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Managing Ingrown Douglas-fir Stands for Biodiversity, Forage, and Timber:

The Farwell Canyon Project
Fifth-year Post-treatment Results

2008

BRITISH COLUMBIA
The Best Place on Earth

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Ordell Steen and Harold Armleder

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ABSTRACT

The Farwell Canyon project was established to explore treatment options for enhancing undergrowth vegetation cover, forage production, and tree growth in densely ingrown Douglas-fir stands of the Interior Douglas-fir very dry mild (IDFxm) biogeoclimatic subzone. Fire scar and tree age analyses along with stand structure observations suggest that many of these ingrown stands were considerably more open before European settlement.

Stem reduction treatments applied to two ingrown sites in 2001 included logging only (L), logging plus juvenile thinning (LT), and logging plus thinning plus underburning (LTB). No-treatment (NT) areas were also established. The logging treatment was modified from standard practices to harvest small merchantable stems and to initiate thinning of juvenile stems. The objective of this report is to compare third- and fifth-year (2003 vs. 2006) vegetation composition, forage production, and tree regeneration responses to these treatments on one site.

Douglas-fir regeneration density increased in all treatments between 2003 and 2006. Cover of grasses increased substantially, due primarily to increased cover of pinegrass (*Calamagrostis rubescens*). The number of plots with bunchgrasses increased even though mean cover of bunchgrasses did not increase significantly. Shrub and forb cover remained generally low on all treatments. Biomass of combined forbs and graminoids increased significantly from 2003 to 2006 but did not differ significantly among treatments.

These early results suggest that the logging treatment, with or without additional treatments, is leading to increased vascular plant cover and forage production. Tree regeneration density is still relatively low. The thinning and underburning treatments have reduced the fire hazard and prepared the stand for follow-up treatments to maintain a more open stand structure.

The stand treatments applied in this study should be combined with other treatments to create various stand structures across the IDFxm landscape, corresponding to historic variability of disturbances within the IDFxm subzone.

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INTRODUCTION

The Farwell Canyon Project was initiated in 2001 to explore options for treating densely ingrown Douglas-fir stands in the Interior Douglas-fir very dry mild (IDFxm) biogeoclimatic subzone. This subzone includes the lowest-elevation forests at the northern extent of the IDF zone in British Columbia (Steen and Coupé 1997). These dry forests are strongly dominated by Douglas-fir and commonly border on, or are intermixed with, dry grasslands. Many stands, especially on north- and east-facing slopes, are densely ingrown, with a closed layer of small (< 25 cm diameter at breast height [dbh]) Douglas-fir stems beneath a very open canopy of widely spaced larger (> 40 cm dbh) trees (Steen 2005). In the deep shade beneath the small stems, the undergrowth vegetation is dominated primarily by mosses and a sparse cover (< 10%) of vascular plants formed of few species (typically < 10). Forage production for wildlife and livestock is very low. Vascular plant cover is generally greatest in ingrowth layer gaps, which occur beneath the crowns of large trees and on other dry microsites.

Stand structure and age observations along with fire scar analyses clearly indicate that many of these ingrown stands were more open before European settlement in the mid- to late 1800s. Fire scar analyses in the northern IDF zone show that low- to mixed-severity fires were frequent before European settlement but essentially ceased by the early to mid-1900s (Douglas 2001; Iverson et al. 2002; Daniels 2005). These fires would have limited tree establishment and early survival, but would not have killed many of the large trees with thick, fire-resistant bark (Taylor and Baxter 1998; Daniels 2005), resulting in open stands of wide-crowned trees. Additional observations supporting the conclusion that stands were more open include (1) the relatively young age (mostly 60–120 years) of the dense layer of small stems, (2) the multi-aged larger stems that range from about 200 to more than 350 years, (3) the characteristic open-grown form (large spreading branches) of many large trees, and (4) the relatively rapid early radial growth of many larger trees, indicating open spacing.

Treatment options for reducing stem densities in these ingrown IDFxm stands include mechanical and/or underburning treatments. However, the effects of these treatments on undergrowth vegetation, post-treatment tree regeneration, tree growth, and stand structure development are not well understood. It is expected that a more open stand will lead to enhanced undergrowth richness and diversity as well as increased forage production and increased Douglas-fir stem growth. Increased stem growth is desired not only for increased timber value but also for long-term recruitment of large, high-value wildlife trees. Effects of treatments on subsequent tree regeneration establishment need to be better understood to avoid stimulating dense regeneration that returns the stand to its previously ingrown structure. Effects on stand structure development need to be better understood to determine if the ingrown stands can be managed to achieve structures with full or nearly full site occupancy by large, wide-crowned trees. A well-developed grassy undergrowth has been noted repeatedly beneath well-developed canopies of large, wide-crowned trees on IDFxm sites.

Current silviculture practices in IDFxm Douglas-fir stands are based on a selection system that harvests stems from all size classes ≥ 17.5 cm dbh. Stems

< 17.5 cm dbh are normally protected from damage, to the extent possible, to fully restock the stand. In this study, the density of stems to retain in the treated stands was guided by a goal to maintain, or at least not substantially reduce, stand-level growth. The minimum tree density required for this was estimated by extrapolation of stand density–stand growth relationships from Douglas-fir forests on the University of British Columbia Fraser Research Forest (K. Day, pers. comm., June 2001). From a timber management perspective, the goal was to increase individual tree stem growth by harvesting and thinning while maintaining overall stand-level growth. It was not an objective of the project to necessarily return stands to a very open, pre-ingrowth structure.

The objective of this report is to compare second- and fifth-year effects of timber harvesting, tree thinning, and underburning treatments on:

- undergrowth vegetation composition;
- herbaceous biomass production; and
- tree seedling density.

This study was initiated on two sites but data from only one site (Site 2) are used for the comparison of second- and fifth-year results. Due to limited resources, no underburning treatment was applied to Site 1, and post-treatment monitoring data were not collected at Site 1 until 2006. Future analyses will consider treatment effects at both sites.

STUDY SITES

The two study sites are in the IDFxm biogeoclimatic subzone, approximately 70 km southwest of Williams Lake, B.C. Elevations are 960 and 1025 m on Sites 1 and 2, respectively, and both sites are on gentle (mostly 5–25%) north- to northeast-facing slopes. Both sites were selected to be readily accessible for demonstration purposes. Soils are well- to moderately well-drained Orthic Gray Luvisols with a loam surface texture. Percent mineral soil exposure before harvest averaged < 1%.

Stands on both sites were strongly dominated by Douglas-fir, which comprised 96% of the total basal area of trees ≥ 12.5 cm dbh in each stand. Total basal area was 29.9 and 31.3 m^2/ha on Sites 1 and 2, respectively. Other tree species included a few lodgepole pine and trembling aspen. Before treatment, both stands included a dense subcanopy of small (< 22.5 cm dbh) Douglas-fir stems, which strongly shaded the forest floor. On Site 2, these stems were nearly all 80 to 120 years old with a slightly bimodal age distribution, suggesting periods of peak ingrowth establishment in 1880–1900 and again in 1910–1920. Highest densities were in the 2.5- to 7.4-cm diameter class (Table 1). Smaller stems were less dense (Table 1), presumably because the sites were fully occupied. Trees greater than 40 cm dbh occurred as scattered individuals, or more commonly in small groups of three to four trees, with a density of 30–40 stems per hectare. These stems were from 150 to more than 300 years old. Cruised timber volumes before logging were 178 and 182 m^3/ha on Sites 1 and 2, respectively.

TABLE 1 *Pre-treatment stems per hectare of all tree species by diameter (dbh) class*

Diameter (cm) at 1.3 m	Stems per hectare	
	Site 1	Site 2
0–2.4	440	2084
2.5–7.4	1666	2384
7.5–12.4	494	905
12.5–22.4	222	488
22.5–32.4	174	128
32.5–42.4	48	33
42.5–52.4	8	22
52.5–62.4	10	10
≥62.5	9	5

The pre-treatment undergrowth vegetation on both sites consisted primarily of mosses (especially *Pleurozium schreberi* and *Hylocomium splendens*), with few graminoids, forbs, or shrubs. On some microsites occupied by a group of Douglas-fir trees > 40 cm dbh, the subcanopy of small stems was absent and the undergrowth had a greater percent cover of grasses, shrubs, and forbs. Principal graminoid species on the sites were pinegrass (*Calamagrostis rubescens)*, sedges (*Carex richardsonii* and *Carex rossii*), and bluegrasses (*Poa* spp.). Grassland bunchgrasses such as bluebunch wheatgrass (*Pseudoroegnaria spicata)* and spreading needlegrass (*Achnatherum richardsonii)* were present with small cover values in some plots. Principal forbs included nodding onion (*Allium cernuum)*, showy aster (*Aster conspicuus)*, wild strawberry (*Fragaria virginiana)*, and Rocky Mountain butterweed (*Senecio streptanthifolius)*. Principal lichen genera were *Peltigera* and *Cladonia.*

METHODS

The study has a completely randomized split-plot design in which the main plot factor is stand treatment (no treatment, logged only, logged plus thinned, logged plus thinned plus underburned) and the split-plot factor is year of assessment (2003 and 2006). Each of the four treatments was applied to each of three treatment units within Site 2 (Figure 1) as described below. In the analyses reported here, treatments are replicated only within this single site and conclusions regarding fifth-year effects apply only to this site.

No Treatment (NT)

Three no treatment areas (Figure 2) were established as untreated controls for demonstration and comparison on Site 2. They were selected by Riverside Forest Products Ltd. (now Tolko Industries Ltd.) as within-stand wildlife tree patches and all contained large diameter, older trees as scattered individuals or in small groups. No-treatment areas on Site 2 ranged from 0.4 to 2 ha.

Logged Only (L) Treatment

In the logged only treatment (Figure 3), timber harvesting was the only treatment and was not followed by juvenile thinning or underburning. The logged only treatment was applied to four 80 × 80 m treatment units on Site 2. Plots

FIGURE 1 *Map of treatment areas on Site 2.*

and grazing exclosures were established in three of the units. The size of each treatment unit was selected to ensure that a buffer of at least one tree length (approximately 22 m) would surround a growth and yield plot with a radius of 15.96 m. Treatment unit locations were centred on randomly selected cruise plot centres and points midway between cruise plot centres.

Timber harvesting was planned by Riverside Forest Products Ltd. and conducted in late summer (early August to mid-September) 2001. Harvesting was done with a fellerbuncher and grapple-skidders, although some of the largest trees were hand-felled and grapple skidded. The harvesting plan used a "BDq" approach, leaving a residual stand basal area of 15.4 m^2/ha on Site 2 (49% of pre-harvest basal area). The residual basal area was considered the minimum to maintain, or at least not substantially reduce, stand-level growth over the long term (K. Day, pers. comm., June 2001). The selected diminution quotient was 1.2 for Site 2 and the largest-diameter stem included in the planned cut was 62.5 cm dbh. Larger stems were unharvested. Harvesting on Site 2 reduced the density of stems ≥ 12.5 cm dbh from 685 to 262 stems per hectare. The number of stems < 12.5 cm dbh was reduced from 4094 to 1247 stems per hectare. Mineral soil exposure on vegetation monitoring plots within this treatment averaged 7%.

FIGURE 2 *A no treatment area on Site 2, 2006.*

FIGURE 3 *A logged only treatment area on Site 2, 2006.*

An important aspect of this treatment was that normal harvesting practices were modified to include stems as small as 12.5 cm dbh, compared with the normal minimum harvest diameter of 17.5 cm. Stems between 12.5 and 17.5 cm dbh made up 12% of the total stand volume on Site 2. A principal benefit of harvesting the smaller-diameter stems was that many more small (< 17.5 cm dbh) stems were removed than in a normal operation. Many juvenile stems < 12.5 cm dbh were cut by the fellerbuncher head, which was left running ("hot-sawing") while approaching merchantable stems > 12.5 cm dbh. The smaller minimum harvest diameter also allowed greater retention of large, old trees while harvesting the same total volume.

Logged Plus Thinned (LT) Treatment

Because this project was established primarily to demonstrate and evaluate a modified operational timber harvest, this treatment formed the matrix treatment and was applied to > 50% of both sites. In this treatment (Figure 4), the logged only treatment was following by manual thinning of juvenile stems (< 12.5 cm dbh). The objective of the thinning treatment was to retain only those juvenile stems that were considered to have a high potential for growth response and a high potential to form a desirable crop tree. These stems had > 30% live crown, straight stems, no galls or cankers or logging damage, and a distance of at least 1.5 m from another juvenile stem. All other juvenile stems were cut and slashed. Thinning was initiated in October 2001 and completed in early March 2002. Thinning reduced post-logging juvenile stem density from 1247 to 335 stems per hectare across Site 2 as a whole. Mineral soil exposure in vegetation monitoring plots within this treatment averaged 15%.

FIGURE 4 *A logged and thinned treatment area on Site 2, 2006.*

Logged Plus Thinned Plus Underburned (LTB) Treatment

In this treatment (Figure 5), the stand was logged and thinned as in the previous treatment and then underburned to remove accumulated slash. Due to limited time and resources for burning, this treatment was applied only to Site 2. The overall objectives of the burning treatment were:

- to reduce the volume of thinning and logging slash to provide an environment for native grassland vegetation establishment;
- to reduce wildfire hazards; and
- to create fuel conditions in which an open stand structure could be maintained by repeated periodic ground fires (low densities of tree regeneration and low volumes of small-diameter woody ground fuels).

Underburning was conducted on 3 days in spring 2002, 1 day in fall 2002, and 3 days in spring 2003. Monitoring plots were established only on the area burned on May 27, 2002, because of logistic and resource limitations to the establishment of livestock exclosures on other underburned areas. The three LTB treatment units are separated by skid trails, which generally did not burn because of little downed woody fuels. On the May 27 underburn, fuels < 2.5 cm diameter in the juvenile thinning and logging slash ignited readily using hand-held drip torches and approximately 1.5 ha were burned. Preburn woody fuel loadings were about 60 Mg/ha[1], including approximately 26 Mg/ha of fine (< 7.0 cm diameter) fuels. Although slash consumption was nearly continuous, little forest floor other than surface litter was consumed because of high moisture levels in the forest floor materials resulting from the recent snowmelt. Mineral soil exposure in vegetation monitoring plots averaged 9%. Most (68%) of the forest floor surface was charred and some very

FIGURE 5 *A logged, thinned, and underburned treatment area on Site 2, 2006.*

1 Mg = a megagram or 1000 kg

large (>30 cm diameter) pieces of woody debris were completely consumed.

Because of high fuel loadings and a higher than planned flame height, several (10%) of the trees, especially in the subcanopy, were severely scorched (all or most needles scorched). On most (79%) trees, scorched needles were not evident or were restricted to the lower third of the canopy.

Livestock Exclusion

Livestock exclosures were built in 2003 around all vegetation and tree seedling monitoring plots within logged treatments on Site 2 to avoid confounding effects of cattle grazing on vegetation composition and production. Exclosures were not built in the no treatment (NT) areas until April 2007 because there was little forage to attract domestic livestock and thus little likelihood of livestock impacts to the vegetation. Exclosures were built around these plots in April 2007 because tree mortality due to western spruce budworm attack stimulated forage production and the potential to attract livestock, although no evidence of livestock use of these areas was found.

Plot Layout

Before timber harvesting, 40 tree regeneration density plots (50 m^2, r = 3.99 m) and 40 undergrowth vegetation plots (100 m^2, r = 5.64 m) were established systematically at cruise plot centres throughout Site 2. Pre-treatment plots were not located specifically within treatment units because, except for the NT units, boundaries of the treatment units were not established until logging was completed.

In summer 2003, vegetation and tree regeneration monitoring plots were re-established in a cluster pattern within treatment units on Site 2 so that plots could practically be located within grazing exclosures. In the logged plus thinned (LT) treatment, which covered most of the site, and in the logged only (L) treatment, clusters were established at three randomly selected locations. In the underburned (LTB) treatment, three plot clusters were established on the May 27, 2002 burn area.

Each plot cluster includes five vegetation composition plots (100 m^2, r = 5.64 m), five tree density plots (50 m^2, r = 3.99 m) nested within the vegetation plots, and 10 forage production plots (1 m^2, r = 0.56 m), with two located adjacent to each vegetation plot. In the NT, L, and LT treatments, the central vegetation plot of each cluster was on a cruise plot centre and the other four were located at 15 m in each of the four cardinal directions. In the LTB treatment, vegetation composition and tree density plots were established within three burned areas separated by largely unburned skid trails. Plots were at 20-m intervals along a linear transect midway between the skid trails. As in other treatment units, two forage production plots were located adjacent to each vegetation plot.

Data Collection

Vegetation composition Percent ground cover of each shrub, graminoid, forb, moss, and lichen species within each vegetation composition plot on Site 2 was visually estimated and recorded in August 2003 and August 2006. The total cover of each growth form was estimated by summing percent cover of each species within the growth form. Bluegrasses (*Poa* spp.) were combined because of the difficulty of consistently distinguishing different species in the field.

Tree stem density Number of stems of each tree species in each tree density plot was recorded by species and layer, based on stem size classes. Layers 1–4

include stems ≥ 12.5 cm dbh, 7.5–12.4 cm dbh, < 7.5 cm dbh but ≥ 1.3 m tall, and < 1.3 m tall, respectively (Silviculture Interpretations Working Group 1992). Layer 4, or seedlings, is the focus of the monitoring. In 2006, the vitality of each stem in Layers 1–3 was recorded as class 1 (live and > 70% of branchlets with green needles), class 2 (live and < 70% of branchlets with green needles), or class 3 (tree dead). Stems in Layer 4 were noted as live or dead. In 2006, the number of stems in Layer 4 on a skid trail was recorded separately from those not on a skid trail.

Forage production In each forage production plot (1 m^2, r = 0.56 m), all herbaceous plants more than 2 cm tall were clipped at 2 cm above the surface and sorted into graminoids (grasses and sedges) and forbs. Only plant material that was assumed to have been produced during the current growing season was collected. Older material, produced during a previous growing season, was identified by its grey colour and very dry condition.

Collected plant material was stored in paper bags, air-dried for 1 week, oven-dried at 40°C for 48 hours, and weighed immediately. Ovendry weight was recorded to the nearest 0.01 g.

Data Analyses

Vegetation composition, tree seedling (stems < 1.3 m tall) density, and forage production data from Site 2 were analyzed by ANOVA, using a completely randomized split-plot design. Analyses were conducted on plot cluster averages (averages of 5 or 10 plots) for all variables to minimize zero values and reduce skew of the data. Contrast analyses of treatment effects tested the significance of differences between:

- NT compared with the average of all other (L, LT, LTB) treatments,
- L compared with LT treatments, and
- LT compared with LTB treatments.

Contrast analyses of treatment × year interaction effects tested whether the above differences were significant in both years, that is:

- year × NT compared with all other treatments,
- year × L compared with LT treatments, and
- year × LT compared with LTB treatments.

In all analyses, differences were considered significant at $\alpha = 0.05$.

Pre-treatment data were not included in the analyses since these data were collected from throughout the site on a systematic grid rather than within treatment unit locations that were selected following logging. Pre-treatment data were summarized for anecdotal comparisons to 2003 and 2006 data.

Vegetation analyses included the effects of treatments and year on mean cover of shrubs, graminoids, forbs, mosses, lichens, bunchgrasses, pinegrass (*Calamagrostis rubescens*), invasive alien and weedy species, total vascular plant cover, and mean number of vascular plant species per plot. Bunchgrass species were analyzed separately because of interest in restoring or enhancing their representation in open forests of the IDFxm. Invasive alien species listed under provincial regulation (Invasive Plants Regulation under *Forest and Range Practices Act*) and other "weedy" species were analyzed separately because of concern that site disturbance and mineral soil exposure may provide an environment for spread of these species.

Tree seedling analyses tested the effects of treatment and year on density of live Douglas-fir seedlings. Forage production analyses tested the effects of treatment and year on graminoid biomass, forb biomass, and combined graminoid and forb biomass. Shrub biomass was not sampled.

RESULTS

Tree Density and Condition

Douglas-fir was the only trees species of stems ≥ 1.3 m tall on either site. In both years, mean stem densities in Layers 2 (stems 7.5–12.4 cm dbh) and 3 (stems ≥ 1.3 m tall and < 7.5 cm dbh) generally decreased with increasing treatment from NT to LTB (Table 2).

By 2006, trees on Site 2 had been substantially affected by spruce budworm, with the heaviest infection in Layers 2 and 3 (Table 3). Since stems in these layers typically have a small leaf area and a high proportion of needles < 3 years old, budworm attack resulted in 30% or more dead needles on many

TABLE 2 *Mean (and SD) number of live stems per hectare in Layers 1 (dbh ≥ 12.5 cm), 2 (dbh = 7.5–12.4 cm), and 3 (stem ≥ 1.3 m tall and dbh < 7.5 cm) by treatment on Site 2. All stems were Douglas-fir.*

	Treatment			
Year	**NT**	**L**	**LT**	**LTB**
Layer 1				
2003	506 (370)	186 (206)	280 (224)	254 (192)
2006	514 (340)	226 (212)	254 (192)	266 (144)
Layer 2				
2003	706 (528)	386 (404)	146 (244)	0 (0)
2006	742 (516)	360 (332)	120 (198)	0 (0)
Layer 3				
2003	1800 (1042)	1054 (1004)	0 (0)	66 (164)
2006	2486 (1504)	1346 (1208)	26 (70)	40 (112)

TABLE 3 *Mean percent of stems in Layer 2 (7.5–12.4 cm dbh) and Layer 3 (≥ 1.3 m tall and < 7.5 cm dbh) within three condition classes in each treatment on Site 2. Class 1 = live with < 30% dead needles; class 2 = live with ≥ 30% dead needles; class 3 = stem dead (all needles dead or fallen). "NS" = no stems present.*

	Treatment			
Condition class	**NT**	**L**	**LT**	**LTB**
Layer 2				
1	22	33	78	NS
2	72	67	22	NS
3	6	0	0	NS
Layer 3				
1	8	26	0	0
2	71	56	50	100
3	21	18	50	0

of these stems. The high needle mortality in these layers certainly resulted in increased light to the understorey compared with 2003, although light was not measured.

Tree Seedling Density

Douglas-fir was the only species of tree seedlings (stems < 1.3 m tall) recorded in 59 of 60 plots on Site 2 in 2006. A single lodgepole pine stem was recorded in one plot.

Mean density of live Douglas-fir seedlings on Site 2 increased between 2003 and 2006 (Table 4) with a significant year × treatment interaction effect (Table 5). Densities in 2006, but not 2003, were significantly greater in the logged treatments (L, LT, and LTB) than in the untreated area (Table 5). Densities did not differ significantly between the L and LT treatments or the LT and LTB treatments in either year (Table 5).

The number of Douglas-fir seedlings in the plots was greatly influenced by the presence of a skid trail. In plots that included any portion of a skid trail, concentration of seedlings on a skid trail (percentage of total seedlings that were on a skid trail divided by percentage of plot area within skid trail) ranged from 1.3 to 9.5.

Undergrowth Vegetation

Mosses The most dramatic effect of the treatments on undergrowth vegetation was a sharp decline in live moss ground cover (Table 6). Live moss cover in 2003, 2 years after logging, on Site 2 was < 30% on all treatments and < 10% on the LTB treatment, compared with approximately 60% across the site before logging. The decline continued to 2006, when live moss cover was

TABLE 4 *Mean (and SD) number of Douglas-fir seedlings per hectare (Layer 4: stems < 1.3 m tall) on Site 2 by treatment and year*

	Treatment			
Year	**NT**	**L**	**LT**	**LTB**
2003 Live	240 (380)	786 (2448)	214 (358)	66 (164)
2006 Live	286 (290)	920 (1966)	894 (1210)	934 (766)
2006 Total	400 (430)	1066 (2040)	946 (1210)	946 (758)

TABLE 5 *ANOVA* P *values for assessing significance of live Douglas-fir seedling (stems < 1.3 m tall) density differences among treatments and between years*

Source	*P* value
Treatment	0.648
NT vs. others	0.335
L vs. LT	0.537
LT vs. LTB	0.911
Year	0.002
Year × Treatment	0.038
Year × NT vs. others	0.040
Year × L vs. LT	0.080
Year × LT vs. LTB	0.514

TABLE 6 *Mean (and SD) percent cover of vegetation growth forms and selected species by treatment and year. Pre-treatment values (2001) are averages across the entire site rather than within individual treatment units.*

Growth form/ Species	Year	Treatment			
		NT	L	LT	LTB
Mosses (live)	Pre-treat	----------60.6 (24.1)----------			
	2003	26.39 (30.04)	22.99 (25.59)	24.47 (27.39)	5.72 (7.29)
	2006	26.55 (30.35)	8.59 (11.48)	6.27 (7.65)	1.60 (2.02)
Lichens	Pre-treat	----------1.8 (2.2)----------			
	2003	0.19 (0.29)	0.06 (0.07)	0.11 (0.18)	0.05 (0.09)
	2006	0.42 (0.57)	0.09 (0.13)	0.25 (0.44)	0.03 (0.03)
Total vascular	Pre-treat	----------7.2 (8.6)----------			
	2003	10.09 (10.66)	18.23 (16.12)	10.09 (11.83)	9.54 (5.71)
	2006	23.22 (27.12)	43.78 (29.25	31.92 (23.52)	42.84 (17.41)
Shrubs	Pre-treat	----------0.4 (1.1)----------			
	2003	1.98 (3.31)	5.07 (8.26)	2.73 (4.86)	3.43 (3.98)
	2006	8.02 (14.88)	15.77 (24.13)	9.73 (13.55)	17.03 (21.30)
Graminoids	Pre-treat	----------5.0 (5.7)----------			
	2003	7.1 (8.2)	11.8 (12.83)	7.5 (10.1)	7.3 (5.5)
	2006	19.6 (25.1)	35.1 (25.9)	25.3 (21.4)	37.5 (17.4)
Pinegrass	Pre-treat	----------3.5 (4.2)----------			
	2003	3.97 (5.31)	10.13 (11.27)	5.47 (8.01)	6.87 (5.66)
	2006	16.03 (23.08)	31.53 (26.31)	19.47 (21.61)	34.07 (18.45)
Bunchgrasses	Pre-treat	----------0.6 (2.0)----------			
	2003	0.08 (0.17)	0.01 (0.02)	0.11 (0.24)	0.01 (0.17)
	2006	0.23 (0.49)	0.08 (0.13)	0.35 (0.57)	0.21 (0.32)
Forbs	Pre-treat	----------1.7 (2.5)----------			
	2003	0.98 (1.64)	3.00 (4.14)	1.20 (1.50)	0.89 (1.07)
	2006	1.17 (1.74)	3.95 (4.90)	2.95 (3.84)	2.21 (2.74)
Weedy species	Pre-treat	----------0.07 (0.17)----------			
	2003	0.01 (0.02)	0.09 (0.11)	0.13 (0.18)	0.10 (0.14)
	2006	0.04 (0.07)	0.09 (0.12)	0.38 (0.56)	0.51 (0.81)

<10% on all treatments except NT. Live moss cover remained essentially constant on the NT treatment between 2003 and 2006 but declined on the logged (L, LT, LTB) treatments; there were significant year × treatment interaction effects (Table 7). Moss cover was significantly greater on the NT than the other treatments in 2006 but not in 2003. Moss cover was significantly less on the LTB than on the LT treatment (Table 7). On the LTB treatment, loss of pre-treatment feathermosses (especially *Pleurozium schreberi*) was partially compensated for by establishment of fire moss (*Ceratadon purpureus*) on mineral soils exposed by the fire.

Lichens Lichen ground cover was significantly reduced in the treated areas compared with the NT treatment on Site 2 (Tables 6 and 7). However, lichen

TABLE 7 *ANOVA* P *values for assessing significance of vegetation differences among treatments and between years.* P *values ≤ 0.05 are bolded.*

	Plant growth form or species group								
Source	**Moss**	**Lichen**	**Total vascular**	**Shrub**	**Graminoid**	**Pinegrass**	**Bunchgrass**	**Forb**	**Weedy**
Treatment (T)	**< 0.001**	**0.036**	0.475	0.171	0.586	0.470	0.421	**0.029**	0.083
NT vs. others	**< 0.001**	**0.012**	0.239	0.382	0.296	0.260	0.781	**0.049**	0.058
L vs. LT	0.876	0.229	0.303	0.716	0.411	0.329	0.112	0.078	0.175
LT vs. LTB	**< 0.001**	0.124	0.590	0.455	0.485	0.350	0.297	0.490	0.650
Year (Y)	**< 0.001**	0.149	**0.003**	0.077	**0.003**	**0.006**	0.056	0.062	**0.053**
Y × T	**0.009**	0.499	0.758	0.977	0.751	0.789	0.866	0.755	0.277
Y × NT vs. others	**0.011**	0.223	0.384	0.717	0.423	0.526	0.896	0.354	0.342
Y × L vs. LT	0.479	0.546	0.846	0.823	0.749	0.662	0.430	0.597	0.299
Y × LT vs. LTB	**0.016**	0.374	0.551	0.981	0.473	0.439	0.838	0.776	0.480

cover did not differ significantly between the L and LT or the LT and LTB treatments (Table 7), even though lichen cover tended to be lowest on the burned (LTB) treatment.

Total vascular plants Mean vascular plant cover (all species combined) increased significantly on Site 2 between 2003 and 2006 (Tables 6 and 7). Differences between the NT and the other plots were not statistically significant, due to large variability within treatments.

The average number of vascular plant species per 100-m² plot on Site 2 increased significantly ($P < 0.001$) from 5.2 in 2003 to 8.4 in 2006. Although increases tended to be smallest in the NT plots, there were no significant treatment × year interaction effects ($P = 0.813$) and increases were not significantly greater in the treated (L, LT, and LTB) than in the untreated (NT) plots ($P = 0.293$).

The number of species that occurred on > 10% of the 60 plots also increased slightly from 38% in 2003 to 46% in 2006. That is, species were slightly more widely distributed in 2006 than in 2003.

Shrubs Mean percent shrub cover on Site 2 tended to increase slightly on all treatments from 2003 to 2006 (Table 6) although differences between years and between treatments were not statistically significant (Table 7). Mean percent cover of shrubs across all treatments in 2006 (0.5%) was similar to mean cover across the stand before logging (0.4%). Shrub species with the highest mean cover in 2006 were prickly rose (*Rosa acicularis*), common snowberry (*Symphoricarpos albus*), and northern gooseberry (*Ribes oxyacanthoides*).

Graminoids Mean percent ground cover of graminoids (grasses and sedges) increased significantly on Site 2 from 2003 to 2006 (Tables 6 and 7) and accounted for most of the total increase in vascular plant cover. However, there were no statistically significant differences between treatments and no significant treatment × year interaction effects (Table 7).

In 2006, grasses (especially pinegrass [*Calamagrostis rubescens*]) dominated the visual aspect of the undergrowth on most portions of Site 2. Pinegrass increased significantly on Site 2 from 2003 to 2006 (Figure 6; Tables 6 and 7)

and accounted for most of the total increase in graminoid and vascular plant cover. Although pinegrass was least abundant on the NT areas, there were no significant differences among the treatments in either year (Table 7). Mean percent cover of pinegrass on Site 2 before logging was 3.5%, which increased slightly by 2003 and substantially by 2006 (Table 6). That is, the principal increase in pinegrass cover occurred after 2003, more than 2 years following the treatments. This interpretation is consistent with visual assessments, which suggested that the principal increase in pinegrass cover occurred in years 4 and 5.

Due to the interest in restoring grassland bunchgrass species to open forests in dry IDF subzones (Newman et al. 2004; Steen 2005; Newman and Parminter 2007), the cover of bunchgrass species was assessed separately on the two blocks. Species present on the sites were bluebunch wheatgrass (*Pseudoroegneria spicata*), porcupine grass (*Hesperostipa curtiseta*), spreading needlegrass (*Achnatherum richardsonii*), Columbia needlegrass (*Achnatherum nelsonii*), and junegrass (*Koeleria macrantha*). The number of plots (out of 60) on Site 2 in which at least one of these grass species was present increased from 15 (25%) in 2003 to 34 (57%) in 2006. Before logging on Site 2, one or more of these species was present on 3 (14%) of 22 plots. Although combined cover of these grasses tended to increase slightly from 2003 to 2006 (Table 6), differences between years were not statistically significant. Pre-treatment mean percent cover of bunchgrasses was relatively high (Table 6) because two plots located beneath large veteran trees had cover values > 5%.

Forbs Differences in the mean percent ground cover of forbs between 2003 and 2006 (Table 6) were not statistically significant (Table 7). However, treatment had a significant effect on mean cover of forbs, with cover on the NT treatment being significantly less than on the other treatments (Table 7). Increasing intensity of treatment from L to LT and from LT to LTB had no significant effect on mean forb cover in either year (Table 7).

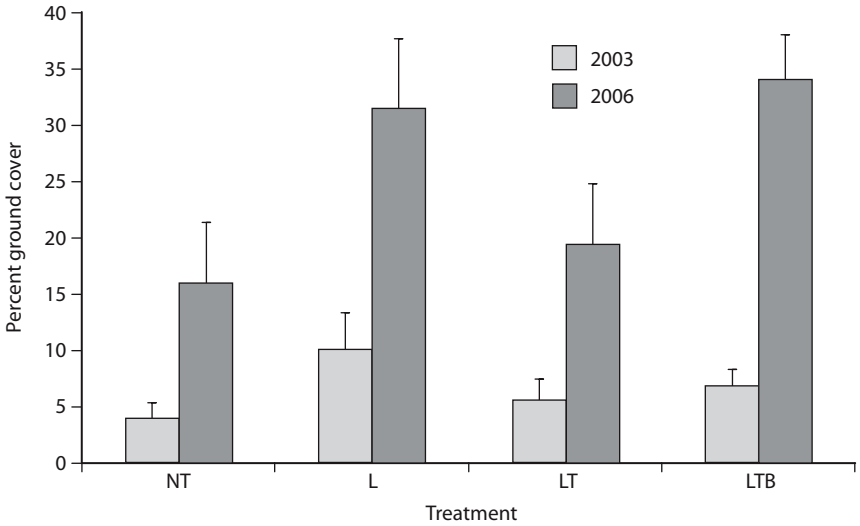

FIGURE 6 *Mean (+ 1 SE) percent ground cover of pinegrass (*Calamagrostis rubescens*) on Site 2 by treatment and year.*

Showy aster (*Aster conspicuus*) was the only forb species with mean cover ≥ 1% on Site 2. Other forb species with mean cover > 0.1% included fireweed (*Epilobium angustifolium*), northern bedstraw (*Galium boreale*), annual hawksbeard (*Crepis tectorum*), showy daisy (*Erigeron speciosus*), dryland goldenrod (*Solidago spathulata*), and dandelion (*Taraxacum officinale*).

Weeds The potential establishment of weedy species, especially invasive alien species listed under provincial regulation (Invasive Plants Regulation under *Forest and Range Practices Act*), is a concern wherever native vegetation is disturbed and mineral soil is exposed. In this study the potential establishment of weeds on the underburned treatment was a special concern.

Canada thistle (*Cirsium arvense*) is the only species listed by the B.C. Invasive Plants Regulation that was recorded on Site 2 in either year. It was not recorded on any plots in 2003 and on only one plot, with a ground cover of 5%, in 2006.

Several other weedy species were recorded on many plots on Sites 1 and 2 but mean combined cover of these species was < 1% on all treatments. Weedy species that had a mean percent ground cover ≥ 0.5% on Site 2 are annual hawksbeard, fireweed, dandelion, Canada thistle, and salsify (*Tragopogon* spp.).

The mean cover of weedy species on Site 2 increased only very slightly but significantly from 2003 to 2006 (Tables 6 and 7). Although weedy species were slightly more abundant on the treated than the NT plots, the treatments did not have a significant effect on percent cover of weedy species (Table 7).

Forb and graminoid biomass Differences in standing live biomass of forbs and graminoids between 2003 and 2006 (Figure 7; Table 8) were statistically significant for graminoids, forbs and combined forbs and graminoids (Table 9). There were no significant biomass differences among treatments in either year (Table 9).

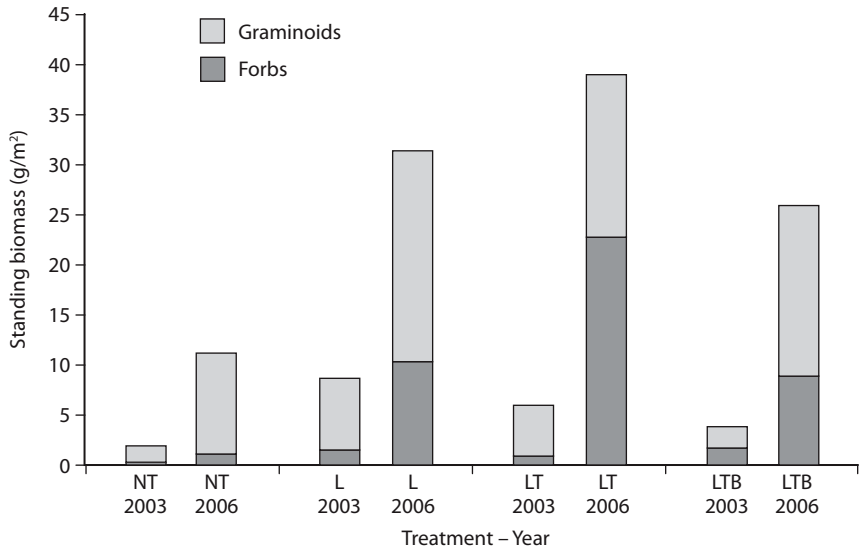

FIGURE 7 *Mean standing biomass (g/m²) of forbs and graminoids on Site 2 by treatment and year.*

TABLE 8 *Mean (and SD) standing biomass (g/m²) of forbs and graminoids on Site 2 by treatment and year*

	Treatment			
Year	**NT**	**L**	**LT**	**LTB**
Forbs				
2003	0.25 (0.77)	1.62 (3.85)	0.93 (1.65)	1.81 (3.33)
2006	1.14 (10.21)	10.51 (15.17)	22.98 (64.02)	8.87 (14.50)
Graminoids				
2003	1.68 (2.82)	7.17 (20.83)	5.00 (9.98)	1.98 (2.64)
2006	10.21 (16.19)	21.11 (26.31)	16.34 (21.02)	17.16 (19.87)

TABLE 9 *ANOVA* P *values for assessing significance of forb and graminoid biomass differences among treatments and between years.* P *values ≤ 0.05 are bolded.*

Source	Graminoid	Forb	Total
Treatment (T)	0.417	0.180	0.122
NT vs. others	0.184	0.987	0.369
L vs. LT	0.820	0.188	0.258
LT vs. LTB	0.458	0.349	0.227
Year (Y)	**0.002**	**0.011**	**< 0.001**
Y × T	0.901	0.205	0.371
Y × NT vs. others	0.534	0.154	0.132
Y × L vs. LT	0.789	0.190	0.479
Y × LT vs. LTB	0.692	0.139	0.409

DISCUSSION AND MANAGEMENT IMPLICATIONS

Opening of the forest canopy by the modified harvest treatment, with or without additional thinning or underburning, has apparently set the two stands on a trend towards meeting project objectives for undergrowth vegetation. All three logged treatments (logged, logged plus thinned, and logged plus thinned plus underburned) resulted in significant increases from 2003 to 2006 in mean percent ground cover of vascular plants and significant reductions in cover of live mosses and lichens. Among vascular plants, graminoid (grass and sedge) cover increased the most, while shrub and forb cover increased only slightly and insignificantly during this period. Increased graminoid cover was due primarily to substantial increases in the cover of pinegrass.

A principal goal of the treatments has been to provide conditions for bunchgrasses to become abundant in the undergrowth, but by 2006, mean percent cover of bunchgrasses had not increased insignificantly. The increased frequency of bunchgrasses suggests that these species are becoming more widely present and that their mean cover may increase in the future. However, whether pinegrass dominance of the current undergrowth will limit further establishment and growth of bunchgrasses has yet to be seen. Other studies in southeastern British Columbia IDF forests (Newman and

Wurtz 2004; Newman et al. 2004; Newman and Parminter 2007) have reported similar increases in pinegrass abundance and variable response of bunchgrasses following canopy opening. They have suggested that pinegrass can be a tenacious site occupant that limits bunchgrass establishment. However, both pinegrass and bunchgrasses have increased following canopy opening in some ponderosa pine and dry Douglas-fir forests in British Columbia (Newman et al. 2004; Krebs 2006; Newman and Parminter 2007).

The general absence of significant differences between treatments in vascular plant cover is due to the large variation in cover values within each of the treatments and to the increased mean cover of vascular plants on the untreated (NT) plots. Increases on the untreated plots likely resulted from increased light due to the substantial dieback and mortality of subcanopy trees as a result of spruce budworm infestation beginning in 2004. Plant cover increases in the NT plots may also have resulted partly as a result of increased side-lighting from adjacent logged areas into the NT understorey. Light was not measured in this study.

In contrast to vascular plants, moss cover was significantly reduced by the logging treatments (L, LT, and LTB) compared with the untreated area. As expected, the underburned treatment had the smallest moss cover in both 2003 and 2006. Decreasing cover of forest mosses may be an early stage in the development of a more grassland-like vegetation beneath an open forest canopy.

The increased biomass of combined graminoids and forbs in 2006 compared with 2003 must be evaluated in the context of annual weather patterns. In southeastern British Columbia, Page et al. (2005) and Newman and Parminter (2007) conclude that forage production differences between years were due in part to growing-season precipitation differences. In this study, however, precipitation and temperature data recorded at Williams Lake suggest that weather did not contribute to the production differences. Both 2003 and 2006 were years of similarly below-normal April to September total precipitation (84% and 72% in 2003 and 2006, respectively) and above-normal mean temperature (106% and 109%, respectively). April to September precipitation was near normal (97%) in 2005 and above normal (123%) in 2004.

The substantial increase in ground cover of graminoids (especially pinegrass) on the study sites did not occur until more than 2 years following logging and thinning in 2001. A similar delay in response of grasses, especially pinegrass, to canopy opening has been noted by others (Newman et al. 2004; Newman and Parminter 2007). Page et al. (2005) documented a decline in many undergrowth species, including grasses, following logging, mechanical thinning, and underburning of dry Douglas-fir and ponderosa pine stands in southeastern British Columbia but they attributed the decline at least partially to a drought during the monitoring period. A similar decline was not noted in this study.

The potential spread and increase of invasive alien and other weedy species are concerns whenever site treatments expose mineral soil or result in decline of native vegetation layers, including mosses. However, these species have not become a significant concern on any of the treatments in this study. Canada thistle is the only listed invasive alien species that was recorded on the two sites and other "weedy" species increased only very slightly from 2003 to 2006. Although logging resulted in 7–15% mineral soil exposure in

this study, spring underburning resulted in little additional mineral soil exposure by 2006.

The reasons underlying the lack of statistically significant forage production differences between treatments were probably the same as those causing the lack of significant vascular plant cover differences. Weather differences did not likely play a significant role in biomass production differences.

Substantial thinning of ingrown stands can be expected to create an environment conducive to Douglas-fir regeneration establishment and growth. This regeneration must be limited if stands are to be maintained in an open condition. Density of Douglas-fir regeneration in the two stands is reasonably low at present but may increase significantly over the next 30 years without follow-up treatments. Maintenance burns or additional mechanical treatments will likely be required even though development of a vigorous grass cover may reduce the rate of regeneration establishment over the long term. A principal benefit of the initial underburning treatment in this project is that fine fuels have been reduced, creating fuel conditions that allow subsequent low-severity maintenance burns.

The stand structure goals and treatments applied to stands of this study should not be applied to all ingrown stands of the IDFxm. Restoration management goals should be based on an understanding of historic disturbance regimes, especially fire, and the resulting historic stand structure variability within the IDFxm. Management that seeks to retain the historic variability will contribute to conservation of landscape-level habitat and wildlife diversity.

Fire regimes within the northern IDF zone were of mixed severity, including both low- and high-severity fires (Iverson et al. 2002; Daniels 2005). Characterized by variable fire severity and frequency, this fire regime results in a landscape with various stand structures (Agee 2005; Arsenault and Klenner 2005; Feller 2005; Gray 2005; Everett et al. 2007). Although spatial considerations introduce some uncertainty regarding the frequency of low-severity fires (Baker and Ehle 2001; Arsenault and Klenner 2005), they were probably the most extensive fire-severity class in the low-elevation IDFxm (Iverson et al. 2002; Daniels 2005), similar to lowest elevations in other regions (Gayton 1996; Sherriff and Veblen 2006, 2007). Low-severity fires burned through the understorey, killing few large trees. However, high-severity fires also occurred and killed most trees, resulting in nearly complete stand replacement (Iverson et al. 2002; Arsenault and Klenner 2005; Daniels 2005). High-severity fires sometimes affected only patches within larger stands, resulting in small-scale stand structure variability.

Tree regeneration may have been dense following high-severity fires and in areas where previously open stands had escaped fire for a relatively long period. During periods of extended drought, the frequency and total area of high-severity fires likely increased (Weir et al. 1995; Daniels 2005). Topography also likely affected the frequency of fires, with the most frequent fires on warm, dry slopes (Gray 2005). The resulting pattern of stand structures on the landscape was dynamic, reflecting the changing pattern of low- and high-severity fires and length of time since fire.

Management goals for densely ingrown stands should include a diversity of stand structures on the landscape, balanced by timber, range, and other resource use objectives. Multi-aged stands with only small patches of dense regeneration, such as those created in this project, should be common, corre-

sponding to the historic area of frequent low-severity fires. Other multi-aged stands with more extensive dense regeneration layers, as well as even-aged stands, should also be present, especially on cooler, moister sites. Where timber production is not a principal objective, stands with very low densities can be created, while in other areas stands with moderate densities such as those in this project should be created.

Priority for management action should be to reduce stem densities in stands that were historically open because these stands are among the most altered from their historic structure (Brown et al. 2004). Most importantly, the current dominance of the landscape by densely ingrown stands needs to be shifted to a more diverse landscape that will provide habitat and forage for a wide range of wildlife and domestic species.

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