Thinning of a Ponderosa Pine/Douglas-Fir Forest in South-Central BC: Impacts on Understorey Vegetation

Research Report

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Abstract

The ponderosa pine and Douglas-fir forests in the Interior of British Columbia, Canada, are facing problems such as forest in-growth mainly due to fire suppression, reducing grazing land area. This study focused on the use of thinning to reduce forest stand density and restore understorey species diversity and increase aboveground biomass productivity. Data were collected over a 4-year period. Species richness and diversity were generally lower under the canopy of ponderosa pine and Douglas-fir trees than outside the canopy. Species diversity was reduced by thinning at one site but unaffected by thinning at the other. Total understorey biomass increased up to 80% within 3 to 4 years after thinning. Depending on site and year, biomass production of one or more plant groups, such as forb, shrub, or graminoid, increased. Reduction in litter depth was observed at both sites due to the removal and/or reduction of needle sources. Variations in species composition existed among blocks and between sites, suggesting greater sampling size may be needed in future research to better capture the spatial variability. Thinning reduces stand density and thereby reduces fuel load and enhances understorey species productivity.

KEYWORDS: Douglas-fir; ponderosa pine; ecological restoration; biomass production; forest in-growth; thinning; tree encroachment

Introduction

In the American Southwest and within the Rocky Mountains of North America, frequent fires historically created and maintained grasslands, shrublands, and conifer forest savannas (Barrett 1994). However, fire suppression in forest management over the last 100 years, at least in part, has resulted in forest in-growth and tree encroachment into grasslands, which has also allowed fuel accumulation and increased the risk of intense wildfires (Covington & Sackett 1984; Daigle 1996; Gayton 1996). Other human activities, such as heavy livestock grazing, may have also contributed (Arsenault & Klenner 2005; Klenner et al. 2008). Forest in-growth and tree encroachment are reducing grazing land areas in Interior British Columbia (BC), Canada (Bai et al. 2004). Decreased rangeland health, lower biomass productivity, and reduced carrying capacity for livestock and wildlife are major concerns to ranchers. More recently the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) epidemic has become a severe problem in the Interior of BC (BC Ministry of Forests 2005) opening up pine forests including ponderosa pine (*Pinus ponderosa* Dougl.).

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Prescribed burning, thinning, and the combination of the two are being widely used to control forest in-growth and tree encroachment and enhance understorey biomass production (Allen et al. 2002; Noss et al. 2006). This is in agreement with the goal of ecosystem restoration aimed at the recovery of ecosystem health (Society for Ecological Restoration International 2002) and historical forest structure (Covington et al. 1997; Allen et al. 2002). Ground fuel loads in the dry ponderosa pine and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests in the Interior of BC, however, are low, and using prescribed burning to reduce ground fuel may not be critical for preventing catastrophic fires (Ducherer et al. 2009). Thinning can be most effective in forests that are too dense to burn due to the risk of crown fire and areas that have nearby markets for small diameter trees (Pollet & Omi 2002), serving as an alternative for restoration of understorey vegetation especially when burning is not applicable.

The effects of prescribed burning on ponderosa pine and Douglas-fir forests in the American Southwest, Rocky Mountains, and BC have been studied and reported (e.g., Allen et al. 2002; Ducherer et al. 2009). The effects of thinning, on the other hand, have received much less attention, especially the longer-term effects on understorey plant communities (e.g., Thomas et al. 1999). Ideally, removing the tree canopy increases the amount of light reaching the forest floor and understorey and, consequently, increases understorey plant abundance and species richness (Thomas et al. 1999). Page et al. (2005) found a positive correlation between understorey species abundance and light intensity before thinning in southern BC. Understorey vegetation responds to increased light after thinning; therefore, the greatest responses are expected within the first several years following thinning (Thomas et al. 1999). Removing the tree canopy can also increase soil temperatures (Strickler & Edgerton 1976) and decrease soil respiration (Streigl & Wickland 1998). In addition, reducing or eliminating competition of overstorey trees can increase soil water and mineral nutrient availability for understorey plants (Peltzer et al. 1998) and allow colonization by herbaceous species (Smit & Rethman 2000). Riegel et al. (1995) found that altering canopy structure within ponderosa pine forests by thinning changed understorey species biomass production, but the relative composition of graminoids, forbs, and shrubs remained unchanged. Mitchell et al. (1983) observed increased resistance to mountain pine beetle and increased tree vigor in thinned lodgepole pine stands.

Precipitation in southern BC's forests, especially during the summer, is less than that in most Southwestern ponderosa pine forests (McLean & Marchand 1968). Therefore, the responses of these forests to restoration treatments may differ from those in the American Southwest. The frequent droughts in these forest types often compromise the effect of thinning and delay the beneficial effect of thinning on understorey vegetation (Page et al. 2005). The objectives of this study were to determine the short-term effects of thinning on understorey species diversity and biomass production in the ponderosa pine and Douglas-fir forests of Interior BC. It was hypothesized that removing trees by thinning increases species diversity, ground cover, and aboveground biomass production of understorey vegetation in ponderosa pine and Douglas-fir forests.

Methods

Site description

Most grasslands in Southern Interior BC are adjacent to dry ponderosa pine and Douglas-fir forests and can be classified into three zones according to elevation: lower grassland (*Pseudoroegneria spicata–Artemisia tridentata*), middle grassland (*P. spicata–Poa secunda*), and upper grassland (*P. spicata–Festuca campestris*) (McLean & Marchand 1968). The two pastures in this study, Coal Mine Pasture (121°35'W 50°46'N; 1050 m) and Gladys Lake Pasture (121°33'W 50°44'N; 1250 m), are located in the upper grassland zone in South-Central BC. Both pastures are classified as Interior Douglas-fir Very Dry Hot Thompson Variant (IDFxh2) using the Biogeoclimatic Ecosystem Classification system (Meidinger & Pojar 1991).

Annual precipitation from the closest weather station in Kamloops was 264, 268, 277, 254, and 221 mm from 1998 to 2002, respectively (Environment Canada 2005). The average growing season had a mean temperature of 16°C for 1999 to 2002. The upper grassland zone, located at a slightly wetter and higher elevation, is characterized by 280 to 330 mm of precipitation with the growing season lasting from April to mid-July and with some plants also regrowing in September (McLean & Marchand 1968).

Black Chernozemic soils are dominant in the upper grassland zone (van Ryswyk et al. 1966). The plant associations at these sites are Douglas-fir–*Festuca campestris* (McLean & Marchand 1968). Gladys Lake Pasture is grazed by cattle, managed by a range tenure holder, and administered by the BC Ministry of Forests, Lands and Natural Resource Operations. Grazing was scheduled for July 1 to July 15 in 2000 and 2001 for Gladys Lake Pasture with a stocking rate of 100 animal unit months (AUM) on 231 ha. Coal Mine Pasture was used by wildlife only.

Experimental and treatment design

This study was a randomized complete block design with five replicates and repeated at two sites, Coal Mine Pasture and Gladys Lake Pasture. Five pairs of plots, 40 x 50 m in size, were established at each site in April 1998. One plot of each pair was thinned in October 1998. In the thinned plots, all trees with a diameter at breast height (dbh) of ≤ 20 cm were cut at ground level using chainsaws and removed. Larger trees were left standing to maintain the forest stand. Pre-thinning tree densities for Coal Mine Pasture and Gladys Lake Pasture were similar ($P > 0.05$), with 998 and 830 stems ha^{-1}, respectively. Post-thinning tree densities averaged 115 and 73 stems ha^{-1} for Coal Mine Pasture and Gladys Lake Pasture, respectively, resulting in about 10% of trees being left.

Experiment 1: Thinning effects on forest understorey vegetation

This experiment assessed the effects of thinning on understorey vegetation. Two north–south transects, 20 m in length, were established at the centre of each plot. The first transect was positioned at a location that was representative of the average understorey composition of the plot and the second transect was placed 10 m to the left of the first.

Data collection

Quadrats (0.4 x 0.5 m) were placed every 2 m on the right side of each 20 m transect for a total of 10 per transect. Percent canopy cover (Barbour et al. 1999) of each vascular plant species, litter (bark, needles, and other dead plant materials), and bare soil were visually estimated between June and July in 1998 (before treatment) and in 1999 and 2002 (after treatment) within these quadrats. The height of live vegetation and the depth of litter within each quadrat were also measured in three sub-samples. Aboveground biomass of understorey plants was determined in late July 2002 on the left side of each transect at 5 and 15 m in 0.4 x 0.5 m quadrats by hand clipping plants to ground level. Clipped plant materials were oven-dried at 60°C for 24 hr and weighed. Samples were then sorted into shrubs, forbs, live graminoids, and dead graminoids and weighed separately.

Data analysis

Species cover from quadrats along the two 20-m transects were averaged for each plot. Species richness (R), species evenness (E), and the Shannon-Wiener Diversity Index (*H'*) (Barbour et al. 1999) were calculated for each plot and year using PC-ORD (McGarigal et al. 2000). Data were then analyzed separately within each year using Analysis of Variance (ANOVA) (SAS Institute 1995) to determine the effect of thinning treatment. Data from 1998, 1999, and 2002 were combined for ordination with rare species (species that occurred in ≤ 2 plots or 10% of the plots) removed (McGarigal et al. 2000). Cover data were relativized by the species maximum and tested with Detrended Correspondence Analysis (DCA). Scores of the first three axes of DCA were calculated and analyzed with ANOVA to determine the effect of year and treatment on plot separation along the three axes. Ground cover including rocks, logs, bare soil, litter, and lichens, the cover of functional groups including forbs, graminoids, shrubs, and total cover, and litter depth and vegetation height were analyzed within years using ANOVA to determine the effects of thinning (Snedecor & Cochran 1980). The graminoid group included grasses, sedges, and rushes. The shrub category also included trees (< 0.5 m tall) but excluded pasture sage (*Artemisia frigida* Willd.), which was considered a forb. Standing crop of forbs, live graminoids, dead graminoids, shrubs, and total understorey standing crop were analyzed using ANOVA. Means were separated using the Least Significant Difference test (LSD) (Snedecor & Cochran 1980). A significance value of $P \leq 0.05$ was used except for biomass for which $P < 0.10$ was used.

Experiment 2: The influence of tree canopy on understorey response to thinning

This experiment assessed the effects of thinning on understorey vegetation as influenced by individual tree canopies. Four ponderosa pine and four Douglas-fir trees within each plot were selected. Four Douglas-fir and four ponderosa pine trunks were selected in each thinned plot based on basal diameters that were similar to the control plots. Trees selected had intermediate sizes, relatively straight stems, and regular (round) and even (equal dimensions in all directions) canopies. Trees with partial canopy overlaps were avoided.

Crown projection area was estimated by visually projecting the edges of the canopy down to the soil surface (Barbour et al. 1999). Linear regression equations were developed for each tree species to describe the relationship between basal diameter and crown projection area, which was used to estimate crown projection areas of trees removed by thinning.

Data collection

A transect was laid out from the base of each ponderosa pine or Douglas-fir tree in all four cardinal directions, and four locations for quadrats along each transect were defined: 1) tree stem (Q1); 2) halfway between the tree stem and edge of the crown projection area (Q2); 3) 30 cm inside the edge of the crown projection area (Q3); and 4) 60 cm outside the edge of the crown projection area (Q4) (see Figure 1). Quadrat 3 (Q3) was not measured when the crown projection area was too small to separate Q2 from Q3. A 0.3 x 0.3 cm quadrat was used for Q1–Q4 to determine percent cover (Barbour et al. 1999) of ground cover and canopy cover of understorey species in June 2001 and 2002. Understorey aboveground biomass was determined in 0.3 x 0.3 m quadrats by hand clipping plants to ground level. Quadrats for biomass determination were placed at the left side of each transect, within and outside the tree canopy (at the same location as Q2 and Q4). Biomass was averaged for Q2 and for Q4 in all four directions. Clipped materials were processed as described before. Coal Mine Pasture was sampled in August 2001 and July 2002. Gladys Lake Pasture was sampled in July and early August 2001 and in June 2002.

Data analysis

Species composition data along the four cardinal directions from each tree stem were averaged by quadrat position (Q1, Q2, Q3, or Q4). Data were combined from trees within each plot (sub-samples) then averaged according to quadrat locations. All three quadrats under the canopy (Q1, Q2, and Q3) were averaged for ground cover because of the low cover and referred to as "under canopy." Species diversity indices R, E, and *H'* were calculated for under the canopy using Q2 and outside the canopy using Q4 for each plot and year using PC-ORD and analyzed within years (2001 and 2002) using the General Linear Model (GLM) (SAS Institute 1995). DCA was performed as previously described. Scores of the first three axes of DCA were calculated and analyzed with GLM to determine whether the effect of treatment and canopy cover type on species composition can be separated along the three axes.

Ground cover, the canopy cover of functional groups, litter depth, and vegetation height were averaged according to quadrat location within each plot and analyzed within years using GLM to determine the effect of canopy removal and quadrat location. Data of the three quadrats under the tree canopy were then combined and analyzed again using GLM. Standing crop of forbs, live graminoids, dead graminoids, shrubs, and total understorey standing crop were also analyzed with GLM as previously described. Means were separated using LSD (Snedecor & Cochran 1980). A significance value of $P \leq 0.05$ was used except for biomass for which $P \leq 0.10$ was used.

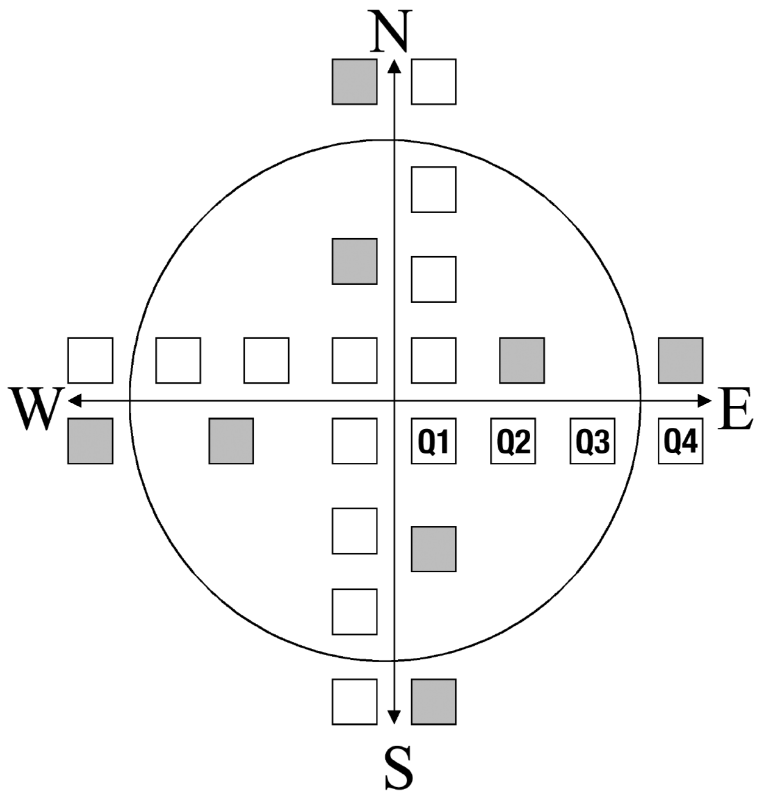

Figure 1: Layout of transects and quadrats surrounding the tree stem under and outside the canopy projection area. Un-hatched squares are quadrat locations for ground cover and species composition. Aboveground biomass was determined in hatched squares.

Results

Experiment 1: Thinning effects on forest understorey vegetation

Understorey plant species composition and diversity

Species diversity indices (R, E, and *H'*) at both sites were not different ($P > 0.05$) between the control and the thinning treatment before thinning in 1998 (Table 1). Thinning treatment reduced R at Coal Mine Pasture in the first (1999, $P = 0.033$) and fourth (2002, $P = 0.030$) years after thinning. E was similar in the control and the thinning treatment at Coal Mine Pasture in 1999 ($P = 0.130$) and 2002 ($P = 0.132$). *H'* was greater in the control than thinning in 1999 ($P = 0.037$) but not in 2002. None of these parameters were different between the control and the thinning treatment at Gladys Lake Pasture in 1999 and 2002.

Table 1: Thinning effects on species richness (R), species evenness (E), and the Shannon-Wiener Diversity Index (*H'*) at Coal Mine Pasture and Gladys Lake Pasture, BC. Thinning was conducted in October 1998.

Site/Year	Treatment	R	E	*H'*
Coal Mine Pasture				
1998	Control	20.4 a[1]	0.75 a	2.3 a
	Thinning	18.2 a	0.63 a	1.8 a
	P-value	0.097	0.099	0.077
1999	Control	21.2 a	0.76 a	2.3 a
	Thinning	13.4 b	0.67 a	1.7 b
	P-value	0.033	0.130	0.037
2002	Control	23.0 a	0.74 a	2.3 a
	Thinning	17.0 b	0.65 a	1.84 a
	P-value	0.030	0.132	0.061
Gladys Lake Pasture				
1998	Control	22.0 a	0.80 a	2.5 a
	Thinning	23.6 a	0.75 a	2.4 a
	P-value	0.347	0.167	0.478
1999	Control	26.2 a	0.77 a	2.5 a
	Thinning	24.4 a	0.73 a	2.3 a
	P-value	0.360	0.330	0.280
2002	Control	26.8 a	0.78 a	2.6 a
	Thinning	24.2 a	0.74 a	2.4 a
	P-value	0.180	0.285	0.123

[1] Means with different letters within a column, site, and year are significantly at $P \le 0.05$.

Plots were separated along the first three axes of DCA based on plant species composition (Figure 2). For Coal Mine Pasture, plots of the three years were separated by Axes 1 and 2 and the control was separated from the thinning treatment by Axis 3 ($P < 0.001$). The order of year along Axis 1 was 1998, 1999, and 2002 from left to right. The separation of treatments within years along Axis 3 was only significant in 2002 ($P = 0.010$), indicating that species composition was similar in the control and thinned plots in the first year, but it was different between treatments in the fourth year. For Gladys Lake Pasture, treatments were separated by Axes 1 ($P = 0.011$) and 3 ($P = 0.049$), but years were not separated by the first three axes (Figure 3).

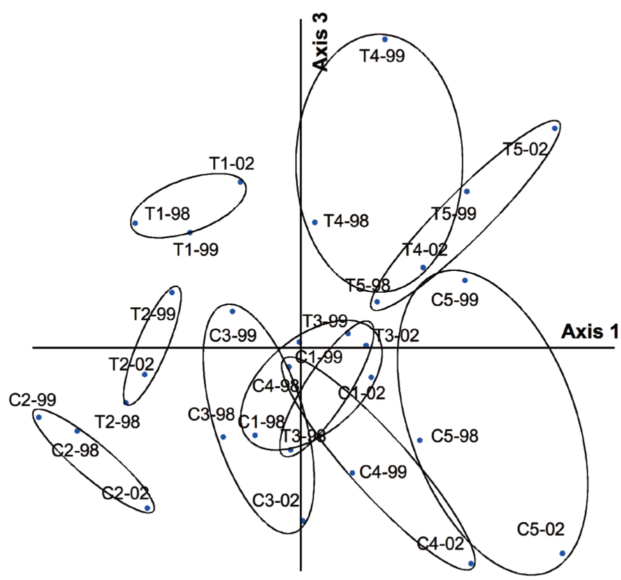

Figure 2. Separation of thinned (T) and control (C) plots along Axes 1 and 3 of Detrended Correspondence Analysis (DCA) at Coal Mine Pasture, BC. Repeated measurements of the same plots in 1998, 1999, and 2002 were grouped.

Coal Mine Pasture was dominated by rough fescue (*Festuca campestris*) and arrow-leaved balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.). Gladys Lake Pasture was dominated by Kentucky bluegrass (*Poa pratensis* L.), but rough fescue and arrow-leaved balsamroot were not common. Bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh.) A. Löve.) was of minor importance at both sites. The abundance of individual species fluctuated from year to year. The relative importance of pinegrass (*Calamagrostis rubescens* Buckl.) in the control plots at Coal Mine Pasture tended to be lower in 1999 and 2002 compared to 1998. However, the importance of pinegrass in the thinned plots was consistent among the three years. Timber milkvetch (*Astragalus miser* Dougl. ex Hook) increased after thinning at Gladys Lake Pasture.

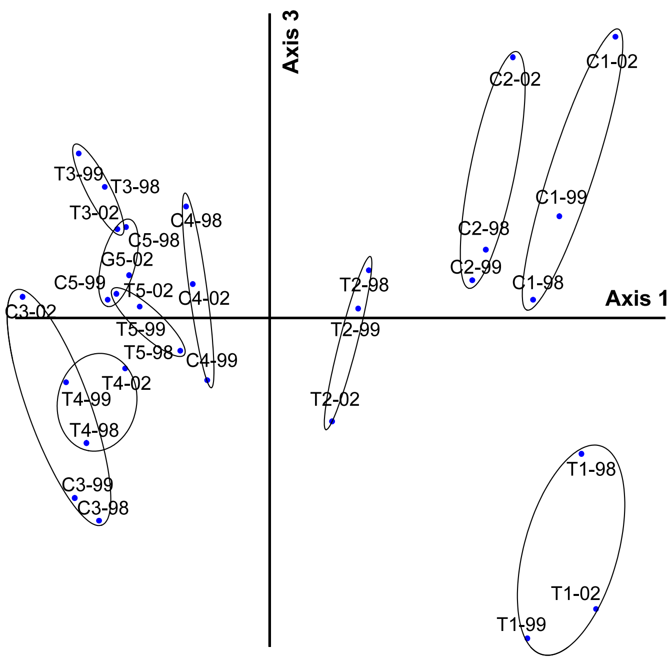

Figure 3. Separation of thinned (T) and control (C) plots along Axes 1 and 3 of Detrended Correspondence Analysis (DCA) at Gladys Lake Pasture, BC. Repeated measurements of the same plots in 1998, 1999, and 2002 were grouped.

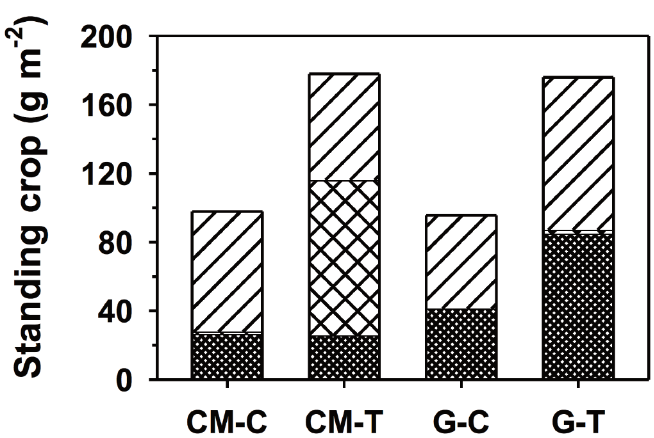

Figure 4. Comparison of understorey biomass production (standing crop) between thinned (T) and control (C) at Coal Mine Pasture (CM) and Gladys Lake Pasture (G), BC, in 2002. The order of stacked bars is forb, shrub, and graminoid from the bottom to the top.

Ground cover

The cover of rocks and decomposed logs was low and similar between treatments (data not shown). The cover of bare soil, litter, lichens, total vegetation (overall average = 43%), litter depth, and vegetation height was also similar between treatments.

Biomass production in the understorey

Understorey biomass after thinning was greater than the control at both sites (Figure 4; P = 0.081 and 0.090 for Coal Mine Pasture and Gladys Lake Pasture, respectively). Aboveground biomass of forb, shrub, and graminoid was not significantly different between treatments at both sites ($P >$ 0.10).

Experiment 2: The influence of tree canopy on understorey response to thinning

Understorey plant species composition and diversity

Species richness (R) was greater outside the canopy than under the canopy of Douglas-fir and ponderosa pine in 2001 at Coal Mine Pasture (P = 0.017) and in 2001 and 2002 at Gladys Lake Pasture (P = 0.025 and P = 0.007) (Tables 2 and 3). Species evenness (E) was greater outside the canopy than under the canopy only for Coal Mine Pasture in 2001

(P = 0.023). The Shannon-Wiener Diversity Index (*H'*) was greater outside the canopy than under the canopy in 2001 at Coal Mine Pasture ($P < 0.001$) and Gladys Lake Pasture ($P = 0.046$) and in 2002 at Gladys Lake Pasture ($P = 0.009$). The thinning treatment and tree species (Douglas-fir versus ponderosa pine) had no effect on R, E, or *H'* ($P > 0.05$).

Table 2. Effects of thinning on species richness (R), species evenness (E), the Shannon-Wiener Diversity Index (H'), and canopy cover of forb and graminoid under and outside the canopy of ponderosa pine (PP) and Douglas-fir (DF) at Coal Mine Pasture, BC. Thinning was conducted in October 1998.

Year/ Location	Tree species/ Treatment	R	E	*H'*	Forb cover (%)	Graminoid cover (%)
2001						
Under canopy	PP-Control	10.7 a[1]	0.66 a	1.5 a	12 a	7 a
	DF-Control	10.4 a	0.71 a	1.6 a	7 a	7 a
	PP-Thinned	10.0 a	0.64 a	1.5 a	9 a	9 a
	DF-Thinned	11.8 a	0.74 a	1.7 a	11 a	8 a
	Mean	**10.7 B[2]**	**0.69 B**	**1.6 B**	**10 A**	**8 A**
Outside canopy	PP-Control	13.3 a	0.77 a	2.0 a	11 a	7 a
	DF-Control	13.6 a	0.75 a	1.9 a	9 a	9 a
	PP-Thinned	12.5 a	0.71 a	1.8 a	13 a	9 a
	DF-Thinned	14.0 a	0.72 a	1.9 a	11 a	7 a
	Mean	**13.4 A**	**0.73 A**	**1.9 A**	**11 A**	**8 A**
2002						
Under canopy	PP-Control	13.1 a	0.69 a	1.8 a	11 ab	5 a
	DF-Control	12.5 a	0.75 a	1.8 a	8 b	5 a
	PP-Thinned	11.4 a	0.67 a	1.6 a	12 a	6 a
	DF-Thinned	14.2 a	0.74 a	1.9 a	13 a	6 a
	Mean	**12.8 A**	**0.71 A**	**1.8 A**	**11 A**	**6 B**
Outside canopy	PP-Control	16.3 a	0.79 a	2.2 a	10 a	7 a
	DF-Control	15.2 a	0.72 a	1.9 a	13 a	7 a
	PP-Thinned	14.8 a	0.74 a	2.0 a	15 a	7 a
	DF-Thinned	15.8 a	0.73 a	2.0 a	11 a	6 a
	Mean	**15.5 A**	**0.74 A**	**2.0 A**	**12 A**	**7 A**

[1] Means with different lower case letters within a column, site, and year are significantly at $P \leq 0.05$.
[2] Means with different capital letters within a column and year (under vs. outside canopy) are significantly different at $P \leq 0.05$.

Thinning increased forb cover outside the canopy of ponderosa pine at Gladys Lake Pasture in 2001 ($P = 0.034$) and under the tree canopy of Douglas-fir at Coal Mine Pasture in 2002 ($P = 0.026$; Tables 2 and 3). Shrub cover was low and similar under and outside the canopy and between thinning treatments at both sites. Graminoid cover was mostly unaffected by canopy, treatment, and tree species.

Dominant species surrounding ponderosa pine and Douglas-fir were similar along transects at both sites. Richardson's needlegrass (*Achnatherum richardsonii* (Link) Barkworth) was less abundant outside than under the canopy of ponderosa pine but was similar under and outside Douglas-fir canopy at Coal Mine Pasture. At Gladys Lake Pasture, timber milkvetch increased after thinning under ponderosa pine compared to the control but remained the same under Douglas-fir.

Table 3. Effects of thinning on species richness (R), species evenness (E), the Shannon-Wiener Diversity Index (H'), and canopy cover of forb and gramnoid under and outside the canopy of ponderosa pine (PP) and Douglas-fir (DF) at Gladys Lake Pasture, BC. Thinning was conducted in October 1998.

Year/ Location	Tree species/ Treatment	R	E	*H'*	Forb cover (%)	Graminoid cover (%)
2001						
Under canopy	PP-Control	9.7 a[1]	0.76 a	1.7 a	13 a	10 a
	DF-Control	13.4 a	0.75 a	2.0 a	13 a	13 a
	PP-Thinned	18.0 a	0.85 a	2.4 a	23 a	12 a
	DF-Thinned	16.3 a	0.71 a	2.0 a	14 a	18 a
	Mean	**14.3 B[2]**	**0.77 A**	**2.0 B**	**16 A**	**13 A**
Outside canopy	PP-Control	14.5 a	0.81 a	2.1 a	14 b	8 a
	DF-Control	15.0 a	0.78 a	2.1 a	19 ab	13 a
	PP-Thinned	20.5 a	0.83 a	2.5 a	23 a	18 a
	DF-Thinned	17.4 a	0.70 a	2.0 a	15 b	21 a
	Mean	**16.9 A**	**0.78 A**	**2.2 A**	**23 A**	**15 A**
2002						
Under canopy	PP-Control	21.0 a	0.83 a	2.5 a	23 a	12 a
	DF-Control	20.5 a	0.78 a	2.4 a	20 a	16 a
	PP-Thinned	12.8 a	0.81 a	2.0 a	26 a	11 a
	DF-Thinned	16.0 a	0.80 a	2.2 a	22 a	18 a
	Mean	**17.6 B**	**0.80 A**	**2.3 B**	**23 A**	**14 A**
Outside canopy	PP-Control	24.0 a	0.88 a	2.8 a	24 a	12 a
	DF-Control	21.6 a	0.77 a	2.4 a	30 a	14 a
	PP-Thinned	16.5 a	0.85 a	2.4 a	30 a	10 a
	DF-Thinned	20.3 a	0.83 a	2.5 a	28 a	18 a
	Mean	**20.6 A**	**0.83 A**	**2.3 A**	**28 A**	**14 A**

[1] Means with different lower case letters within a column, site, and year are significantly at $P \leq 0.05$.
[2] Means with different capital letters within a column and year (under vs. outside canopy) are significantly different at $P \leq 0.05$.

Ground cover and understorey vegetation

Litter cover was greater under the canopy than outside the canopy at Coal Mine Pasture in 2001 ($P = 0.001$) and 2002 ($P = 0.001$; Table 4); the same response was observed at Gladys Lake Pasture in 2001 ($P = 0.017$; Table 5). Under the canopy, litter was mainly composed of coniferous needles, while dead forbs and grasses composed litter outside the canopy. Litter cover was greater under ponderosa pine than under Douglas-fir at both sites, but the reduction in litter cover by thinning was only significant between tree species at Coal Mine Pasture in 2002 ($P = 0.036$; Tables 4 and 5). Litter depth was greater under the canopy than outside the canopy at Coal Mine Pasture in 2001 and 2002 ($P = 0.001$ and < 0.001, respectively) and at Gladys Lake Pasture in 2001 and 2002 ($P = 0.004$ and 0.004, respectively). Litter cover and litter depth decreased while lichen cover increased from the centre to the edge of the canopy projection area (data not shown). Generally, thinning reduced litter depth under both tree species at both sites (Tables 4 and 5). Litter depth was reduced by thinning under the canopy of Douglas-fir in 2001 ($P = 0.026$) and under the canopy of ponderosa pine in 2002 ($P = 0.005$) at Coal Mine Pasture. Lichen cover was greater outside than under the canopy at Coal Mine Pasture in 2002 ($P = 0.001$). Total veg-

Table 4. Effects of thinning on litter cover, litter depth, lichen cover, total vegetation canopy cover, and vegetation height under and outside the canopy of ponderosa pine (PP) and Douglas-fir (DF) at Coal Mine Pasture, BC. Thinning was conducted in October 1998.

Year/ Location	Tree species/ Treatment	R	E	*H'*	Forb cover (%)	Graminoid cover (%)
2001						
Under canopy	PP-Control	97 a[1]	4.3 a	<1 a	20 a	29.7 a
	DF-Control	90 a	3.1 b	3 a	16 a	27.3 a
	PP-Thinning	95 a	3.7 ab	2 a	26 a	32.8 a
	DF-Thinning	94 a	2.7 c	2 a	24 a	29.6 a
	Mean	**94 A[2]**	**3.4 A**	**2 A**	**22 A**	**29.8 A**
Outside canopy	PP-Control	87 a	2.3 a	6 a	19 a	27.5 a
	DF-Control	80 a	2.0 a	6 a	20 a	25.3 a
	PP-Thinning	87 a	2.9 a	5 a	31 a	29.5 a
	DF-Thinning	83 a	2.3 a	8 a	27 a	24.9 a
	Mean	**84 B**	**2.4 B**	**6 A**	**24 A**	**26.8 B**
2002						
Under canopy	PP-Control	96 a	4.8 a	1 a	16 a	35.7 a
	DF-Control	89 b	3.5 b	4 a	13 a	30.4 a
	PP-Thinning	92 ab	3.2 b	3 a	25 a	32.1 a
	DF-Thinning	90 b	3.0 b	5 a	22 a	31.2 a
	Mean	**92 A**	**3.6 A**	**3 B**	**19 A**	**32.3 A**
Outside canopy	PP-Control	79 a	2.6 a	12 a	18 a	33.4 a
	DF-Control	78 a	2.1 a	8 a	20 a	31.5 a
	PP-Thinning	82 a	2.6 a	12 a	23 a	31.1 a
	DF-Thinning	79 a	2.5 a	10 a	24 a	30.9 a
	Mean	**80 B**	**2.4 B**	**10 A**	**21 A**	**31.7 A**

[1] Means with different lower case letters within a column, site, and year are significantly at $P \leq 0.05$.
[2] Means with different capital letters within a column and year (under vs. outside canopy) are significantly different at $P \leq 0.05$.

etation cover was also greater outside the canopy at Gladys Lake Pasture in 2002 ($P = 0.034$). Except for Coal Mine Pasture in 2001, where plant heights were greater under the canopy than outside the canopy ($P = 0.044$), vegetation height was not significantly different under or outside the tree canopy.

Aboveground biomass production

Total understorey biomass was between 60 and 140 g m^{-2} (Figure 5). Total understorey biomass was generally greater after thinning compared to the control under both tree species. Greater total understorey biomass after thinning at Gladys Lake Pasture was caused by increased forb biomass in 2001 ($P = 0.009$) and both greater forb ($P = 0.002$) and graminoid ($P = 0.057$) biomass in 2002. Greater total understorey biomass after thinning at Coal Mine Pasture was caused by greater shrub biomass in 2001 ($P = 0.017$). Differences in understorey biomass between tree species were not significant.

Discussion

Even though species richness and diversity were generally lower under the canopy of ponderosa pine and Douglas-fir trees than outside the canopy in our study, thinning had no consistent effect on these plant community characteristics the first 4 years after treatment. Species diversity was reduced by thinning at one site but unaffected by thinning at the

Table 5. Effects of thinning litter cover, litter depth, lichen cover, total vegetation canopy cover, and vegetation height under and outside the canopy of ponderosa pine (PP) and Douglas-fir (DF) at Gladys Lake Pasture, BC. Thinning was conducted in October 1998.

Year/ Location	Tree species/ Treatment	R	E	*H'*	Forb cover (%)	Graminoid cover (%)
2001						
Under canopy	PP-Control	100 a[1]	3.2 a	<1 a	24 a	32.4 a
	DF-Control	98 a	3.3 a	1 a	27 a	27.3 a
	PP-Thinning	99 a	2.2 a	<1 a	35 a	26.8 a
	DF-Thinning	97 a	2.0 a	2 a	32 a	27.0 a
	Mean	**98 A[2]**	**2.5 A**	**1 A**	**29 A**	**28.4 A**
Outside canopy	PP-Control	99 a	1.9 a	<1 a	25 a	30.7 a
	DF-Control	76 a	2.0 a	3 a	32 a	21.8 a
	PP-Thinning	96 a	2.1 a	4 a	42 a	28.1 a
	DF-Thinning	96 a	2.0 a	4 a	36 a	26.9 a
	Mean	**92 B**	**2.0 B**	**3 A**	**33 A**	**26.9 A**
2002						
Under canopy	PP-Control	98 a	4.1 a	1 a	35 a	35.4 a
	DF-Control	97 a	3.1 a	3 a	35 a	29.8 a
	PP-Thinning	97 a	2.4 a	2 a	38 a	28.5 a
	DF-Thinning	91 b	2.2 a	9 a	41 a	27.9 a
	Mean	**96 A**	**2.9 A**	**4 A**	**37 B**	**30.4 A**
Outside canopy	PP-Control	95 a	2.2 a	7 a	36 a	32.3 a
	DF-Control	89 a	2.2 a	11 a	44 a	29.8 a
	PP-Thinning	95 a	2.4 a	8 a	39 a	26.5 a
	DF-Thinning	90 a	2.0 a	12 a	46 a	27.8 a
	Mean	**92 A**	**2.3 B**	**10 A**	**41 A**	**29.1 A**

[1] Means with different lower case letters within a column, site, and year are significantly at $P \leq 0.05$.
[2] Means with different capital letters within a column and year (under vs. outside canopy) are significantly different at $P \leq 0.05$.

other site. Previous reports suggest that thinning trees enhances species diversity, but the increase usually occurs more than 10 years after thinning (Bailey et al. 1998; Thomas et al. 1999). The relatively small, short-term effect of thinning and sometimes burning possibly reflects adaptation of these ecosystems to low intensity disturbances (Metlen et al. 2004). Relatively stable species richness but increased cover of native grasses was reported 5 to 12 years following thinning in the ponderosa pine–bunchgrass forests of Arizona (Griffis et al. 2001). Increases in the abundance of graminoids after thinning are related to increased amounts of light in ponderosa pine forests (Naumburg & DeWald 1999).When Douglas-fir forests in the Pacific Northwest of the U.S. were repeatedly thinned, understorey cover initially decreased 1 year after thinning, but it recovered and species richness increased within 3 years (Thysell & Carey 2001). Species richness increased 2 years after thinning in pinyon–juniper woodlands in central Mexico (Brockway et al. 2002). Short term increase in species abundance is usually associated with exotic species and high treatment intensity (Griffis et al. 2001). Low precipitation compared to similar vegetation in the Pacific Northwest of the U.S., minimum disturbance to the soil during thinning using chainsaw, and relatively low tree density before thinning at our study sites may have contributed to the slow response of understorey species to thinning treatment.

Thinning trees generally increases biomass productivity of understorey plants especially when pre-treatment stand density is high (McConnel & Smith 1970; Uresk & Severson 1998; Brockway et al. 2002). Total understorey biomass increased up to 80% within 3 to 4 years after thinning in the ponderosa pine and Douglas-fir forests in the present study. Depending on sites and years, biomass production of one or more functional groups, such as forb, shrub, or graminoid, may increase. Uresk and Severson (1998) also reported that eliminating or reducing the overstorey in ponderosa pine forests increases understorey biomass production.

A negative correlation between litter and understorey richness/productivity was found by Xiong and Nilsson (1999) based on a meta-analysis. It should be noted, however, thinning treatments should have an explicit and long-term commitment to restore frequent surface fire in these ecosystems to satisfy "ecological restoration" (Allen et al. 2002).

The two study sites are within the same biogeoclimatic zone but differ in elevation, which affects temperature and precipitation (van Ryswyk et al. 1966; Peet 2000) and understorey species composition. Coal Mine Pasture is at a lower elevation than Gladys Lake Pasture and precipitation may be more limiting to plants. Differences in land use between Coal Mine Pasture and Gladys Lake Pasture were also reflected in understorey species composition. The dominance of Kentucky bluegrass, an increaser species (McLean & Marchand 1968), at Gladys Lake Pasture is related to its grazing history. Spatial variability within each site was reflected in the high heterogeneity in species composition and the degree of response to thinning treatment.

Implications

Significant increases in understorey biomass can be expected 3 to 4 years after thinning in the dry forests of Interior BC. In this study, thinning was shown to enhance biomass production for livestock. However, potential benefits for species diversity may require more time because of the restraints of climatic conditions in this region compared to the Pacific Northwest of the U.S. Overall, thinning is an effective management tool in reducing tree canopy cover and fuel load in dry forests and can be used as an alternative to prescribed burning for understorey vegetation restoration when the latter is not feasible, for example, at sites close to communities or without sufficient surface fuels.

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Test Your Knowledge

How well can you recall the main messages in the preceding article?
Test your knowledge by answering the following questions.

Thinning of a Ponderosa Pine / Douglas-Fir Forest in South-Central BC: Impacts on Understorey Vegetation

1. Increased understorey biomass at Coal Mine Pasture following thinning was due to which component:
    - a. Graminoid
    - b. Shrub
    - c. Forb

2. Irrespective of thinning, plant litter accumulation was:
    - a. Greater outside the tree canopy.
    - b. Was unaffected by tree canopy.
    - c. Greater under the tree canopy.

3. Species richness (R) was:
    - a. Significantly less following thinning at both sites.
    - b. Significantly greater following thinning at Gladys Lake Pasture.
    - c. Significantly less following thinning at Coal Mine Pasture.

Answers: 1=b; 2=c; 3=c