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Understorey responses to mechanical restoration and drought within montane forests of British Columbia

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Abstract

Pre- and post-thinning relationships between forest overstorey and understorey characteristics at sites in both the Interior Douglas-fir (IDF) and Ponderosa Pine (PP) biogeoclimatic zones in the East Kootenay region of southeast British Columbia were investigated to quantify understorey responses to dry forest restoration thinning. Pre-thinning data consistently indicated that understorey shrub and herb abundance were positively associated with light intensity and inversely with tree density (i.e., ingrowth) at both locations. Immediately after thinning, greater reductions in tree density or increases in understorey light were generally associated with greater reductions in understorey species richness, diversity, and shrub and herb cover; however, the presence of drought conditions complicated this effect. Overall, the results indicate that while the effects of ingrowth appear detrimental to understorey vegetation, the disturbance caused by mechanical thinning, particularly when accompanied by drought, can reduce the abundance of many important understorey characteristics in the short term. These results have management implications for areas where forest restoration using commercial thinning is being considered.

KEYWORDS: *bunchgrass, diversity, herbage production, ingrowth, thinning.*

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Introduction

Dry inland forests of ponderosa pine (*Pinus ponderosa*) or interior Douglas-fir (*Pseudotsuga menziesii*) in pure stands or mixtures with other species, such as lodgepole pine (*Pinus contorta* var. *latifolia*) or western larch (*Larix occidentalis*), are widespread from Mexico to southern British Columbia (Wright and Bailey 1982). Before 1900, dry forest types were characterized by frequent, low severity surface fires at intervals of about 13 years at low elevations (Arno *et al.* 1995). The combination of frequent understorey fires and rare stand-replacing fires resulted in multi-aged stands and a mixture of grasslands and open forest.

In the late 1800s, harvesting preferentially removed many large ponderosa pine and Douglas-fir. Introduction of fire suppression in the early 1900s enhanced understorey conifer regeneration in dry forests across North America (Kaye *et al.* 1999). These two activities, combined with unregulated grazing, changed forest stand structures from relatively open canopy, older-aged forests to closed canopy, young forests (Veblen *et al.* 2001). In the East Kootenay region of British Columbia, where approximately 250 000 ha of dry forest historically experienced frequent, low-intensity fires (5–50 years), an estimated 3000 ha of open forest is lost annually to ingrowth and encroachment (Gayton 1997). This number is similar to estimates elsewhere in British Columbia (Bai *et al.* 2001).

Within ingrown forests of North America, changes in forest structure and the understorey have received considerable attention because of reductions in forage availability for livestock and wildlife (Pase 1958; Cooper 1960; Ffolliott and Clary 1982; Bojorquez *et al.* 1990). Understorey light has been shown to be the leading indicator of overstorey influences on understorey vegetation (Lieffers and Stadt 1993; Comeau *et al.* 1998). Increased shading by conifers has favoured invasion of mesophytic shrubs and herbs into historically dry stands (Lunan and Habeck 1973). For example, pinegrass (*Calamagrostis rubescens*), a rhizomatous perennial that remains abundant under partial shade, is prevalent under moderately dense Douglas-fir canopies (Steele and Geier-Hayes 1993). Lack of light and increased competition from pinegrass, in turn, may limit the abundance of plants such as bluebunch wheatgrass (*Pseudoroegneria spicata*), a native species important for wildlife and cattle grazing (Willms *et al.* 1980).

Contemporary ecosystem management strives to maintain ecological integrity, including species composition (Naumberg and DeWald 1999), as well as maintain vegetation that supports multiple uses, such as cattle grazing and wildlife habitat. Moreover, the effect of conifer encroachment on understorey species diversity is receiving increased attention (Thomas *et al.* 1999). As a result, an understanding of overstorey–understorey relationships is increasingly guiding ecosystem restoration efforts to mitigate the negative impacts of ingrowth and encroachment (Fiedler and Carlson 1992; Covington *et al.* 1997; Kaye *et al.* 1999; Ritchie and Harksen 1999). The current restoration targets for the proportion of shrubland, grassland, and open and managed forest in British Columbia are outlined in Table 1.

An understanding of overstorey–understorey relationships is increasingly guiding ecosystem restoration efforts to mitigate the negative impacts of ingrowth and encroachment.

Although dry forest restoration treatments have been used in several areas of North America, most research has examined a narrow set of treatment effects. Moreover, prescribed burning has been studied extensively, but less attention has been paid to the effect of the thinning necessary to restore more natural stand structure before fire reintroduction (Smith and Arno 1999). Restoration of dense stands generally begins with selective thinning to remove excess understorey and weak overstorey trees that may lead to an undesirable high intensity prescribed fire (Arno *et al.* 2000).

This study was designed to assess the effects of ingrowth on the understorey within two forests at low elevations in British Columbia, and to monitor understorey responses to thinning treatments aimed at restoring historical stand structure. Specific objectives were to:

- quantify specific overstorey–understorey relationships within existing forest stands; and
- determine the initial effect of forest thinning on understorey species composition, diversity, and herbage biomass.

Implications of these findings are discussed in the context of habitat and forest management.

TABLE 1. Restoration targets[a] for various habitat components on public land in the East Kootenay Trench of British Columbia (2000–2030)

Habitat component	Current distribution (% of Trench)	Final distribution target (% and ha of Trench)	Target tree density (stems per hectare)
Shrubland	5	5 (12 500)	0
Grassland	10	23 (57 500)	≤ 75
Open forest	Open and managed	31 (77 500)	76–400
Managed forest	forest are 85 combined	41 (102 500)	400–5000

[a] Targets are achieved within the Crown NDT4 landbase at the forest district level (Province of British Columbia 1997).

Methods

Study Area

This research was conducted in the East Kootenay region of southeastern British Columbia. The East Kootenay has an upland continental climate with well-defined seasons. Summers are warm and dry, and winters are cold with deep valley inversions (Marsh 1986), which frequently cause warmer temperatures at low elevations (McLean and Holland 1957). Mean monthly air temperatures vary from –8.3 to 18.2°C. Average annual precipitation is 384.5 mm, with May and June being the wettest months. Snowfall averages 147.9 cm. This project began in 1999 when precipitation and temperatures were near average; however, 2000 and 2001 were dry with approximately 45% and 35%, respectively, of the long-term average growing season precipitation (192.7 mm) falling between May 1 and September 30.

The Sheep Creek North and Wolf Creek range units, two forest areas situated 20 km apart (49°58' N; 115°43' W), were selected for this project. Both contain important wildlife habitat including ungulate wintering range. Commercial uses include timber production and cattle grazing. Large ponderosa pine and Douglas-fir were selectively harvested during the 1930s to produce railway ties.

The Sheep Creek site lies in the Kootenay dry mild Interior Douglas-fir (IDFdm2) biogeoclimatic zone, which is characterized by climax stands of Douglas-fir with an understorey dominated by pinegrass and shrubs, such as birch-leaved spirea (*Spiraea betulifolia* ssp. *lucida*), soopolallie (*Shepherdia canadensis*), and saskatoon (*Amelanchier alnifolia*) (Braumandl and Curran 1992). The Wolf Creek site is located in the Kootenay dry hot Ponderosa Pine (PPdh2) biogeoclimatic zone, which is characterized by open stands of Douglas-fir and ponderosa pine with an understorey of pinegrass and bunchgrasses, including rough fescue and bluebunch wheatgrass. The Sheep Creek and Wolf Creek sites are hereafter referred to as the Interior Douglas-fir (IDF) and Ponderosa Pine (PP) sites, respectively. Overstorey and understorey characteristics for each location before thinning are summarized in Table 2. Soils at the IDF and PP sites are predominantly Orthic Eutric Brunisols (Lacelle 1990).

Experimental Design and Thinning Treatments

In 1999, a systematic grid of 22-m diameter timber cruise plots was established. Only plots identified as in the IDFdm2 or PPdh2 biogeoclimatic zone, and with slopes of less than 5%, were selected for monitoring. Slopes greater than 5% were excluded to remove strong moisture gradients as a confounding factor in the interpretation of ingrowth. This process resulted in 15 and 18 permanent macroplots at the IDF and PP sites, respectively. All subsequent vegetation sampling was conducted within these macroplots during the 3-year period (1999–2001).

In the first phase of restoration, commercial logging companies thinned and (or) slashed forest stands at the two sites from near full crown closure to between 20% and 70% closure (Powell *et al.* 1999). The IDF and PP sites were treated in June 1999 and in June–July 2000, respectively. Thinning consisted of cutting and removing any commercially valuable intermediate-sized timber (i.e., subdominant trees); slashing involved cutting undesired tree species and low quality, diseased, and juvenile stems (< 20 years old) within all macroplots at both sites (Powell *et al.* 1999). Slashed material was left on site. Large-diameter (i.e., veteran) trees and snags were retained. Given the variable history of each macroplot and the resulting forest conditions, each macroplot received a unique thinning treatment. Instead of uniform treatments among macroplots, natural variability in the degree of initial ingrowth resulted in the harvesting or slashing of a variable number of trees, with the more ingrown stands receiving more thinning.

Vegetation Sampling

Macroplots at both sites were sampled for overstorey characteristics before thinning during the summer of 1999, and again after thinning in June 2000 and July 2001 for the IDF and PP sites, respectively. Tree density, diameter at breast height, and height of codominant trees were determined in each macroplot using standard variable plot (prism) methods (Husch *et al*. 1982). Post-thinning overstorey values were obtained by subtracting the density, basal area, and volume of trees removed from each macroplot from pre-thinning stand estimates (Table 2).

Understorey vegetation and light intensity were sampled in 1999 at both sites using three 10 m long linear and parallel-oriented permanent transects within each macroplot. All macroplots were resampled in 2000 and 2001, which corresponded to 1 and 2 years after thinning in the IDF site and immediately after thinning and 1 year later in the PP site. Only herb biomass was sampled at the PP site in 2000 because of the recent disturbance of thinning.

Subplots and quadrats for measuring understorey vegetation and light were located along each transect. Canopy cover (%) of all understorey vascular plant species was estimated in 0.1-m^2 microquadrats positioned every metre (n = 20) along the two outermost transects (Daubenmire 1959). Herbaceous species richness was determined by counting the total number of species in all microquadrats (no. per 0.1 m^2) per macroplot. Total herb species diversity was determined using the Shannon–Wiener diversity index ($H' = -\sum p_i \log[\pi]$) (Bonham 1983). Shrub cover was estimated ocularly within twenty 2-m^2 (1 × 2 m) macroquadrats nested overtop the microquadrats.

The density of common native bunchgrasses, including rough fescue (*Festuca campestris*), Idaho fescue (*Festuca idahoensis*), bluebunch wheatgrass, Richardson's needlegrass (*Stipa richardsonii*), needle-and-thread grass (*Stipa comata*), and stiff needlegrass (*Stipa occidentalis* var. *pubescens*), was assessed in two 10-m^2 (1 × 10 m) belted subplots established along each outside transect. The density of shrubs was assessed

TABLE 2. Comparison of pre-thinning overstorey and understorey characteristics between sites in the Interior Douglas-fir (IDF) and Ponderosa Pine (PP) biogeoclimatic zones (1999), and the impact of thinning on final overstorey characteristics at each location

Strata (treatment)	Variable	IDF Mean	IDF SD	PP Mean	PP SD	p-value
Understorey (Pre-thinning)	Bunchgrass canopy cover (%)[a]	1.6	1.6	7.2	1.4	**< 0.001**
	Pinegrass canopy cover (%)	9.9	5.6	16.7	11.6	**0.05**
	Shrub canopy cover (%)	14.7	5.1	7.1	3.0	**< 0.001**
	Carex canopy cover (%)[a]	0.6	0.2	4.9	5.1	**< 0.001**
	Forb canopy cover (%)	8.4	5.8	8.7	5.3	0.86
Overstorey (Pre-thinning)	Volume (m^3/ha)[a]	126.8	63.5	75.3	44.4	**0.008**
	Density (stems per hectare)[a]	503.6	367.4	705.3	457.5	0.23
	Understorey light (%)	27.3	7	33.5	10	**0.05**
Overstorey (Post-thinning)	Volume (m^3/ha)	59		27		
	Density (stems per hectare)	243		192		
	Understorey light (%)	54		64		

[a] P-values are reported based on analysis using transformed data. Means and standard deviations (SD) of original data are presented.

similarly in two 20-m^2 (2 × 10 m) belted subplots, also centred on the outside transects. Shrubs included the common browse species saskatoon and antelope-brush (*Purshia tridentata*). Above-ground current annual understorey biomass was estimated by sampling four 0.5-m^2 (0.5 × 1 m) previously unsampled mesoquadrats systematically located on the centre transect of each macroplot. Biomass in all mesoquadrats was harvested to ground level in early September after peak growth was reached. Samples were then sorted according to native bunchgrasses, pinegrass, other grasses, upland sedges (*Carex* spp.), forbs, and shrubs; oven-dried at 60°C to constant mass; and weighed.

The amount of understorey light was measured 30 cm above-ground over each 0.1-m^2 microquadrat using a LI-COR® LAI-2000 Plant Canopy Analyzer (Welles and Norman 1991). Light was assessed as the ratio of understorey light to light measured simultaneously from a vantage point with an unobstructed sky view. All light measurements were taken on evenly cloudy days, or in the morning or evening when cloud cover was minimal.

Statistical Analysis

All data were checked for normality before analysis. Non-normal data were square root transformed (tree volume and density; pinegrass, bunchgrass, shrub, sedge, and forb biomass; bunchgrass, sedge, and bryophyte canopy cover) or log+1 transformed (saskatoon canopy cover and density). Where transformations were necessary, negative values resulting from a lower dependent response value after thinning were made positive by adding the lowest value in the data set to each observation. Additionally, data were always transformed uniformly within a response variable across sites and years to allow comparisons. All differences were considered significant at $p < 0.10$, unless indicated otherwise.

Quantitative analyses were conducted in two stages. In the initial understorey sampling, the variation in overstorey characteristics among macroplots at each site defined the treatments. Understorey light is the primary independent variable in this investigation; however, tree density and timber volume were also assessed as independent variables because of the widespread availability of data from timber operations. Within each site, average light intensity per macroplot was regressed against the independent variables, including species richness, diversity, biomass yield (PP site only), and the cover of various vegetation classes. Curvilinear regression did not significantly improve goodness of fit (R^2) over simple linear regression; therefore, only results from the latter analyses are reported.

In the second stage of the analysis, understorey changes occurring from the pre-thinning sampling year (i.e., 1999) to after thinning were assessed against the change in forest overstorey (and understorey light) during the same period. Because each site was thinned in different years, the relevant period between sampling intervals for analysis varied between locations. At the PP site, differences were examined from 1999 to 2001 only; at the IDF site, differences in understorey and overstorey were assessed from 1999 to 2000 (1-year response) and from 1999 to 2001 (2-year response). Herbage yield was not assessed at the IDF site because pre-thinning yields had not been estimated. Thinning effects were analyzed by regressing (Steel *et al.* 1997) the change within each independent overstorey variable (tree density, timber volume, and light) against the change in biomass yield (PP site only), canopy cover, or density of each vegetation group. Within a site, treatment averages of each response variable were calculated for each permanent macroplot and regressed against the independent variables from the same.

Results

Pre-thinning Relationships

Pre-thinning understorey characteristics differed between the IDF and PP sites (Table 2). On average, the PP site had greater ($p < 0.05$) bunchgrass, pinegrass, and sedge canopy cover, but had less shrub cover than the IDF site. Although initial tree densities were similar ($p > 0.10$), the IDF site had greater ($p < 0.01$) timber volume and less ($p < 0.05$) understorey light.

At the IDF site, understorey light was positively ($p < 0.10$) associated (Table 3) with saskatoon canopy cover and density (Figure 1), as well as total live herb canopy cover (Figure 2). Only birch-leaved spirea cover was associated ($p < 0.05$) with overstorey tree density (Table 3).

At the PP site, understorey light was positively ($p < 0.10$) associated with 10 understorey variables (Table 3), including bunchgrass, forb, shrub, sedge, and total live herb (Figure 2) canopy cover, along with herbaceous species diversity (Figure 3) and richness. Saskatoon canopy cover and density (Figure 1) were again positively related to light at the PP site. Initial light levels, however, were negatively ($p < 0.01$) related to sedge biomass (Table 3).

TABLE 3. Summary of significant ($p < 0.10$) pre-thinning relationships between the understorey variables and understorey light or overstorey tree density. Only regressions with $p < 0.10$ are reported.

Site	Independent variable	Dependent variable	R^2	RMSE[d]	*p*-value	Equation
IDF (Sheep Creek) ($n = 15$)[a]	Light (proportion of full)	Saskatoon canopy cover (%)[b]	0.22	0.31	0.08	$y = -0.16 + 2.41x$
		Saskatoon density (no. per 20 m^2)[b]	0.30	0.45	0.03	$y = -0.14 + 3.88x$
		Total herb canopy cover (%)	0.32	12.37	0.03	$y = 1.99 + 110.61x$
	Tree density (stems per hectare)	Birch-leaved spirea cover (%)	0.30	5.48	0.04	$y = -3.49 + 0.48x$
PP (Wolf Creek) ($n = 18$)	Light (proportion of full)	Species richness (no. per 80 m^2)	0.18	6.01	0.07	$y = 10.81 + 25.92x$
		Species diversity	0.26	0.19	0.03	$y = 0.47 + 0.97x$
		Bunchgrass canopy cover (%)[b]	0.29	8.9	0.02	$y = 6.68 + 0.11x$
		Forb canopy cover (%)	0.67	4.80	< 0.001	$y = -4.39 + 39.93x$
		Total herb canopy cover (%)	0.44	17.65	0.002	$y = 17.76 + 144.7x$
		Shrub canopy cover (%)	0.20	2.96	0.06	$y = 2.37 + 13.60x$
		Saskatoon canopy cover (%)[b]	0.33	0.21	0.01	$y = 0.20 + 1.39x$
		Saskatoon density (no. per 20 m^2)[b]	0.49	0.27	0.02	$y = 0.74 + 2.33x$
		Sedge canopy cover (%)[b]	0.35	0.92	0.008	$y = -0.14 + 6.25x$
		Sedge biomass (kg/ha)[b, c]	0.63	0.31	0.006	$y = 1.95 - 0.5x$

[a] Understorey biomass data were not collected at the IDF site in 1999.
[b] Statistics reported based on analysis using transformed data. Equations refer to original data.
[c] These data use only 10 field macroplots because production data were not collected at all 18 macroplots in 1999.
[d] Root mean square error.

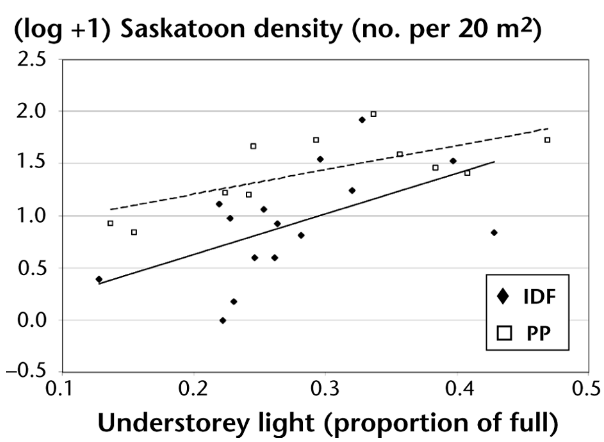

FIGURE 1. Initial empirical relationship between saskatoon shrub density and understorey light at the IDF ($y = 0.14 + 3.88x$; $r^2 = 0.30$) and PP ($y = 0.74 + 2.33x$; $r^2 = 0.49$) sites in 1999.

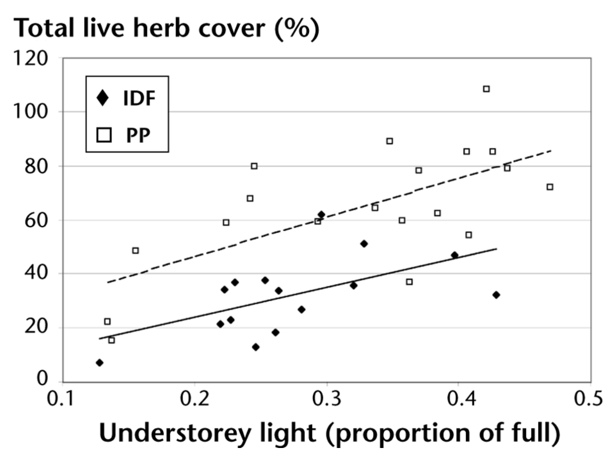

FIGURE 2. Initial empirical relationship between total live herb cover and understorey light at the IDF ($y = 1.99 + 110.6x$; $r^2 = 0.32$) and PP ($y = 17.8 + 144.7x$; $r^2 = 0.44$) sites in 1999.

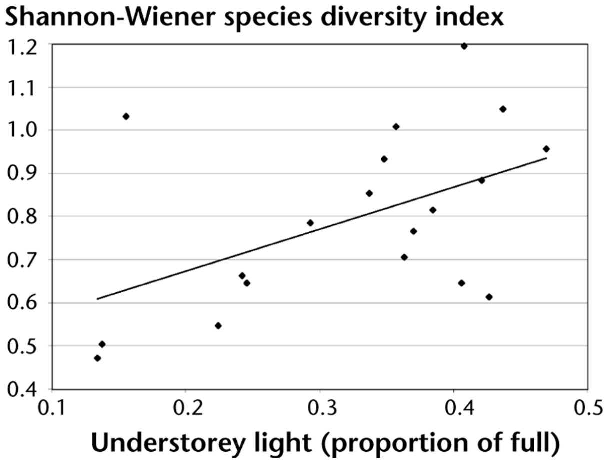

FIGURE 3. Initial relationship between Shannon–Wiener species diversity and understorey light at the PP ($y = 0.47 + 0.97x$; $r^2 = 0.25$) site in 1999.

Post-thinning Relationships

Post-thinning overstorey characteristics are shown in Table 2. Thinning removed an average of 68 and 48 m^3/ha of timber at the IDF and PP sites, respectively. Merchantable stem density decreased by 261 and 513 stems per hectare at the IDF and PP sites, leaving less than 250 stems per hectare. Understorey light (measured as % of full sunlight) increased by 27–30%.

Interior Douglas-fir Thinning Responses

Overall, total bunchgrass density increased ($p < 0.10$) at the IDF site between 1999 and 2001 by 6.1 plants per 10 m^2, while birch-leaved spirea, shrub, and bryophyte cover declined ($p < 0.05$) by 4.0, 6.4, and 6.8%, respectively. Thinning at the IDF site generally resulted in few detectable changes to the understorey (Table 4), even after 2 years. In 2000, saskatoon density declined ($p < 0.10$) with increased thinning intensity, as reflected by either the number of trees (Figure 4) or volume of timber removed. In 2001, a negative response ($p = 0.10$) was observed in bunchgrass density in relation to the change in light associated with thinning 2 years earlier (Table 4).

Ponderosa Pine Thinning Responses

At the PP site, pinegrass and total herb cover declined ($p < 0.05$) by 7.4 and 28.7%, respectively, from 1999 to 2001. Reductions in bunchgrass and forb biomass ($p < 0.05$) for this same period were 21.7 and 25.2 kg/ha, respectively.

Increased thinning, as defined by greater reductions in tree density and timber volume, and increased understorey light were consistently associated with a reduction ($p < 0.10$) in the cover of pinegrass (Figure 5), bryophytes, and total live herb (Table 5). Species richness was also negatively ($p < 0.10$) associated with increased light following thinning (Table 5; Figure 6).

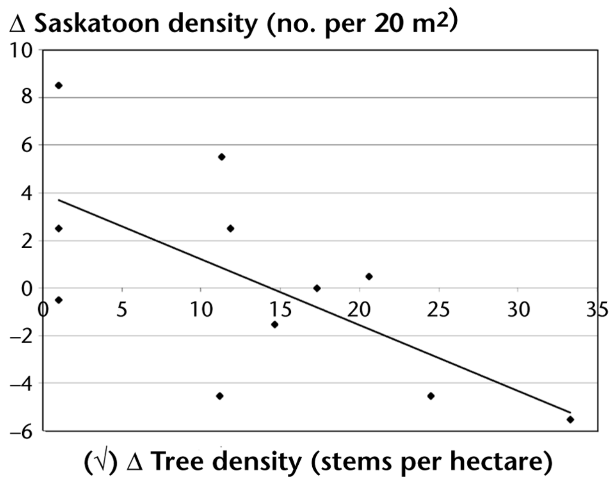

FIGURE 4. Change in (Δ) saskatoon shrub density (no. per 20 m^2) regressed against Δ tree density at the IDF site ($y = 3.98 – 0.26x$; $r^2 = 0.43$) between 1999 and 2000.

TABLE 4. Relationship of changes in (Δ) tree overstorey with thinning to subsequent understorey changes from 1999 to 2000, and 1999 to 2001, at the IDF site ($n = 15$). Only regressions with $p < 0.10$ are reported.

Time period	Independent variable	Dependent variable	R^2	RMSE[b]	*p*-value	Equation
1999–2000	Δ tree density (stems per hectare)	Δ saskatoon density (no. per 20 m^2)[a]	0.43	3.45	0.03	$y = 3.98 – 0.26x$
	Δ volume (m^3/ha)	Δ saskatoon density (no. per 20 m^2)[a]	0.36	3.83	0.07	$y = 3.82 – 0.53x$
1999–2001	Δ light (%)	Δ bunchgrass density (no. per 10 m^2)[a]	0.22	0.68	0.08	$y = 5.09 – 2.83x$

[a] Statistics reported based on analysis using transformed data. Equations refer to original data.
[b] Root mean square error.

TABLE 5. Relationship of changes in (Δ) tree overstorey with thinning to subsequent understorey changes at the PP site (n = 18) from 1999 to 2001. Only regressions with p < 0.10 are reported.

Time period	Independent variable	Dependent variable	R^2	RMSE[b]	p-value	Equation
1999–2001	Δ light (%)	Δ species richness (no. species per 80 m^2)	0.17	4.29	0.09	$y = 2.15 - 10.5x$
		Δ total cover (%)	0.16	16.61	0.10	$y = 39.7 - 15.6x$
		Δ pinegrass cover (%)	0.30	6.92	0.02	$y = 0.33 - 24.9x$
		Δ bryophyte cover	0.25	1.54	0.05	$y = 1.14 - 3.87x$
		Δ total biomass (kg/ha)[a]	0.22	3.72	0.06	$y = 3.08 - 11.3x$
	Δ tree density (stems per hectare)	Δ pinegrass cover (%)	0.30	7.10	0.02	$y = -0.92 - 0.34x$
		Δ bryophyte cover	0.20	1.38	0.10	$y = 0.93 - 0.05x$
	Δ volume (m^3/ha)	Δ pinegrass cover (%)	0.24	7.40	0.04	$y = -1.17 - 1.08x$
		Δ bryophyte cover	0.20	2.34	0.09	$y = 0.95 - 0.17x$

[a] Change in total understorey biomass was assessed from 1999 to 2001 only on the 10 plots sampled before thinning in 1999.
[b] Root mean squre error.

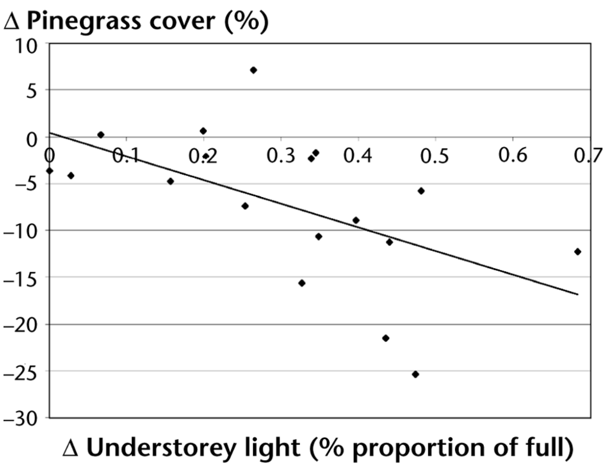

Figure 5. Change in (Δ) pinegrass cover regressed against Δ understorey light at the PP site ($y = 0.33 - 24.9x$; $r^2 = 0.30$) between 1999 and 2001.

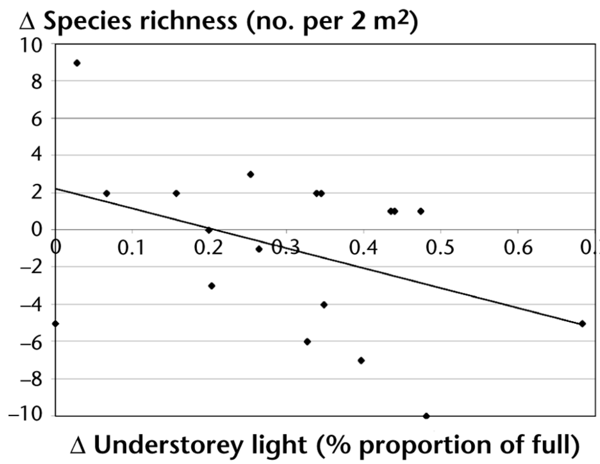

Figure 6. Change in (Δ) species richness regressed against Δ understorey light at the PP site ($y = 2.15 - 10.5x$; $r^2 = 0.17$) between 1999 and 2001.

Discussion

Pre-thinning Overstorey–Understorey Relationships

Among the overstorey variables examined in the pre-thinning data, understorey characteristics at both sites were more closely associated with light intensity than tree density or timber volume. As in other studies documenting overstorey effects, these results show understorey light is associated with plant species presence and abundance as measured by density and canopy cover (Lieffers and Stadt 1993; Naumberg and DeWald 1999); overstorey tree characteristics (e.g., stem density, timber volume) were more closely associated with understorey biomass (Riegel et al. 1995; Naumberg and DeWald 1999). Neither tree density nor timber volume reflects the spatial distribution of trees or their crown cover. In contrast, light intensity is a more direct indication of the above-ground competitive influence within forest stands.

Low light intensity was associated with low herb cover and species richness in the understorey of more heavily ingrown stands. Less diverse communities, in turn, are less resilient or likely to recover from

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disturbances, such as grazing and fire (Tilman and Downing 1994; Naumberg and DeWald 1999). Lower diversity and species richness under closed canopies have been observed in other studies of North American fire-maintained ecosystems (Covington *et al.* 1997; Uresk and Severson 1998). In any restoration effort, these characteristics should be considered when alleviating ingrowth.

Initial differences in understorey plant communities between sites, particularly greater bunchgrass cover at the PP location, were likely the result of varied overstorey or ecosite conditions. Historically, PP sites are more open, warmer, and drier, and therefore better suited to support shade-intolerant bunchgrasses (Braumandl and Curran 1992). In contrast, IDF sites were relatively closed, moister, and therefore conducive to supporting shrubs, including saskatoon and birch-leaved spirea (Braumandl and Curran 1992).

Despite site differences, results from both the IDF and PP locations consistently reflect the negative association of bunchgrass and palatable shrub (e.g., saskatoon) vegetation classes with high tree crown cover or low light levels. As light declines, more productive and light-demanding species disappear, allowing the establishment and growth of other species better suited to the changing conditions (Knowles *et al.* 1999). Notably, birch-leaved spirea cover was one of the few species apparently favoured by ingrowth, as suggested by its positive association with tree density.

In the current study, the lack of an association between pinegrass cover and light is likely related to the shade tolerance of pinegrass (Lunan and Habeck 1973; Steele and Geier-Hayes 1993). Replacement of desirable forage species with less palatable ones has implications for the management of wild and domestic herbivores throughout the East Kootenay region of British Columbia. This area is particularly important as fall and winter range for wildlife (Hudson *et al.* 1976); however, pinegrass rapidly loses forage quality with advancing maturity (Freyman 1970), and limited or declining forage is at least partially responsible for the conflict between wildlife and livestock managers (Wikeem and Ross 2002).

The lack of significant pre-thinning relationships between the overstorey and forage biomass is contrary to other results that document a strong negative relationship between this variable and crown closure (Pase 1958; Cooper 1960; Ffolliott and Clary 1982; Bojorquez *et al.* 1989; Knowles *et al.* 1999). In fact, Dodd *et al.* (1972) concluded that crown tree cover could be used to assess herbage production in range surveys of British Columbia Douglas-fir forests. The lack of significant associations between the overstorey and herbage production in our study may reflect the relatively advanced degree of ingrowth across our study sites, limited macroplot sample sizes (particularly at low levels of canopy closure), or generally poor opportunities for herbage growth because of droughty conditions. The lone significant relationship found was a negative association between sedge biomass and light, which was unexpected given the positive relationship between sedge canopy cover and light. These seemingly contradictory patterns may be caused by numerous sedge plants at increased light levels, the size and biomass of which may have been limited by either competition from other herbs or severe drought, leading to lower biomass yield. In any case, sedge contributed little to total yield (7%), and thus was considered to have limited implications for management.

Understorey Responses to Thinning

The observed reductions in understorey diversity, pinegrass cover, and saskatoon density with increased thinning were likely due to the mechanical disturbance of selective tree harvesting combined with the post-thinning growth environment. Given that the outcome of thinning will depend on initial plant community structure and composition (Thomson 1982; Thomas *et al.* 1999), differences between the two sites (as determined by landscape-scale variation) likely account for some of the differential response to thinning between sites. At the IDF site, shrubs such as saskatoon and bunchgrasses appear to have been directly damaged by logging and tree removal. Shrubs may be particularly susceptible to mechanical thinning because they maintain above-ground perennial biomass, which may account for several studies indicating shrub biomass yield does not respond favourably to thinning within xeric ecosystems (McConnell and Smith 1965; Riegel *et al.* 1992; Thomas *et al.* 1999); however, the absence of a negative relationship between thinning intensity and saskatoon density 2 years after treatment suggests this important shrub species may be recovering.

At the PP site, the greater number of trees removed and the timing of thinning during the growing season (i.e., July) may have been important factors influencing understorey responses. In the short term, the loss of total herb, pinegrass, and bryophyte cover represents lost biodiversity; these species are important ecosystem components responsible for protecting soils and meeting other land use needs (e.g., wildlife habitat and livestock grazing). Moreover, these results suggest that the detrimental impact of physical site disturbance should be evaluated against the potential benefit to plants and the plant community by increased resources such as light. Similar conclusions have been made in other studies (Thomas *et al.* 1999; Thysell and Carey 2001). The lack of response in total herb canopy cover to thinning is consistent with other studies that found plant cover was slow or limited in recovery after thinning (Riegel *et al.* 1995; Ross 2001), and highlights the long-term nature of ecosystem restoration treatments.

The understorey responses to thinning we observed were likely affected by the unusually low rainfall of 2000 and 2001. Although physical disturbances of the soil such as compaction would have been reduced during these conditions and could therefore be considered beneficial, dry conditions after thinning could also have prevented the establishment and recovery of herbaceous species following mechanical disturbance. In the current study, the return of average precipitation, coupled with longer periods after thinning, would probably result in more rapid and greater recovery of the understorey.

Specific mechanisms accounting for the observed understorey changes at both sites are not clear. Responses to forest thinning may be related to altered light or below-ground resource availability such as nutrients and water, the latter of which would have been particularly limiting during a drought. Previous studies have shown that thinning increases soil moisture (Riegel *et al.* 1992; Feeney *et al.* 1998; Kaye and Hart 1998b). In northeastern Oregon, Riegel *et al.* (1992) reported that increased soil water in response to thinning added 2 months to the effective growing season, leading to greater understorey biomass. We did not have similar results in our study. Other investigations have found thinning increases plant nutrients through enhanced

The observed reductions in understorey diversity, pinegrass cover, and saskatoon density with increased thinning were likely due to the mechanical disturbance of selective tree harvesting combined with the post-thinning growth environment.

nitrogen mineralization (Riegel *et al.* 1992; Kaye and Hart 1998a). Further changes in understorey composition are likely as vegetation release from shading continues. These changes may also accelerate for those plant species adapted to exploit increases in moisture availability, particularly with the cessation of drought.

The impact of ungulate (both livestock and free-ranging wildlife) herbivory, particularly at the IDF site, may also have placed additional stress on the forest understorey, further limiting plant community recovery over the study period. This region is known for its ample public grazing and important winter wildlife habitat (Hudson *et al.* 1976). Mean measured levels of total forage use at the IDF site were 65% and 70% from June to September of 2000 and 2001, respectively. This level is well above the generally accepted utilization maximum of 50% removal of total seasonal production, and suggests grazing with cattle the first year after thinning may not be prudent, especially if wildlife use in the area is also high. Moreover, if thinning is undertaken in areas prone to drought, those disturbances to the plant community that are under the influence of management should be minimized. Alternatively, treating a large enough area to disperse animals may minimize the impact of grazing on vegetation recovery.

Another consideration when using thinning as a restoration tool is that opening the overstorey may favour early successional species or invasive weeds (Thomas *et al.* 1999; Thysell and Carey 2001), particularly if few native herbs remain after thinning. Early germination, rapid growth, and allocation of resources to above-ground biomass enable weeds to pre-empt resource use by their competitors (Sheley *et al.* 1996; Herron *et al.* 2001). Although no weeds were found in the pre-thinning plant communities sampled in 1999, two thinned plots at the IDF site had the noxious weed Canada thistle (*Cirsium arvense* var. *horridium*) present during 2001. Increases in exotic species at the IDF site could be temporary as weed species have been known to have "transient occupancy" (Thysell and Carey 2001).

Overall, these results indicate that some caution and flexibility should be maintained when applying thinning treatments. For example, to minimize impacts on the understorey and ensure recovery of the plant community, it may be better to conduct restoration activities on frozen soils and (or) protective snow cover. Winter harvesting is known to reduce compaction of forest soils (Maynard and MacIsaac 1998; Krzic *et al.* 2005).

Finally, the time it takes for a plant community to positively respond to mechanical thinning should also be monitored, given that prompt recovery is critical for maintaining stable habitat and forage supply for wild ungulates and livestock (Riegel *et al.* 1992). Monitoring can also be used to recognize areas under restoration that may be susceptible to overutilization by ungulates, particularly immediately after thinning.

Conclusions

An initial assessment of the relationship between the forest overstorey or light, and the understorey within ingrown IDF and PP forests of British Columbia indicated that the abundance of important forage species such as saskatoon, as well as herbaceous species including bunchgrasses, were generally negatively associated with greater forest closure and lower light levels. Initial (1–2 year) changes within the understorey of commercially thinned forests tended to be negative, with greater reductions in understorey plant cover and diversity associated with increased thinning intensity, although drought during recovery likely exacerbated these effects. These results highlight challenges associated with using thinning and mechanical disturbance to restore montane forests and conserve the understorey in southeastern British Columbia. Potential adverse effects may be alleviated by minimizing mechanical disturbance, avoiding treatment during drought years, conducting treatments on frozen and snow-covered soils, or reducing other disturbances such as grazing in the years immediately after treatment. Practitioners should also recognize that at least two full growing seasons (longer under drought conditions) will be needed to significantly increase understorey cover and biomass. Finally, continued monitoring is advised to fully assess the long-term impacts of commercial thinning and other management activities on understorey recovery and ecosystem restoration.

The abundance of important forage species such as saskatoon, as well as herbaceous species including bunchgrasses, were generally negatively associated with greater forest closure and lower light levels.

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Test Your Knowledge . . .

Understorey responses to mechanical restoration and drought within montane forests of British Columbia

How well can you recall some of the main messages in the preceding research report? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. In this study, the lack of an association between pinegrass cover and light is likely related to:
   A) pinegrass is shade tolerant
   B) pinegrass only grows in the understorey
   C) pinegrass is light sensitive
   D) none of the above

2. Based on results of this study, when using thinning and mechanical disturbance to restore montane forests, resource managers should:
   A) avoid treatments during periods of drought
   B) use small-scale mechanical equipment only
   C) thin large areas
   D) thin during periods of drought

3. Findings suggest that, to minimize the impacts of grazing on vegetation recovery, managers should:
   A) treat small areas in patches
   B) treat large areas to disperse animals
   C) exclude animals from treated areas
   D) avoid grazing within one year of thinning

ANSWERS

1. A   2. A   3. B and D