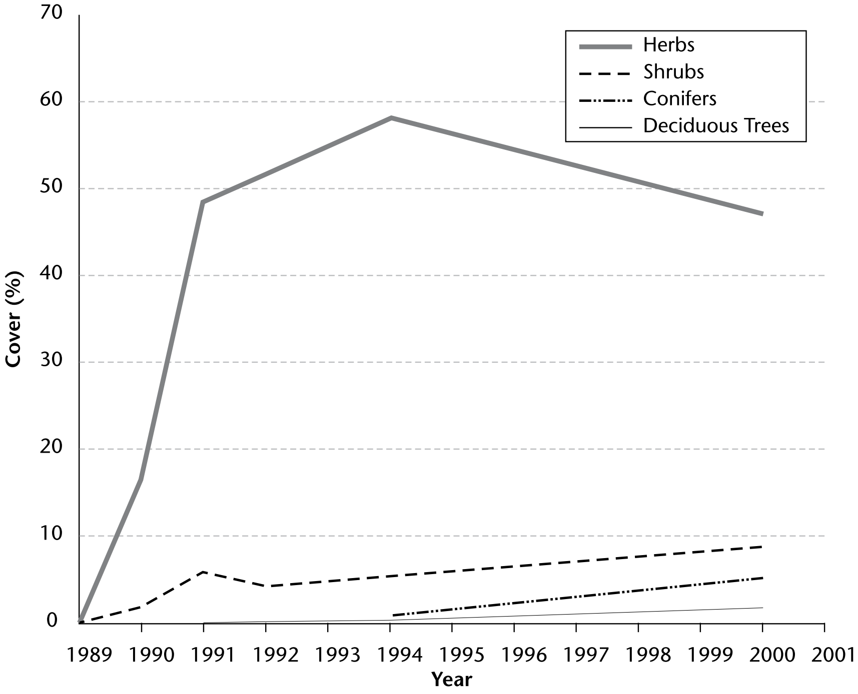

FIGURE 3 *Total tree, shrub, and herb cover after burning at the West Twin study site.*

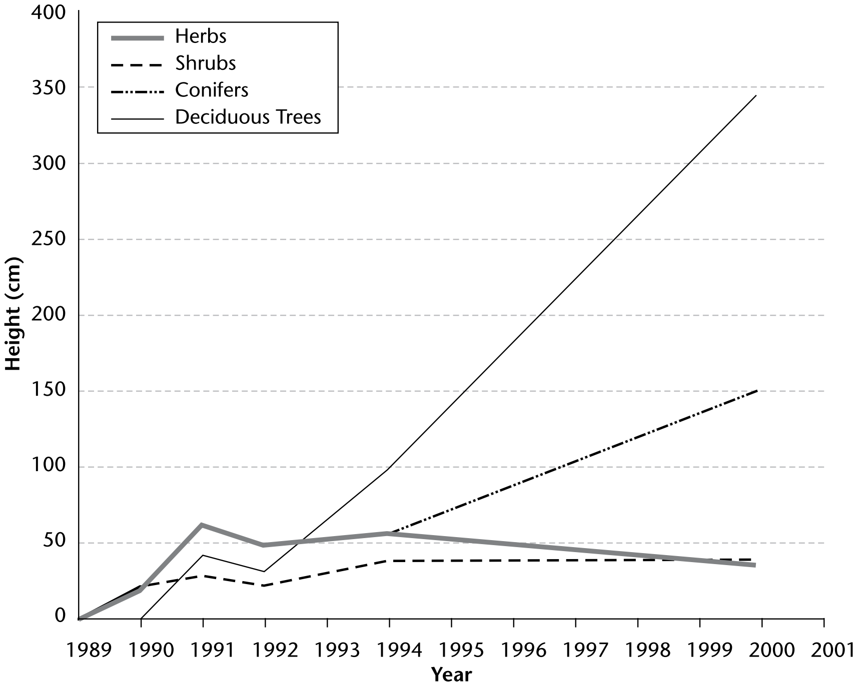

FIGURE 4 *Tree, shrub, and herb height after burning at the West Twin study site.*

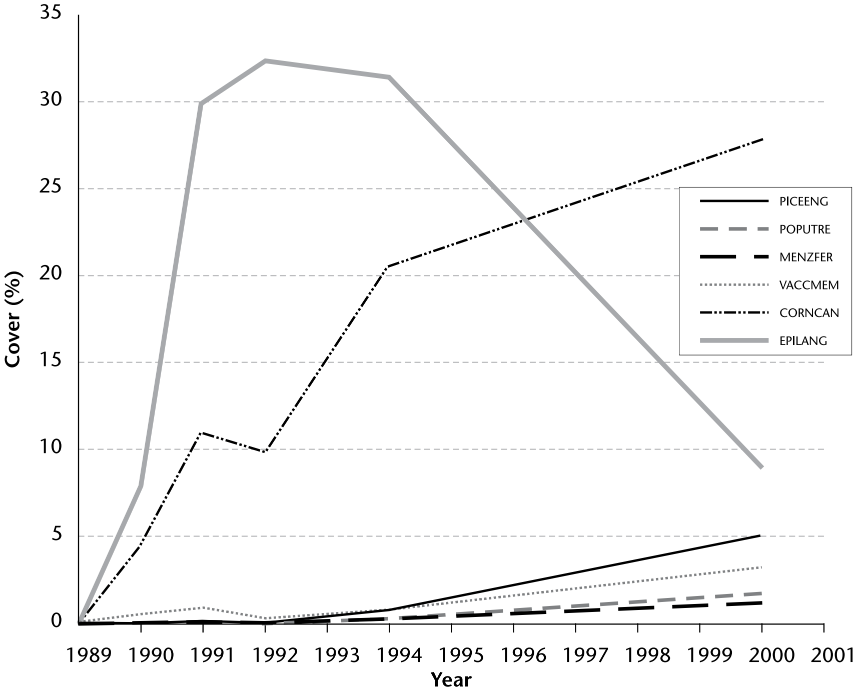

FIGURE 5 *Change in percent cover of selected species at the West Twin study site.*

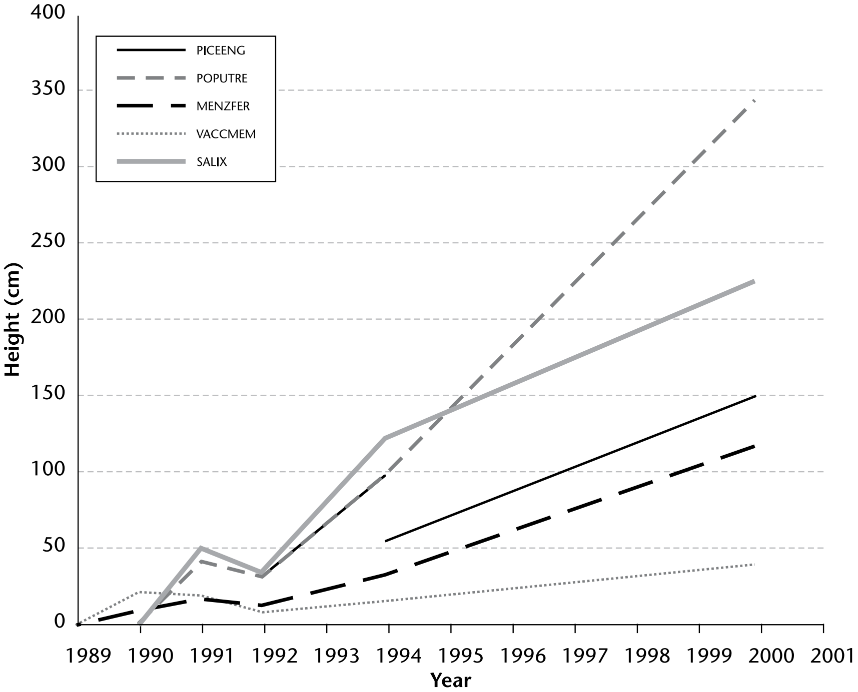

FIGURE 6 *Change in height of selected trees and shrubs at the West Twin study site.*

TABLE 5 *Seedling size at time of planting (1990), 1995, and 2000*

Year	**n**	**Mean seedling height (cm) ± SE**	**Mean seedling root collar diameter (mm) ± SE**
1990 (time of planting)	200	17.94 ± 1.9	2.34 ± 0.58
1995	172	43.66 ± 2.1	11.5 ± 0.64
2000		Approx. 150[a]	

[a] In 2000, seedling height was estimated in the vegetation plots, but individual trees were not remeasured.

Deciduous trees and shrubs *Populus balsamifera* and *Salix* sp. were the primary deciduous trees on the site after burning. *Populus tremuloides* appeared to establish initially from wind-dispersed seed and then expanded into new plots over time, likely by suckering. It was observed in almost half of the plots by the year 2000, was about 3.5 m tall, and had an average cover of 1.75% (Table 4; Figures 5 and 6). *Salix* sp. also established from off-site seeds and was first observed 2 years after the site was burned. It was growing in over 20% of the plots by year 11, was about 2.25 m tall, and had a mean cover of 1.74% (Table 4; Figure 6).

Menziesia ferruginea and *Vaccinium membranaceum* were observed in 93% of the plots before burning. *Menziesia ferruginea* resprouted in about one-third of these plots the year after burning and gradually re-established in additional plots. By year 11, it was noted in 65% of the plots. Although by year 11 *M. ferruginea* had achieved a height comparable to its height before burning (i.e., over 1 m), its cover was lower (Table 4; Figures 5 and 6). *Vaccinium membranaceum* resprouted in most of these plots the year after burning and increased in cover over time. By year 11, it had established in 91% of the plots, it was about 40 cm tall, and its cover was comparable to that observed before burning (3.2%) (Table 4; Figures 5 and 6). *Lonicera involucrata* was found in 10% of the plots before burning. It resprouted in most of these plots 1 year after burning. By year 11, its cover was similar to that observed before burning (i.e., < 0.5%). No seedlings of any of these three species were observed after burning (Table 4).

Sambucus racemosa, Rubus idaeus, and *Sorbus scopulina* were not evident in any plots before burning; however, the first year after burning, germinants from buried seeds of the first two species were found in 77% and 40% of the plots, respectively. Successive sampling indicated that many germinants died after the first year. By year 11, *S. racemosa* was present in 56% of plots and was, on average, 50 cm tall; *R. idaeus* was present in 61% of the plots and was, on average, 25 cm tall. *Sorbus scopulina* occurred in 8.7% of the plots (Table 4).

Although parent plants of *Ribes laxiflorum* and *Rubus parviflorus* were observed only in one or two plots before burning, germinants from buried seeds were noted in about one-half of the plots by year 11. Both species increased in presence over time. By year 11, both species were about 30 cm tall. *Ribes lacustre* was present in 30% of the plots before burning. It resprouted and established from buried seed in additional plots over time. It was over 40 cm tall and present in 39% of the plots by year 11 (Table 4).

Herbs Most of the herbaceous species that were originally present resprouted after the site was burned. *Rubus pedatus* was found in 93% of the plots initially, was not observed for a few years after burning in over one-half of these plots, and was present in 30% of the plots by year 5. *Gymnocarpium dryopteris* and *Tiarella unifoliata* ssp. *trifoliata* resprouted in most plots on which they occurred before burning. Cover of both of these species remained low. *Cornus canadensis,* which was found in all the plots with significant cover before burning, resprouted in all the plots and increased in cover by year 11 to become a prominent component of the site (Figure 5). *Streptopus lanceolatus* and *Clintonia uniflora* declined in presence for a few years after the fire, then increased in presence. *Veratrum viride* resprouted in all plots. No seedlings of any of these species were observed after burning (Table 4).

Epilobium angustifolium, which was present with low cover and frequency before burning, established in all plots by year 2 and was a dominant species on the site for many years. By year 5, *E. angustifolium* had declined in cover as the site became occupied by conifers, deciduous trees, and tall shrubs (Table 4; Figure 5).

Although *Carex* sp. were not evident before burning, germinants of seedbank origin were observed in over 20% of the plots by year 11. A number of new invasive herb species, including *Anaphalis margaritacea, Cirsium* sp., *Hieracium albiflorum, Taraxacum* sp., *Onopordum acanthium,* and *Calamagrostis canadensis* and other grasses, established from off-site seed sources. These species continued to establish over time (Table 4).

Bryophytes Most of the forest bryophytes originally observed in the site did not survive the fire and were not evident by year 11. *Marchantia polymorpha, Racomitrium* sp., and *Polytrichum* sp. were not observed in the original forest, but were found in some plots after burning (Table 4).

4 DISCUSSION

4.1 Relationship between Fire Weather Indices, Forest Floor Moisture Content, and Fuel Consumption

This was a very severe burn. It consumed over one-half of the duff layer and woody fuels—considerably more woody fuel consumption than predicted by the PFP. Duff and woody fuel consumption levels were higher than those found on other monitored slashburns (Hamilton and Peterson 2003). This is likely due to the heavy fuel loads observed on this site.

Although commonly used to predict fire hazard related to slashburning, the CFFWIS was developed to predict moisture content in the forest floor in mature forests. In this case, good agreement was observed between predicted and actual duff moisture content when Lawson et al.'s (1997) equation for southern British Columbia was used to convert DMC to duff moisture content.

The fuel loading was particularly high on this site, and since duff moisture levels appeared to be close to those expected, it is likely that the high fuel loads contributed to the higher-than-expected woody fuel consumption.

FIGURE 7 *Photos of the site post-burn,* Ⓐ *year 1,* Ⓑ *year 2,* Ⓒ *year 5, and* Ⓓ *year 11, after burning.*

4.2 Response of Vegetation Community to Burning

Because most of the native vascular plants on this site were sufficiently adapted to survive burning, at least some individuals survived and resprouted. These plants either have deeply buried rhizomes that can survive fires or have buried seed that germinates after burning (Haeussler et al. 1990; U.S. Department of Agriculture 2006). Species of open forests (e.g., *Cornus canadensis*), which are well adapted to open, dry environments with high levels of sunlight, proliferated in the open cutblock, whereas *Gymnocarpium dryopteris,* a shade-adapted fern, declined in cover. *Vaccinium membranaceum* appeared to tolerate burning somewhat better than *Menziesia ferruginea*, likely because of differences in the resilience of its rhizomes to burning; however, *M. ferruginea* appeared to grow faster than *Vaccinium membranaceum* and was taller by year 11. *Lycopodium annotinum* did not persist after burning, likely because it is very shallowly rooted and its spores and subterranean gametophytes are readily consumed by fire (Matthews 1993).

Most of the forest mosses did not survive burning and had not re-established by year 11. Bryophytes are shallowly rooted and are readily consumed by fires. Because they do not have long-lived seeds (as do vascular plants), bryophytes generally re-establish slowly (although some species, such as *Polytrichum* sp., colonize disturbed areas quite rapidly).

The fire on this site consumed 54% of the organic layer. The consumption of such a high percentage likely resulted in significant nutrient losses (Feller 1997), drying out of the LFH layer, and exposure of the mineral soil. These conditions favoured invasive weed species that are better adapted to more extreme conditions (e.g., poorer soil and hotter and drier conditions with fluctuating temperatures) than are native species. This site had more weedy species than other ESSF sites (Hamilton and Peterson 2003).

Regrowth of some species was quite slow. This may be attributable to the severity of the conditions on the site after burning. Also, the rapid establishment of planted conifers appeared to restrict the expansion of other species.

The ability of most native species found on the site to re-establish, either by resprouting or through germination from buried seeds after burning, suggests that these ecosystems experienced fires regularly in the past. The fact that viable buried seeds of plants that were not present above ground were fairly common on the site demonstrates that some native species have seeds that are viable for long periods of time.

5 CONCLUSIONS

The main conclusions of this study are as follows:

- Burning increased the number of native species on the site by stimulating the germination of buried seeds of shade-intolerant plants.
- Fire favoured species such as *Vaccinium membranaceum* over other shrubs such as *Menziesia ferruginea*.
- Most of the native vascular plants on this site were sufficiently adapted to survive burning; therefore, at least some individuals survived and resprouted.
- Species of open forests (e.g., *Cornus canadensis*), which are well adapted to open, dry environments with high levels of sunlight, proliferated in the

open cutblock, whereas *Gymnocarpium dryopteris*, a shade-adapted fern, declined in cover.
- For many years, *Epilobium angustifolium* was the dominant herb.
- Fire also led to the loss of some shallowly rooted species, such as *Lycopodium annotinum*, and the establishment of new species, including *Salix* and *Populus,* which are important for wildlife.
- Most of the forest mosses did not survive burning and had not re-established by year 11.
- Regrowth of some native forest species was quite slow.
- The consumption of a high percentage of the forest floor favoured the establishment of invasive species.
- Planted conifer establishment was quite successful and growth was quite rapid.
- Eleven years after burning, the site was dominated by small spruce trees, aspen, *Vaccinium membranaceum, Menziesia ferruginea, Epilobium angustifolium, Cornus canadensis, Calamagrostis canadensis,* and *Polytrichum* sp.

5.1 Management Implications

The main management recommendations that can be drawn from this study are:

- Better tools are needed to predict fire effects on cutblocks.
- Fire has a role in maintaining the diversity of native species; however, it can lead to the loss of some shallowly rooted native species.
- Severe burns can encourage weedy species establishment and should be avoided.
- Burning encouraged the establishment of berry-producing shrubs, which are highly valued by wildlife, as well as *Salix* and *Populus* species, which provide wildlife forage.
- Even though the fire was very severe, conifer establishment appeared to have been successful.

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APPENDIX 1 Means and standard errors for species cover based on least-squares estimates

	Mean cover (%)					
Species	**1988**	**1990**	**1991**	**1992**	**1994**	**2000**
Trees						
Picea engelmannii × glauca	0.107 ± 0.49				0.823 ± 0.49	5.11 ± 0.56
Abies lasiocarpa	0.240 ± 0.071					0.03 ± 0.081
Populus tremuloides			0.093 ± 0.348	0.080 ± 0.348	0.303 ± 0.348	1.75 ± 0.37
Populus balsamifera		T				T
Total trees	**0.347 ± 0.495**		**0.093 ± 0.495**	**0.080 ± 0.495**	**1.127 ± 0.495**	**1.78 ± 0.566**
Shrubs						
Menziesia ferruginea	9.10 ± 0.50	0.067 ± 0.502	0.207 ± 0.502	0.147 ± 0.502	0.323 ± 0.502	1.27 ± 0.57
Vaccinium membranaceum	3.28 ± 0.43	0.517 ± 0.43	0.880 ± 0.43	0.340 ± 0.43	0.757 ± 0.43	3.26 ± 0.49
Ribes lacustre	0.607 ± 0.141	0.047 ± 0.141	0.283 ± 0.141	0.143 ± 0.141	0.183 ± 0.141	0.487 ± 0.161
Rubus parviflorus	0.400 ± 0.652	1.12 ± 0.652	1.52 ± 0.652	1.93 ± 0.652	1.74 ± 0.652	0.81 ± 0.734
Lonicera involucrata	0.367 ± 0.216	0.103 ± 0.216	0.200 ± 0.216	0.333 ± 0.216	0.117 ± 0.216	0.24 ± 0.245
Ribes laxiflorum	0.003 ± 0.080	0.013 ± 0.080	0.727 ± 0.080	0.160 ± 0.080	0.237 ± 0.080	0.22 ± 0.0915
Rubus idaeus		0.080 ± 0.191	0.490 ± 0.191	0.490 ± 0.191	0.687 ± 0.191	0.71 ± 0.216
Sambucus racemosa		0.163 ± 0.181	1.670 ± 0.181	0.720 ± 0.181	0.863 ± 0.181	0.55 ± 0.207
Sorbus scopulina		0.017 ± 0.069	0.033 ± 0.069	0.020 ± 0.069	0.020 ± 0.069	0.17 ± 0.072
Vaccinium ovalifolium		0.003 ± 0.002			0.003 ± 0.002	
Ribes sp.		0.013 ± 0.003				
Salix sp.			0.067 ± 0.577	0.040 ± 0.577	0.167 ± 0.577	1.74 ± 0.608
Total shrubs	**13.76 ± 1.19**	**2.14 ± 1.19**	**6.08 ± 1.19**	**4.32 ± 1.19**	**5.10 ± 1.19**	**9.45 ± 1.36**
Herbs						
Gymnocarpium dryopteris	16.07 ± 0.96	0.157 ± 0.96	0.687 ± 0.96	0.81 ± 0.96	0.68 ± 0.96	1.53 ± 1.09
Cornus canadensis	6.07 ± 2.56	4.690 ± 2.56	11.00 ± 2.56	9.90 ± 2.56	20.53 ± 2.56	27.91 ± 2.90
Streptopus lanceolatus	3.68 ± 0.36	0.800 ± 0.36	0.623 ± 0.36	1.023 ± 0.36	0.95 ± 0.36	0.67 ± 0.41
Rubus pedatus	1.32 ± 0.101	0.093 ± 0.101	0.297 ± 0.101	0.14 ± 0.101	0.103 ± 0.101	0.17 ±0.116
Clintonia uniflora	1.27 ± 0.314	0.160 ± 0.314	0.233 ± 0.314	0.20 ± 0.314	0.423 ± 0.314	1.16 ± 0.355
Epilobium angustifolium	0.043 ± 2.42	8.02 ± 2.42	30.03 ± 2.42	32.33 ± 2.42	31.50 ± 2.42	9.04 ± 2.77
Tiarella unifoliata ssp. *trifoliata*	0.070 ± 0.079	0.067 ± 0.079	0.397 ± 0.079	0.247 ± 0.079	0.047 ± 0.079	0.03 ± 0.09
Tiarella unifoliata ssp. *unifoliata*	0.063 ± 0.048	0.143 ± 0.048	0.270 ± 0.048	0.103 ± 0.048	0.047 ± 0.048	0.06 ± 0.055
Veratrum viride	0.170 ± 0.165	0.150 ± 0.165	0.183 ± 0.165	0.367 ± 0.165	0.133 ± 0.165	0.11 ± 0.188
Dryopteris expansa	0.143 ± 0.035		0.017 ± 0.035	0.003 ± 0.035	0.037 ± 0.035	
Galium triflorum	0.007 ± 0.009		0.020 ± 0.009	0.020 ± 0.009	0.003 ± 0.009	
Lycopodium annotinum	0.007 ± 0.002					
Equisetum arvense	0.003 ± 0.545	0.333 ± 0.545	0.333 ± 0.545	1.000 ± 0.545	0.567 ± 0.545	0.74 ± 0.622
Equisetum scirpoides		0.100 ± 0.978	1.70 ± 0.978	2.00 ± 0.978	1.35 ± 0.978	0.02 ± 1.116
Carex sp.		0.003 ± 0.052	0.217 ± 0.052	0.103 ± 0.052	0.063 ± 0.052	0.04 ± 0.059
Athyrium filix-femina		0.003 ± 0.026	0.050 ± 0.026	0.050 ± 0.026	0.040 ± 0.026	0.03 ± 0.030
Epilobium ciliatum		0.007 ± 0.046	0.040 ± 0.046	0.117 ± 0.046	0.047 ± 0.046	T
Poaceae		1.67 ± 1.67	2.17 ± 1.67	3.00 ± 1.67	1.337 ± 1.67	1.83 ± 1.89
Streptopus amplexifolius		0.003 ± 0.002		0.003 ± 0.002		
Anaphalis margaritacea			0.033 ± 0.130	0.050 ± 0.130	0.097 ± 0.130	0.94 ± 0.14
Castilleja sp.			0.033 ± 0.014			
Aster conspicuus			0.007 ± 0.003			
Asteraceae			0.017 ± 0.007			
Viola sp.			0.007 ± 0.003	0.003 ± 0.003		
Unknown				0.007 ± 0.002	0.003 ± 0.002	
Calamagrostis canadensis				0.033 ± 0.69	0.020 ± 0.69	2.20 ± 0.79
Hieracium albiflorum					0.017 ± 0.022	0.25 ± 0.025
Hieracium sp.					0.007 ± 0.007	0.03 ± 0.008
Arnica latifolia					0.010 ± 0.008	0.02 ± 0.009

Appendix 1 (Continued)

	Mean cover (%)					
Species	**1988**	**1990**	**1991**	**1992**	**1994**	**2000**
Senecio triangularis					0.017 ± 0.015	0.05 ± 0.018
Taraxacum officinale					0.023 ± 0.007	0.01 ± 0.008
Cirsium sp.					0.010 ± 0.003	T
Juncus sp.					0.003 ± 0.002	T
Phleum sp.					0.003 ± 0.001	T
Calamagrostis rubra						0.15 ± 0.048
Caltha leptosepala						T
Actaea rubra						T
Onopordum sp.						T
Orthilia secunda						T
Total herbs	**28.9 ±**	**16.4 ±**	**48.4 ±**	**51.5 ±**	**58.1 ±**	**47.0 ± 4.73**
Bryophytes						
Barbilophozia lycopodioides	10.7 ± 0.87					
Pleurozium schreberi	8.7 ± 0.54	0.003 ± 0.54				
Ptilium crista-castrensis	7.4 ± 0.73					
Dicranum sp.	2.0 ± 0.12	0.007 ± 0.12				
Hylocomium splendens	0.33 ± 0.11					
Brachythecium hylotapetum	0.003 ± 0.001					
Rhytidiadelphus triquetrus	0.02 ± 0.003					
Polytrichum commune	0.003 ± 0.14					0.43 ± 0.16
Marchantia polymorpha		0.043 ± 0.06	0.19 ± 0.06	0.24 ± 0.06	0.033 ± 0.06	0.04 ± 0.07
Racomitrium sp.		0.003 ± 0.002	0.003 ± 0.002			
Polytrichum sp.			0.007 ± 0.64		0.73 ± 0.64	3.70 ± 0.73
Total bryophytes	**29.2 ± 2.06**	**0.06 ± 2.06**	**0.20 ± 2.06**	**0.24 ± 2.06**	**0.77 ± 2.06**	**4.17 ± 2.35**