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Understory Response to Fuel Reduction Treatments in the Blue Mountains of Northeastern Oregon

Abstract

Understory response to fuel reduction treatments was evaluated in fire-adapted ponderosa pine-Douglas-fir forests in northeastern Oregon. Treatments included: no management (control), prescribed fall burning (burn), low thinning (thin), and low thinning followed by prescribed fall burning (thin/burn), replicated four times in a completely randomized design. Treatment effects were observed in the first growing season after burning and three seasons after thinning. Species richness of the understory vegetation was significantly lower in the thin than in the control, but Shannon-Weaver's index of diversity was not affected by fuel reduction treatments. Graminoid cover was not influenced by treatment, forb cover was reduced in treatments that included thinning, and shrub and total cover were reduced in treatments that included burning. Individual species responded to treatment in a manner consistent with their life history characteristics. Prairie Junegrass cover increased in those treatments that included burning, while cover of other graminoid species was not significantly influenced. The thin treatment significantly lowered elk sedge and total cover, but did not strongly influence the cover of other species. Prairie Junegrass frequency increased significantly in the burned treatments, while western needlegrass frequency was significantly reduced. Frequency of other species tended to remain the same in all treatments. Resilience of community diversity to fire and the consistent effect of burning on individual species demonstrate their adaptation to frequent low-intensity fire, and the subsequent moderate impact of low thinning and fall prescribed burning on understory vegetation.

Introduction

Ponderosa pine-Douglas-fir (*Pinus ponderosa*-*Pseudotsuga menziesii*) forests throughout the interior West exist in a weakened, fire-prone condition, created by fire exclusion policies favored over the last 100 yr (Covington et al. 1997, Johnson 1998, Smith and Arno 1999, Department of the Interior 2002). In these ecosystems, encroachment into grasslands and increasing density of coniferous regeneration have resulted in a less diverse and less vigorous understory community (Hall 1977, Mutch et al. 1993, Covington et al. 1997, Johnson 1998, Smith and Arno 1999). Understory diversity, composition, and abundance is of particular interest due to impacts on forest ecosystem processes such as primary productivity, nutrient cycling, hydrology (Harrod 2001), and forage impacts that come with changes in community structure and composition (Bedunah et al. 1988, Hall 1977). Thinning and prescribed burning treatments have been suggested to simulate or return historic disturbance processes to ecosystems de-

pendent on fire (Mutch et al. 1993, Covington et al. 1997, Smith and Arno 1999). Fuel reduction and ecosystem restoration are important objectives of these treatments.

Fuel reduction projects can slow or stop the spread of a canopy fire, allowing more effective suppression or reduced burn intensity (Pollet and Omi 2002). However, relatively little is known about the ecological implications of these treatments. This paper investigates the understory component of the Hungry Bob Fuel Reduction Project, a study to assess the effects of fire and fire-surrogate treatments on the ponderosa pine-Douglas-fir forest communities in the Blue Mountains of northeastern Oregon (Figure 1). The Hungry Bob study is one of 13 sites in the Fire/Fire Surrogates (FFS) Project, a national network designed to evaluate the effects of thinning and burning treatments on fuels, wildfire hazard, and ecosystem structure and process in long-needled conifer forests (Weatherspoon 2000).

Greater availability of water, light, and nutrients due to thinning and fire may have dramatic effects on the diversity, distribution, cover, and species composition of the understory. Many

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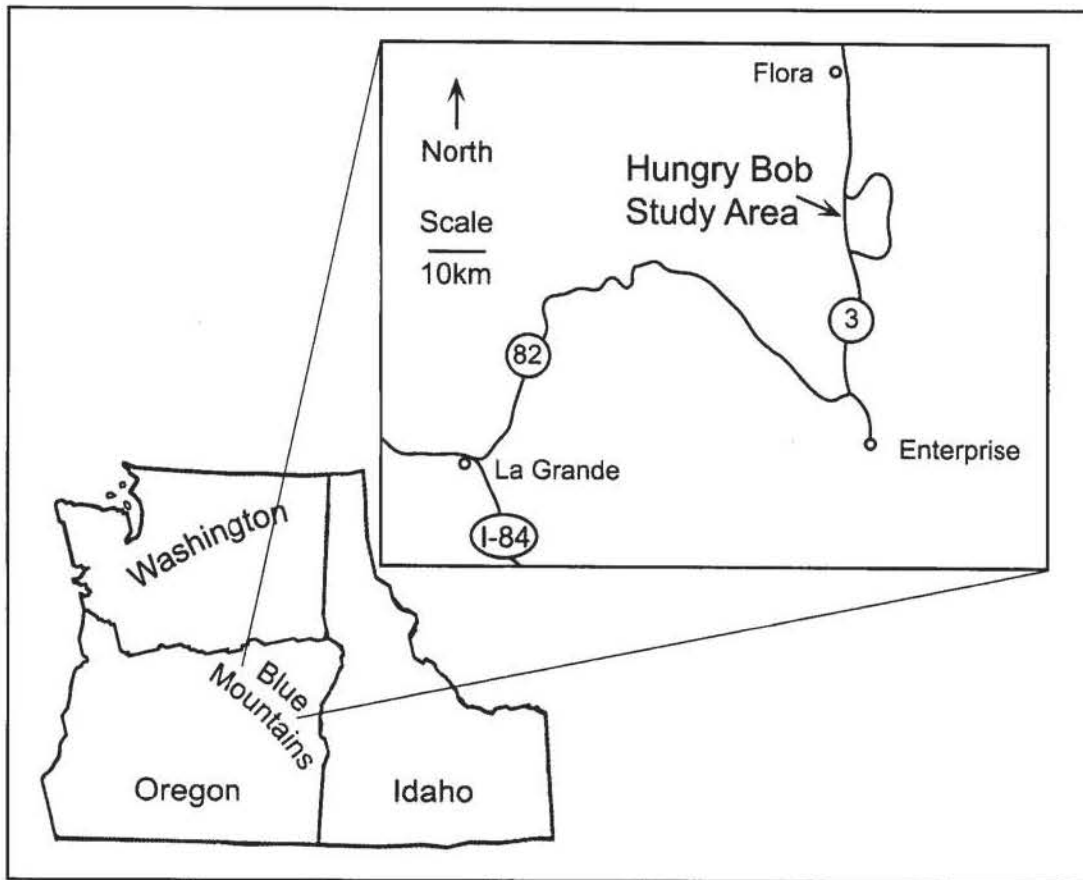


Figure 1. Location of Hungry Bob FFS study area, 45 km north of Enterprise, Oregon.

investigators report that species diversity is highest immediately after disturbance (Ahlgren 1960, Conway 1981, Abrams and Dickman 1982, Grant and Loneragan 2001). Others have reported that diversity typically does not peak until several growing seasons after the disturbance; instead, disturbance events often reduce diversity in the short term (Nieppola 1992, Collins et al. 1995, Lehmkuhl 2002). For example, timber harvesting in the mixed-conifer forests of eastern Washington had little effect on species diversity 3 yr after harvest, though diversity was reduced until that time (Scherer et al. 2000).

While disturbance may create the conditions for greater diversity, other factors tend to prevent an increase (Collins et al. 1995). The short-term negative influence of disturbance on understory diversity is often explained by interspecific competition. Rhizomatous or vegetatively reproduc-

ing species can respond quickly to low-intensity disturbance and exclude species attempting to colonize a site (Stickney 1986, Grant and Loneragan 2001). In thin-only treatments if the soil is not disturbed, subsequent dominance of resprouting species is particularly pronounced (Dyrness 1973). Even under more extreme conditions such as a severe burn, vegetative reproducers can dominate the immediate postfire vegetation and reduce species richness (Turner et al. 1997).

In the ponderosa pine forests of central Oregon, prescribed broadcast burning increased species richness and diversity of the understory while decreasing shrub cover (Busse et al. 2000). In Arizona, prescribed burning in pine forests increased understory productivity and the dominance of grasses over forbs (Harris and Covington 1983). As an example of species-specific response,

prescribed burning in western Montana increased Scouler's willow (*Salix scouleriana*) but decreased bitterbrush (*Purshia tridentata*), while thinning had the opposite effect (Ayers et al. 1999). Thinning alone increased understory cover in western Montana (Smith and Arno 1999), and dramatically increased the cover of grasses in eastern Washington (McConnell and Smith 1970).

Life history characteristics such as growth phenology and mechanism of reproduction could strongly influence species response to treatments. Most native species found in this region complete their life cycles early in the season, so that fires in the late summer or early fall are less damaging (Antos et al. 1983). Rhizomatous species, such as elk sedge (*Carex geyeri*), pinegrass (*Calamagrostis rubescens*), and western yarrow (*Achillea millefolium*) have the ability to resprout after being top killed, giving them a head start after fires of low intensity (USDA Natural Resource Conservation Service 2002). Pinegrass and western yarrow reproduce rhizomatously and from seed, allowing for survival and dispersal after disturbance and giving them an advantage over species that primarily reproduce vegetatively, such as elk sedge. Similarly, arrowleaf balsamroot (*Balsamorhiza sagittata*) resprouts every year from a thick caudex, even though it depends on seed for dispersal. Intense burns can leave arrowleaf balsamroot undamaged, simply preparing a seedbed for the next year's seed crop (Smith and Fischer 1997).

Perennial bunchgrasses, such as Idaho fescue (*Festuca idahoensis*) and western needlegrass (*Achnatherum occidentale*), tend to have a thick mat of plant material protecting their roots (USDA Natural Resource Conservation Service 2002). Accumulation of dead material over the years can lead to increased susceptibility to fire if this material burns too intensely. In the grasslands of southern Idaho, fire mortality actually increased with increasing bunch size (Wright and Klemmedson 1965). Time since burning strongly influences bunch size, potentially explaining Idaho fescue's variable response to fire, e.g., reduced cover (Johnson 1998, Busse et al. 2000), or maintained frequency (Tveten and Fonda 1999). More loosely tufted grasses, such as prairie Junegrass (*Koeleria macrantha*), can survive burns that kill bigger bunchgrasses, thus retaining a seed source on site and leading to greater increases in subse-

quent years (Wright and Klemmedson 1965, Antos et al. 1983).

Despite copious, yet often anecdotal, descriptions of species response to natural and human-caused disturbance, there is little empirical evidence of understory response to management action from replicated treatments. We compared understory response across four fuel management alternatives: broadcast burning (burn), thinning (thin), thinning followed by broadcast burning (thin/burn), and no fuel reduction (control) three seasons after thinning and one growing season after burning. These treatments are evaluated in the context of a replicated, completely randomized design, a powerful design that is unique in the ecological literature (Hurlbert 1984, Michener 1997). Data collected for this study may also be used in meta-analyses with other FFS sites, allowing inference to much larger geographic areas. Results of this study should be appropriate for inference to similar low elevation ponderosa pine-Douglas-fir forests of the Blue Mountains.

Specific objectives of this study are: 1) to compare understory species richness, diversity, and evenness among treatments, and 2) to identify trends and short-term treatment effects on mean cover and frequency of understory species.

Study Area

The Hungry Bob Study Area is located in the Blue Mountains of northeastern Oregon between the Davis and Crow Creek drainages, 45 km north of Enterprise (Figure 1). For the 30-yr period from 1971 to 2001, mean yearly temperature was 7°C (45°F) with an average of 151 frost-free days, and the mean annual precipitation was 49.9 cm, the majority of which fell between September and June (National Climate Data Center 2003).

The research stands were second-growth ponderosa pine and Douglas-fir forests mostly comprising trees 60-90 yr old, but with clumps of regeneration and occasional older trees up to 200 yr. Grazing is a traditional land use in the study area and continues as a consistent factor across all of the treatment units. The historical fire regime was one of low intensity and high frequency (Hall 1977, Mutch et al. 1993); however, fire has not been a significant process in the study area since the initiation of fire exclusion in the early 1900s. All of the research areas have been harvested previously, six of the units as recently as

TABLE 1. Pre- and posttreatment mean tree densities, by treatment, at the Hungry Bob study area.

	Control	Burn	Thin	Thin/burn
Treatment dates	None	Fall 2000	Summer 1998	Summer 1998/Fall 2000
1998 basal area (m ² /ha)	17.2	15.6	20.8	16.2
2001 basal area (m ² /ha)	19.6	15.7	14.4	10.5
1998 trees/ha	274.4	231.4	411.8	317.0
2001 trees/ha	281.3	217.5	218.4	154.1
1998 % of maximum SDI	34.5	31.9	43.5	34.4
2001 % of maximum SDI	38.5	31.8	29.0	21.5
1998 saplings/ha	219.9	51.0	255.9	88.3
2001 saplings/ha	276.7	36.6	203.4	16.0

1986. Pre-treatment stocking levels of the overstory ranged from 32 to 43% of maximum Stand Density Index (SDI) (Reineke 1933, Long 1996), a relatively open forest structure (Table 1).

Methods

Study Design

Research units were selected and treatments assigned using a completely randomized design. The units were randomly selected from a large pool of second growth ponderosa pine-Douglas-fir stands that exhibited relatively homogeneous elevation, aspect, slope, plant association, soil type (Table 2), basal area, trees per ha, and saplings per ha (Table 1). Treatments were randomly assigned at the stand level and included: thin-from-below (thin), thin-from-below followed by fall

prescribed broadcast burn (thin/burn), fall prescribed broadcast burn (burn), and a no-action treatment referred to by the FFS study as a control. If the characteristics of all units had been identical before treatments were randomly assigned, the no-action treatments would have been true controls; this was obviously not the case. We use term control for ease of interpretation. A total of 16 experimental units were included in the study, with 4 units receiving each treatment. Experimental units ranged from 10 to 20 ha.

Basal area in the two treatments that received thinning averaged 18.5 m²/ha (38.8% maximum SDI) prior to harvest in 1998. Thinning in 1998 reduced SDI by about 33% from pretreatment levels. In 2001, basal area averaged 14.4 m²/ha in the thin treatment and a somewhat lower 10.3 m²/ha in the thin/burn due to burn-related mortality

TABLE 2. Site characteristics by treatment unit at the Hungry Bob study area. Elevation, aspect, and slope are treatment unit means. Plant associations follow Johnson and Simon (1987).

Treatment Unit	Elevation (m)	Aspect (degrees)	Slope (degrees)	Plant Association	Soil Series
Control 1	1113	108	10	Douglas-fir/snowberry	Melhorn
Control 2	1333	296	15	Douglas-fir/spiraea	Melhorn
Control 3	1412	345	5	Douglas-fir/snowberry	Olot
Control 4	1286	218	7	Douglas-fir/snowberry	Fivebit
Burn 1	1192	50	4	Ponderosa pine/snowberry	Bocker
Burn 2	1374	230	11	Douglas-fir/snowberry	Fivebit
Burn 3	1260	84	5	Ponderosa pine/Idaho fescue	Bocker
Burn 4	1169	82	5	Ponderosa pine/snowberry	Olot
Thin 1	1380	286	5	Douglas-fir/snowberry	Larabee
Thin 2	1361	283	6	Douglas-fir/snowberry	Fivebit
Thin 3	1305	292	12	Douglas-fir/snowberry	Fivebit
Thin 4	1235	51	7	Douglas-fir/snowberry	Melhorn
Thin/burn 1	1186	297	7	Ponderosa pine/snowberry	Bocker
Thin/burn 2	1183	274	5	Ponderosa pine/snowberry	Bocker
Thin/burn 3	1388	221	9	Douglas-fir/snowberry	Fivebit
Thin/burn 4	1174	297	5	Ponderosa pine/snowberry	Fivebit

(Table 1). The cutting prescription was designed to reserve dominant and codominant crown classes, and enhance natural clumping. The stands were thinned in 1998 (Table 1) with a cut-to-length system using a harvester and a forwarder operating within designated corridors. All cut trees were limbed in the corridor, and the slash was left in place to be trampled by the forwarder. All live trees >32 cm dbh were left standing.

Burning prescriptions were designed to allow mortality of trees representing a designated percentage of pretreatment basal area. Mortality targets for trees 20–51 cm dbh were <30% for ponderosa pine, <40% for Douglas-fir, and <70% for grand fir (*Abies grandis*). For trees >51 cm dbh, target mortality percentages were <20% for ponderosa pine, <30% for Douglas-fir, and <50% for grand fir. Fuel bed mass was targeted for reduction to <6,725 kg/ha of material <8 cm in diameter.

Prescribed broadcast burning was conducted in fall 2000 (Table 1). All plots in the burn and thin/burn treatments burned nearly completely in fairly uniform and low-intensity fires, consuming 75% of the grasses and exposing <25% mineral soil. Fuel bed mass was reduced to 2,242 kg/ha of material <8 cm in diameter, based on fuels sampling conducted by USDA Forest Service Forestry and Range Sciences Laboratory, La Grande, Oregon.

Field methods

Research units were selected based on homogeneity of physical characteristics (Table 2). Due to inherent natural variability, however, there were still discrepancies among units. To quantify these differences, plant association, elevation, effective aspect, slope, pretreatment SDI (Reineke 1933), pretreatment overstory cover, and pretreatment seedling crown ratio were collected by plot before treatments were implemented in 1998. The dominant soil type (Bocker, Fivebit, Larabee, Melhorn, or Olot) was assigned based on previous soil mapping conducted by USDA Forest Service Forestry and Range Sciences Laboratory, La Grande, Oregon. Plant association was classified according to Johnson and Simon (1987). SDI was calculated using the summation technique (Long 1996) with maximum density values and species-specific exponents from Cochran et al. (1994).

A systematic grid of 25–30 sampling points was established within each unit. Sample points were 50 m apart and at least 50 m from stand edges. At each grid point, aspect was estimated to the nearest 1° azimuth using a compass, and slope was estimated to the nearest 1° inclination using a clinometer. Effective aspect was calculated as a combined variable of slope and aspect in accordance with Stage (1976). Elevation of each site was estimated to the nearest 15 m from USGS contour maps.

Posttreatment measurements were taken during the early summer of 2001, 3 yr after thinning and the first growing season after burning. Circular 400 m² plots, centered on every grid point, were used for estimating understory cover. Percent cover of all vascular plants was estimated to the nearest 1% for values up to 10%, and to the nearest 10% for all values >10%. A plant did not need to be rooted in the plot to contribute cover. Botanical nomenclature follows Hitchcock and Cronquist (1973). In 2001, voucher specimens were collected and filed at the Eastern Oregon University Herbarium (EOSC).

All trees within each 400 m² sample plot were identified by species and assessed as live or dead. Diameter at breast height was measured to the nearest 0.1 cm using a diameter tape. Height was measured to the nearest 0.1 m using a clinometer or a telescoping height pole. Crown ratio (percent of the bole with live foliage) was estimated to the nearest 1% for all seedlings ≤1.37 m tall. To accurately characterize the overstory canopy cover, we used a moosehorn densitometer 2 m from the plot center in each of the four cardinal directions, and one observation at the plot center. Each observation in which live foliage appeared was tallied. Percent overstory canopy cover for the treatment unit was then derived using equation 1:

$$[1] \quad \text{Canopy Cover} = \frac{X}{N} * 100$$

where X is the number of observations in which foliage was viewed, and N is the total number of observations within the unit.

Analytical Methods

Treatment effects on the understory vegetation were investigated by ANOVA on the adjusted means of response variables: diversity, cover, and

frequency of the understory. Statistical analyses were conducted using SPSS software (versions 9.0.0 and 10.0.7, SPSS Inc.). The significance level was set at $P=0.05$ before the research began. Understory cover and frequency values were normalized with a natural logarithmic transformation for the analysis, then converted back to cover and frequency values to aid in interpretation. Adjusted means were obtained via regression equations formed using stepwise forward and backward multiple linear regressions (Ott 1993), a technique favored by Brosnoks et al. (2001) for analyzing changes in understory richness, and McKenzie et al. (2000) for investigating overstory influences on understory vegetation.

A general linear model was used to adjust for differences in physical parameters among units. Parameters were not included if the probability of their coefficient (β) was >0.05 . An extra least squares F-test was conducted to determine if the dummy variables for soil were significant; they were subsequently retained or eliminated as a group based on this test (Ott 1993). When the most parsimonious model had been derived, response variables were described only by the set of parameters that explained a significant portion of their variability; highly correlated or insignificant parameters were not included in the final models.

Once the best fitting model had been obtained, adjusted mean values were calculated for each treatment using parameter values averaged over the entire study. Another least squares F-test (Ott 1993) was used to determine if treatment had a significant influence on the response variable. Response variable adjusted means were then evaluated for significant differences using a least significant differences (LSD) test that uses the student's *t* distribution to test the probability of observing the calculated difference between treatments if the response variable was actually the same.

Understory diversity was investigated using three response variables: species richness, Shannon's index of diversity, with associated minimum and maximum possible values to aid in comparisons (Shannon and Weaver 1949), and Pielou's index of evenness (Pielou 1975). Only the posttreatment understory vegetation data were used for this portion of the analysis due to inadequate sampling before treatment. All three diversity measures were calculated at the plot (400 m²) level.

Mean cover and frequency were used to describe the abundance of understory lifeforms (graminoid, forb, and shrub) and species. This analysis was also done using only posttreatment vegetation data. Mean plot-level cover was calculated for each treatment unit. Frequency was calculated as the number of sample plots in which a species was found, divided by the total number of sample plots in the unit. Principal components analysis (PCA) was used to suggest combinations of understory species that would best explain the variance in the data set.

Results

Diversity

Plot level species richness was lower in the three fuel reduction treatments than in the control in 2001. Differences in effective aspect among treatments ($P=0.006$) explained 64% of the variance in species richness, allowing the effects of treatment on richness to be more clearly isolated. As a group, treatments were not significant in the model.

Adjusted mean species richness was not significantly reduced in those treatments that received burning, relative to the control (Table 3). The thin treatment, however, significantly reduced plot-level richness relative to the control ($P=0.03$). This treatment had the lowest plot-level species richness with an average of five fewer species than the control in 2001. Differences in species richness among the three fuel reduction treatments were not significant.

TABLE 3. Adjusted means by treatment for plot level species richness, Shannon-Weaver index of diversity (H'), and Pielou's index of evenness (J') in 2001, 3 yr after thinning and 1 yr after burning at the Hungry Bob study area. Unlike superscripts among treatments indicate a significant difference. Within a diversity measure, values without superscripts are not significantly different among treatments.

	Control	Burn	Thin	Thin/burn
Species richness	25.5 ^a	23.1 ^{ab}	20.5 ^b	22.9 ^{ab}
H' Maximum	3.2 ^a	3.1 ^{ab}	3.0 ^b	3.0 ^b
H' Diversity	1.7	1.9	1.7	2.0
H' Minimum	0.8	1.0	1.0	0.8
J' Evenness	0.53	0.62	0.57	0.65

There were no significant differences in H' (Shannon's diversity index) among treatments in 2001 (Table 3). A linear model with pretreatment seedling crown ratio ($P=0.01$) accounted for 45% of the observed variation, and was used to adjust H' treatment means to account for differences among the 16 treatment units. Due to low within-treatment variability, $H'_{\max}$ (the maximum possible value for H') was significantly lower in those treatments that included thinning. The difference between the observed H' and $H'_{\max}$ was not different among treatments, making a stronger case for no differences in H' among treatments.

Distribution of understory cover was not strongly affected by treatments. Variability in J' (Pielou's index of evenness) values was best explained by a linear model ($r^2=0.395$) that included pretreatment seedling crown ratio ($P=0.025$), thus this model was used to adjust for differences among units. Treatment variables were not significant as a group, providing insufficient evidence to support the hypothesis that fuel reduction treatments influenced J' values. When individual treatments were compared to the control, significant changes were still not observed (Table 3).

Cover

As indicated by the PCA (ordinations available at the USDA Forest Service Forestry and Range Sciences Laboratory, La Grande, Oregon), changes in cover due to treatment were best explained by elk sedge, pinegrass, and Idaho fescue, leading to grouping by lifeform. Fuel reduction treatments did not significantly affect the adjusted mean cover of graminoids (Figure 2). Forb cover was highest in the control, and significantly reduced in the thin ($P=0.039$) and thin/burn ($P=0.022$) treatments. The two treatments that included burning supported only 20-25% of the shrub cover observed in the control in 2001 (Figure 2). These differences were significant for the burn ($P=0.003$) and thin/burn ($P=0.004$).

Investigation of the adjusted mean cover of four graminoids (elk sedge, pinegrass, Idaho fescue, and prairie Junegrass) helped explain some of the interspecific dynamics that were observed in response to treatments (Table 4). Thin treatments significantly reduced elk sedge cover, with highest cover values in the control. Of the four graminoids investigated, pinegrass had the highest cover in

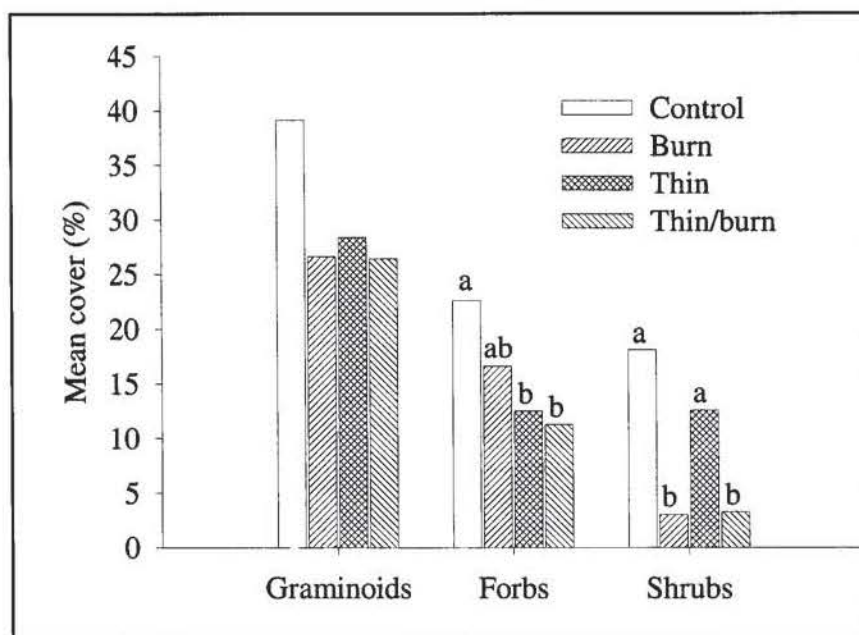


Figure 2. Adjusted mean lifeform cover (percent), by treatment, at the Hungry Bob Study area in 2001, 3 yr after thinning and 1 yr after burning. Unlike superscripts among treatments indicate a significant difference. For a given lifeform, values without superscripts are not significantly different among treatments.

TABLE 4. Adjusted mean cover (percent) for four dominant graminoid species and total plot cover, by treatment, at the Hungry Bob study area in 2001, 3 yr after thinning and 1 yr after burning. Unlike superscripts among treatments indicate a significant difference. For a given species, mean cover values without superscripts are not significantly different among treatments.

Species	Control	Burn	Thin	Thin/burn
Elk sedge	14.1 ^a	5.3 ^{ab}	2.7 ^b	2.6 ^{ab}
Pinegrass	15.4	8.8	16.4	17.8
Idaho fescue	1.4	1.2	3.9	4.2
Prairie Junegrass	0.1 ^a	1.7 ^{ab}	0.3 ^a	3.0 ^b
Total plot cover	95.7 ^a	50.5 ^b	60.7 ^{ab}	42.3 ^b

all treatments. The thin/burn treatment resulted in the highest mean pinegrass cover at 17.8%. Idaho fescue was highest in treatments that included thinning and lowest in the burn and control treatments. Fuel reduction treatments appeared to favor prairie Junegrass cover, particularly those that involved burning. The thin/burn treatment had significantly higher prairie Junegrass cover than the control ($P=0.03$), despite significantly reduced total cover ($P=0.007$) (Table 4).

Frequency

For 119 of 191 species (62%), frequency of occurrence did not differ from the control by more than 10% in any treatment. Results of the PCA suggested focusing the analysis of the frequency data on the response of western yarrow, elk sedge, Idaho fescue, prairie Junegrass, arrowleaf balsamroot, and western needlegrass. In 2001, western yarrow was present in at least 80% of the sample plots in every treatment, making it the most frequently occurring species overall (Table 5) and showing its stability to all treatments. This tolerance to disturbance was evidenced by pinegrass as well. Elk sedge and western needlegrass appeared to favor relatively undisturbed conditions, with the highest frequencies for those species occurring in the control. Treatments that included burning significantly reduced the frequency of western needlegrass ($P=0.022$ for the burn and $P=0.018$ for the thin/burn). Three species tended to either increase after, or at least endure, treatments: Idaho fescue, prairie Junegrass, and arrowleaf balsamroot. Idaho fescue, although relatively unaffected by treatment, was highest in the burn. The thin/burn treatment significantly increased the frequency of prairie Junegrass

($P=0.036$). All treatments more than doubled the frequency of arrowleaf balsamroot (Table 5).

TABLE 5. Adjusted mean frequency for species identified through PCA as representative of overall changes in frequency, by treatment, at the Hungry Bob study area in 2001, 3 yr after thinning and 1 yr after burning. Unlike superscripts among treatments indicate a significant difference. For a given species, mean frequencies without superscripts are not significantly different among treatments.

Species	Control	Burn	Thin	Thin/burn
Western yarrow	0.97	0.95	0.80	0.98
Pinegrass	0.82	0.73	0.84	0.69
Western				
needlegrass	0.49 ^a	0.07 ^b	0.26 ^{ab}	0.02 ^b
Elk sedge	0.89	0.52	0.79	0.41
Idaho fescue	0.51	0.81	0.55	0.62
Prairie Junegrass	0.48 ^a	0.81 ^{ab}	0.52 ^a	0.90 ^b
Arrowleaf				
balsamroot	0.15	0.29	0.37	0.34

Discussion

Overall, fuel reduction treatments did not radically influence the understory vegetation in this study. One reason may be that the species present on the study sites have mostly evolved with relatively frequent fire (Johnson 1998). Additionally, the moderate intensity of both thinning and burning treatments in this study (probably tied to the disturbance history of the sites) would likely elicit only moderate responses from the understory vegetation. Responses observed in this study were also short term – 3 yr for thinning response and only 1 yr for burning-related treatments. Johnson (1998) observed that many species decreased in cover 1 yr after wildfire, but increased in abundance in subsequent years.

First-year response to the burn and thin/burn treatments showed no significant changes in understory species richness or overall diversity in these drier pine-fir forests, reflecting adaptations to a low-intensity fire environment. There was, however, a trend of increasing evenness, consistent with the findings of Grant and Loneragan (2001), in both of the treatments involving fire. They attributed increased species evenness after burning to reductions in plant densities. This observation held at our site as well, where treatments with higher evenness had the lowest total plant cover.

The thin treatment resulted in species richness that was significantly lower than the control in 2001, even though other measures of diversity related to this treatment were not influenced. This result was consistent with reductions in diversity observed by others (Nieppola 1992, Collins et al. 1995, Scherer et al. 2000). The observations of Scherer et al. (2000) suggest that an increase in richness in the thin treatment may be forthcoming. In fact, peak richness in all treatments may not be observed for several growing seasons (Nieppola 1992, Collins et al. 1995, Lehmkuhl 2002).

Some researchers have found that fire tends to increase understory cover within the first year, particularly of graminoids (Harris and Covington 1983, Covington et al. 1997, Busse et al. 2000), while others have observed no response, or even a decrease in grass and shrub cover in the first year after disturbance (Gruell et al. 1982, Johnson 1998, Ayers et al. 1999). In each of the previous cases where grass and shrub cover remained the same or decreased, however, cover in succeeding years exceeded the pre-burn condition, suggesting that future remeasurement of this study may show a reversal of the current decline.

Greater graminoid and shrub cover in response to thin treatments has often been reported in the literature (McConnell and Smith 1970, Dyrness 1973, Bedunah et al. 1988). McConnell and Smith (1965) noted that the 3 yr response to geometric thinning of young ponderosa pine stands in eastern Washington resulted in a significant, though relatively minor increase in forage production. Reduced forb cover in the thin treatment could be due to slash cover, and a subsequent reduction in vegetative cover. Cover is expected to increase, based on studies indicating that peak response to thinning is observed 11-30 yr after treatment in lodgepole pine (*Pinus contorta*) forests (Conway 1981), and more than 8 yr posttreatment in ponderosa pine forests (McConnell and Smith 1970). Cover response to treatments can also be partly explained by the management history of the sites. Given the modest density reduction in the overstory, a dramatic understory response would not be expected.

Understory species responded similarly in the two treatments that involved burning. However, prairie Junegrass, a species that responds rapidly to increased resource availability (Wright and

Klemmedson 1965, Antos et al. 1983, Johnson 1998), exhibited significantly greater cover and frequency in the thin/burn treatment than in the control. In contrast, elk sedge, total cover, and forb cover exhibited negative responses to the thin/burn that were similar to responses in the burn, but of even greater in magnitude. This could suggest greater burning intensity than in the burn treatment, possibly because of harvest-generated fuels.

Pinegrass and Idaho fescue retained about the same cover in the burn as in the control. In the thin/burn, Idaho fescue, a documented fire-maintainer (Tveten and Fonda 1999), and prairie Junegrass, tended to increase. Life-history characteristics such as sparse bunching, prolific seeding, and rapid seedling establishment may explain why prairie Junegrass had significantly more cover in treatments that included burning than in the control, even though total plot cover was reduced.

Cover of individual species changed little in response to thinning alone. Lack of cover response from colonizing species (such as prairie Junegrass and western yarrow) in the thin treatment suggests that new sites for establishment were not created during the harvest operations. If slash generated from thinning was the mechanism for reductions in total and elk sedge cover, then it follows that safe-sites (patches of exposed mineral soil) were not created by the thin treatment alone.

Frequency of occurrence for individual species reflected trends similar to the cover responses. Once again trends observed in the burn were simply exaggerated in the thin/burn, with the exception of the Idaho fescue response. Western yarrow and pinegrass tolerated all treatments, though pinegrass frequency was somewhat reduced in the thin/burn. Western needlegrass and elk sedge were reduced in all treatments, but especially those that involved burning. This suggests that burning may reduce the frequency of these species on the landscape. The treatments that involved burning evoked a higher frequency of Idaho fescue, prairie Junegrass, and arrowleaf balsamroot than the control, indicating that these species are fire-increasers that can capitalize on increased resources as long as a seed source is retained on-site. A more subdued response in the thin/burn than the burn treatment from Idaho fescue, which has been documented as sensitive to intense fire (Conrad and Poulton

1968), could suggest that the additional slash fuels in the thin/burn treatment resulted in burning that was too hot for survival of this perennial bunchgrass. Conversely, prairie Junegrass and arrowleaf balsamroot, which survive and even increase after more intense burns (Antos et al. 1983, Smith and Fischer 1997, Johnson 1998), made greater gains in the thin/burn than in the burn.

Short-term understory vegetation responses to thinning and burning treatments in this study were modest, with variability brought about by among-species differences in life-history characteristics. Each species responds to treatment in a fashion unique to that species and the conditions under which treatments have been applied. The long-term and geographically dispersed research underway in the national FFS study is focused on identifying the nature and strength of these re-

sponses. Using this knowledge as it becomes available, future applications of fire and fire-surrogate treatments can be tailored to achieve more specific objectives, optimizing the effectiveness of management actions.

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Literature Cited

- Abrams, M. D., and D. I. Dickman. 1982. Early revegetation of clear-cut and burned jack pine sites in northern lower Michigan. *Canadian Journal of Botany* 60:948-954.
- Ahlgren, C. E. 1960. Some effects of fire on reproduction and growth of vegetation in northeastern Minnesota. *Ecology* 41:431-445.
- Antos, J. A., B. McCune, and C. Bara. 1983. The effect of fire on an ungrazed western Montana grassland. *American Midland Naturalist* 110:354-364.
- Ayers, D. M., D. J. Bedunah, and M. G. Harrington. 1999. Antelope bitterbrush and Scouler's willow response to a shelterwood harvest and prescribed burn in western Montana. *Western Journal of Applied Forestry* 14:137-143.
- Bedunah, D., W. Pflingsten, G. Kennett, and E. Willard. 1988. Influence of stand canopy density to forage production. Pages 99-107 *In* W. C. Schmidt (editor), *Proceedings-Future Forests of the Mountain West: A Stand Culture Symposium*. USDA Forest Service General Technical Report INT-243. Intermountain Research Station, Ogden, Utah.
- Brososke, K. D., J. Chen, and T. R. Crow. 2001. Understory vegetation and site factors: implications for a managed Wisconsin landscape. *Forest Ecology and Management* 146:75-87.
- Busse, M. D., S. A. Simon, and G. M. Riegel. 2000. Tree-growth and understory response to low-severity prescribed burning in thinned ponderosa pine forests of central Oregon. *Forest Science* 46:258-268.
- Cochran, P. H., J. M. Geist, D. L. Clemens, R. R. Clausnitzer, and D. C. Powell. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. USDA Forest Service Research Note PNW-513. Pacific Northwest Research Station, Portland, Oregon.
- Collins, S. L., S. M. Glenn, and D. J. Gibson. 1995. Experimental analysis of intermediate disturbance and initial floristic composition: Decoupling cause and effect. *Ecology* 76: 486-492.
- Conrad, C. E., and C. E. Poulton. 1968. Effect of fire on Idaho fescue and bluebunch wheatgrass. *Journal of Range Management* 19:138-144.
- Conway, T. 1981. Understory response to varied spacing intervals of *Pinus contorta* in western Montana. M.S. Thesis, Montana State University, Bozeman, Montana.
- Covington, W. W., P. Z. Fule, M. M. Moore, S. C. Hart, T. W. Kolb, J. N. Mast, S. S. Sackett, and M. R. Wagner. 1997. Restoring ecosystem health in *Pinus ponderosa* forests of the Southwest. *Journal of Forestry* 95:23-29.
- Department of the Interior. 2002. Protecting people and sustaining resources in fire-adapted ecosystems – A cohesive strategy. Available online at www.fireplan.gov/cohesive.cfm.
- Dyrness, C. T. 1973. Early stages of plant succession following logging and burning in the west Cascades of Oregon. *Ecology* 54:57-69.
- Grant, C. D., and W. A. Loneragan. 2001. The effects of burning on the understory composition of rehabilitated bauxite mines in W. Australia: Community changes and vegetation succession. *Forest Ecology and Management* 145:255-279.
- Gruell, G. E., W. C. Schmidt, S. F. Arno, and W. J. Reich. 1982. Seventy years of vegetative change in a managed ponderosa pine forest in western Montana: Implications for resource management. USDA Forest Service General Technical Report INT-130. Intermountain Research Station, Ogden, Utah.
- Hall, F. C. 1977. Ecology of natural underburning in the Blue Mountains of Oregon. USDA Forest Service PNW R6-ECOL-79-001. Pacific Northwest Research Station, Portland, Oregon.

- Harris, F. R., and W. W. Covington. 1983. The effect of fire on nutrient concentration and standing crop of understory vegetation in *Pinus ponderosa*. Canadian Journal of Forest Research 13:501-507.
- Harrod, R. J. 2001. The effect of invasive and noxious plants on land management in eastern Oregon and Washington. Northwest Science 75:85-89.
- Hitchcock, C. L., and A. Cronquist. 1973. Flora of the Pacific Northwest. University of Washington Press, Seattle, Washington.
- Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.
- Johnson, C. G., Jr. 1998. Vegetation response after wildfires in national forests of northeastern Oregon. USDA Forest Service R6-NR-ECOL-TP-06-98. Pacific Northwest Region, Portland, Oregon.
- Johnson, C. G., Jr., and S. A. Simon. 1987. Plant associations of the Wallowa-Snake Province. USDA Forest Service R6-ECOL-TP-225B-86. Portland, Oregon.
- Lehmkuhl, J. F. 2002. The effects of spring burning and grass seeding in forest clearcuts on native plants and conifer seedlings in coastal Washington. Northwest Science 76:46-60.
- Long, J. N. 1996. A technique for the control of stocking in two-storied stands. Western Journal of Applied Forestry 11:59-61.
- McConnell, B. R., and J. G. Smith. 1965. Understory response three years after thinning pine. Journal of Range Management 18:129-132.
- McConnell, B. R., and J. G. Smith. 1970. Response of understory vegetation to *Pinus ponderosa* thinning in eastern Washington. Journal of Range Management 23:208-212.
- McKenzie, D., C. B. Halpern, and C. R. Nelson. 2000. Overstory influences on herb and shrub communities in mature forests of western Washington, U.S.A. Canadian Journal of Forest Research 30:1655-1666.
- Michener, W. K. 1997. Quantitatively evaluating restoration "experiments": Research design, statistical analysis, and data management considerations. Restoration Ecology 5:324.
- Mutch, R. W., S. F. Arno, J. K. Brown, C. E. Carlson, R. D. Ottmar, and J. L. Peterson. 1993. Forest health in the Blue Mountains: A management strategy for fire-adapted ecosystems. USDA Forest Service General Technical Report PNW-310. Pacific Northwest Research Station, Portland, Oregon.
- National Climatic Data Center. 2003. Enterprise 20 NNE. Available online at www.ncdc.noaa.gov/oa/ncdc.html.
- Nieppola, J. 1992. Long-term changes in stands of *Pinus sylvestris* in southern Finland. Journal of Vegetation Science 3:475-484.
- Ott, R. L. 1993. An Introduction to Statistical Methods and Data Analysis: Fourth Edition. Wadsworth Duxbury Press, Belmont, California.
- Pielou, E. C. 1975. Ecological Diversity. Wiley, New York.
- Pollet, J., and P. N. Omi. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. International Journal of Wildland Fire 11:1-10.
- Reineke, L. H. 1933. Perfecting a Stand Density Index for even-aged forests. Journal of Agricultural Research 46:627-638.
- Scherer, G. J., D. Zabowski, B. Java, and R. Everett. 2000. Timber harvesting residue treatment Part II: Understory vegetation response. Forest Ecology and Management 126:35-50.
- Shannon, D. E., and W. Weaver. 1949. The Mathematical Theory of Communication. University of Illinois Press, Urbana, Illinois.
- Smith, H. Y., and S. F. Arno (editors). 1999. Eighty-eight years of change in a managed ponderosa pine forest. USDA Forest Service General Technical Report RMRS-23. Rocky Mountain Research Station, Ogden, Utah.
- Smith, J. K., and W. C. Fischer. 1997. Fire ecology of the forest habitat types of northern Idaho. USDA Forest Service General Technical Report INT-363. Intermountain Research Station, Ogden, Utah.
- Stage, A. R. 1976. An expression for the effect of aspect, slope, and habitat type on tree growth. Forest Science 22:457-460.
- Stickney, P. F. 1986. First decade plant succession following the Sundance forest fire, northern Idaho. USDA Forest Service General Technical Report INT-197. Intermountain Research Station, Ogden, Utah.
- Turner, M. G., W. H. Romme, R. G. Gardner, and W. W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. Ecological Monographs 67: 411-433.
- Tveten, R. K., and R. W. Fonda. 1999. Fire effects on prairies and oak woodlands on Fort Lewis, Washington. Northwest Science 73:145-158.
- USDA Natural Resources Conservation Service. 2002. The PLANTS Database, Version 3.5. National Plant Data Center, Baton Rouge, Louisiana. Available online at <http://plants.usda.gov>.
- Weatherspoon, C. P. 2000. A proposed long-term national study of the consequences of fire and fire-surrogate treatments. Pages 117-126 In L. F. Neuenschwander, K. C. Ryan, G. E. Goldberg (editors), Proceedings Joint Fire Science Conference and Workshop. University of Idaho, Moscow, Idaho.
- Wright, H. A., and J. O. Klemmedson. 1965. Effect of fire on bunchgrasses of the sagebrush-grass region in southern Idaho. Ecology 46:680-688.

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