RESEARCH REPORT

23

Response of Vegetation to Burning in a Subalpine Forest Cutblock in Central British Columbia: Otter Creek Site

Evelyn Hamilton and Les Peterson

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British Columbia

Ministry of Forests
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ABSTRACT

Vegetation development on a spring burn, fall burn, and unburned cutblock was monitored for 11 years after the site was burned. By year 11, the vegetation on the unburned site was dominated by subalpine fir, which survived the logging, shrubs, and herbs. The burned sites were dominated by herbs and shrubs. Vegetation on the burned sites was generally shorter than on the unburned site. Shrub cover was higher on the unburned site in year 11. Most of the species present prior to logging survived on the burned and unburned sites. *Vaccinium membranaceum, Menziesia ferruginea, Rhododendron albiflorum,* and *Epilobium angustifolium* were dominant species by year 11. More invasive early seral herb species were established on the burned treatment than on the unburned treatment by year 11 and therefore the species diversity was greater on the burned treatment compared with the unburned treatment by that time.

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INTRODUCTION

Prescribed burning has been widely used in British Columbia to facilitate reforestation on cutblocks. The implications of prescribed fire on the revegetation processes in these ecosystems are poorly known. Interest is increasing in managing forests in ways that more closely emulate natural disturbance regimes and ecological processes. More information on the role of fire in maintaining ecological processes in these systems is needed.

Post-fire succession depends on response of existing species, establishment of new species, plant growth rates, and the interaction between species. Establishment of new species from off-site sources is determined by many factors including the availability of seed sources and substrate conditions. Generalized successional pathways have been described for some montane and subalpine forests (Arno et al. 1985). Early successional vegetation development after forest sites were logged and site prepared have been described for some subalpine forests in British Columbia (Dawson 1985; Ketcheson et al. 1985).

Plant response to burning depends on the tolerance of species to burning and the timing and severity of the fire. The severity of the burn is influenced by the depth, type, and moisture content of the humus layer; the moisture content and type of fuels; and site conditions such as slope and weather conditions at the time of burning (e.g., wind speed, temperature, and humidity). Individual plant species tolerance is determined by the capacity to regenerate by vegetative or sexual means after a fire. Vegetative regeneration (e.g., root crown sprouting, root suckering) success is determined by the location of the buds and resprouting ability. Deeply buried buds will be more protected from consumption by burning or heat (McLean 1969). Resprouting ability varies with species and plant age and vigour. Species with sufficiently deeply buried seeds that are stimulated to germinate after a fire can successfully colonize a site (Bond and van Wilgen 1996).

The estimated fire return interval for stand-replacing fires in the subalpine forest ranges from 140 to over 500 years (D. Lloyd, pers. comm., 2003). We know relatively little about the tolerance of subalpine forest understorey species to fires of varying severity or about their mode of establishment after a disturbance. Little is known about the successional dynamics in the subalpine zone such as rates of regrowth of species and interactions among species and patterns of species replacement.

Re-establishment of trees after wildfires in the subalpine forest zone can be slower than at lower elevations and open shrub and meadows often persist for many years (Agee 1993). On a wet cold Engelmann Spruce–Subalpine Fir (ESSFwc2) subzone site, rhizomatous herbs such as *Valeriana sitchensis, Arnica latifolia,* and *Athyrium filix-femina* survived slashburning and resprouted; and pioneer species such as fireweed, *Luzula parvifolia,* and *Valhodea atropurporea* established from seed in the first growing season after burning (Appendix 1) (Lloyd et al. 1997; Miege and Lloyd 2000). Information about the basic autecology and means by which they re-establish after fire is available for many plant species that occur in the subalpine forests of British Columbia (Haeuessler et al. 1990; USDA 2001).

The seed bank in ESSFwc2 subzone sites contains a relatively large number of buried seeds, many of which may germinate after a site is logged. Mature forest and early successional species are both represented in the seed bank. Most of the seeds belong to the species that are most abundant on the site and are found in the top 3 cm of the forest floor (Yearsley 1993). This study was undertaken to determine the response of individual species in the wet cold variant of the Engelmann Spruce–Subalpine Fir biogeoclimatic zone (ESSFwc2) after the trees were harvested and the site burned. Prescribed burning was carried out in the spring and fall to attempt to provide different fire severities. Changes in vegetation composition and structure after burning were monitored. Tolerance of individual species to burning, as indicated by their presence and cover after burning, their mode of establishment or re-establishment after burning, and changes in their cover over time, were determined. Changes in height over time were determined for some shrub species. Plots were monitored for 11 years after site preparation treatment.

We hypothesized that the species in the ESSF would be more sensitive to fire than those in ecosystems where fire was more frequent. Because of the long interval between fires in the ESSF, the seed bank was not expected to contain as many viable seeds as would be the case in ecosystems that were burned more frequently. Post-fire growth rates were expected to be slower in the subalpine than at lower elevations due to cooler climatic conditions and short growing season. It was anticipated that the spring burn would be less severe than the fall burn, because the large fuels and forest floor were expected to be wetter in the spring. Differences in plant phenology at the time the site was burned in the spring versus fall burn treatments were expected to lead to varying rates of regrowth immediately after burning.

STUDY SITE DESCRIPTION AND SITE HISTORY

The study site is located at 1600 m elevation on a southeast-facing slope near Camp Six Creek on the Otter Creek Forest Road in the Clearwater Forest District in south-central British Columbia (Figure 1). It lies within the wet cold subzone variant of the Engelmann Spruce–Subalpine Fir biogeoclimatic zone (ESSFwc2) (Meidinger and Pojar [compilers and editors] 1991). The site, in a mid-slope position, is gently sloping and fairly smooth. Before logging, the site included approximately 175 stems/ha of Engelmann spruce and 681 stems/ha of subalpine fir over 2 m in height. Parent materials are morainal till. The soil moisture regime is predominantly subhygric, receiving seepage from upslope and remaining wet for much of the growing season. The forest floor on the site was approximately 4–7 cm thick. The site was classified as ESSFwc2/06 or Subalpine fir (Bl)–Valerian–Oak fern site association (Lloyd et al. 1990).

Total shrub cover before logging was about 50%. *Menziesia ferruginea*, *Ribes lacustre, Rhododendron albiflorum,* and two

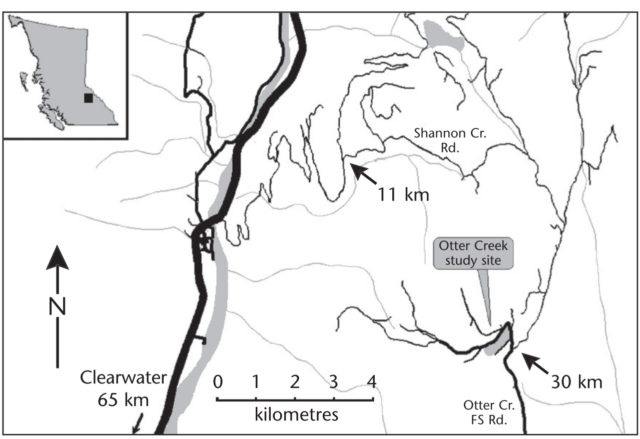

FIGURE 1 *Location of the Otter Creek study site.*

huckleberries *(Vaccinium membranaceum* and *Vaccinium ovalifolium)* accounted for 80% of the shrub cover in each treatment unit prior to logging. Total herb layer cover averaged 58% prior to logging. Oak fern *(Gymnocarpium dryopteris)* and *Sitka valerian (Valeriana sitchensis)* were the dominant species. The dominant bryophytes were *Brachythecium hylotapetum* and *Mnium glabrescens*.

When the site was logged in the winter of 1987/88, 1–2 m of snow covered the ground. This protected the vegetation, soil, and some of the residual trees from damage during logging. The burn treatments were done in the spring and fall of 1989. Spruce seedlings were planted operationally throughout the site in the summer of 1990, but not inside the 3 × 3 m sample plots established for vegetation monitoring. In addition, subalpine fir and pine trees were planted in experimental blocks in the different treatments in 1990 (Eberle 1996). Residual trees were evident on the unburned treatment.

METHODS

STUDY DESIGN

Plots were established on the study site in the summer of 1988, before logging in the winter of 1988/89. After the site was logged it was then divided into three treatment areas: spring burn, fall burn, and unburned control (Figure 2). The plots established before logging were monitored for 11 years after the site was site prepared. The number of plots in each treatment is not ultimately equal because the site was divided into treatment types after the plots were established and it was not always possible to divide the site into an equal number of plots in each treatment (because of limitations related to protecting plots during the burning treatments).

SAMPLE PLOTS

Sample plots (3 × 3 m) were located at 15-m intervals along five 150-m transects before logging (Figure 2). Initially, 15 plots in the unburned treatment unit were established but one was destroyed by road development, leaving 14 plots to monitor.

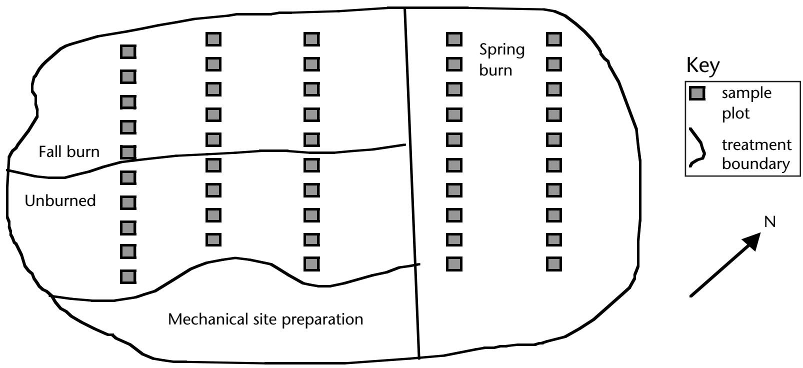

FIGURE 2 *Distribution of sample plots within the research site at Otter Creek.*

The spring burn and fall burn treatment areas contain 20 and 15 plots, respectively. Vegetation sampling was conducted in late July or August in 1988, 1990, 1991, 1992, 1994, and 2000 (i.e., pre-harvest and 1, 2, 3, 5, and 11 years after the site was burned). The spring burn plots were also sampled on August 17, 1989, just over 2 months after the site was burned.

Ocular estimates of the percentage cover of each plant species were recorded at each plot during each sampling period. Total vegetation and total shrub, herb, and moss cover were also estimated in some years. Measurements of average height were recorded for dominant shrub and herb species. For shrubs, height was measured on each sample date, while herb height measurements were recorded only during the pre-harvesting and 11-year post-treatment sampling.

During the first two post-treatment sampling sessions (1990 and 1991) the mode of establishment/re-establishment of each species was recorded whenever it could be determined. Establishment was categorized as "resprout" if new stems sprouted from existing plant structures, or as "seed" if post-treatment germination from seed was evident.

FIRE EFFECTS MONITORING

Forest floor and fuel consumption were determined using adaptations from standard methodologies (Trowbridge et al. 1987). Twelve depth-of-burn (DOB) pins were arranged in a grid pattern within each sample plot just prior to burning. The litter depth at each pin was measured before burning, and the depth of burn and remaining forest floor depth were recorded after burning. The forest floor consumption results are based on 218 pins in the spring burn and 168 in the fall burn.

Three fuel triangles (30 m per side) were used in each of the spring and fall burn treatments to determine pre-burn fuel loading and consumption in various size classes using a line intersect method (Trowbridge et al. 1987). Fuels less than 7 cm in diameter were classified as "fine fuels" and those greater than 7 cm were classed as "large fuels."

Standard fire weather variables were also recorded before and during the fires to document the fire weather indices at the two times the site was burned (Canadian Forestry Service 1987).

ANALYSIS/ANALYTICAL APPROACH

Because each site preparation treatment unit is replicated only once, interpretation of results is subject to a number of restrictions and assumptions. Since the study is pseudo-replicated (Hurlbert 1984), extrapolation of results to other locations is statistically inappropriate. Data were analyzed as if the plots were treatment replicates, rather than sub-samples of the treatment unit; plot locations were deemed random despite the standardized layout approach used. Given these assumptions, the design used was a split-plot ANOVA. Burn was the main-plot factor and time was the split-plot factor. Furthermore, the error term was modelled using the spatial power structure in PROC MIXED (SAS 2001). A confidence level of 95% ($\propto = 0.05$) was used as the measure of significance in all statistical tests.

Multi-Response Permutation Procedures (MRPP) in PC-ORD (McCune and Mefford 1999) were used to evaluate the similarities between the species composition in the three treatment areas prior to burning. The mean cover of individual species in each treatment area before treatment was also compared.

The PROC MIXED procedure in SAS was used to generate the post-burn vegetation statistics (SAS 2001). Contrasts were used to compare mean species cover in burn versus unburned and spring burn versus fall burn treatments. Contrasts were not done on species with low occurrence values (many zero cover values) because these statistics do not perform well under such conditions. Average cover of each species in each treatment was calculated using all plots, including plots that did not contain that species. Average height was calculated using only plots in which the species occurred.

PROC GENMOD (SAS 2001) was used to examine the percentage presence data (i.e., number of plots in which a species occurred). A logistic regression model was specified that allowed testing of differences in species presence between treatments during each sample year. Two contrasts were specified: one compared burned and unburned treatments and the other compared spring and fall burn treatments.

PROC MIXED was also used to compare the average forest floor depth before and after burning in the two burn treatments.

RESULTS

PRE-HARVEST CONDITIONS: COMPARISON OF TREATMENT AREAS

Analysis of the pre-harvest vegetation data with Multi-Response Permutation Procedures in PC-ORD showed that the plots in the three treatment areas were not significantly different in terms of species composition ($p = 0.15$). In few cases was there a significant difference in the cover of a species in the three treatment areas prior to the application of the treatment. All of the plots were considered to belong to the same plant association (D. Meidinger, pers. comm., 2001).

The pre-burn forest floor depth was not significantly different between the spring burn (4.75 cm) and fall burn (5.61 cm) treatments ($p = 0.4116$) (Table 1).

EFFECTS OF BURNING ON FOREST FLOOR

The spring burn was carried out on June 7, 1989, and the fall burn on September 12, 1989. Both the spring and fall burns were considered low-severity fires. Fire weather indices suggested that the forest floor and fuels were drier at the time of the spring burn (FWI = 10) than during the fall burn (FWI = 4) (Table 1). Air temperature was 16°C, relative humidity was 40%, and winds were negligible on June 7, 1989. On September 12, 1989, air temperature was 17°C, relative

TABLE 1 *Characteristics of the spring and fall burns sampled in this study*

Treatment variables	Treatment	
	Spring burn	Fall burn
Logging date	Winter 1988/1989	Winter 1988/1989
Slashburn date	June 7, 1989	Sept. 12, 1989
Conditions at the time of burning		
Temperature (°C)	16	17
Relative humidity (%)	40	53
Wind speed (km/h)	1	11
Fine fuel moisture code (FFMC)	91	85
Duff moisture code (DMC)	28	8
Drought code (DC)	60	38
Initial spread index (ISI)	5	4
Build up index (BUI)	28	10
Fire weather index (FWI)	10	4
Pre-burn fuel (slash) loading (kg/m^2)	10.7	14.2
Pre-burn forest floor depth in cm (x ± s.e.)	4.75 ± 0.686	5.61 ± 0.596
Conditions after burning		
Total fuel (slash) consumption (kg/m^2)	1.6	3.4
Percentage of total fuels (slash) consumed	15	24
Percentage of large fuels (>7 cm) consumed	16	8
Forest floor (duff) remaining in cm (x ± s.e.)	3.48 ± 0.526	5.03 ± 0.474
Depth of burn in cm (x ± s.e.)	1.18 ± 0.173	0.58 ± 0.596
Percentage of forest floor (duff) burned	24.9	10.4
Percentage of pins with DOB = 0 cm	14.2	47.6

humidity was 53%, and winds were about 11 km/h (Table 1).

The spring burn consumed more of the forest floor (24.9% of 4.75 cm) than did the fall burn (10.4% of 5.61 cm); however, the fall burn removed twice as much of the large fuels (3.4 kg/m^2 or 16% of 10.7 kg/m^2) as did the spring burn (1.6 kg/m^2 or 8% of 14.2 kg/m^2). Both fires removed about 60% of the fine fuel. Although most of the surface of the forest floor was blackened by both fires, nearly one-half of the pins in the fall burn showed no measurable duff reduction, compared with only 14% of the spring burn pins (Table 1).

RESPONSE OF PLANT COMMUNITY TO FOREST CANOPY REMOVAL AND SLASHBURNING

General pattern of revegetation on the unburned and burned treatment

On the unburned site the post-harvest plant community was initially dominated by *Menziesia ferruginea*, *Rhododendron albiflorum, Vaccinium membranaceum,* and *Vaccinium ovalifolium,* with *Valeriana sitchensis, Gymnocarpium dryopteris, Tiarella unifoliata,* and other species below the taller shrubs. The *Abies lasiocarpa* advanced regeneration not killed by the winter logging became the dominant vegetation by year 11. *Menziesia* and *Rhododendron* remained the leading shrubs, with less cover of *Vaccinium* spp. *Valeriana sitchensis* increased in cover for about 5 years and then declined. *Athyrium filix-femina, Gymnocarpium dryopteris,* and other herbs persisted, with only small changes in cover over the 11-year period. The impact of burning on these species was still evident 11 years later (Tables 2 and 3; Figures 3–5; Appendix 2).

On the fall burn area, the understorey was initially dominated by *Menziesia ferruginea, Vaccinium membranaceum, Vaccinium ovalifolium,* and *Rhododendron albiflorum* with *Valeriana sitchensis, Gymnocarpium dryopteris,* and *Tiarella unifoliata.* After the site was burned, *Epilobium angustifolium* proliferated and was the dominant vegetation cover for over 5 years before declining. *Gymnocarpium dryopteris* recovered and increased in cover rapidly. *Streptopus lanceolatus* increased in cover and then declined. Over time *Vaccinium membranaceum* became a dominant shrub on this treatment, along with

TABLE 2 *Mean cover of plants found at Otter Creek, pre-logging and during subsequent sampling sessions in the unburned, spring burn, and fall burn treatments*

	Treatment	Unburned (n=14)						Spring Burn (n=20)						Fall Burn (n=15)					
	Year	Pre-logging	1 1990	2 1991	3 1992	5 1994	11 2000	Pre-logging	1 1990	2 1991	3 1992	5 1994	11 2000	Pre-logging	1 1990	2 1991	3 1992	5 1994	11 2000
	Species code																		
Tree layer	ABIELAS	9.93	4.92	5.25	6.67	8.55	20.53		0.25	0.25	0.05	0.10	0.15	4.60					
	PICEENG	1.51	2.19	2.20	1.32	1.52	1.06	0.80	0.35	0.35	0.10	0.15	1.29	1.43					0.63
Shrub layer	MENZFER	24.32	22.3	25.0	15.2	14.26	20.28	20.50	1.98	2.10	1.30	2.03	5.40	21.33	2.20	3.30	3.21	3.73	7.87
	VACCMEM	11.03	11.7	14.4	8.24	7.67	6.81	8.65	3.08	4.86	2.20	3.90	10.35	10.87	3.38	7.13	5.63	5.27	13.53
	VACCOVA	6.24	6.53	8.46	3.99	4.46	5.67	7.95	0.90	3.05	0.79	1.68	2.75	11.13	2.43	4.57	1.83	3.40	4.60
	RHODALB	11.34	4.05	5.02	3.84	3.84	8.20	19.80	0.81	1.73	0.95	1.43	3.10	6	1.61	2.44	1.97	2.07	3.67
	RIBELAC	2.55	5.64	6.20	6.70	4.72	6.15	0.95	0.26	0.55	0.28	0.41	0.46	3.20	0.56	1.53	0.94	1.14	1.20
	SAMBRAC1	0.36	1.44	1.43	2.14	0.71	0.36		1.03	4.02	1.73	2.38	1.23		0.12	3.70	1.27	1.03	0.67
	SORBSIT							0.50	0.20	0.20	0.05	0.25	0.25	0.40		0.13	0.07	0.03	0.13
	RUBUIDA								0.05	0.30	0.16	0.21	0.11			0.20	0.13	0.23	0.20
	RUBUPAR					0.04	0.36												
	RIBELAX											0.03							
	SALIX												0.26						0.01
	RIBES		0.01																
Herb layer	EPILANG	0.14	2.19	1.44	2.54	1.93	3.96		1.96	25.45	29.9	25.90	9.35		0.37	11.20	25.53	25.40	10.27
	GYMNDRY	25.56	23.1	25.1	22.37	31.90	21.33	28.75	1.30	4.78	2.45	3.75	5.25	26.33	11.70	14.67	14.47	16.21	16.13
	VALESIT	11.40	25.4	22.5	24.94	29.94	11.30	15.05	9.06	14.55	8.53	10.08	9.53	17.07	13.60	17.87	17.47	15.07	13.33
	ATHYFIL	4.68	7.72	6.56	5.06	4.23	3.62	1.85	1.25	1.40	1.25	1.28	0.93	4	3.60	4.47	2.53	2.27	1.87
	TIARTRI2	4.70	25.5	15.2	9.37	5.60	2.86	8.15	3.58	5.53	2.28	2.61	2.53	7.20	6.13	15.13	6.30	5.90	3.73
	CLINUNI	1.35	1.47	2.05	3.70	2.45	1.43	2.30	0.23	0.78	0.48	1.20	1.68	2.13	0.61	2.97	2.13	4.13	2.87
	ARNICOR	1.57	3.79	3.46	1.96	1.25	0.25	3.66	4.38	8.23	1.73	3.20	4.46	0.22	1.33	4.40	1.57	2.21	1.07
	STRELAN	6.51	7.67	9.69	9.12	8.75	5.59	6.30	1.14	7.65	3.65	7.65	6.05	6.20	6	12.07	15.20	18.60	11.40
	VIOLGLA	2.67	3.17	2.01	2.14	2.31	1.26	1.01	0.36	1.46	0.55	0.51	0.63	2.28	2.01	3.73	2.40	2.73	2.40
	CALACAN	0.04	0.25	1.07	0.51	0.51	0.43	0.01		0.33	0.28	0.28	0.30		0.27	1.93	2.40	2.67	3.01
	MITEBRE	2.24	2.94	3.33	1.52	1.09	1.20	2.31	0.53	1.29	1.50	1.81	1.98	2.03	1.69	4.73	4.07	5.93	5.13
	VERAVIR	2.45	4.17	3.68	4.37	4.42	4.69	2.25	1.40	2.53	2.05	1.90	2.55	4.47	7.47	8.67	7.53	6.27	7.47
	LUZUPAR	0.01	0.07		0.07	0.03	0.01	0.01	0.19	0.73	0.58	0.96	0.65	0.22	0.78	0.20	0.15	0.45	0.94
	OSMOBER	0.01	0.43	0.29	0.11	0.16		0.11	0.05	0.25	0.08	0.05	0.09	0.12	1.07	2.67	0.74	0.13	0.15
	RUBUPED	3.31	1.53	3.53	2.06	2.17	1.20	1.05				0.03	0.08	1.07	0.47	0.90	0.41	0.78	0.81
	DRYOEXP	0.62	2.75	1.77	0.69	0.62	0.41	0.65						1.47	1.60	1.53	0.41	0.47	0.33
	POACEAE				0.04	0.04		0.06	0.78	0.85	0.85	0.69	0.56		0.50	0.13	0.11	0.21	0.34
	HIERALB		0.01	0.14	0.04	0.01	0.07			0.50	0.09	0.83	0.71				0.01	0.02	0.27
	CAREX		0.01						0.66	1.15	0.48	0.48	0.15		0.01	0.73	0.41	0.23	0.37
	PLATANT							0.06	0.01		0.01	0.01	0.01	0.01	0.05	0.11	0.01	0.01	0.07
	EPILCIL	0.01	0.07						0.04	2.65	0.27	0.04				0.37	0.01	0.01	0.01
	SENETRI					0.01	0.15				0.01	0.15	0.34		0.07	0.47	0.20	0.40	0.20

	GALITRF	0.01	0.21	0.21	0.03	0.07								0.13		0.03	0.01	0.03	0.07
	TIARTRI1	0.09	0.72	0.72			0.13	0.20		0.01		0.01	0.01	0.41					
	STREAMP				0.07	0.03								0.33	0.53	1.87	0.43	0.20	0.20
	ANAPPUL1									0.06	0.16	0.77	1.67			0.03	0.07	0.33	0.93
	PLATSTR											0.01	0.01	0.03	0.07	0.07	0.07	0.04	0.07
	EPILOBI								0.01	1.30					0.07	2.67	0.03	0.01	
	HERAMAX	0.07	0.29	0.36	0.36	0.72	0.71												
	HIERACI								0.01	0.20	0.03	0.20	0.16						0.01
	LISTCOR	0.21	0.10	0.07		0.01		0.12						0.05					
	VIOLORB					0.04	0.04					0.18	0.25					0.11	0.13
	MITELLA										0.03	0.05	0.05				0.27	0.47	0.27
	ARNILAT					0.04	0.07						0.05					0.47	0.70
	CAREAEN								0.25	0.75	0.26	0.16	0.03						
	MITEPEN									0.10	0.15	0.15	0.10						
	PEDIBRA	0.15						0.05				0.01	0.25						
	VIOLA									0.10	0.07	0.04	0.09						
	MAIARAC		0.04												0.03			0.01	
	EQUIARV												0.08					0.01	1.20
	LUPINUS								0.01			0.03	0.15						
	ORTHSEC	0.01												0.03					
	TARAXAC										0.03	0.03							
	LYCOANN														0.01	0.01			
	BROMCIL												0.03						0.07
	CIRSIUM														0.01				
	GEOCLIV		0.04																
	ASTERAC												0.05						
	BROMUS																		0.13
	LUPIARC												0.10						
	MITENUD								0.15										
	ANTEANA																		0.40
Moss layer[a]	BRACHYL	20.88						33.86						21					
	RHIZGLA	11.76						4.61						10.40					
	BARBLYC	4.98						1.95						5.48					
	DICRPOL	0.22						3.50						1.13					
	MARCPOL							0.01						0.40					
	PLEUSCH							0.86						0.80					
	POLYJUN							0.25						0.07					
	RHYTROB	0.71						0.36						0.07					
Totals[a]	HERBS	46.96	69.6	82.06	66.21	72.84	49.54	62.50	23.50	68.50	55	64	73.65	63.67	36.67	79.33	73	72	71
	MOSSES	38.55						45.40						39.35					
	SHRUBS	50.08	41.8	54.36	36.86	34.36	47.58	52.65	7	14.75	5.85	10.50	24.25	48.67	11.29	20.67	13.60	15.13	37.33

a Sampling of the moss layer was done only in 1988 (pre-logging). Note that *Arnica cordifolia* and *Arnica latifolia* are listed separately in this table, but are not differentiated for this discussion.
See Appendix 1 for full plant names.

Menziesia and *Rhododendron* (Tables 2 and 3; Figures 5–7; Appendix 2).

On the spring burn sites it took longer for species other than fireweed *(Epilobium angustifolium)* to establish or recover after burning. Fireweed remained the leading species for over 5 years, after which *Vaccinium, Menziesia,* and *Rhododendron* became dominant. *Vaccinium membranaceum* appeared to be favoured somewhat over other shrubs by the more severe spring burn (Tables 2 and 3; Figures 5, 8, and 9; Appendix 2).

Changes in total shrub and herb cover over time on the burned and unburned treatment

Total shrub cover was the same in all treatment blocks before logging. After logging, shrub cover was lower in the burned plots than in the unburned plots in all post-treatment years. No difference between shrub cover in the spring versus fall burn plots was observed until year 11, when the cover in fall burn plots was greater ($p = 0.05$) (Table 2).

Total herb cover was slightly lower in the unburned treatment area compared with the burned treatment areas prior to logging ($p = 0.02$). Total herb cover in the spring and fall burn areas was comparable pre-burn. After logging, herb cover increased in all treatments and remained comparable in all treatments in most years. By year 11, the herb cover in the burned area was higher than that in the unburned treatments ($p = 0.002$) (Table 2).

Species diversity and floristic composition

The number of species in the areas that received different treatments was similar prior to logging (i.e., 27–31 species). More species were observed in the two burned treatments areas 11 years after burning (42 in the spring burn and 41 in the fall burn), compared with the unburned treatment (30). New species included weedy invasives such as *Hieracium albiflorum*, *Cirsium*, and species such as *Carex aenea* that were stimulated to germinate from buried seed (Table 2).

Orthilia secunda disappeared from the site after logging and *Listera cordata* was lost from the burned plots, persisting only in the unburned treatment.

Response of Individual Plant Species to Forest Canopy Removal and Slashburning

Conifers

Subalpine fir *(Abies lasiocarpa)* Subalpine fir was observed in 43% (6) of the unburned and 33% (5) of the fall burn plots prior to logging (Table 3). Some stems survived the winter harvesting treatment but few survived in the burn treatments. Subalpine fir trees were observed in one spring burn plot in year 11, but not in any fall burn plots. Subalpine fir persisted in the six unburned plots and established in an additional four unburned plots. Fir was more frequently found in unburned plots compared with burned plots in all years ($p < 0.006$) (Table 3). By year 11, trees had an average height of about 4 m and cover of 20% in the unburned plots and were a significant component of the vegetation (Figures 3–5).

In a separate study on this site, Eberle (1996) reported better diameter and volume growth of subalpine fir trees planted in small experimental plots in the burned site than in the unburned site after 5 years, but reported no difference in seedling height.

Engelmann spruce *(Picea engelmannii)* Engelmann spruce was recorded in 14% (2) of the unburned plots, 20% (3) of the fall burn plots, and 10% (2) of the spring burn plots prior to logging (Tables 2 and 3). It was eliminated from the burn treatment plots when they were burned. Spruce seedlings were planted throughout the treatment units after logging or logging and burning, but not within the vegetation monitoring plots. For the first 3 years after sites were treated, spruce was of minor significance. By year 11, it was recorded in 29% of the unburned plots, 75% of the spring burn plots, and 60% of the fall burn plots. Spruce was less frequent in unburned plots compared with burned plots in all years ($p < 0.01$) (Table 3). By year 11, spruce cover was just under 1% and not significantly different in different treatments ($p = 0.82$). The cover would have been due to spruce tree foliage that overtopped the sample plots, originating from trees rooted outside of the plots and possibly some natural regeneration (Figures 3–5). Average tree height on unburned plots was about 2 m compared with 54 cm on the burned treatments by year 11.

Eberle (1996) noted that the spruce seedlings planted in

TABLE 3 *Frequency of occurrence[a] of plants at Otter Creek, pre-logging and during subsequent sampling sessions in the unburned, spring burn, and fall burn treatments*

	Treatment	Unburned (n=14)						Spring Burn (n=20)						Fall Burn (n=15)					
	Year	Pre-logging	1	2	3	5	11	Pre-logging	1	2	3	5	11	Pre-logging	1	2	3	5	11
	Species code																		
Tree Layer	ABIELAS	6	6	6	6	10	10		1	1	1	1	1	5					
	PICEENG	2	5	5	5	7	4	2	1	1	1	1	15	3					9
Shrub Layer	MENZFER	14	14	14	14	14	14	19	14	12	17	17	17	14	7	12	13	14	15
	RHODALB	7	6	8	7	8	8	18	12	13	13	14	14	5	4	7	4	5	5
	VACCMEM	13	13	13	13	13	13	19	19	20	20	20	20	13	12	15	15	15	15
	VACCOVA	11	13	13	14	13	13	19	9	15	16	16	16	15	9	11	13	14	14
	RIBELAC	9	10	11	11	11	11	3	2	7	5	7	8	7	8	7	9	10	12
	SAMBRAC1	1	2	1	1	1	1		14	15	16	13	12		8	7	8	6	4
	SORBSIT							1	1	1	1	1	1	2		1	1	1	1
	RUBUIDA								1	2	3	5	3			1	2	3	2
	RUBUPAR					1	1												
	RIBELAX											1							
	SALIX												2						1
	RIBES		1																
Herb Layer	EPILANG	1	4	3	5	7	8		16	20	20	20	20		9	10	14	14	13
	GYMNDRY	14	14	14	14	14	14	19	16	16	17	16	18	15	13	14	14	15	15
	VALESIT	14	14	14	14	14	14	19	14	13	15	19	18	14	14	15	15	13	15
	ATHYFIL	7	7	7	7	8	7	2	2	3	2	3	4	8	5	6	7	7	7
	TIARTRI2	12	14	14	14	14	13	20	18	19	19	19	19	14	14	15	15	15	13
	CLINUNI	8	7	8	8	9	8	9	7	8	8	9	10	6	7	7	7	7	7
	ARNICOR	6	5	6	8	5	2	10	14	14	13	17	18	7	6	9	9	10	7
	STRELAN	14	14	14	14	14	14	20	17	19	20	20	20	15	14	15	15	15	15
	VIOLGLA	9	10	11	10	8	8	9	9	12	9	9	10	10	11	12	13	11	12
	CALACAN	2	2	3	3	3	2	1	0	2	2	2	2		1	3	3	2	3
	MITEBRE	12	13	14	14	13	11	16	8	15	15	16	17	9	9	12	12	12	12
	VERAVIR	12	12	12	13	13	13	12	10	12	13	14	14	13	12	13	13	13	13
	LUZUPAR	1	1		1	4	2	2	6	8	8	13	17	5	5	2	5	8	10
	OSM0BER	2	4	2	2	5		4	1	2	2	2	4	5	9	8	9	7	5
	RUBUPED	5	5	7	6	7	8	6				2	3	5	2	3	3	5	4
	DRYOEXP	5	6	5	5	4	4	3						5	5	4	5	5	4
	POACEAE				1	2		2	3	2	4	8	9		2	1	3	3	4
	HIERALB		1	1	1	2	1			4	6	12	14				1	3	6
	CAREX		1						6	7	9	7	4		1	2	4	7	5
	PLATANT							2	1		2	1	1	2	3	4	2	1	1
	EPILCIL	1	1						3	17	13	3	0			2	2	1	1
	SENETRI					1	2				2	3	7		2	2	2	2	2

	GALITRF	1	1	1	1	1								1		1	1	1	2
	TIARTRI1	5	3	2			1	4		1		2	1	3					
	STREAMP				1	1								2	4	8	7	3	2
	ANAPPUL									2	5	12	15			1	1	2	6
	PLATSTR											2	1	1	1	1	1	2	2
	EPILOBI								2	5					3	1	1	1	
	HERAMAX	1	1	1	1	1	1												
	HIERACI								2	2	2	2	4						1
	LISTCOR	2	2	2		1		5						4					
	VIOLORB					2	1					6	5					3	2
	MITELLA										1	1	1				2	2	2
	ARNILAT					1	1						1					1	6
	CAREAEN								1	1	2	2	2						
	MITEPEN									1	1	1	1						
	PEDIBRA	1						1				1	2						
	VIOLA									1	5	4	4						
	MAIARAC		1												1			1	
	EQUIARV												2					1	2
	LUPINUS								1			1	1						
	ORTHSEC	1												1					
	TARAXAC										1	1							
	LYCOANN														1	1			
	BROMCIL												2						2
	CIRSIUM														1				
	GEOCLIV		1																
	ASTERAC												1						
	BROMUS																		1
	LUPIARC												1						
	MITENUD								2										
	ANTEANA																		1
Moss Layer[b]	BRACHYL	13						20						15					
	RHIZGLA	12	1					19						9					
	BARBLYC	10						13						11					
	DICRPOL	3						13						7					
	MARCPOL							1						2					
	PLEUSCH							8						4					
	POLYJUN							1						1					
	RHYTROB	1						6						2					
Totals[b]	HERBS	14	14	14	14	14	14	20	20	20	20	20	20	15	14	15	15	15	15
	MOSSES	14						20						15					
	SHRUBS	14	14	14	14	14	14	20	20	20	20	20	20	15	14	15	15	15	15

a Number of plots in which the species occurred.

b Sampling of the moss layer was done only in Year 0 (1988) prior to logging. See Appendix 1 for full plant names.

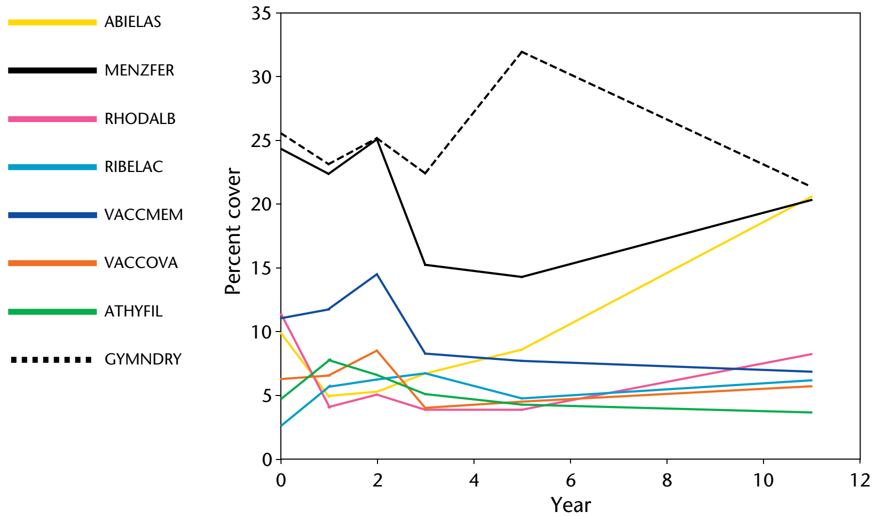

FIGURE 3 *Change in vegetation cover on the unburned treatment. (Year 0 is pre-logging cover.)*

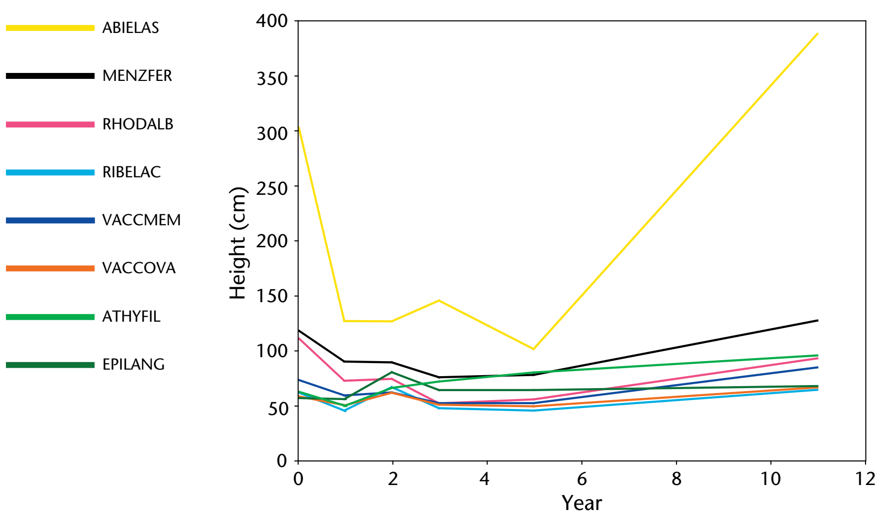

FIGURE 4 *Change in vegetation height on the unburned treatment. (Year 0 is pre-logging height.)*

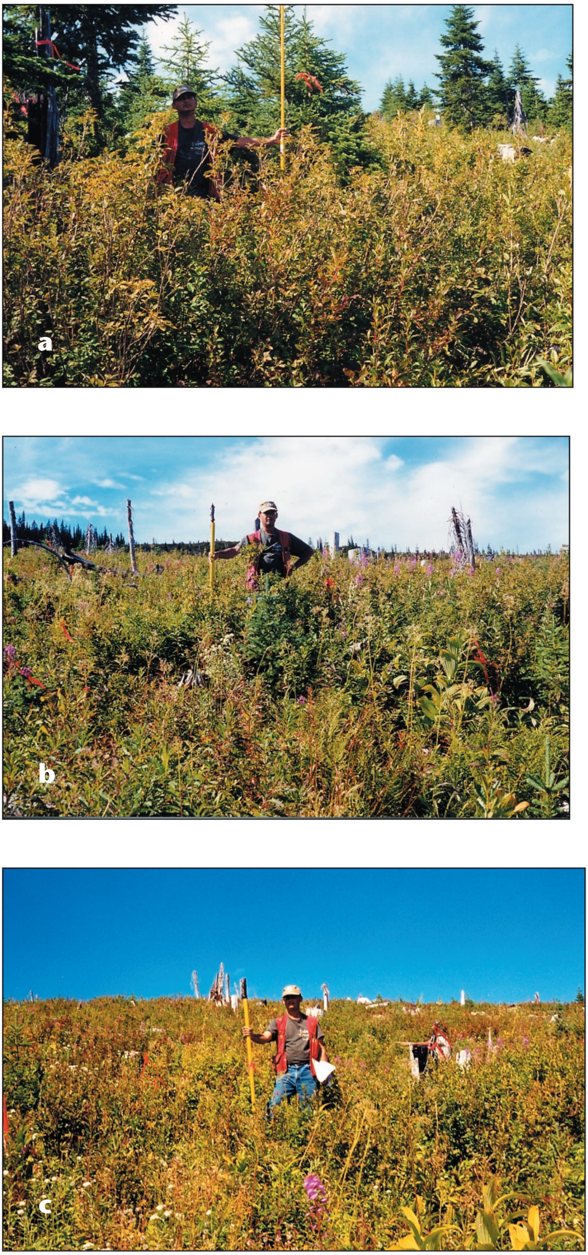

FIGURE 5 *Photos illustrating vegetation development on a) unburned, b) fall burn, and c) spring burn treatments in year 11.*

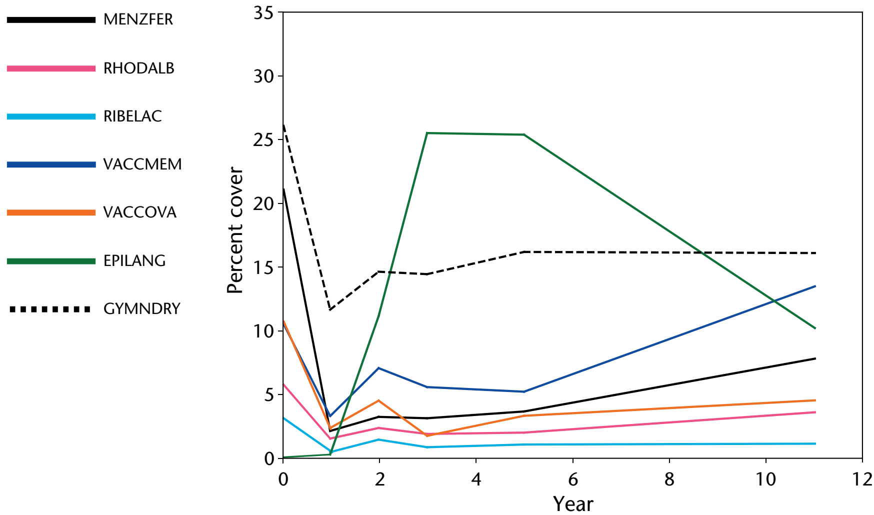

FIGURE 6 *Change in vegetation cover on the fall burn treatment. (Year 0 is pre-logging cover.)*

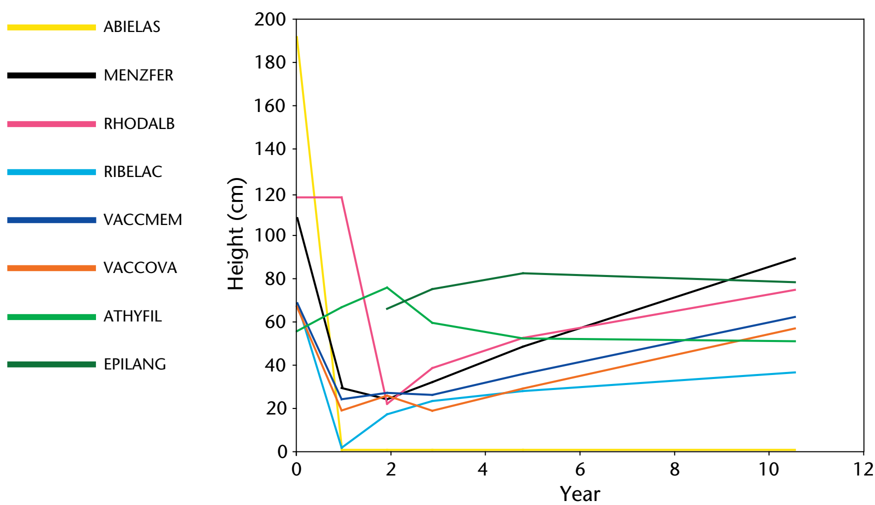

FIGURE 7 *Change in vegetation height on the fall burn treatment. (Year 0 is pre-logging height.)*

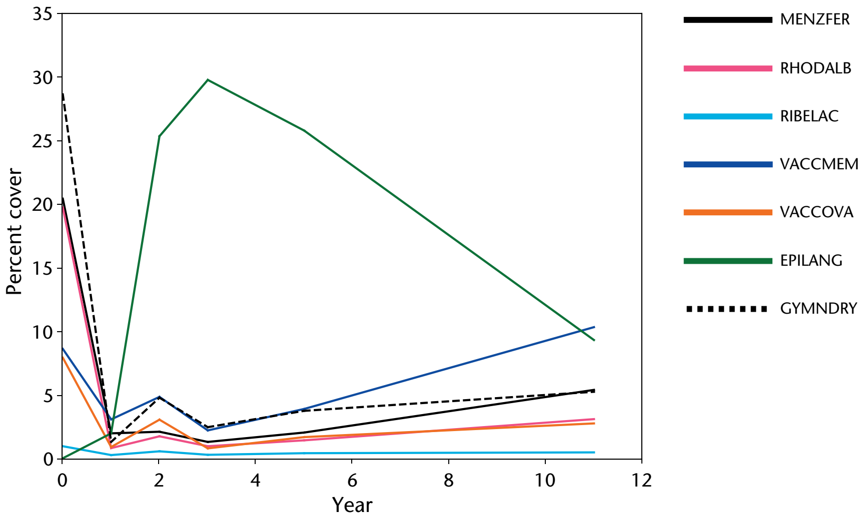

FIGURE 8 *Change in vegetation cover on the spring burn treatment. (Year 0 is pre-logging cover.)*

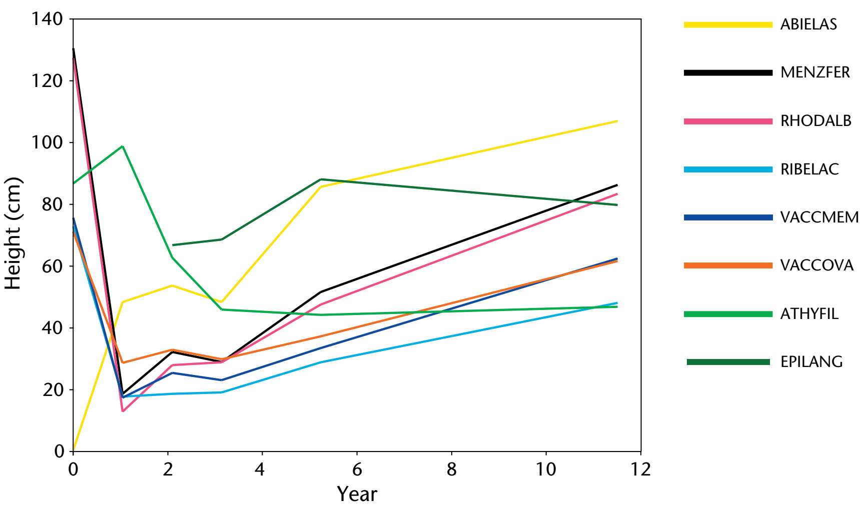

FIGURE 9 *Change in vegetation height on the spring burn treatment. (Year 0 is pre-logging height.)*

small experimental plots in the burned treatments showed slightly better height and diameter growth than did those on the unburned treatment in year 5; however, the difference was not statistically significant at that time.

Shrubs

General Shrub cover was reduced by burning, causing a significant shift in the structure of the vegetation from shrub/herb community to a herb-dominated community for at least 5–10 years. On the unburned treatment, vegetation structure changed from a shrub/herb community to a small tree–dominated community with the release of the subalpine fir advanced regeneration.

False azalea *(Menziesia ferruginea)* False azalea is a shade-tolerant shrub that resprouts from the root crown and adventitious stem buds and extends by stem layering (Haeussler et al. 1990; Habeck 1992). It demonstrates best vigour in partially shaded subalpine forest openings (Brooke et al. 1970).

False azalea was present in all unburned and all but one spring and fall burn plot prior to logging. Average cover and height were similar on all treatment areas (Table 2).

False azalea persisted in all unburned plots in all sample years and was less frequent in burned plots compared with unburned plots the first 2 years after burning ($p < 0.005$) (Table 3). There was no difference in presence in spring versus fall burn treatment in any year ($p > 0.05$).

We did not observe any false azalea seedling establishment, so re-establishment in the burned plots was presumed to have occurred through resprouting. By year 11, presence recovered to pre-harvest levels in fall burn plots, but was slightly below pre-harvest levels in spring burn plots.

Cover was not significantly different from pre-harvest levels in unburned plots in year 11 ($p = 0.36$). Cover was lower in the burned area than in the control plots in all post-burn treatment years ($p < 0.02$). There was no difference in the cover of false azalea in spring versus fall burn plots in any post-burn sampling year ($p > 0.65$). False azalea cover was lower in year 11 than it had been pre-logging in burned sites ($p < 0.004$) (Figures 3–5).

The height of false azalea was not significantly different from pre-harvest levels in year 11 in unburned plots ($p = 0.29$). Plants were shorter in the burned plots than in the unburned plots in all post-burn sample years ($p = 0.004$). There was no difference in the height in spring versus fall burn plots in any post-burn year ($p > 0.24$) (Figures 6–8).

These results show that false azalea can survive and resprout after low-severity burning, but abundance is reduced for at least 11 years. This finding is similar to that reported in Haeussler et al. (1990). The lack of seedling establishment is consistent with the findings of Yearsley (1993). Little is known about reproduction by seed for this species (Haeussler et al. 1990; Habeck 1992).

White-flowered rhododendron *(Rhododendron albiflorum)*
White-flowered rhododendron is a moderately shade-tolerant rhizomatous, deciduous shrub that grows to 2 m in height (Haeussler et al. 1990).

Rhododendron albiflorum was a significant component of the understorey in the forests on this site. Mean cover ranged from 6 to nearly 20% in the treatment units prior to logging (Table 2). It was present in 50% (7) of the unburned, 90% (18) of the spring burn, and 33% (5) of the fall burn plots prior to logging (Table 3).

We observed limited damage to rhododendron from winter logging alone, consistent with other studies (Haeussler et al. 1990). It was observed in all but four of the 18 spring burn plots and all but one of the five fall burn plots in which it occurred prior to burning by the end of the second year after burning. Percentage presence was lower in the fall burn treatment compared with the spring burn treatment in most years ($p < 0.05$) (Table 3); this is likely due to initial differences in presence rather than treatment effects.

There was no difference in cover on the burned versus unburned or spring versus fall burn plots in any post-burn year ($p > 0.26$). However, because the cover on the spring burn site was notably higher than that on the fall burn site prior to treatment, results should be interpreted with caution. Cover values in year 11 were lower than those observed before logging on the spring burn plots ($p < 0.0001$). However, in the fall burn and unburned plots, cover was not significantly different from pre-harvest levels by year 11 ($p > 0.37$) (Table 2). This result suggests that the more severe spring burn had more of an impact on the species than did the fall burn.

There was no significant difference in the height of plants on burned versus unburned or on spring versus fall burn plots by year 11 ($p > 0.21$). Plant heights in year 11 were not different from heights prior to logging in the unburned plots ($p = 0.1$). In year 11, plants in burned plots were shorter than they had been pre-burn ($p < 0.005$) (Figures 4, 7, and 9).

Our results are generally consistent with those of Mather (1987) who reported that burning set this species back for 10–15 years on ESSF sites in the Kamloops Forest Region. *Rhododendron albiflorum* typically re-establishes by sprouting from root crowns and stems buds, and spreads by rhizomes and layering (Haeussler et al. 1990). No germinants were observed on this site. Yearsley (1993) did not find any germinants on this or any other burned ESSF sites. Establishment from seeds is reportedly rare (Haeussler et al. 1990).

Black huckleberry *(Vaccinium membranaceum)* Black huckleberry is a low- to medium-height, densely branched, erect, rhizomatous, deciduous shrub (Haeussler et al. 1990). It was the second most common shrub on the study site prior to logging and was present in 93% (13) of unburned, 95% (19) of spring burn, and 87% (13) of fall burn plots prior to logging with an average cover of about 10% (Tables 2 and 3). Black huckleberry plants established by resprouting were noted in all the plots in which it had occurred prior to logging after the sites were burned. There was no evidence of the plant in some plots until 2 years after burning. It was also noted in plots in which it had not occurred prior to burning.

Cover on burned plots was lower than on unburned plots 1 and 2 years after burning ($p = 0.02$), after which there was no difference in cover ($p > 0.2$). No difference in cover on spring versus fall burn plots was apparent in any year ($p > 0.36$). There was no significant difference in cover values observed 11 years after treatments, compared with pre-harvest levels in any treatment ($p > 0.23$) (Figures 3, 6, and 8).

Plants on unburned plots were taller than those on burned plots in all post-burn sample years ($p < 0.009$). There was no difference in the height of plants on spring versus fall burns in any post-burn year ($p > 0.3$). There was no difference in heights pre-logging versus 11 years after treatment for any treatment ($p > 0.07$) (Figures 4, 7 and 9).

Black huckleberry reproduces vegetatively from adventitious buds on rhizomes and root crowns and rarely reproduces by seed (Stark 1989; Ingersoll and Wilson 1990). Viable *Vaccinium* seeds were found in the top 3 cm of the forest floor prior to burning on this site; however, no germinants were evident on this or seven other burned ESSF sites (Yearsley 1993). Black huckleberry shows considerable variability in its response to burning, depending on burn severity and site factors (Simonin 2000). We found extensive resprouting after burning and no establishment from seeds, consistent with observations from other studies (Haeussler et al. 1990). We did not observe the high plant mortality or slow regrowth observed on other sites, which may have experienced more severe fires (Haeussler et al. 1990).

Oval-leaved blueberry *(Vaccinium ovalifolium)* Oval-leaved blueberry is a spreading, diffusely branched deciduous shrub (Haeussler et al. 1990). It was present in 79% of unburned, all but one spring burn (95%), and all fall burn plots prior to logging (Table 3). Average pre-logging cover in the treatment areas was 8.5% (Table 2).

Some plots showed no evidence of resprouting *V. ovalifolium* until 2 years after the site was burned. By year 11, plants were not observed in four of 19 spring burn plots and one of the 15 fall burn plots in which they occurred prior to burning.

Winter logging alone had little impact on plant cover. Burning significantly reduced oval-leaved blueberry cover compared with the unburned control treatment 1 and 2 years after burning ($p = 0.01$). No difference in cover on spring versus fall burn plots was apparent in any year ($p > 0.37$). There was no difference in cover before and 11 years after harvesting on the unburned plots ($p = 0.7$). In year 11, cover values were lower than they had been prior to burning ($p < 0.005$) (Figures 3, 6, and 8).

Up until year 11, plants on unburned plots were taller than those on burned plots ($p < 0.02$). There was no difference between the height of plants on spring burn versus fall burn plots in any post-burn year ($p > 0.23$). There was no difference in the height of plants in year 11 compared with that observed pre-logging on all treatments ($p > 0.15$) (Figures 4, 7, and 9).

Oval-leaved blueberry was susceptible to being eliminated by fire and regrew slowly on other sites (Lafferty 1972; Green et al. 1984; Hawkes et al. 1990). *Vaccinium ovalifolium* reproduces primarily through sprouting from dormant basal buds or underground rhizomes (Camp 1942; Hayes and Garrison 1960; Achuff 1989). We found extensive resprouting but no establishment from seed, consistent with other reports (Haeussler et al. 1990; Tirmenstein 1990). No *Vaccinium* germinants were evident after burning on this or seven other burned ESSF sites, even though viable *Vaccinium* seeds were found in the top 3 cm of the forest floor on this site (Yearsley 1993).

Red elderberry *(Sambucus racemosa)* Red elderberry is a tall shrub or small tree with cane-like stems (Haeussler et al. 1990). On our study site it was found in only one of the 49 plots prior to logging (Table 3). After burning, buried seeds germinated in 7% (1) of the unburned plots, 85% (17) of the spring burn plots, and 67% (10) of the fall burn plots. Many of the germinants did not survive. By year 11, red elderberry was found in 7% (1) of the unburned, 60% (12) of the spring burn, and 27% (4) of the fall burn plots. Percentage presence was consistently higher in the burned plots versus unburned plots ($p < 0.01$) (Table 3). Cover was low and no significant differences were observed between any treatments in most years ($p > 0.27$) except in year 2 when the flush of germinants in the burned plots resulted in more cover in the burned versus unburned plots ($p = 0.04$). Plants in the burned treatments grew slowly in height, and were slightly over 40 cm tall on average by year 11.

Sambucus racemosa is a long-term seed banker and also regenerates vegetatively from sprouts on stems, rhizome suckers, and layering (Crane 1989). Seeds distributed throughout the upper 5 cm of the forest floor on this site were viable (Yearsley 1993). Germinants were found on this and six of the seven other burned ESSF sites (Yearsley 1993). Consistent with other studies, we found that red elderberry established readily from buried seed and resprouted after burning (Crane 1989; Haeussler et al. 1990). The burned plots appeared to provide a more favourable environment for red elderberry, possibly because the fire stimulated more seed germination and reduced competition from other species. However, red elderberry did not become a major component of the early seral stand, even after 11 years.

Black gooseberry *(Ribes lacustre)* *Ribes lacustre* is a spreading to erect deciduous shrub that can grow up to 1.5 m tall. It is shade intolerant to moderately shade tolerant (Noste and Bushey 1987).

Black gooseberry was a relatively minor component of the forest understorey on this site prior to logging. Average pre-logging cover was less than 3.2% (Table 2). It was present in 64% (9) of the unburned, 15% (3) of the spring burn, and 47% (7) of the fall burn plots prior to logging (Table 3). *Ribes lacustre* persisted in all the unburned plots in which it had occurred prior to logging and appeared in two additional unburned plots. It persisted in all the plots in which it had occurred prior to burning and was observed in an additional six spring burn and six fall burn plots.

Cover was lower on the burned versus unburned in all years ($p < 0.04$). There was no difference in cover on spring versus fall burn plots in any post-burn year ($p > 0.66$) (Figures 3, 6, and 8). There was no difference in height on the spring versus fall burn plots in any post-burn year ($p > 0.42$) (Figures 4, 7, and 9).

Black gooseberry resprouted and established from buried seeds on burned plots on this site, as it had on other sites (Fischer and Clayton 1983; Rowe 1983; Kramer and Johnson 1987; Noste and Bushey 1987; Hamilton and Yearsley 1988). Germinants were also observed on two other burned ESSF sites (Yearsley 1993). Consistent with other studies, we found that black gooseberry grew relatively slowly even on this moist, rich cutblock (Haeussler et al. 1990; Carey 1995). Optimal conditions may not occur on some sites until other vegetation cover establishes moderating site conditions (Carey 1995).

Sitka mountain ash *(Sorbus sitchensis)* *Sorbus sitchensis* is a tall deciduous shrub or tree that can grow to 6 m. It is shade intolerant, persisting in openings (Mathews 1993). Seeds are dispersed by birds and mammals and can remain viable in the soil for many years (Mathews 1993). Mountain ash resprouted in the one spring burn plot in which it had occurred prior to burning and in one of the two fall burn plots (Table 3). No germinants were noted in this study or in Yearsley's intensive study on this and other ESSF sites (Yearsley 1993).

Red raspberry *(Rubus idaeus)* Red raspberry is a deciduous shrub, with erect biennial canes arising from a perennial rhizome (Haeussler et al. 1990). Red raspberry was not present in any of the plots prior to logging. Plants that appeared to have established from seed were noted in 25% (5) of the spring burn plots and 27% (4) of the fall burn plots and not in any unburned plots (Table 3). Burning seemed to favour establishment of germinants. By year 11, plants were observed in 15% (3) of the spring burn and 13% (2) of the fall burn plots. Average cover of red raspberry did not exceed 0.25% in any year on any treatment (Table 2).

Red raspberry is a long-lived seed banker that establishes in disturbed sites (Haeussler et al. 1990). Seed bank germinants were observed on one of the eight ESSF sites sampled by Yearsley (1993). Whitney (1986) found that most seeds germinate in the first year after disturbance (Whitney 1986).

Red raspberry did not expand rapidly to occupy available space on this site, as reported in other studies (Tirmenstein 1989). This was perhaps due to the heavy vegetation cover on the site. Red raspberry is shade intolerant, decreasing as the canopy closes, with few plants/clones persisting for more than 12 years (Tirmenstein 1989). It is also strongly nitrophilous (Haeussler et al. 1990) and its expansion may have been limited by a lack of available nitrogen due to interference by ericaceous species or soil conditions. Red raspberry may be close to its elevational limits at this site, and therefore the results may not be representative for the species (D. Lloyd, pers. comm., 2003).

Thimbleberry *(Rubus parviflorus)* *Rubus parviflorus* is a rhizomatous, deciduous shrub, with short-lived canes, which grows to a height of 2.5 m. It is not common above 1200 m in the interior (Haeussler et al. 1990) and was a minor component in the burned ESSF cutblocks in this area (Yearsley 1993).

No parent plants were evident on the site prior to logging (Table 2). Thimbleberry established in one unburned plot on this site, apparently from seed (Table 3). Thimbleberry established from buried seeds in one of the burned ESSF sites monitored by Yearsley (1993), but she did not observe this on our study site. Thimbleberry seeds are noted for their ability to remain viable for a long time, and fire is known to stimulate germination of buried seeds (Tirmenstein 1989).

We did not observe enhanced germinant survival on burned versus unburned sites, as is sometimes reported (e.g., Morgan 1984). There may have been insufficient seeds in the forest floor prior to burning for differences due to burning to be evident. Seed production is often sparse at high elevations (Haeussler et al. 1990).

Willow *(Salix* spp.*)* There were no willows on the site prior to logging. Willow established in two spring burn and one fall burn plot by year 11 (Table 3). Willows have short-lived seeds and commonly seed-in to disturbed sites. They usually establish shortly after disturbance, before full site occupancy (Haeussler et al. 1990).

Herb layer

General Herb cover declined immediately after burning, followed by a rapid increase in cover. Total herb cover increased to pre-burn levels by year 11. During this time herb cover in the unburned treatment area increased as well.

Fireweed *(Epilobium angustifolium)* Fireweed is an invasive species that produces numerous readily distributed light seeds and can rapidly establish in disturbed sites through seeding-in and extension from "pseudorhizomes" (Haeussler et al. 1990). Fireweed was observed on only one plot prior to logging (Table 3). It established in 57% (8) of the unburned control plots, all spring burn plots, and 93% (14) of the fall burn plots by 1 year after the site was burned. Presence was higher in the burned treatment versus control in all years ($p < 0.007$) (Table 3).

Cover increased dramatically in the first few years on the burned plots, reaching a maximum of 25–30%, and then began declining around year 5 (Table 2). Fireweed rapidly invades severely burned sites and can form dense stands (Haeussler et al. 1990). Maximum cover is usually achieved within a few years and can remain static for a number of years (Haeussler et al. 1990).

Average cover on unburned sites remained less than 5%. Cover was significantly higher on the burned versus unburned areas 2, 3, and 5 years after treatment ($p < 0.0003$). In year 2, cover on the fall burn site was less than that on the spring burn site ($p = 0.003$); after that there was no significant difference in cover in spring versus fall plots ($p > 0.32$). Fireweed cover declined over time in the burned plots (Figures 6 and 8). Height increased and then decreased on burned plots (Figures 7 and 9).

Observations of fireweed behaviour on this site are similar to those reported by others (Haeussler et al. 1990). Fireweed seedlings were observed on burned sites and to a lesser extent on unburned sites. Some parent plants occurred on the site prior to logging. Fireweed appeared to expand rapidly by both vegetative reproduction and seed germination for several years, and then its cover declined. Establishment is generally limited where soil disturbance is minimal or where the understorey is well established (Eis 1981; Haeussler et al. 1990). Growth rates are reduced in deep shade (Myerscough and Whitehead 1966; Myerscough 1980). Fireweed is strongly nitrophilous (Haeussler et al. 1990) and may decline as nutrients are depleted.

Lady fern *(Athyrium filix-femina)* Lady fern is a deciduous perennial fern that spreads vegetatively through division of its stout chaffy rhizome (Page 1982; Haeussler et al. 1990).

Prior to logging, lady fern was found on 50% (7) of the unburned, 10% (2) of the spring burn, and 53% (8) of the fall burn plots (Table 3). Average cover was less than 5% (Figures 3–5). Height tended to decrease over time on burned plots (Figures 7 and 9).

Lady fern generally persisted and resprouted in plots after burning. It also appeared in new plots where it had not been observed prior to burning. There were no differences in cover on burned versus unburned or spring versus fall burn plots in any post-burn sampling year ($p > 0.23$) except in year 1 when there was less in the burned plots versus unburned plots ($p = 0.05$). By year 11, there was no difference in the cover compared with pre-treatment levels in all treatments ($p > 0.3$).

No germinants from spores were observed in the intensively studied plots on this or other ESSF sites (Yearsley 1993). Our results are consistent with those observed elsewhere—lady fern generally survives burning on wetter sites but its presence may be reduced for some time (Haeussler et al. 1990; Hawkes et al. 1990). On this site, which was moist, the prescribed burns were of low severity and usually did not kill the plant.

Oak fern *(Gymnocarpium dryopteris)* Oak fern is a small delicate fern, with long creeping rhizomes, common in shaded habitats (Parish et al. [editors] 1996).

It was the most abundant species in the herb layer prior to logging, with an average cover of 27% (Table 2). It was found on all but one plot prior to logging. Oak fern was initially lost from 15% (3) of the spring burn plots and 13% (2) of the fall burn plots but was observed in all but one spring burn plot by year 11 (Table 3).

Fire significantly reduced oak fern cover. Cover on the unburned control was higher than on the burned plots in all post-burn years ($p < 0.04$). Cover was lower in the spring burn than on the fall burn plots in all post-burn years (p values ranged from 0.085 to 0.32 for the contrasts in different years). In the burned plots, cover was lower in year 11 than it had been prior to harvesting ($p < 0.03$). There was no difference in the cover on unburned plots before logging compared with 11 years after logging ($p = 0.35$) (Figure 3).

Oak fern was significantly reduced by burning initially, especially on the more severely burned spring burn treatment. This result suggests that it is fairly fire sensitive (Mueggler 1965; Stickney 1986; Snyder 1993). Oak fern rhizomes are shallow and delicate and could be readily consumed by burning. It was not negatively affected by forest canopy removal alone, consistent with observations from other wet, high-elevation areas (Mueggler 1965), indicating tolerance to open conditions on wet sites. No germinants from spores were found on this or other ESSF sites (Yearsley 1993). Resprouting was the sole means of re-establishment noted on this site.

Spiny wood fern *(Dryopteris expansa)* Spiny wood fern is a large fern of mesic forests where light levels are low and humidity is high (Vitt et al. 1988; Douglas et al. 2000).

It was found in 36% (5) of the unburned, 15% (3) of the spring burn, and 33% (5) of the fall burn plots prior to logging. It persisted after logging in three unburned plots and was observed intermittently on another three unburned plots. The somewhat more severe spring burn eliminated spiny wood fern from all the plots in which it had occurred prior to burning. It resprouted in all fall burn plots in which it had occurred prior to burning (Table 3).

In year 1, cover was lower in the burned versus unburned plots ($p = 0.007$) and lower in the spring versus fall burn plots ($p = 0.05$). Cover remained low with no difference in cover between treatments after year 1 ($p > 0.06$). There was no difference in cover in year 11 compared with that prior to harvesting in all treatments ($p > 0.09$).

No germinants from spores were found in the intensively studied burned plots on this or other ESSF sites (Yearsley 1993). *Dryopteris expansa* is fairly sensitive to burn severity and could be eliminated by burning.

Heart-leaved twayblade *(Listera cordata)* *Listera cordata* is an orchid of moist forests that has delicate shallow roots that would be readily destroyed by fire (Douglas et al. 2001b). It was observed in 14% (2) of the unburned, 25% (5) of the spring burn, and 27% (4) of the fall burn plots during pre-harvest sampling. It was evident for a few years after logging in the two unburned plots where it occurred prior to logging and in one additional plot. It was not seen in any plots after they were burned (Table 3). No germinants were observed in any plots. The shallow roots were apparently consumed by burning, and establishment by other means (i.e., seed bank or seed rain) had not occurred by year 11. Orchids including *Listera cordata* depend on a mycorrhizal network, and the removal of other plants through clearcutting negatively affects their survival (Smith and Read 1997).

Mitrewort *(Mitella breweri* and *Mitella pentandra)* *Mitella breweri* and *Mitella pentandra* are plants of moist forests with slender rhizomes (Douglas et al. 2000). The two species occurred on the site but could not always be differentiated, so they have been combined for this discussion.

Mitella spp. were present on 86% (12) of the unburned, 80% (16) of the spring burn, and 60% (9) of the fall burn plots prior to logging with a mean cover about 2% (Tables 2 and 3). These mitreworts persisted after logging on all plots where they were observed prior to logging and were noted in two additional plots. *Mitella* spp. persisted on all burned plots and established in three more spring burn and four more fall burn plots. Seed bank germinants were noted in two of the unburned plots.

Yearsley (1993) observed that seeds of *Mitella* spp. that were likely *Mitella breweri* were abundant throughout the forest floor; however, no germinants were observed after burning on the sites she studied.

Rosy twistedstalk *(Streptopus lanceolatus)* *Streptopus lanceolatus* is a perennial lily adapted to cool moist forests (Douglas et al. 2001b). Rosy twistedstalk was present on every plot prior to logging with average of 6% cover (Tables 2 and 3). It persisted in all plots after logging and burning, resprouting after burning. There was no difference in frequency of occurrence in any treatment in any year ($p > 0.12$).

There was little change in the cover on unburned plots over time. Cover increased dramatically in the fall burn plots and then declined. Eleven years after logging, cover was not significantly different among treatments ($p = 0.1$).

No germinants were found in the intensively studied plots on this or other ESSF sites (Yearsley 1993).

One-leaved foamflower *(Tiarella trifoliata* var. *unifoliata)* One-leaved foamflower is a small delicate species of moist forest and meadows (Douglas et al. 2000). It was present in all plots prior to logging, with an average cover of 7% (Tables 2 and 3). *Tiarella trifoliata* var. *unifoliata* persisted in all the logged plots and resprouted in all but one spring burn plot.

Cover in the burned treatments was less than that in the unburned treatments 1, 2, and 3 years after burning ($p < 0.05$). In the control and fall burn plots cover increased during the first few years, after which it declined.

Germinants were observed on this site. No seed bank germinants were observed by Yearsley (1993) on this or other burned ESSF sites. The open environment created by canopy removal favoured *Tiarella trifoliata* var. *unifoliata* for a few years, but because it is a low-growing plant it was readily overtopped by taller species over time.

Sitka valerian *(Valeriana sitchensis)* Sitka valerian is a species of cool moist montane forests and meadows. It has stout branched rhizomes, is moderately shade-tolerant, and increases in vigour after canopy removal (Haeussler et al. 1990).

Sitka valerian was present in all unburned, all but one spring burn (95%) and all but one fall burn plot (93%) prior to logging (Table 3). It resprouted on most plots after burning. Germinants were observed in one unburned and one fall burn plot. It was not observed in some of the more severely burned spring burn plots for several years, but was present continuously in the fall burn plots.

Cover was significantly lower on burned versus unburned treatments 1, 3, and 5 years after treatments ($p < 0.01$) (Table 2). There was no significant difference in the cover on spring versus fall burn plots in any post-treatment year ($p > 0.07$). By year 11, cover values were not significantly different from preharvest values in any treatment ($p > 0.16$).

Sitka valerian recovers quickly from light to moderate fires, while severe fires kill the rhizomes (Haeussler et al. 1990). The fires on this site were not severe enough to significantly affect the plants. Yearsley (1993) found germinants in unburned forest floor samples collected from this site, but no germinants were observed on this or other ESSF sites after they were burned. Sitka valerian tolerated some degree of shading on this site, but its cover declined on the unburned site as it was overtopped by other species.

Indian hellebore *(Veratrum viride)* Indian hellebore is a robust perennial plant with a deep taproot that is tolerant of disturbance and resprouts readily after fire (Parish et al. [editors] 1996; D. Lloyd, pers. comm., 2003). It was found in 86% (12) of the unburned, 60% (12) of the spring burn, and 87% (13) of the fall burn plots prior to logging. *Veratrum viride* persisted on all except one spring burn plot, and was observed in one new unburned and three new spring burn plots (Table 3). It appears to be favoured somewhat by the conditions found after forest canopy removal and burning. No germinants were found in the intensively studied plots on this or other ESSF sites (Yearsley 1993).

Mountain sweet-cicely *(Osmorhiza berteroi)* Mountain sweet-cicely is a perennial herb with a well-developed taproot typical of mesic open forests and forest edges in the lowland and montane zones (Douglas et al. 1998). *Osmorhiza berteroi* persisted in all of the unburned plots, resprouted in most of the burned plots, and established in new plots in all treatments over time (Table 3). A related species, *Osmorhiza claytonii,* has a short-lived seed bank and resprouts from the root stalk after fire (Pavek 1992). No seed bank germinants of *Osmorhiza berteroi* were observed on this site during this or earlier studies (Yearsley 1993).

Bog orchids *(Platanthera* spp.*)* Bog orchids are shallowly rooted non-rhizomatous plants that grow in moist meadows, coniferous forests, and wetlands in the lowland, montane, and lower subalpine zones in British Columbia (Douglas et al. 2001b). Bog orchids were observed in 10% (2) of the spring burn and 20% (3) of the fall burn plots prior to logging. Fire eliminated bog orchids from one fall burn plot (Table 3) and they were observed intermittently in two other spring and two other fall burn plots. No germination from buried seeds was observed in Yearsley's study on this and other ESSF sites (Yearsley 1993).

Five-leaved bramble *(Rubus pedatus)* Five-leaved bramble is common throughout British Columbia in moist to mesic open forests, glades, and stream banks in the lowland to subalpine zones (Douglas et al. 1999b). It is a perennial herb with slender creeping stolons. *Rubus pedatus* was observed in 36% (5) of the unburned, 30% (6) of the spring burn, and 33% (5) of the fall burn plots prior to logging (Table 3). It was eliminated from four spring burn plots and two fall burn plots, and established in an additional three unburned, one spring burn, and two fall burn plots over time. The fires were apparently severe enough to eliminate it from some plots, but not others. Percentage presence was lower in the burned versus unburned treatment in all post-burn years ($p < 0.04$), and presence was lower in the more severe spring burn compared with the fall burn. Although mature *Rubus pedatus* plants were evident on the sites, no germinants from the forest floor were observed on this site by Yearsley in her intensive study of this and other ESSF sites (Yearsley 1993).

Queen's cup *(Clintonia uniflora)* Queen's cup is a small perennial herb with a slender rhizome found primarily in mature, warm, moist coniferous forests (Parish et al. [editors] 1996). It was observed in 57% (8) of the unburned plots, 45% (9) of the spring, and 40% (6) of the fall burn plots. *Clintonia uniflora* persisted on all unburned, and resprouted after burning on eight of nine spring burn and all fall burn plots in which it occurred prior to logging. It also established on one additional unburned, spring, and fall burn plot by year 11 (Table 3).

Clintonia uniflora is typically top-killed and then resprouts after fire, although high-severity burns will eliminate it from a site (Habeck 1991). It usually decreases in abundance following fire (Habeck 1991). No seed bank germinants were observed on this site or other burned ESSF sites (Yearsley 1993). It was tolerant of the low-severity fire that occurred on this site, declining when overtopped by taller species.

Arnica *(Arnica cordifolia* and *Arnica latifolia)* *Arnica cordifolia* is a sun- and shade-tolerant, perennial herb with an upright stem arising from a long slender creeping rhizome (Reed 1993). *Arnica latifolia* is also a rhizomatous perennial common at mid to high elevations in forests and openings (Parish et al. [editors] 1996). The two species hybridize and it was not always possible to differentiate them, so they were combined for this discussion.

Arnicas were observed in 43% (6) of the unburned, 50% (10) of the spring burn, and 47% (7) of the fall burn plots prior to logging. They persisted for many years in two of the six unburned plots, nine of the 10 spring burn plots, and five of the seven fall burn plots in which they had occurred prior to logging. They were also noted in five more unburned, nine more spring burn, and four more fall burn plots over time (Table 3). However, by year 11, Arnicas were found only on three unburned plots and cover was low. By year 11, presence was lower in the unburned versus burned plots ($p < 0.001$). Presence was higher in burned versus unburned plots in years 5 and 11 ($p < 0.011$).

The greater cover of other species appeared to have shaded out this low-growing plant on the unburned plots. In contrast, it continued to expand into new burned plots throughout the study period likely by resprouting and seeds.

No seed bank germinants were found on burned or unburned plots on this site or on other burned ESSF sites (Yearsley 1993). Viable *Arnica cordifolia* seeds were found to a depth of 10 cm on some sites in Idaho (Kramer and Johnson 1987). However, Romme et al. (1995) reported low viability of seeds collected from plants growing on a recently burned site in Wyoming. The increase in presence and expansion in cover observed on this site (Table 2) is similar to that observed in some other clearcut subalpine sites (Crouch 1985; Reed 1993). *Arnica cordifolia* resprouted rapidly from rhizomes after fires and then declined and in some cases disappeared by 10 years after burning (Reed 1993). Expansion by sprouting from rhizomes and seed rain has been documented from other sites and both mechanisms may have been operating at this site (Grier-Hayes 1989; Reed 1993).

Small-flowered woodrush *(Luzula parviflora) Luzula parviflora* is a rhizomatous perennial rush common at mid to high elevations in open forests and disturbed sites (Parish et al. [editors] 1996). It was present in 7% (1) of the unburned, 10% (2) of the spring burn, and 33% (5) of the fall burn plots prior to logging. It was observed at some time in 36% (5) of the unburned, 85% (17) of the spring burn, and 73% (11) of the fall burn plots. By year 11, it was present in 14% (2) of the unburned, 85% (17) of the spring burn, and 67% (10) of the fall burn plots. Presence was higher in the burned treatment versus unburned treatment in all post-burn years ($p < 0.05$) (Table 3). Cover was generally low in all years in each treatment.

Luzula parviflora was reported to be common in early seral stands in the ESSF (Lloyd et al. 1997). We observed germinants on this site. Yearsley (1993) found viable seeds down to a depth of 6 cm in the forest floor on this site; germinants were more abundant in unburned plots than in burned plots. She also observed germinants in one other burned ESSF site (Yearsley 1993).

Pearly everlasting *(Anaphalis margaritacea)* Pearly everlasting is a perennial herb with rhizomes and wind-dispersed seed, common in meadows, open forests, cutover areas, and roadsides (Douglas et al. 1998). It was not found prior to logging and occurred only in the burned plots on this site. It was not detected until 2 years after burning and subsequently increased in both cover and frequency over time. By year 11, it had established on 75% (15) of the spring burn plots and on 40% (6) of the fall burn plots (Table 3). In years 5 and 11, presence was higher in burned treatment versus control ($p < 0.005$), and was higher on the spring versus fall burn ($p < 0.04$). Cover was greater on spring versus fall burn plots and on burned versus unburned plots in year 11 ($p < 0.03$). It appears to have established from seeds blown onto the site from adjacent areas. Pearly everlasting is known to seed-in readily on disturbed ground (Wood and Del Moral 2000). Yearsley (1993) found seed-origin germinants in three of eight burned ESSF sites she studied. Apparently the vegetation cover on the unburned sites was sufficiently dense to preclude establishment of pearly everlasting.

White-flowered hawkweed *(Hieracium albiflorum)* *Hieracium albiflorum* is a perennial herb with a woody root and light seeds, common in disturbed areas such as roadsides and fields (Douglas et al. 1998). It was not observed in any of the plots during pre-logging sampling (Table 3). Although it grew in some unburned plots, its cover and frequency in these sites were low (Tables 2 and 3). White-flowered hawkweed was observed in 75% (15) of the spring burn plots and 53% (8) of the fall burn plots at some point in time. Once noted in a plot, it generally persisted. The percentage of plots in which it was found increased over time. In year 11, presence was higher in the burned versus unburned treatment ($p < 0.0001$). Presence was higher in the spring versus fall burn after year 2 ($p < 0.02$). In year 11, cover was higher in burned versus unburned plots and in spring versus fall burn plots ($p = 0.01$). We also observed *Hieracium* plants that could not be identified, which may have been *Hieracium albiflorum* in another three spring burn plots and one fall burn plot. Our observations were consistent with that of others (i.e., that white-flowered hawkweed is a weedy species that seeds-in to open habitats) (Romme et al. 1995; Wood and Del Moral 2000). It established more readily in the burned plots than in the unburned plots. The latter had less soil disturbance and more vegetation cover, making establishment from off-site seed more difficult.

Sedges *(Carex* spp.*)* Sedges were not observed in any of our plots prior to logging (Table 2). Germinants were observed in 60% (12) of the spring burn and 67% (10) of the fall burn plots and briefly in one of the unburned control plots. Presence was higher in the burned plots versus unburned plots by year 2 and thereafter ($p < 0.01$). Fire appeared to stimulate the germination of buried seeds. Germinants in the burned plots were sometimes evident in one year and then not in subsequent years. New germinants appeared for the first few years. Yearsley (1993) found buried *Carex* spp. seeds in her intensive study of this site and in two other burned ESSF sites. Some of the sedges were determined to be *Carex aenea,* a common species in British Columbia, typically found in dry disturbed sites and open forests in lowland and montane zones (Douglas et al. 2001a). Some *Carex* spp. exhibit long-term seed banking ability (Mathews 1992; Snyder 1992).

Arrow-leaved groundsel *(Senecio triangularis)* Arrow-leaved groundsel is common in moist to mesic meadows, stream banks, avalanche tracks, and forest openings from the lowland to lower alpine zone. It is a perennial herb with a fibrous-rooted, woody stem base or rhizome and light wind-borne seeds (Douglas et al. 1998).

Senecio triangularis was not noted in any plots prior to logging (Tables 2 and 3). It established in the burned plots first and continued to appear in new plots. By year 11, it was found in 14% (2) of the unburned plots, 35% (7) of the spring burn, and 20% (2) of the fall burn plots. Differences in presence between treatments were not significant in any year ($p > 0.05$); however, the more severe spring burn appeared to favour establishment. Once established, *Senecio triangularis* generally persisted. Average cover in each treatment remained below 0.5%. No differences in cover between spring and fall burn treatments, or between burned versus unburned treatments, were noted in any year sampled.

DISCUSSION

GENERAL PATTERN

Most of the vascular plant species native to this site were tolerant of the conditions experienced on this site after logging and burning. Changes in floristic composition occurred, with the addition of plants previously restricted to the seed bank and species that seeded-in from off-site. Some of these new additions were short lived and may depend on nutrient flushes that are not sustained. There were more new species in the burned treatment than in the control. Subalpine fir trees that survived logging became prominent on the unburned site by year 11. On the burned sites, trees were killed by burning and the dominant vegetation was herbs, with a significant cover of shrubs by year 11.

SPECIES RESPONSE TO LOGGING

Most of the vascular plant species that grew on the site prior to logging persisted after the forest was logged. *Orthilia secunda* was the only vascular plant that was not observed after the logging-only treatment. *Orthilia* depends on mycorrhizae associated with living trees (Smith and Read 1997) and therefore would be expected to decline when the trees are removed. The non-vascular plants were not monitored post-logging, so assessments of their fate after logging could not be made.

Most of the understorey shrubs species found in the forest re-established after burning by resprouting. *Menziesia ferruginea, Rhododendron albiflorum, Vaccinium membranaceum, Vaccinium ovalifolium,* and *Sorbus sitchensis* resprouted after burning. *Menziesia* and *Rhododendron* recovered more slowly than the *Vaccinium membranaceum* (Table 4).

Rubus parviflorus and *Rubus idaeus* were not found in any plots prior to logging and *Sambucus racemosa* was found only in one plot. Fire appeared to enhance the germination of seeds of *Ribes lacustre*, *Ribes laxiflorum,* and *Sambucus racemosa* (Table 4).

Most herbaceous species resprouted after burning. *Rubus pedatus, Listera cordata,* and *Orthilia secunda* were sometimes eliminated from plots by burning. These plants have slender stolons or rhizomes that would be readily consumed by fire. *Listera* and *Orthilia* also depend on mycorrhizae linked to live trees (Smith and Read 1997) (Table 4).

Gymnocarpium dryopteris, Clintonia uniflora, and *Arnica cordifolia/latifolia* were fairly tolerant of burning and recovered at a moderate rate. These species have relatively slender rhizomes that would be consumed by severe fires (Douglas et al. 1998, 2000, 2001a). However, since they were fairly abundant prior to burning, these species were not eliminated by fire. *Osmorhiza berteroi*, a tap-rooted species, also recovered at a moderate rate (Table 4).

Athyrium filix-femina, Veratrum viride, and *Valeriana sitchensis* were tolerant of and favoured by burning, in the short term. These species have relatively robust rhizomes that tolerate burning (Haeussler et al. 1990). *Streptopus lanceolatus* recovered rapidly after burning. *Tiarella trifoliata* ssp. *unifoliata* proliferated for a brief time after burning. Both of these species have slender rhizomes that would be consumed by severe fires; however, because they were common prior to burning there were usually some plants that survived in all plots (Table 4).

Fire appeared to enhance the germination of buried seeds of *Carex* and *Luzula parviflora. Epilobium angustifolium, Anaphalis margaritacea, Hieracium albiflorum,* and *Senecio triangularis* appeared to establish primarily from seeds blown onto the site. Burning enhanced the establishment success of some of these species (Table 4).

TABLE 4 *Classification of species according to mode of establishment, enhancement of establishment by burning, degree of fire tolerance, and speed of recovery after burning*

Shrubs		*Vaccinium membranaceum* [6, 7]
		Vaccinium ovalifolium [6]
		Menziesia ferruginea [6]
		Rhododendron albiflorum [6]
		Sambucus racemosa [1, 7, 9]
		Ribes lacustre [1, 2, 6, 9]
		Rubus idaeus [1, 3, 9]
		Ribes laxiflorum [6, 7]
Herbs	ORIGINAL SPECIES	
	Tolerant with fairly rapid recovery	*Veratrum viride* [6]
		Athyrium filix-femina [6]
		Valeriana sitchensis [1, 3, 6, 7]
		Tiarella trifoliata ssp. *unifoliata* [1, 2, 6]
		Streptopus lanceolatus [6]
	Moderately tolerant with moderate rate of recovery	*Clintonia uniflora* [6]
		Osmorhiza berteroi [6]
		Gymnocarpium dryopteris [6]
		Arnica cordifolia/latifolia [1, 3, 6]
		Viola glabella [1, 6, 8]
	Fire sensitive	*Listera cordata*
		Orthilia secunda
		Rubus pedatus [6]
	INVADERS	*Epilobium angustifolium* [1, 4, 6, 8, 9]
		Epilobium ciliatum [1, 3, 7, 9]
		Hieracium albiflorum [1, 5, 8]
		Arnica cordifolia/latifolia [1, 5]
		Anaphalis margaritacea [1, 5, 9]
		Senecio triangularis [1, 5]
		Luzula parviflora [1, 7, 9]
		Carex spp. [1, 7, 9]
		Cirsium spp. [1, 8]

1 Species established from seed on this site (seed rain or seed bank) (data source is this study)
2 Establishment from buried seed noted on this site (data source is this study)
3 Appears to have established from buried seed on this site (data source is this study)
4 Some plants established from seed on this site (apparently seed rain) (data source is this study)
5 Appears to have established from seed rain on this site – no germinants observed but establishment pattern suggests seed origin (i.e., no parent plants noted on site and delayed establishment)
6 Resprouted after the fire on this site
7 Establishment from buried seed on this site noted by Yearsley 1993 (unburned greenhouse samples)
8 Establishment from seed on this site noted by Yearsley 1993 – seed rain or seed bank
9 Establishment from seed on other ESSF sites noted by Yearsley 1993 (seed rain or seed bank)

Species that were abundant prior to burning, have a robust rhizome, and/or tolerate exposed site conditions recovered the most rapidly after burning.

COMPARISON OF SPRING BURN VERSUS FALL BURN

It was anticipated that the spring burn would be less severe than the fall burn, because the large fuels and forest floor were expected to be wetter in the spring. However, the site was wetter in the fall than in the spring and therefore the spring burn was slightly more severe. Differences in plant phenology at the time the site was burned in the spring versus fall burn treatments were expected to lead to varying rates of regrowth after burning. The significance of these two factors in explaining the subsequent responses cannot be readily differentiated.

There was little difference between the cover of most understorey species in fall versus spring burn plots by year 11. Differences that occurred were small and in some cases likely attributable primarily to differences in cover prior to burning.

There were more weedy species on the more severe spring burn treatment after 11 years, likely because of the greater opportunity to establish since exposed mineral soil was more common and other competing vegetation was less abundant on the spring burn.

COMPARISON TO OTHER ZONES

Some of the species typical of the Engelmann Spruce–Subalpine Fir zone such as *Menziesia ferruginea* and *Rhododendron albiflorum* appeared to be more sensitive to fire than shrubs typical of the Sub-Boreal Spruce and the Interior Cedar–Hemlock zones, where fire was generally more frequent. For example, *Vaccinium membranaceum,* common in these lower-elevation zones, appears to be more tolerant of fire than *Menziesia* or *Rhododendron*.

MANAGEMENT IMPLICATIONS

Burning produces a significant shift from a shrub- and herb-dominated understorey community to a herb-dominated community in the cutblocks initially. Over time the shrub component regains prominence. This shift may have significant implications for wildlife habitat and ecological functioning.

These results suggest that burning can help maintain the natural diversity of plant species in the ecosystem, by promoting the germination of buried seeds of plants that are not present in the above-ground community, such as *Carex aenea* and *Sambucus racemosa.*

Burning promotes the invasion of weedy early seral species.

Burning appears to favour *Vaccinium membranaceum* over other shrubs typical of the ESSF zone, such as *Rhododendron albiflorum* and *Menziesia ferruginea.* Fire can be useful for enhancing the production of black huckleberry fruit, which are important forage for wildlife.

Results from a separate study done on this site suggest that early growth of planted spruce and subalpine fir was somewhat better on burned treatments than on unburned treatments (Eberle 1996).

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APPENDIX 1 Codes, scientific names, and common names of plants recorded at Otter Creek

	Species Code	Scientific name	Common name / Description
Shrub Layer	ABIELAS	*Abies lasiocarpa*	subalpine fir
	MENZFER	*Menziesia ferruginea*	false azalea
	PICEA	*Picea* spp.	unidentified spruce
	PICEENG	*Picea engelmannii*	Engelmann spruce
	RHODALB	*Rhododendron albiflorum*	white-flowered rhododendron
	RIBELAC	*Ribes lacustre*	black gooseberry
	RIBELAX	*Ribes laxiflorum*	trailing black currant
	RIBES	*Ribes* spp.	unidentified *Ribes* (currant/gooseberry)
	RUBUIDA	*Rubus idaeus*	red raspberry
	RUBUPAR	*Rubus parviflorus*	thimbleberry
	SALIX	*Salix* spp.	unidentified willow
	SAMBRAC1	*Sambucus racemosa* ssp. *pubens*	red elderberry
	SORBSIT	*Sorbus sitchensis*	Sitka mountain-ash
	VACCMEM	*Vaccinium membranaceum*	black huckleberry
	VACCOVA	*Vaccinium ovalifolium*	oval-leaved blueberry
Herb Layer	ANAPMAR	*Anaphalis margaritacea*	pearly everlasting
	ANTEPUL1	*Antennaria pulcherrima* var. *anaphaloides*	showy pussytoes
	ARNICOR	*Arnica cordifolia*	heart-leaved arnica
	ARNILAT	*Arnica latifolia*	mountain arnica
	ASTERAC	Asteraceae	unidentified aster
	ATHYFIL	*Athyrium filix-femina*	lady fern
	BROMCIL	*Bromus ciliatus*	fringed brome
	BROMUS	*Bromus* spp.	unidentified *Bromus*
	CALACAN	*Calamagrostis canadensis*	reedgrass
	CAREAEN	*Carex aenea*	bronze sedge
	CAREX	*Carex* spp.	unidentified *Carex*
	CIRSIUM	*Cirsium* spp.	unidentified thistle
	CLINUNI	*Clintonia uniflora*	queen's cup
	DRYOEXP	*Dryopteris expansa*	spiny wood fern
	EPILANG	*Epilobium angustifolium*	fireweed
	EPILCIL	*Epilobium ciliatum*	purple-leaved willowherb
	EPILOBI	*Epilobium* spp.	unidentified *Epilobium*
	EQUIARV	*Equisetum arvense*	common horsetail
	GALITRF	*Galium triflorum*	sweet-scented bedstraw
	GEOCLIV	*Geocaulon lividum*	false toad-flax
	GYMNDRY	*Gymnocarpium dryopteris*	oak fern
	HERAMAX	*Heracleum maximum (lanatum)*	cow-parsnip
	HIERACI	*Hieracium* spp.	unidentified *Hieracium* (hawkweed)
	HIERALI	*Hieracium albiflorum*	white hawkweed

APPENDIX 1 Continued

	Species Code	Scientific name	Common name / Description
	LISTCOR	*Listera cordata*	heart-leaved twayblade
	LUPIARC	*Lupinus arcticus*	arctic lupine
	LUPINUS	*Lupinus* spp.	unidentified *Lupinus*
	LUZUPAR	*Luzula parviflora*	small-flowered wood-rush
	LYCOANN	*Lycopodium annotinum*	stiff club-moss
	MITEBRE	*Mitella breweri*	Brewer's mitrewort
	MITELLA	*Mitella* spp.	unidentified *Mitella*
	MITENUD	*Mitella nuda*	common mitrewort
	MITEPEN	*Mitella pentandra*	five-stamened mitrewort
	ORTHSEC	*Orthilia secunda*	one-sided wintergreen
	OSMOBER	*Osmorhiza berteroi (chilensis)*	mountain sweet-cicely
	PEDIBRA	*Pedicularis bracteosa*	bracted lousewort
	PEDICUL	*Pedicularis* spp.	unidentified *Pedicularis*
	PLATANT	*Platanthera* spp.	unidentified rein orchid
	PLATSTR	*Platanthera stricta*	slender rein orchid
	POACEAE	*Poaceae*	unidentified grass
	RUBUPED	*Rubus pedatus*	five-leaved bramble
	SENETRI	*Senecio triangularis*	arrow-leaved groundsel
	SMILRAC	*Smilacina racemosa*	false Solomon's-seal
	STREAMP	*Streptopus amplexifolius*	clasping twistedstalk
	STRELAN	*Streptopus lanceolatus*	rosy twistedstalk
	TARAXAC	*Taraxacum* spp.	unidentified *Taraxacum*
	TIARTRI1	*Tiarella trifoliata* var. *trifoliata*	three-leaved foamflower
	TIARTRI2	*Tiarella trifoliata* var. *unifoliata*	one-leaved foamflower
	VALESIT	*Valeriana sitchensis*	Sitka valerian
	VERAVIR	*Veratrum viride*	Indian hellebore
	VIOLA	*Viola* spp.	unidentified *Viola*
	VIOLGLA	*Viola glabella*	stream violet
	VIOLORB	*Viola orbiculata*	round-leaved violet
Moss Layer	BARBLYC	*Barbilophozia lycopodioides*	common leafy liverwort
	BRACHYL	*Brachythecium hylotapetum*	woodsy ragged-moss
	BRACHYT	*Brachythecium* spp.	unidentified *Brachythecium*
	CERAPUR	*Ceratodon purpureus*	fire-moss
	DICRANU	*Dicranum* spp.	unidentified *Dicranum*
	DICRPOL	*Dicranum polysetum*	wavy-leaved moss
	MARCPOL	*Marchantia polymorpha*	green-tongue liverwort
	MNIUM	*Mnium* spp.	unidentified *Mnium*
	PLEUSCH	*Pleurozium schreberi*	red-stemmed feathermoss
	POLYJUN	*Polytrichum juniperinum*	juniper haircap moss
	POLYTRI	*Polytrichum* spp.	unidentified *Polytrichum*
	RHIZGLA	*Rhizonium glabrescens*	large leafy moss
	RHYTROB	*Rhytidiopsis robusta*	pipecleaner moss

APPENDIX 2 Cover of total herbs, total shrubs, and selected species in spring burn, fall burn, and unburned treatments

FIGURE 1 *Change in total herb cover over time.*

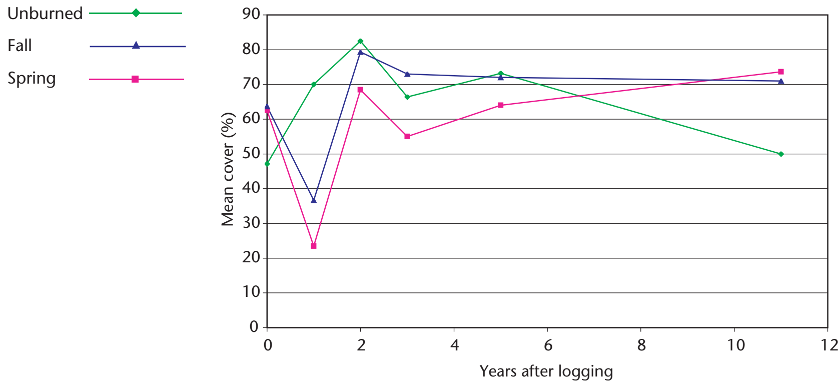

FIGURE 2 *Change in total shrub cover over time.*

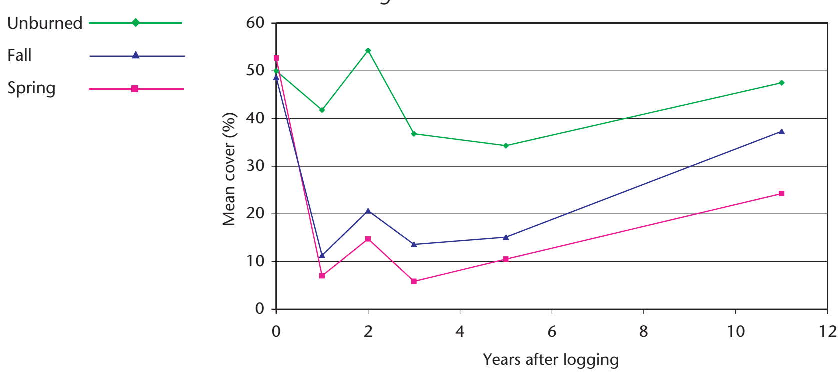

FIGURE 3 *Change in cover of* Menziesia ferruginea *over time.*

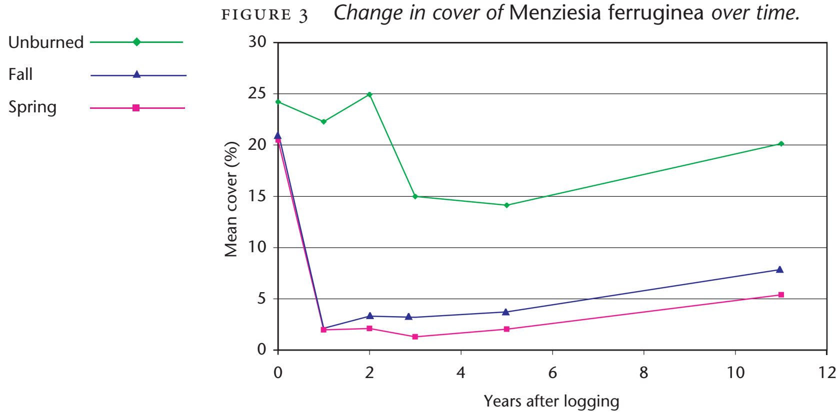

FIGURE 4 *Change in cover of* Rhododendron albiflorum *over time.*

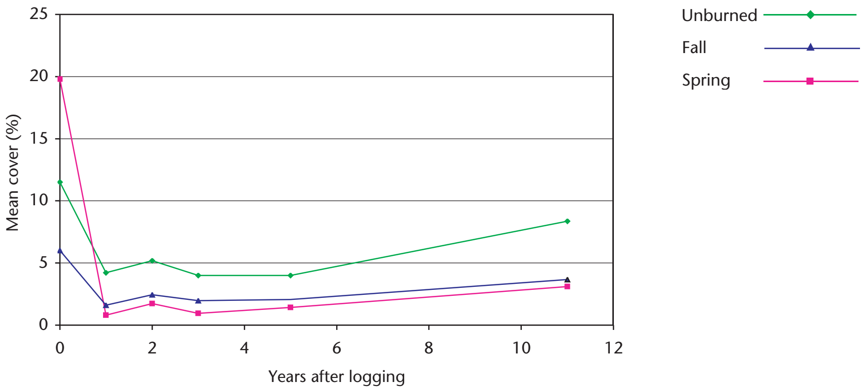

FIGURE 5 *Change in cover of* Ribes lacustre *over time.*

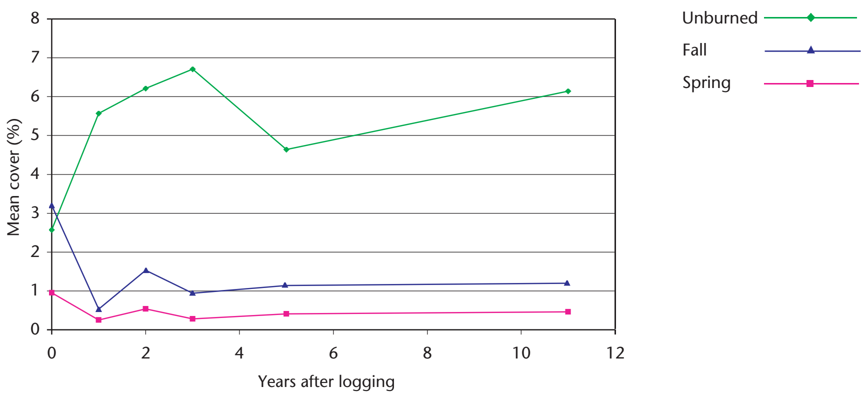

FIGURE 6 *Change in cover of* Vaccinium membranaceum *over time.*

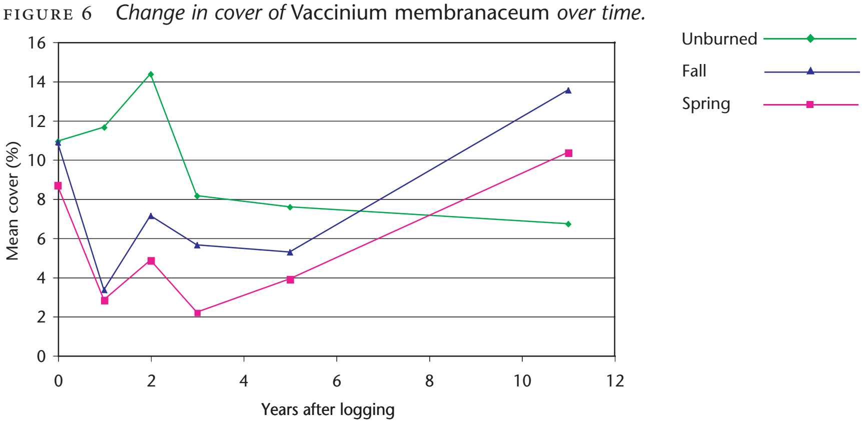

FIGURE 7 *Change in cover of* Vaccinum ovalifolium *over time.*

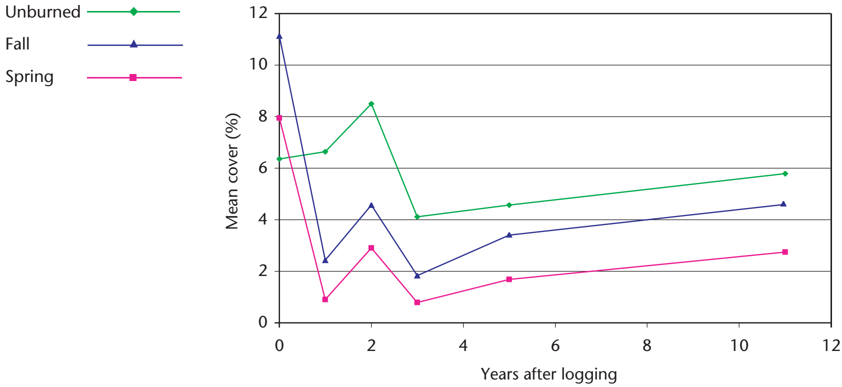

FIGURE 8 *Change in cover of* Arnica Cordifolia *over time.*

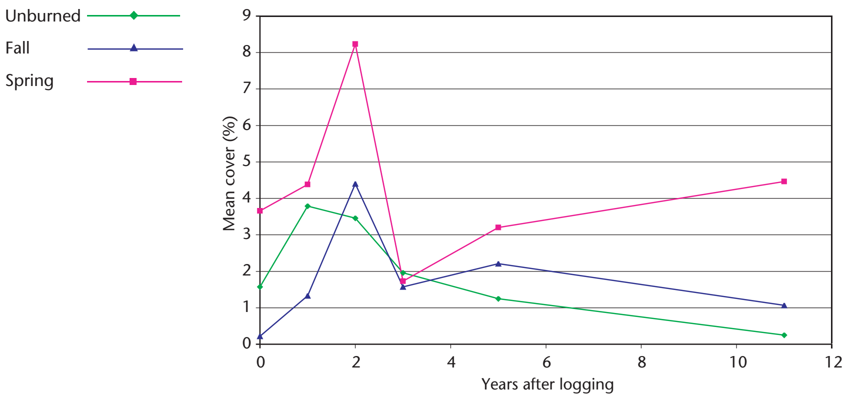

FIGURE 9 *Change in cover of* Athyrium filix-femina *over time.*

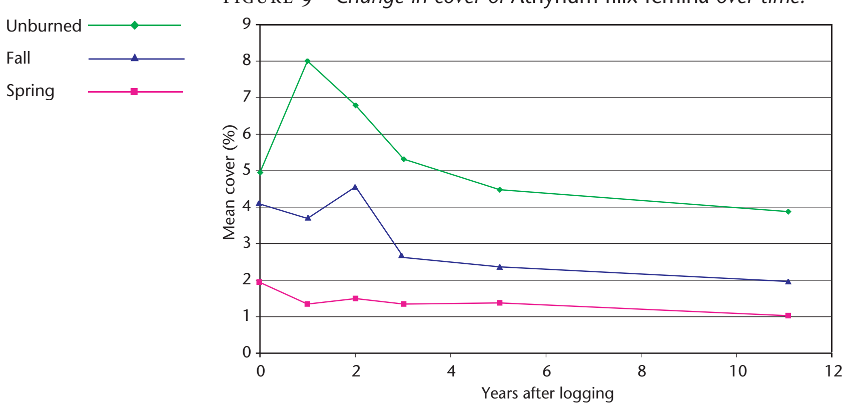

FIGURE 10 *Change in cover of* Clintonia uniflora *over time.*

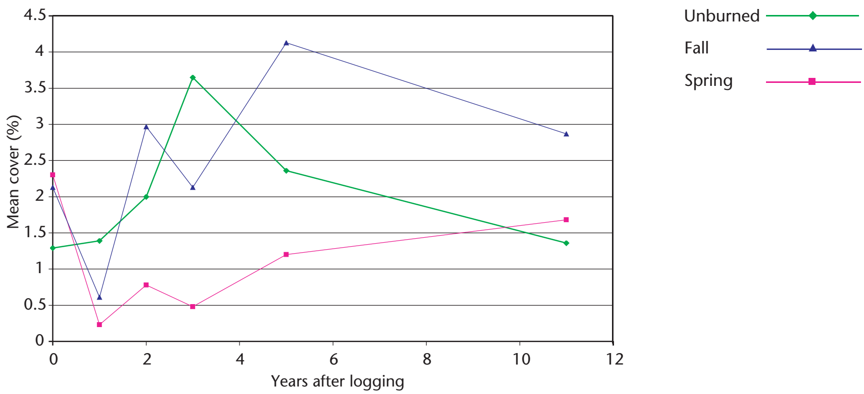

FIGURE 11 *Change in cover of* Dryoperis expansa *over time.*

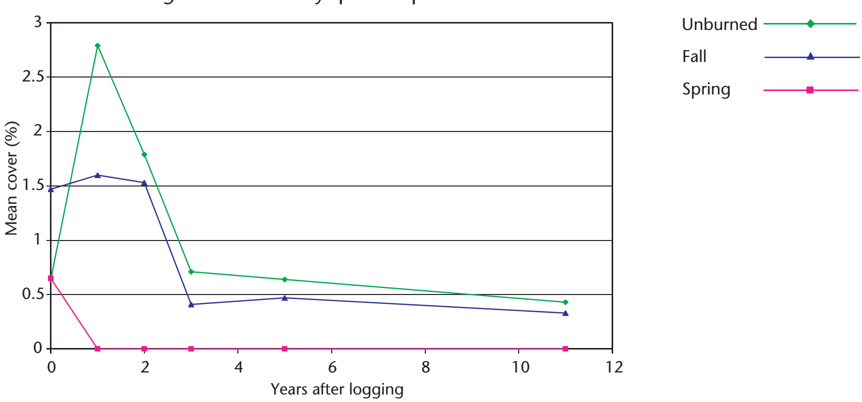

FIGURE 12 *Change in cover of* Epilobium angustifolium *over time.*

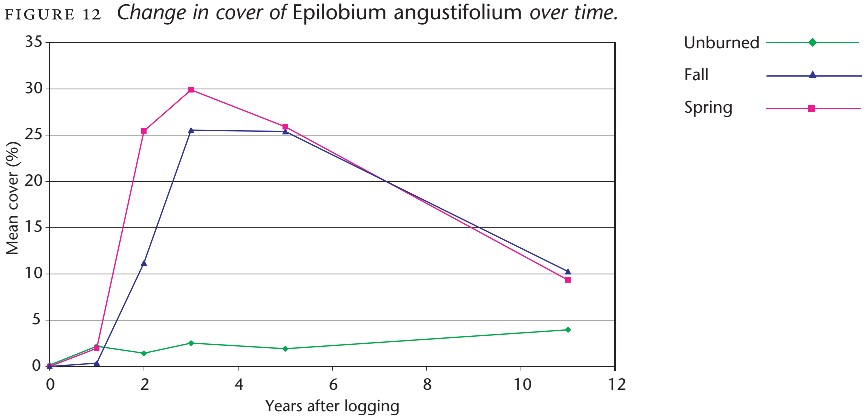

FIGURE 13 *Change in cover of* Gymnocarpium dryopteris *over time.*

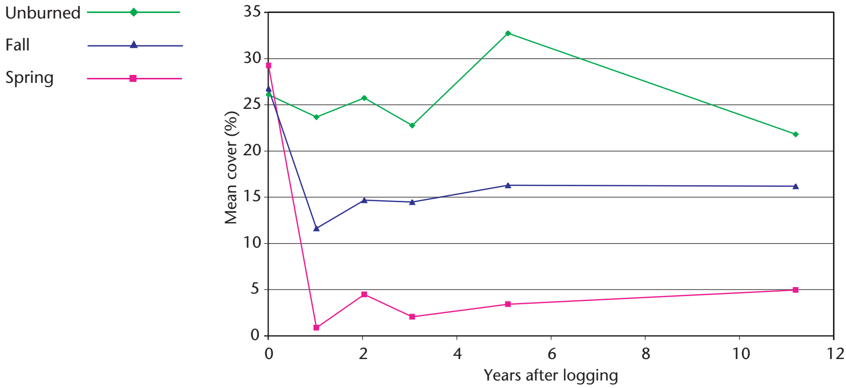

FIGURE 14 *Change in cover of* Mitella breweri *over time.*

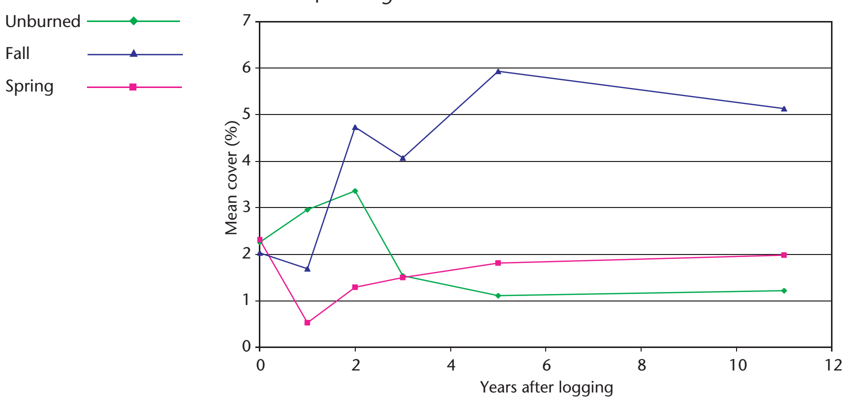

FIGURE 15 *Change in cover of* Rubus pedatus *over time.*

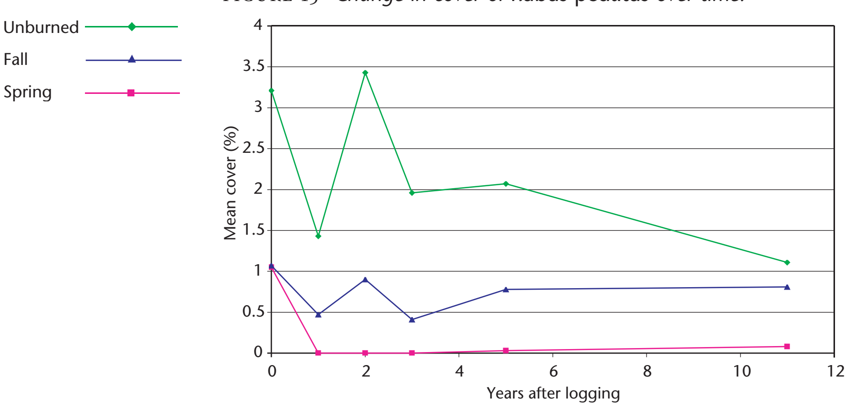

FIGURE 16 *Change in cover of* Sambucus racemosa *over time.*

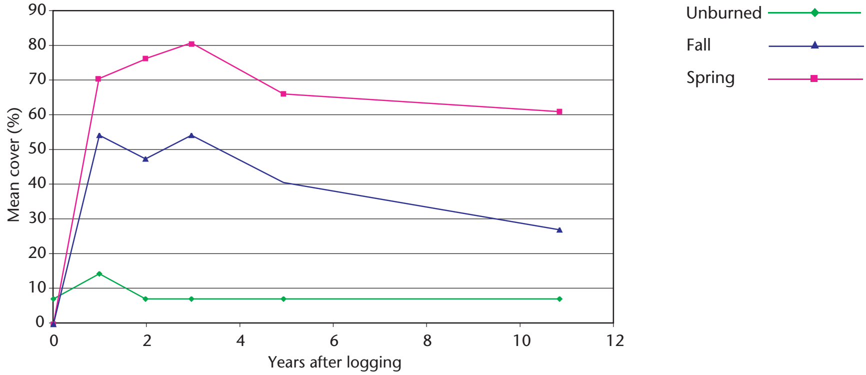

FIGURE 17 *Change in cover of* Streptopus lanceolatus *over time.*

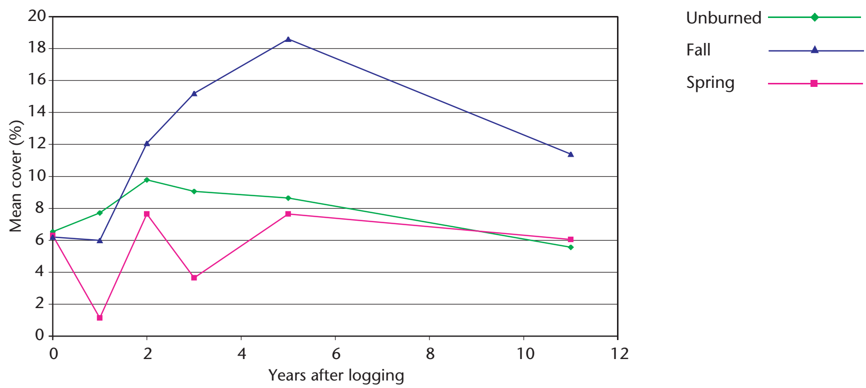

FIGURE 18 *Change in cover of* Tiarella trifoliata *var.* unifoliata *over time.*

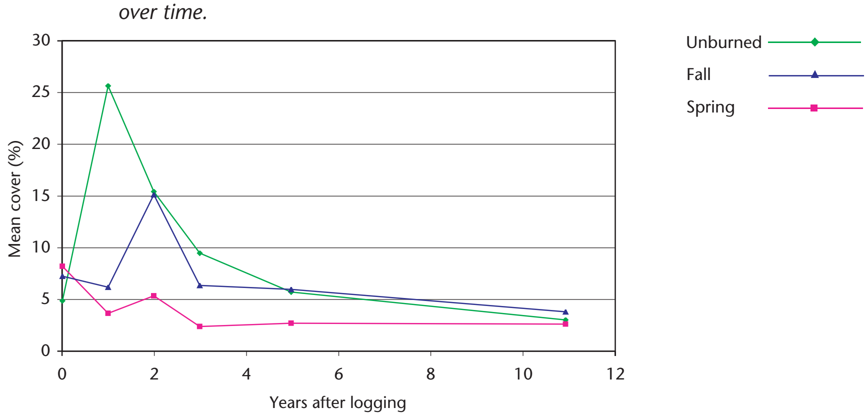

FIGURE 19 *Change in cover of* Valeriana sitchensis *over time.*

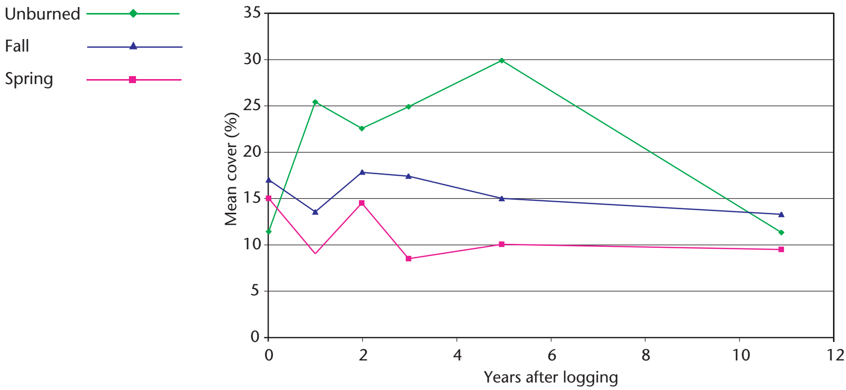

FIGURE 20 *Change in cover of* Veratrum viride *over time.*

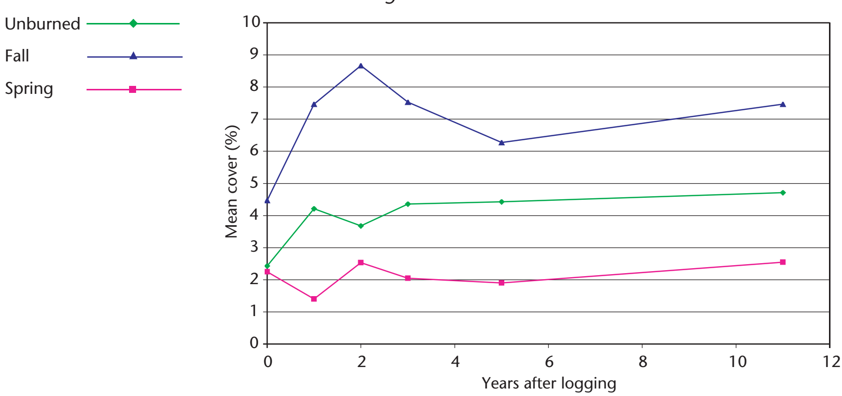

FIGURE 21 *Change in cover of* Viola glabella *over time.*