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Mechanical fuel treatment effects on vegetation in a New Mexico dry mixed conifer forest

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ABSTRACT

While the main objective of many silvicultural treatments in the western US is to reduce fire potential, their effects on overstory regeneration, midstory and herbaceous communities is of importance to land managers. To quantify these effects, we measured overstory regeneration, midstory density by species, herbaceous biomass, species richness and cover in commercial and non-commercial treatments with differing slash prescriptions in dry mixed conifer stands of south central New Mexico. Results indicated that overstory regeneration and shrub density were not significantly affected by treatments, although they did increase at one site which appeared to be more mesic than the others. Herbaceous biomass increased 4 years post-treatment in one non-commercial scatter treatment and 3 years post-treatment in the commercial treatment. Species richness was not affected by any of the treatments. Cover of grasses and forbs remained low in all treatments. Soil cover increased in the commercial treatment; however, it decreased each year following treatment.

1. Introduction

While numerous studies have addressed the impact of commercial harvesting treatments on vegetation response, there is lack of information addressing non-commercial treatments. In the southwestern US, there has been a paradigm shift away from conventional forestry practices toward a new set of treatments that have a primary objective of reducing fuel loads. This has resulted in an increased emphasis on using non-commercial treatments in the region, and most of the current research in the southwest has focused on ponderosa pine dominated forests. An increased understanding of how these treatments affect vegetative communities in the higher elevation dry mixed conifer forests will allow managers to more effectively implement silvicultural treatments and develop new treatments in a multiple-use matrix.

Typically, commercial silvicultural treatments lead to increased herbaceous and midstory production, with the exception of an initial reduction in herbaceous cover post-harvest (Thysell and Carey, 2001). In the western US the majority of work has been done in ponderosa pine forests (Pase, 1958; McConnell and Smith, 1965; Clary and Ffolliott, 1966; McConnell and Smith, 1970; Thompson and Gartner, 1971; Clary, 1975; Uresk and Severson, 1989). Relatively little work has been done in the higher elevation mixed conifer forests and has typically focused on commercial treatments (Young et al., 1967; Wallmo et al., 1972; Dyrness, 1973; Patton, 1976). Little attention has been given to non-commercial (Scherer et al., 2000; Metlen et al., 2004). Those that have examined non-commercial treatments have shown herbaceous cover to remain the same or decrease 1–3 years post-treatment (Scherer et al., 2000; Metlen et al., 2004).

In ponderos pine and mixed conifer forests, commercial treatments generally result in an increase in herbaceous production and cover 1–2 years after harvest which may last for many years. In Arizona, estimated herbaceous production increased by 50 lbs $acre^{-1}$ 2 years after harvest in mixed conifer sites harvested by selection cutting and overstory removal (Patton, 1976). However, understory cover has also been found to decrease the first year post-harvest in Douglas-fir stands in Washington (Thysell and Carey, 2001). Deer forage was 47% greater on clear cut strips than uncut areas 15 years after harvest on lodgepole pine and spruce-fir stands in Colorado (Wallmo et al., 1972). Studies examining non-commercial treatments in mixed conifer stands have shown herbaceous cover to remain the same or decrease 3 years post-harvest (Scherer et al., 2000; Metlen et al., 2004).

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While production is important ecologically, information on species richness and species composition help identify the usefulness of the increase depending on management objectives. For example, herbaceous production is useful when the management objective is to increase forage for ungulates. Clearcuting of old-growth Douglas-fir forests in Oregon lead to areas being dominated by a wide variety of both residual and invasive species (Dyrness, 1973). Species richness response to treatment varies, for example, it increased 1 and 3 years post-treatment in Washington (Thysell and Carey, 2001) and decreased 3 years post-treatment in Oregon (Metlen et al., 2004).

Shrub response to varying levels of tree removal differed among studies (Patton and McGinnes, 1964; Young et al., 1967; McConnell and Smith, 1970; Uresk and Severson, 1989). Shrub production peaked at intermediate levels of overstory crown cover, while current annual growth peaked slightly before this point in relation to canopy closure in ponderosa pine stands of the Black Hills (Uresk and Severson, 1989) and mixed conifer stands in Eastern Oregon (Young et al., 1967). Shrub production increased slightly on thinned ponderosa pine stands in Washington (McConnell and Smith, 1970).

The objectives of this study were to identify the effects of different silvicultural treatments on midstory and understory vegetative response in dry mixed conifer stands of the Sacramento Ranger District (Lincoln National Forest, New Mexico).

The three silvicultural treatments were non-commercial thin with a lop and pile slash treatment, non-commercial thin with a lop and scatter slash treatment, and commercial harvest up to 61-cm diameter at breast height (DBH). We hypothesized that: (1) herbaceous biomass, cover and species richness would be highest in commercial harvest treatments followed by non-commercial scatter, non-commercial pile, and untreated controls; (2) midstory density and cover would be highest in commercial harvest treatments followed by non-commercial scatter, non-commercial pile, and untreated controls; (3) herbaceous biomass, cover, and species richness would be greatest in areas that were logged most recently prior to current treatment application.

2. Methods

2.1. Study area

Three sites, Bailey Canyon (Bailey), Cox Canyon (Cox), and Sleepy Grass Campground (Sleepy) were located in the Lincoln National Forest, approximately 3.2–16 km from Cloudcroft, NM within the Sacramento Ranger District. Elevation ranged from 2560 to 2773 m. Average annual rainfall for Cloudcroft, NM is 704.3 mm with 50.1% falling in July–September (World Climate, 2006). Average maximum and minimum temperatures are 14.0 and 0.8 °C respectively (World Climate, 2006). Estimated overstory composition by BA for all site–treatments combined were Douglas-fir (*Psuedotsuga menziesii*) 71.6%, ponderosa pine 12.9%, southwestern white pine (*Pinus strobiformus*) 7.0%, white fir (*Abies concolor*) 6.5%, and aspen (*Populus tremuloides*) 2.0% (Mason, 2006). Overstory composition differed among site–treatment combinations, where the most notable difference was a higher proportion of *Pinus* spp. at Bailey and aspen at Sleepy (Mason, 2006).

Historic treatments and current treatments differed among the three study areas. The Bailey and Sleepy areas were similar in that neither had been commercially harvested in the last 60–100 years, while the Cox site was commercially harvested 20–30 years ago (Mickey Mowter, USFS, personal communication 2006). Bailey and Sleepy sites were relatively dense stands with little herbaceous production compared to the Cox study area which had little overstory regeneration since harvested 20–30 years ago and greater herbaceous production (Mason, 2006).

Treatments in 2003 at Cox and Bailey were a non-commercial thin with slash piled (pile) and a non-commercial thin with slash scattered (scatter). At Cox and Bailey slash remained on site for the entirety of the study. Sleepy was thinned non-commercially in 2002, where perimeter slash piles were burned and interior piles were left for fire wood collection. At the end of the growing season in 2004, Sleepy was commercially harvested where slash was piled at loading decks and removed. Each study area contained an untreated control. Non-commercial treatments were a thin-from-below prescription with a 22.9-cm diameter cap and a 4.9-m spacing requirement. Commercial treatments harvested trees greater than 22.9 cm DBH and less than 61.0-cm DBH. Commercial treatments had a target residual basil area (BA) of 18–23 $m^2\ ha^{-1}$ with an emphasis on removing conifers from within and immediately surrounding clumps of aspen where applicable. All treatments were done by hand crews using chainsaws. The commercial harvest used heavy equipment to skid felled trees to loading decks. Stand structure post-harvest was summarized by Mason et al. (2007).

Cattle were present at Cox and the control treatment at Sleepy, while elk and deer were at all sites. Elk population estimates for the Sacramento Mountains from 1998–2002 range from 3000 to 4000 animals over an area of 434,364 ha (NMDGF, 2006). Estimates of deer populations were not available.

The control treatment at Sleepy and all treatments in Cox were located in the Pumphouse Grazing Allotment, which has been grazed for >30 years by cattle from the middle of May until the middle of October (Rick Newmon, USFS, personal communication, 2005). The number of cattle on the allotment has been between 56 and 64 cattle for the last ~20 years, prior to that, the permit was for 146 cattle (Rick Newmon, USFS, personal communication, 2005). The pile (2004) and commercial (2005) treatments at Sleepy were part of the Pumphouse Grazing Allotment until the 1960s, after which they were no longer grazed by cattle (Anthony Madrid, USFS, personal communication 2006). Treatments at Bailey were located in both the La Luz Grazing Allotment and the James Canyon Grazing Allotment. Cattle grazing was discontinued in the La Luz Grazing Allotment in the 1950s and in the James Canyon Grazing Allotment in 1995 (Anthony Madrid, USFS, personal communication 2006).

2.2. Study design

Sites were selected based on historical treatments, recent treatments, slope, aspect, and cover type. Due to differences in historical and recent treatments among sites, we randomly selected three experimental units for each site–treatment combination (i.e. Bailey-pile $n = 3$; Cox-pile $n = 3$; etc.). Two permanent 100-m transects were systematically placed perpendicular to the contour in each of the experimental units (Mueller-Dombois and Ellenberg, 1974). All transects were placed at least 50 m from the stand boundary to avoid edge bias (Mueller-Dombois and Ellenberg, 1974). The second transect was systematically placed 50–100 m from the first transect. Data collection took place the summers of 2004 through 2007. Bailey was only sampled in 2004 and 2005. At Sleepy, the pile treatment was only sampled in 2004 (2 years post-treatment) and the commercial treatment was sampled for 3 years post-treatment.

2.3. Midstory

Midstory density (woody stems <11.4 cm DBH) was measured in 40 2 m × 5 m subplots along two 100-m transects per experimental unit (Mueller-Dombois and Ellenberg, 1974). Midstory density was recorded as the number of stems per species within each of the 40 subplots. All stems under 2.54 cm DBH were put into one of two height classes (≤1 m and >1 m). For stems >2.54–11.4 cm DBH was recorded. Midstory plants were then broken down into three categories, midstory trees, overstory regeneration and shrubs. Midstory trees were defined as woody plants having a DBH of >2.54 cm and <11.4 cm. Overstory regeneration consisted of conifers and aspens less than 2.54 cm DBH. Shrubs were then defined as any woody deciduous plant except aspen with a DBH <2.54 cm. Species were identified following Ivey (2003) and Carter (1997).

2.4. Understory

Biomass was measured separately for forbs and grass-like plants rooted inside 30 30.48 cm × 60.96 cm frames per experimental unit by clipping all herbaceous vegetation to ground level. Frames were systematically placed every 6 m, with the starting point moved randomly each year to avoid sampling the same place that was clipped the previous year. All biomass samples were oven dried at 60 °C for a period of 48 h and weighed to the nearest tenth of a gram.

Utilization was indexed using stubble height (cm) (Holechek et al., 2001) and the grazed plant method (Roach, 1950) as modified by Jourdonnais and Bedunah (1990). Sampling was done using the line point method (Mueller-Dombois and Ellenberg, 1974) at 1-m intervals along each transect for a total of 200 points per experimental unit. The nearest plant to the point was recorded by species as grazed or un-grazed along with the height to the nearest half centimeter, if the nearest plant was a forb, only grazing status was recorded and the average height and grazing status of the nearest grass was recorded. Only plants within 1 m on both sides of and no more than 0.5 m in either direction along the transect were sampled to avoid double counting plants. Herbaceous plants were identified referencing Ivey (2003) and Allred (2005).

2.5. Cover

Cover was estimated inside 30 1-m^2 frames along two 100-m transects per experimental unit. Frames were systematically placed every 6 m, opposite of clipped frames to avoid sampling clipped areas. Canopy cover (%) was measured from the center of each frame with a spherical densiometer (Lemmon, 1957). Ground cover (aerial coverage for live plants) was estimated using a modified Daubenmire (1959) scale. Woody and herbaceous cover were estimated by species for all plants rooted inside the frame. Cover was also recorded for rock, soil, litter, stem dead, stem live, woody plants ≤1 m tall, woody plants 1–2 m tall, grass, and forbs.

2.6. Data analysis

Data were analyzed separately for each site using proc mixed SAS software version 8.2 (SAS Institute Inc., 1999). Fixed effects in the model were treatment and for variables collected in multiple years, year within treatment. To account for correlation between repeated measures of the same plots, experimental units within treatments were used as random effects. Variance was modeled as being homogenous within sites, and unique to each treatment within a site. The model with the best fit statistics (information criterion) was then selected (Ramsey and Schafer, 2002). However, for data sets that contained multiple variables, the model that best fit the majority of variables was used to analyze all variables in the data set. For descriptive variables in which statistical comparisons were not made, means and SE were calculated using proc means SAS software version 8.2 (SAS Institute Inc., 1999).

Statistical significance was interpreted following Ramsey and Schafer (2002), where the evidence provided by *P*-values was classified as follows: convincing ($P = 0$–0.01), moderate ($P = 0.01$–0.05), suggestive ($P = 0.05$–0.10), and no evidence ($P > 0.10$). When fixed effects were significant ($P < 0.05$) multiple comparisons were tested using least squares means. All reported *P*-values were two tailed.

3. Results

3.1. Midstory trees

The density of midstory trees was reduced in all harvest treatments (Fig. 1), where the evidence was moderate to convincing. There was no difference in midstory tree density between the commercial and pile treatments at Sleepy.

3.2. Overstory regeneration

For overstory regeneration the year–treatment fixed effect at Bailey ($P = 0.04$) was significant. Overstory regeneration increased in all treatments at Bailey from 2004 to 2005 (Fig. 2); however, the differences were only significant in the scatter treatment. Tests of fixed effects were not significant at Cox or Sleepy.

Overstory regeneration was dominated by Douglas-fir, where it had the highest percent composition in all treatments and sites

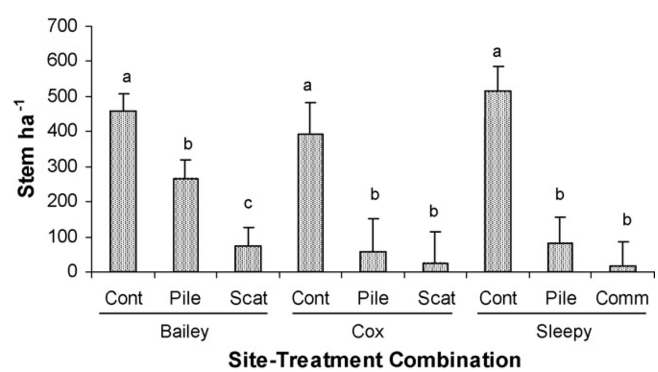

Fig. 1. Least squared means and standard errors for midstory trees (stems >2.54 cm and ≤11.4 cm DBH) in treated and untreated dry mixed conifer stands in the Lincoln National Forest. Within sites means sharing the same letter are not significantly different ($P > 0.10$).

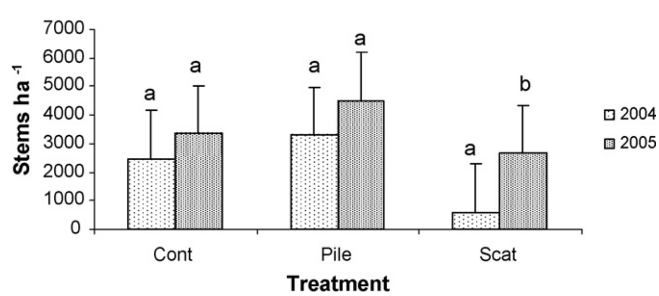

Fig. 2. Least squares means and standard errors for overstory regeneration (conifer and aspen stems <1 m tall and <2.5 cm DBH) in treated and untreated dry mixed conifer stands at the Bailey site, Lincoln National Forest, NM. Within treatments means sharing the same letter are not significantly different ($P > 0.10$).

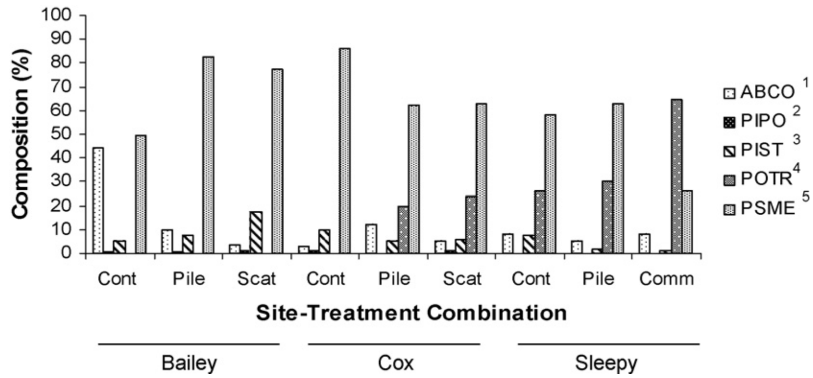

Fig. 3. Percent composition of overstory regeneration (conifer and aspen stems <2.54 cm DBH) by species for treated and untreated dry mixed conifer stands in the Lincoln National Forest, NM. [1]*Abies concolor*, [2]*Pinus ponderosa*, [3]*Pinus stobiformus*, [4]*Populus tremuloides*, [5]*Psuedotsuga menziesii*.

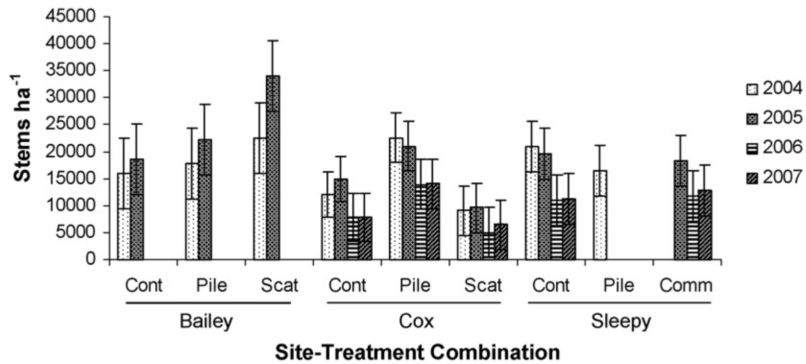

Fig. 4. Least squares means and standard errors for shrubs <1 m tall and <2.5 cm DBH in treated and untreated dry mixed conifer stands in the Lincoln National Forest, NM.

with the exception of the commercial treatment where aspen had the highest percent composition (Fig. 3). White fir and Western white pine were also important components in a few stands. Regeneration of Ponderosa pine was very low (0.0–1.4% composition). One-seed juniper (*Juniperus monosperma*) and pinyon pine (*Pinus edulis*) were observed in some stands however because their densities were very low and they were not observed in the overstory plots they were not included in figures.

3.3. Shrubs

For shrubs <1-m tall the year–treatment fixed effect was significant at Bailey and Sleepy (Fig. 4). All treatments at Bailey tended to have higher densities of shrubs in 2005 than those in 2004. These differences were convincing for the scatter treatment ($P = 0.0084$). The difference was not significant for the pile or control treatments. In both the control and commercial treatments at Sleepy shrub densities decreased significantly from 2005 to 2006. For shrubs >1-m tall and <1-in. DBH the pile treatment (425.0 stems $ha^{-1} \pm 68.9$ SE) at Sleepy had higher densities than both the control (110.4 stems $ha^{-1} \pm 42.4$ SE) and commercial (105.6 stems $ha^{-1} \pm 48.2$ SE) treatments. There were no other significant differences.

Shrubs were dominated by oak (66.9–89.1% composition). Mountain spray (*Holodiscus dumosus*) was also an important component in the pile and scatter treatments at Cox (19.4% and 13.7% composition respectively). Other common species that made up >10% composition in one or more site–treatments included New Mexico locust (*Robinia neomexicana*), Wood's rose (*Rosa woodsii*), snowberry (*Symphoricarpos oreophilus*), western white honeysuckle (*Lonicera albiflora*), and *Ribes* spp.

3.4. Understory

Herbaceous biomass increased significantly the fourth year in the scatter treatment at Cox and the third year post-treatment in the commercial treatment at Sleepy (Table 1). The pile treatment at Cox also appeared to increase in the fourth year; however, the difference was not significant. The majority of the increase in herbaceous production was made up by forbs. In the pile treatment at Cox and the commercial treatment at Sleepy, there was a significant increase in forb biomass in 2007. While grass biomass tended to be higher in 2007, differences were not statistically significant according to tests of fixed effects. However, the magnitude of the effect in the commercial treatment may represent biological significance (1.5 kg $ha^{-1} \pm 9.4$ SE vs. 40.1 kg $ha^{-1} \pm 9.4$ SE).

For species richness (Fig. 5) the year–treatment fixed effect was significant at Cox ($P = 0.0185$). For treatments at Cox, species richness tended to decline from 2004 to 2006 and then stabilize or increase in 2007. The same general pattern was observed at Sleepy; however, fixed effects were not significant so differences of least squares means were not explored.

Herbaceous response did not appear to be influenced by herbivory (Table 2). Overall there was very little grazing activity in the area, with the percent of plants grazed ranging from 8.09% to 0.00% for forbs and 18.63% to 0.76% for grasses.

3.5. Cover

Treatment effects on canopy cover differed by site. At Cox, there were no significant decreases in canopy cover when comparing treatments to the control. However, at Bailey canopy cover was significantly lower in both treatments compared to the control

Table 1
Least Squares means and standard errors (SE) for total herbaceous, grass and forb biomass in treated and untreated dry mixed conifer stands in the Lincoln National Forest, NM.

Treatment	Year	Total (kg ha^{-1})		Grass (kg ha^{-1})		Forb (kg ha^{-1})	
		Mean	SE	Mean	SE	Mean	SE
Bailey							
Control	2004	4.3 A[a] a[b]	8.9	2.1 A a	6.3	2.3 A a	4.0
	2005	1.7 A a	8.9	0.3 A a	6.3	1.4 A a	4.0
Pile	2004	2.3 A a	8.9	0.6 A a	6.3	1.7 A a	4.0
	2005	10.0 A a	8.9	0.7 A a	6.3	9.4 A a	4.0
Scatter	2004	5.4 A a	8.9	3.6 A a	6.3	1.8 A a	4.0
	2005	21.1 A a	8.9	14.8 A a	6.3	6.3 A a	4.0
Cox							
Control	2004	63.7 A a	31.3	32.4 A a	15.8	30.6 A a	16.9
	2005	48.3 A a	31.3	36.7 A a	15.8	12.4 A a	16.9
	2006	54.6 A a	32.6	23.3 A a	16.4	32.2 A a	17.4
	2007	73.1 A a	33.0	35.8 A a	16.7	38.2 A a	17.4
Pile	2004	83.6 A a	32.6	47.3 A a	16.5	36.3 A a	17.2
	2005	39.9 A a	32.6	24.0 A a	16.5	15.9 A a	17.2
	2006	70.8 A a	32.6	31.0 A a	16.5	39.8 A a	17.2
	2007	103.4 AB a	32.6	54.5 A a	16.5	48.9 A a	17.2
Scatter	2004	52.7 A a	32.6	24.2 A a	16.5	28.5 A a	17.2
	2005	51.6 A a	32.6	31.0 A a	16.5	20.6 A a	17.2
	2006	48.1 A a	32.6	22.6 A a	16.5	27.2 A a	17.2
	2007	178.1 B b	32.6	68.6 A a	16.5	109.6 B b	17.2
Sleepy							
Control	2004	7.1 A a	11.8	2.2 A a	9.4	4.9 A a	4.3
	2005	6.8 A a	11.8	2.7 A a	9.4	4.1 A a	4.3
	2006	13.9 A a	11.8	4.3 A a	9.4	9.6 A a	4.3
	2007	8.7 A a	11.8	4.9 A a	9.4	3.8 A a	4.3
Pile	2004	5.7 A	11.8	1.4 A	9.4	4.3 A	4.3
Commercial	2005	13.6 A a	11.8	2.3 A a	9.4	11.4 A a	4.3
	2006	24.5 A a	11.8	1.5 A a	9.4	23.0 A a	4.3
	2007	113.8 B b	11.8	40.1 A a	9.4	73.7 B b	4.3

[a] Within sites, categories and years—means sharing the same upper case letter are not significantly different ($P > 0.10$).
[b] Within site–treatments and categories—means sharing the same lowercase letter are not significantly different ($P > 0.10$).

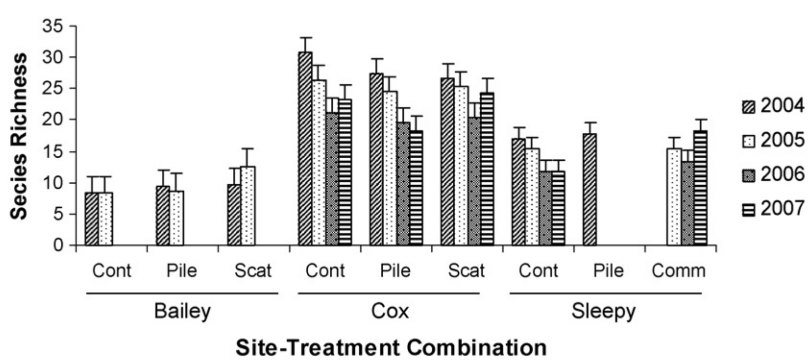

Fig. 5. Least squares means and standard errors for species richness in treated and untreated dry mixed conifer stands in the Lincoln National Forest, NM.

(87.2% ± 2.5 SE) and the scatter treatment (71.2% ± 2.5 SE) was significantly lower than the pile treatment (79.2% ± 2.5 SE). The commercial treatment (55.7% ± 4.6 SE) at sleepy had significantly less canopy cover than both the control (97.9% ± 4.6 SE) and the pile (76.1% ± 4.6 SE) treatments.

Ground cover was dominated by litter (Table 3). Percent cover of grass was less than 5% in all treatments. Sleepy was the only site where either of the fixed effects were significant. Grass cover increased significantly in the commercial treatment from 2005 to 2006 ($P = 0.0160$) and in the control from 2006 to 2007 ($P = 0.0056$); however, the observed levels of increase were very small.

At sleepy the treatment fixed effect was significant for forb cover ($P = 0.0775$) where the commercial treatment had significantly more forb cover than the control ($P = 0.0361$) (Table 3). There was also evidence of differences among years and treatments at Cox ($P = 0.0264$). In 2004 forb cover was greater in the control than the pile treatment ($P = 0.0584$) and the control in 2005 ($P = 0.0030$). Forb cover declined from 2004 to 2005 and increased in 2006.

Woody cover less than 1-m tall was not significantly affected by year or treatment ($P > 0.1000$). For woody cover 1–2-m tall the controls at both Bailey and Sleepy had significantly more cover than the treatments (Table 3).

At Cox the year–site–treatment effect was significant for litter cover ($P = 0.0022$) (Table 3). There was a significant increase in litter cover from 2004 to 2005 in the control ($P = 0.0012$). In the scatter treatment, there was a significant increase from 2004 to 2005 ($P = 0.0042$) and 2005 to 2006 ($P = 0.0075$). There were significant differences among sites and from year to year within treatments for litter cover at Sleepy. Most notable was the lower litter cover in the commercial treatment compared to the pile and control treatments, and the increase in litter cover in the

Table 2
Percent of grass and forbs grazed and average grass height in treated and untreated dry mixed conifer stands in the Lincoln National Forest, NM.

Treatment	Forb % grazed	SE	Grass % grazed	SE	Grass height (cm)	SE
Bailey						
Control	1.2	0.6	7.3	3.6	20.9	2.0
Pile	2.9	1.5	10.8	3.5	23.5	2.8
Scatter	3.0	1.1	15.0	9.0	23.8	1.7
Cox						
Control	1.6	0.6	5.8	1.2	20.0	0.7
Pile	1.8	0.7	4.1	1.2	20.9	0.6
Scatter	1.5	0.7	6.5	1.1	19.5	0.6
Sleepy						
Control	2.1	0.4	2.6	0.6	21.3	0.9
Pile	8.1	2.3	0.8	0.8	17.5	0.9
Commercial	4.6	0.8	4.4	1.5	22.1	1.6

commercial treatment from 2005 to 2006 and 2006 to 2007. At Bailey there was no evidence of differences in litter cover.

For soil cover year and treatment effects were only observed at Sleepy where the commercial treatment had significantly more soil cover than the pile and control treatments (Table 3). However, soil cover decreased in the commercial treatment each year following treatment. These differences were significant ($P \leq 0.10$) between 2005 and 2006.

4. Discussion

4.1. Midstory trees

The reduction in density of midstory trees is to be expected from any non-commercial treatment where the prescription is to remove stems less than 22.86 cm DBH (Fig. 1). It should be noted that most midstory trees remaining in treated stands were oak, which were not specifically targeted by any of the prescriptions. It was observed that most midstory oak trees had little live crown which was correlated to acorn production (Reynolds et al., 1970). Cutting oaks so they will root sprout may be more beneficial to wildlife. However, this may come at the expense of other shrub species and increased surface fire behavior.

4.2. Overstory regeneration

The increase in overstory regeneration (conifers and aspen) <1 m tall in the scatter treatment at Bailey (Fig. 2) was likely due to physical site characteristics as it tended to have a more northerly aspect and appeared to be more mesic than other sites. The observed increase at Bailey and the lack of significant change at the other sites indicates treatments do not significantly reduce overstory regeneration <1 m tall and may lead to increases, depending on site characteristics such as moisture regime. It should be noted that there was a decrease in conifer regeneration due to the commercial treatment; however, this is in contrast to an increase in aspen regeneration (Mason, 2006). While we observed an increase in aspen regeneration we noted a high level of herbivory (75–100% on stems >15.2 cm tall, data not shown) which may impede future overstory establishment.

Overstory regeneration consisted almost entirely of Douglas-fir with the exception of white fir and aspen being an important component in a few stands (Fig. 3). Most notable is the lack of ponderosa pine regeneration in all stands which has been noted in many mixed conifer stands throughout the Southwest (Stein, 1988). While the lack of ponderosa pine regeneration in dense stands is to be expected, as they are shade intolerant, it highlights

Table 3
Least squares means and standard errors (SE) for cover (%) by class, site, treatment and year in dry mixed conifer stands in the Lincoln National Forest, NM.

Treatment	Year	Grass		Forbs		Litter		Soil		Woody ≤1 m tall		Woody >1 m tall	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Bailey													
Control	2004	0.1	0.4	0.2	0.4	83.7	4.2	1.4	0.8	4.0	1.2	1.6	0.3
	2005	0.0	0.4	0.2	0.4	84.7	4.2	0.7	0.8	4.6	1.2	1.1	0.3
Pile	2004	0.1	0.4	0.5	0.4	76.5	4.2	3.2	0.8	5.0	1.2	0.2	0.3
	2005	0.0	0.4	0.4	0.4	80.1	4.2	2.1	0.8	3.8	1.2	0.1	0.3
Scatter	2004	1.1	0.4	1.1	0.4	78.8	4.2	0.7	0.8	4.5	1.2	0.0	0.3
	2005	0.5	0.4	0.8	0.4	73.9	4.2	1.0	0.8	6.2	1.2	0.3	0.3
Cox													
Control	2004	4.2	0.9	10.2	1.7	67.5	3.6	0.6	0.8	3.9	1.7	1.8	0.4
	2005	2.9	0.9	4.9	1.7	78.1	3.6	2.5	0.8	5.1	1.7	0.7	0.4
	2006	3.7	1.0	4.5	1.8	81.9	3.7	0.8	0.8	3.0	1.7	0.5	0.4
	2007	2.9	1.0	4.1	1.8	81.3	3.8	1.9	0.8	3.2	1.7	0.8	0.4
Pile	2004	1.5	1.0	5.1	1.8	71.2	3.9	0.7	0.8	7.3	1.7	1.4	0.4
	2005	2.6	1.0	5.9	1.8	74.2	3.9	1.5	0.8	5.4	1.7	0.3	0.4
	2006	3.5	1.0	7.2	1.8	77.2	3.9	0.5	0.8	5.5	1.7	0.4	0.4
	2007	4.1	1.0	5.4	1.8	79.0	3.9	0.7	0.8	5.1	1.7	0.1	0.4
Scatter	2004	2.8	1.0	6.3	1.8	62.7	3.9	0.1	0.8	4.1	1.7	0.3	0.4
	2005	2.5	1.0	3.6	1.8	70.5	3.9	0.8	0.8	3.3	1.7	0.2	0.4
	2006	3.5	1.0	7.3	1.8	77.6	3.9	0.2	0.8	1.2	1.7	0.1	0.4
	2007	4.3	1.0	6.0	1.8	76.4	3.9	0.1	0.8	1.6	1.7	0.4	0.4
Sleepy													
Control	2004	0.5	0.2	1.4	0.6	82.6	2.5	0.2	1.3	8.5	1.8	3.0	0.7
	2005	0.5	0.2	1.5	0.6	75.1	2.5	1.1	1.3	6.0	1.8	2.1	0.7
	2006	0.5	0.2	1.5	0.6	85.1	2.5	0.3	1.3	3.2	1.8	1.3	0.7
	2007	0.9	0.2	1.5	0.6	88.1	2.5	0.4	1.3	2.8	1.8	0.3	0.7
Pile	2004	0.1	0.2	2.0	0.6	83.4	2.5	0.9	1.3	2.6	1.8	0.2	0.7
Commercial	2005	0.3	0.2	2.4	0.6	61.5	2.5	12.9	1.3	1.8	1.8	0.0	0.7
	2006	0.6	0.2	3.7	0.6	72.9	2.5	6.8	1.3	1.6	1.8	0.0	0.7
	2007	0.7	0.2	4.2	0.6	78.5	2.5	4.9	1.3	1.9	1.8	0.0	0.7

the potential loss of an important stand component in dry mixed conifer forests.

4.3. Shrubs

The observed increase in the density of shrubs <1 m tall at Bailey and not at other sites was likely due to physical site characteristics such as aspect and moisture regime as described above for overstory regeneration (Fig. 4). The reason for the decrease in shrubs <1 m tall in both the control and commercial treatment at Sleepy is unknown. Slight increases in shrub production were observed in Washington ponderosa pine forests 8 years post-harvest (McConnell and Smith, 1970). This suggests that shrub response may be minimal and take several years to observe.

Shrub production, which should be positively correlated to shrub density, may be an important management objective due to its importance to browsing ungulates, small mammals, and birds. Many animals, such as deer and elk, rely on shrub production for a substantial part of their dietary needs. In central New Mexico, shrubs made up 32–61% of elk diets and 60–78% of deer diets in woodland habitats depending on the season (Sandoval et al., 2005). Although, we did not measure ungulate use of shrubs, ungulate use can be a limiting factor facing shrub regeneration and growth. For example, shrub production was 1042 kg ha^{-1} outside of exclosures compared to 2858 kg ha^{-1} inside exclosures in mixed conifer forest in northeast Oregon (Riggs et al., 2000). The fruits and nuts produced by some shrubs can also be an important food source for bears, small mammals and birds, while the shrubs themselves can provide important hiding cover for wildlife (Reynolds et al., 1970).

4.4. Understory

The failure to observe a consistent increase in herbaceous production in the non-commercial treatments (Table 1) was probably due to the small magnitude of effect these treatments had on overstory characteristics such as BA and canopy cover, and little disturbance to the forest floor. However, the increase in the scatter treatment indicates that these treatments can increase herbaceous production. In northeastern Oregon, cover remained the same for grass and decreased for forbs 3 years after harvest in response to similar thin-from-below prescriptions (Metlen et al., 2004). The increase in herbaceous production 3 years post-harvest in the commercial treatment is similar to results published for other commercial treatments. In Arizona, selection cutting and overstory removal resulted in a 56 kg ha^{-1} increase 2 years post-harvest (Patton, 1976). We also noted that herbaceous production tended to be higher in flatter areas where there was more soil and fewer rocks as compared to the steeper, rocky portions of the slope; however, we have no data to substantiate this observation.

The influence of past treatment was evident with Cox sites (commercially harvested 20–30 years prior) producing more herbaceous biomass than Bailey and Sleepy. The greater production at Cox suggests that when treatments significantly reduce the factors suppressing understory vegetation (i.e. BA, canopy cover, and forest floor depth), they have long lasting impacts on herbaceous production. For example, in Colorado clear-cut strips produced 47% more deer forage than uncut strips 15 years after treatment (Wallmo et al., 1972).

Herbivory did not appear to be limiting herbaceous production due to the low levels of grazed plants in all treatments (Table 2). However, we made no attempt to correlate the percentage of grazed plants to utilization because we lacked the requisite data. Increased herbaceous production is an important management objective in many forested systems. Specifically, grazed mountain meadows may benefit from increased forage production in areas that are currently forested and provide little forage production. Providing alternative feeding sites may decrease meadow use and the potential for competition between elk and livestock for forage (Coe et al., 2001; Stewart et al., 2002; Hurd, 2002).

Treatment had no effect on species richness (Fig. 5). However, year effects were significant. The year effect is assumed to be due to differences in the timing, and amount of moisture received during the growing season between years. Species richness has been shown to increase 1 and 3 years post-treatment with variable density thinning on Douglas-fir forests in Washington (Thysell and Carey, 2001) as well as to decrease 3 years post-treatment when thinned-from-below in Oregon ponderosa pine–Douglas-fir forests (Metlen et al., 2004). The reason for these differences may be due to the life history traits of herbaceous plants, site characteristics, and different disturbance factors created by different treatments in different areas.

4.5. Cover

Any treatment that removes standing trees will reduce canopy cover; however, the magnitude of effect was small in the non-commercial treatments relative to the commercial treatment. This is due to the fact that the non-commercial treatments remove fewer trees, which by definition are not dominant trees and thus contribute very little to canopy cover, whereas the commercial treatment removes both dominant and non-dominant trees. The lack of observed changes in canopy cover at Cox was likely due to the relatively open nature of the stands there due to past treatment and the relatively small effect thin from below treatments have on canopy cover.

Ground cover was dominated by litter in all treatments (Table 3). However, commercial harvest reduced litter cover and increased the cover of bare soil due to the mechanical disturbance caused by heavy machinery and the dragging of felled trees. Litter biomass estimates from Mason (2006) suggest the reduction in litter cover was due to reorganization rather than an actual loss of litter. The depth of the forest floor has been shown to negatively affect herbaceous production (Pase, 1958; Clary et al., 1968). Therefore, the decrease in litter cover observed in the commercial treatment may contribute to increasing herbaceous production.

5. Conclusions and management implications

Overstory regeneration and shrub density response to treatments may require more than 2–4 years of observation in dry mixed conifer stands. However, on sites that are more mesic (i.e. Bailey scatter) overstory regeneration and shrubs may begin to increase 2 years post-treatment. Both non-commercial treatments and commercial treatments have the ability to increase herbaceous production. However, the response in non-commercial treatments may be limited and require 4 or more years to observe a difference. The commercial treatment resulted in increased herbaceous production the third year post-treatment. Commercial treatments resulted in greater soil cover immediately after harvest but it decreased within the second year following treatment.

Where the goal of increasing herbaceous and midstory production is a high priority, commercial treatments offer the most potential by significantly reducing the cover, density, and BA of overstory trees and disturbing the often thick and continuous litter layer. Depending on initial stand structure, non-commercial treatments may be able to significantly alter overstory characteristics if applied with this goal in mind. For example, diameter cap and spacing requirements could be adjusted to include larger trees with wider spacing requirements to produce the desired effect. The problem then becomes dealing with the downed woody material.

Cutting some portion of tall, unproductive oaks and midstory shrubs may be warranted to induce root sprouting, resulting in productive new shoots that are accessible to wildlife. Due to drought, meadow encroachment, and high ungulate densities, increased herbaceous and midstory production in forested areas may be important to help relieve pressure on heavily grazed mountain meadows. Future research should address the long-term impact of treatment intensities that fall between the non-commercial and commercial treatments we studied.

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