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Understory response to management treatments in northern Arizona ponderosa pine forests

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Abstract

A range of forest management treatments was applied to ponderosa pine (*Pinus ponderosa*) in northern Arizona. The treatments represented the full range of existing stand disturbance conditions and included forest stands that were unmanaged, thinned, thinned and prescribed burned, and burned by stand-replacing wildfire in order of increasing disturbance intensity. We assessed differences in understory diversity associated with these treatments. We identified 195 species of understory plants, focusing on the distribution of natives and exotics. The abundance of understory plants was more sensitive to changes in management treatments than the overall species richness. Exotics on the whole, responded statistically more strongly to disturbance treatments than did natives. Both the richness and abundance of exotic forbs increased significantly with treatment intensity. Species richness remained stable while abundance of native graminoids increased significantly with treatment intensity through thinned and burned stands. Both then decreased significantly in stands that experienced wildfire. The number of native shrub species decreased significantly with treatment intensity. Overall plant diversity was least in the unmanaged stands and progressively increased with intensity of disturbance/stand treatments. Both prescribed burning and wildfire increased plant diversity; however, stand-replacing wildfire also appeared to substantially increase the diversity of exotic plants.

Keywords: Ponderosa pine; Understory plants; Thinning; Prescribed burning; Wildfire; Forest management; Species richness; Abundance

1. Introduction

For over a century, the natural disturbance regime of northern Arizona's ponderosa pine–bunchgrass forests has been altered through logging, grazing, and fire suppression (Weaver, 1951; Covington et al., 1997). The combination of these activities has led to structural and functional changes in these forests, often resulting in dense stands with low understory plant diversity (White, 1985; Harrington and Sackett, 1992; Covington and Moore, 1994; Fulé et al., 1997). In addition, invasion by exotic plant species has become a concern in recent decades. Exotic species are often aggressive and out-compete native species for resources. Many researchers have noted and documented the invasion of exotic species as a threat to biological integrity of native systems (Coblentz, 1990; Noss, 1990; Soulé, 1990; Tyser, 1992; Vitousek et al., 1996).

The School of Forestry at Northern Arizona University in conjunction with the USDA Forest Service,

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Rocky Mountain Research Station investigated understory plant diversity (species richness and diversity, as defined by Magurran, 1988) in ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) forests near Flagstaff, AZ as part of a larger study, Stand Impacts on Forest Health (STIFH). The goal of this cooperative project is to investigate how landscape level stand treatments affect forest health in northern Arizona and to identify ecological indicators of forest health, defined as the relative condition of a forest based on ecological indicators and collective value judgements of stakeholders (Bailey et al., 2000).

The goal of our study was to compare understory plant diversity between stands of various treatments including control (unmanaged), thinned, thinned and prescribed burned, and burned by stand-replacing wildfire. These stand treatments represent a gradient of ecological disturbance. We define unmanaged treatment as having the least impact on understory species, then thinned, thinned and burned, and the greatest impact is caused by stand-replacing wildfire. We were especially interested in the response of exotic plants within these treatments, and where along the disturbance gradient native understory species were replaced by exotics. We analyzed the data at different scales, based on how managers might view the system, to determine where differences in understory occur among treatments, and at what level managers should monitor to detect these differences. We found that most understory plant species responded positively to increasing disturbance intensity. However, exotic species exhibit a disproportionately large positive response to stand-replacing wildfire.

2. Methods

This study was conducted in Arizona *P. ponderosa*/*Festuca arizonica* Vasey association with and without the *Quercus gambelii* Nutt. phase (USDA Forest Service, 1997) on the Coconino National Forest, Mogollon Plateau in northern Arizona at elevations from 2150 to 2500 m. All data were collected during the summer of 1999. The dominant overstory species was *P. ponderosa* with a small component of *Q. gambelii*. The understory on our study area is characterized by the most common native species: *F. arizonica*, *Elymus elymoides* (Raf.) Swezey, *Cirsium wheeleri* (Gray) Petrak., *Carex* spp., *Muhlenbergia montana* (Nutt.) A.S. Hitchc., *Lupinus argenteus* Pursh, and *Achillea millefolium* L.; and the most common exotic species: *Salsola kali* var. *tenuifolia* Tausch., *Verbascum thapsus* L., *Poa pratensis* L., *Chenopodium graveolens* Willd., *Bromus tectorum* L., and *Descurainia obtusa* (Greene) O.E. Schulz.

Sixteen stands (four treatments$\times$four replicates of each), each from 20 to 80 ha were randomly selected from a larger pool of stands used in the STIFH project. These stands were composed of mature, even-aged blackjack ponderosa pine (trees younger than approximately 125 years) with larger, yellow pine (greater than 64 cm dbh) not exceeding 10 trees/ha. Thinned stands had greater than 30% of their basal area removed between 1987 and 1993, with at least 50% of this coming from diameter classes greater than 30 cm (pulpwood size). Thinned stands had an average basal area of 18.7 m^2/ha (S.D.=6.0) and 312.5 stems/ha (S.D.=96.2). Thinned and prescribed burned stands had thinning treatments as described above and also received a broadcast burn treatment within 3–4 years of thinning (1988–1996). Overstory survival following the broadcast burn was greater than 90%. Thinned and burned stands had an average basal area of 15.4 m^2/ha (S.D.=2.8) and 235.6 stems/ha (S.D.=18.3). Unmanaged stands did not receive a density-altering treatment within the last 30 years, such that the stands have greater than 90% crown closure and relative density greater than 70% (and thus are actively self-thinning). Control stands had an average basal area of 31.9 m^2/ha (S.D.=3.1) and 796.6 stems/ha (S.D.=152.0). Wildfire areas are stands in which greater than 90% of the basal area was killed and/or consumed by wildfire since 1994 (Bailey et al., 2000). The stands that experienced wildfire had no significant remaining live trees; therefore, there is no basal area/ha or stems/ha for this treatment.

Within each stand, 10 plots were established in a grid pattern either 150 or 200 m apart with a buffer of at least 50 m to the stand edge. Two trained botanists searched for plants in a plot 375 m^2 for a total of 11 min (Goff et al., 1982; Moir and Bonham, 1995). After each survey period, the total number of species was tallied (observed species richness), and individual species were given an abundance rating (index of abundance) modified from Shimwell (1971, p. 111)

Table 1
Categories and midpoints used in the description of understory abundance in ponderosa pine on the Coconino National Forest (modified from Shimwell, 1971)

Class	Description	Cover (%)	Midpoint
0	Rare, very sparse	<0.01	0.005
1	Occasional, sparse	<1	0.505
2	Frequent, here and there	<5	3.000
3	Abundant, numerous, common	5–25	15.000
4	Very abundant, numerous, or common	>25	62.500

(Table 1). Each species was categorized as ‘‘native or exotic’’ according to McDougall (1973). Most plants were identified to species, some species were identified to genus, and unknowns were identified at the Deaver Herbarium, Northern Arizona University. We refer to species richness and the number of species, but note that several of these are actually only identified to genus and may contain more than one species.

We tested basal area/ha and stems/ha for differences between treatments using Kruskal–Wallis tests. Bonferroni-corrected multiple comparisons for rank tests were conducted on factors that varied significantly by treatment (Neter et al., 1996, pp. 779–780).

Abundance midpoints (Table 1) and species richness from plots within a stand were averaged separately to find the stand level average for total species, native and exotic species, and species split into native and exotic life forms. Life forms included native and exotic forbs, native and exotic graminoids (grasses and grass-like species) and native other species. Native other species includes both shrubs and cacti and does not include any exotic species. Kruskal–Wallis tests were used to test for variation in the different scales of abundance and species richness of native graminoids, exotic graminoids, native forbs, exotic forbs, and native other species. These tests rank the tested variable in each treatment by its abundance or richness in relation to its abundance or richness in other treatments. Bonferroni-corrected multiple comparisons for rank tests were conducted on factors that varied significantly by treatment (Neter et al., 1996, pp. 779–780).

3. Results

Stand treatments differed significantly from each other for basal area/ha and stems/ha in almost all cases (X^2=13.097, d.f.=3, P=0.004, for both). Thinned stands did not differ from thinned and burned stands because the thinning treatments were identical (asymptotic confidence interval (−1.331, 4.3314)). The only differences between these two stand types are that the thinned and burned stands received a prescribed burn while the thinned-only stand did not.

We identified a total of 195 species of understory plants, 156 natives and 39 exotics. Total ranked species richness did not vary by treatment; however, the total ranked abundance increased with increased treatment intensity (Table 2). Both the ranked species richness and abundance of exotics increased with treatment intensity. Native species do not appear to vary in abundance or richness in response to treatment (Table 2). The ranked species richness and abundance of exotic forbs increased with treatment intensity (Table 2). The ranked species richness of native graminoids remained constant in the control, thinned, and thinned and prescribed burned stands, then fell

Table 2
Results from Kruskal–Wallis rank tests on species richness and abundance of understory species during 1999 among four stand treatments, in ponderosa pine on the Coconino National Forest (d.f. for all comparisons is 3)

Factor	Species richness		Abundance	
	X^2	P-value	X^2	P-value
Total	2.581	0.461	9.110	0.028*
Native	6.589	0.086	3.199	0.362
Exotic	9.231	0.026*	8.757	0.033*
Native forbs	2.404	0.493	6.401	0.145
Exotic forbs	9.750	0.021*	9.772	0.021*
Native graminoids	8.600	0.035*	13.125	0.004*
Exotic graminoids	5.228	0.156	5.393	0.145
Native ‘‘other’’	8.894	0.031*	6.832	0.077*

* Significant results (α=0.05).

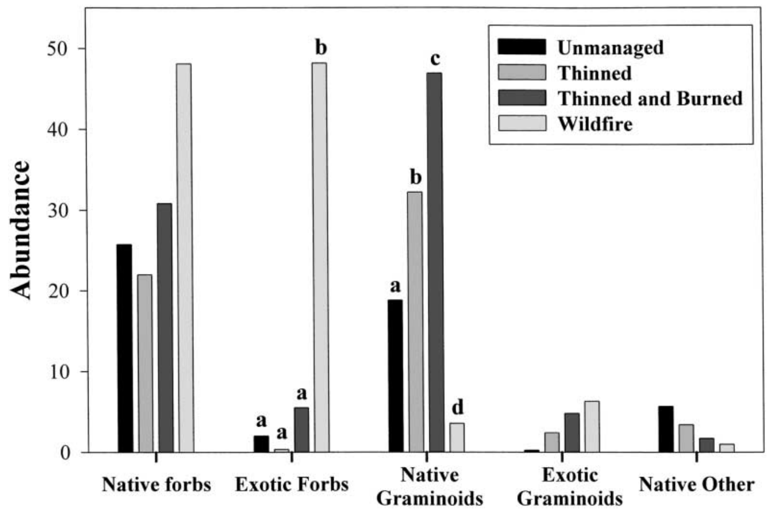

Fig. 1. Abundance of understory species described by life form across four treatments. Letters above bars represent significant differences among treatment types for multiple comparison tests based on ranked comparisons. Lack of letters indicates multiple comparisons were not conducted because original test did not detect significant difference between treatments. Native other category includes shrubs and cacti. Data collected during the summer, 1999, Coconino National Forest, northern Arizona.

dramatically in the stands that experienced wildfire. The ranked abundance of native graminoids increased in response from control to thinned, and thinned and burned stands, then fell significantly in stands that were burned by wildfire (Table 2). The ranked species richness of native shrubs and cacti decreased with treatment intensity, but the ranked abundance did not (Table 2). The ranked abundance and ranked species richness of exotic graminoids, and native forbs did not vary by treatment (Table 2, Figs. 1 and 2).

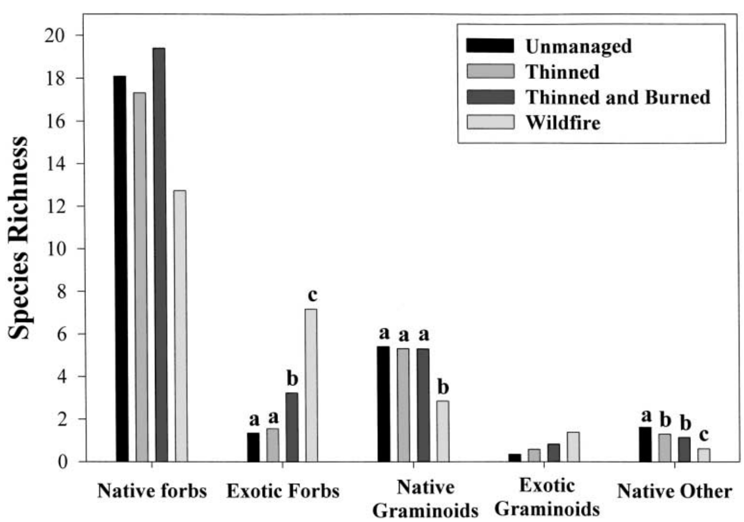

Fig. 2. Species richness of understory species described by life form across treatments. Letters above bars represent significant differences between treatments for multiple comparison tests based on ranked comparisons. Lack of letters indicates multiple comparison tests were not conducted because original test did not detect a significant difference between treatments. Native other category includes shrubs and cacti. Data collected during the summer 1999, Coconino National Forest, northern Arizona.

Results from multiple comparison tests indicated that overall abundance and the abundance (Fig. 1) and species richness (Fig. 2) of exotic forbs were highest in stands that experienced wildfire and decreased with decreasing intensity of treatment. The abundance of native graminoids increased with increasing disturbance intensity, but then dropped dramatically in stands that experienced wildfire. The species richness of native graminoid species did not vary within the first three treatments, but again dropped dramatically in plots that experienced wildfire (Fig. 1).

There were also a number of interesting trends to note in the data. Exotic grasses showed consistent increasing trends in both abundance and species richness as intensity of treatment increased. It is also interesting to note that while abundance of native forbs appeared to have an increasing trend with treatment, the species richness appeared to decline with treatment (Figs. 1 and 2).

4. Discussion

The total number of species did not vary by treatment intensity, but abundance of understory species did increase in response to treatment intensity. Similar responses have been shown in other southwestern studies. Moore and Deiter (1992) found an increase in forage production with a decrease in a stand density index (based on the number of trees and their quadratic mean diameter). Ffolliott et al. (1977) found an increase in the production of herbage on the site of a prescribed burn up to 11 years after the fire. Oswald and Covington (1983) also detected increased biomass of understory in response to increased severity of fire treatment. Turner et al. (1997) noted an increase in opportunistic species with increased burn severity.

While others have demonstrated an increase in understory abundance with disturbance intensity, we demonstrate that this increase in abundance is largely because of a dramatic increase in the abundance of exotic species. Specifically, exotic forbs increased in species richness and abundance in response to an increase in intensity of treatment. Our unmanaged and thinned stands had the fewest exotic forbs, while stands that experienced wildfire had the greatest. Several authors suggest that areas that experience crown fires, like our wildfire plots, may provide good prospects for opportunistic and invading species like many exotics (Beaulieu, 1975; Turner et al., 1997).

We noted a significant, possibly threshold, relationship between native graminoids and treatment. The number of species of native graminoids remains fairly consistent in unmanaged, thinned, and thinned and burned stands, but drops significantly in wildfire stands. The abundance of native graminoids increases significantly with intensity of treatment in unmanaged, thinned, and thinned and prescribed burned stands. Naumburg and DeWald (1999) also noted an increase in the abundance of graminoids in relation to the amount of light received when they looked at grass response to ponderosa pine forest structure. However, we also show a dramatic drop in the abundance of graminoids in stands that experienced wildfire. Others have noted a decline of native grasses in response to fire severity (Harris, 1978; Vose and White, 1991). This relationship appears to indicate that native graminoid species are present across the landscape, but stand treatments, especially prescribed fire, affect their density. The apparent threshold for native graminoids may indicate high severity wildfire negatively impacts the duff layer and soil seedbed. Armour et al. (1984) noted lower grass canopy cover in intensely burned areas. They believe this was caused by the duff layer smoldering and destroying the reproductive material of grass species.

We also noted that the number of native species of shrubs and cacti tends to fall in response to treatment intensity, with a very large decline of species in response to wildfire. Unmanaged stands, with the greatest amount of overstory canopy coverage, have by far the greatest diversity of native shrubs and cacti. This diversity dropped in response to both thinning and thinning and burning, which had more open canopy coverage. The diversity declined again in response to wildfire, which had very little canopy cover. The overall abundance did not follow this pattern and did not vary significantly in response to stand treatments. Tapia et al. (1990) and Moore and Deiter (1992) did not find a pattern in shrub production in relation to overstory measures. Several other researchers found *Ceonothus fendleri*, a common shrub species in northern Arizona, to vigorously sprout after a wildfire (Pearson et al., 1972; Vose and White, 1987), although Vose and White (1991) found that high severity fire decreased *C. fendleri* biomass. Vose and White (1987) found *Rosa woodsii*, another common northern Arizona shrub, decreased after wildfire. Shrub response to forest treatment appears to be dependent on the individual shrub species and the intensity of disturbance, specifically fire.

There appears to be little difference in understory between the unmanaged stands and the stands that were thinned only (treatments occurred 5–12 years ago). Unlike our study, Clary and Ffolliott (1966) found significantly higher herbage production in thinned stands than in unthinned stands 6 years after thinning. The significant increase in herbage production occurred in stands that had been thinned to less than 14 m^2/ha basal area. Our stands ranged from 16 to over 23 m^2/ha basal area. It may be that reducing basal area to this level (16+ m^2/ha) is not enough to elicit a response from the understory species in these stands.

It appears that thinning in combination with prescribed burning has the greatest positive impact on native species, while stand-replacing wildfire tends to favor exotic species. This relationship is statistically demonstrated and also supported by non-significant trends. However, we should be cautious in attributing the differences in understory to stand treatments alone. Each stand has a different disturbance history and different seed sources. All the areas we sampled have also been grazed. Areas that have been burned may have responded to fire with greater nutritional value of forage plants, and consequently, may receive greater grazing pressure from ungulates (cattle, sheep, elk, and deer) (Pearson et al., 1972; Lowe et al., 1978; Harris and Covington, 1983). In addition, the data for this study were collected only during the summer of 1999; therefore temporal changes were not assessed.

5. Conclusions

In fire dominated systems, such as the southwest, the flora of the region is adapted to coexist with fire, whether these adaptations are fire retardant properties or growth responses to burning. Land managers need to know at what scale and at what intensity of treatment exotic species appear to gain a significant foothold in an area. This study suggests native graminoid abundance in particular responds positively to management treatments of thinning and prescribed burning. However, we caution that exotic plants also respond to these treatments. In our study, exotic forb richness increased significantly in the combined thinned and burned treatments. This study also provides evidence of large increases in abundance and species richness of exotic species in response to stand-replacing wildfire. Under extreme treatment, such as stand-replacing wildfire, even native species that respond positively to fire are being replaced by opportunistic and disturbance driven exotic species. The full range of vegetation responses (especially exotic species) in ponderosa pine forests to natural and anthropogenic disturbance remains to be elucidated.

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