TREE THINNING AND PRESCRIBED BURNING EFFECTS ON GROUND FLORA IN ARIZONA PONDEROSA PINE FORESTS: A REVIEW

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ABSTRACT

Ground flora is an important response variable to monitor after tree thinning and prescribed burning treatments designed to restore Arizona ponderosa pine (*Pinus ponderosa* P.& C. Lawson) forests. This paper reviews published literature on the effects of thinning and burning on ground flora in Arizona ponderosa pine forests in five main categories of research: ground flora biomass, species diversity, plant community composition, population processes, and individual species ecology. Research published to date suggests that thinning and burning generally increase ground flora biomass, whereas other categories of research such as community composition and population processes have been little studied in Arizona ponderosa pine forests. Additional research needs include determining the relative importance of soil seed banks, seed dispersal, and site conditions in post-treatment ground flora compositional dynamics using a demographic approach; developing predictive models for exotic species distribution and containment; monitoring long-term (>5 years) treatment effects; and geographically replicating experiments at dispersed sites differing in ecological conditions to determine the spatial and contextual applicability of research findings. To meet desired outcomes of ecological restoration including criteria for high native and low exotic species diversity, treatments supplementary to thinning and burning such as seeding of native species and life-history specific control methods of exotic species might be needed on some restoration sites.

INTRODUCTION

As ecological restoration, including tree thinning and prescribed burning, is increasingly proposed and implemented to reverse undesirable changes in Arizona ponderosa pine (*Pinus ponderosa* P.& C. Lawson) forests, a review of thinning and burning effects on ground flora in ponderosa pine forests is timely. Similar to many other savanna and open-forest ecosystems, including longleaf pine (*Pinus palustris* P. Mill.) savannas in the southeastern United States and oak (*Quercus*) woodlands in southern Arizona (McClaran and McPherson 1999, Platt 1999), ground flora is a dominant component of open-structured ponderosa pine ecosystems (Weaver 1951, Cooper 1960, Ffolliott 1983). Ground flora is a critical response variable for monitoring the effects of treatments during ponderosa pine forest restoration experiments.

Restoration is proposed for many Arizona ponderosa pine forests because over the past century there have been dramatic ecosystem changes increasingly expressed as destructive crown fires (Covington et al. 1994, Allen et al. 2002). Based on historical accounts and tree density reconstructions, presettlement (ca. 1880) ponderosa pine forests were generally less dense and more open-structured than current forests (Cooper 1960, Biswell 1972). Low-intensity but frequent fires (often multiple fires per decade on a site) historically were key processes in these ecosystems (Fulé et al. 1997). After settlement in the late 1800s, fire exclusion and other factors resulted in overall increases in tree densities (Cooper 1960, Biswell et al. 1973, Wright 1978). These higher tree densities combined with livestock overgrazing and fire exclusion were associated with declines in ground flora cover during the 1900s (Arnold 1950, Moir 1966). Fuel buildups and concerns about crown fires, which apparently were rare or absent in presettlement ponderosa pine forests, have provided impetus to reduce small-diameter (<40 cm) tree densities using restoration thinning and prescribed burning (Covington et al. 1997, Allen et al. 2002, Fulé et al. 2002).

Understanding ground flora responses to thinning and burning is fundamental to better comprehend the ecology of ponderosa pine ecosystems, and is of practical importance for predicting vegetation changes after treatments to improve outcomes of ecological restoration. This paper reviews mechanical tree thinning and prescribed burning effects on ground flora in five main categories of research that have been conducted in Arizona ponderosa pine forests: above-ground vegetation biomass (dry weight/unit area), species diversity (species richness or diversity indices), community composition (species present and their abundances), population processes (e.g., seed production and seed bank ecology), and the ecology of individual species. Based on published literature, I evaluate the null hypothesis that thinning and burning do not change ground flora measures such as species diversity or composition. I also identify areas in need of additional research and provide suggestions to improve ground flora research methods.

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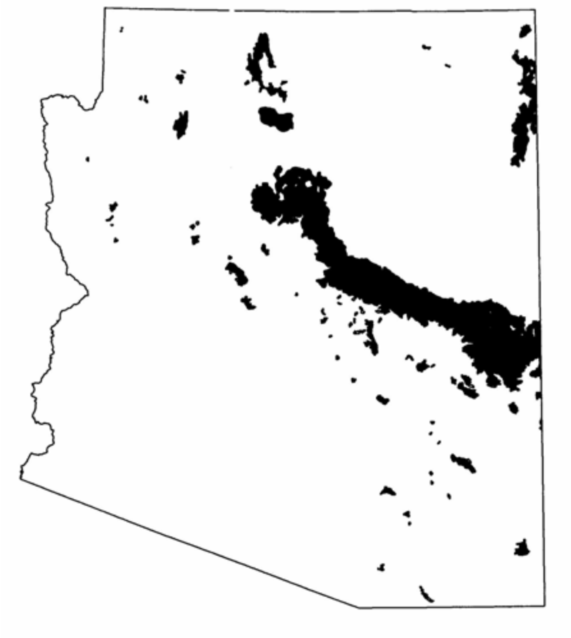

Figure 1. Distribution of forests dominated by ponderosa pine (Pinus ponderosa) in Arizona. Modified from Brown and Lowe (1994).

***Table 1.** Summary of studies evaluating tree thinning and prescribed burning effects on ground-flora biomass in Arizona ponderosa pine forests. Values are total mean standing crop above-ground biomass (kg/ha).*

	Thin/ burn	Control	Reference
Pre[a]	–	–	Clary and Ffolliott 1966
Post (6)[a]	635[b]	422	
Pre	–	–	Harris and Covington 1983
Post (1)	43[c]	33	
Pre	275	139	Oswald and Covington 1984
Post (3)	490	295	
Pre	–	–	Andariese and Covington 1986
Post (2)[d]	46[d]	47	
Post (5)	55	36	
Post (7)	35	11	
Pre	–	–	Covington et al. 1997
Post (1)	299[e]	100	

[a] Pre- and post-treatment, with the time since treatment that post-treatment means were measured indicated in parenthesis (no. years). Dashes indicate that data were not collected or were not published.
[b]Mean of thin-only stands at 4.6 m^2/ha residual basal area.
[C]Mean of June and September sampling dates averaged for sawtimber, pole, and sapling patches within a treatment.
[d]Post-treatment data in this study were collected in the same year but at different sites that had burned 2, 5, and 7 years before sampling; means for this study are averages of pole and sawtimber patches.
[e]Mean of thin only and thin + burn treatments.

DESCRIPTION OF THE LITERATURE

Arizona forests dominated by ponderosa pine occur discontinuously and are concentrated in north-central and eastern Arizona (Fig. 1). Most ground flora research in Arizona ponderosa pine has occurred in northern Arizona in the Coconino National Forest near Flagstaff and in the Grand Canyon area. In evaluating thinning and burning effects on ground flora biomass and diversity, some authors stratified study sites into different categories (e.g., overstory characteristics, treatment intensities) and occasionally for biomass data presented results for different sampling dates within a year (e.g., early and late summer). To develop overall summary tables of published findings for this review, I averaged results for overstory and treatment categories and for seasonal sampling dates within treatments.

VEGETATION BIOMASS

Ground flora standing crop biomass has generally increased after thinning or burning in Arizona ponderosa pine forests, but inference could be improved in many studies by collecting pre-treatment data and repeated temporal measurements (Table 1). One study reporting pre-treatment data (Oswald and Covington 1984) illustrates how an absence of pre-treatment data could have influenced conclusions. Oswald and Covington (1984) found that post-treatment average biomass on burn plots was 195 kg/ha greater than on control plots, but biomass on burn plots had increased only 44% over pre-treatment levels compared to 53% on control plots. This discrepancy occurred because pre-treatment biomass on control plots was only 51% that of burn plots. In studies where pre-treatment data are collected but pre-treatment means are unequal, common in vegetation studies, statistical methods like analysis of covariance can be employed that adjust for pre-treatment differences (Sokal and Rohlf 1995).

Several authors (Harris and Covington 1983, Andariese and Covington 1986, Covington et al. 1997) have reported variations in biomass after prescribed burning among different overstory patches (e.g., sawtimber patches [dominated by trees >30 cm diameter], and pole patches [10-30 cm diameter]). For example, Andariese and Covington (1986) found that at a site burned two years previously, total ground flora biomass averaged 53.5 kg/ha greater in sawtimber patches than in pole patches. Harris and Covington (1983), in contrast, reported that ground flora biomass differed between burned and control plots one year after prescribed burning in pole and sapling (trees <10 cm diameter) patches but not in sawtimber patches. These differential changes were attributed to variations among overstory patches in fuel loading, fire behavior, and pre-burn ground flora composition (Harris and Covington 1983).

The interactive effects on plant biomass of prescribed burning and residual tree densities after mechanical thinning have not been fully explored (Clary et al. 1975, Bojorquez Tapia et al. 1990). In a non-manipulative study on the Kaibab Plateau, Moore and Deiter (1992) published equations showing sharp declines in ground flora biomass with increasing stand density indices. Clary and Ffolliott (1966) found that ground flora biomass was higher in thinned than unthinned stands with residual basal areas of 5-18 m^2/ha, but there was no significant difference among treatments when post-thinning basal area exceeded 18 m^2/ha. Covington et al. (1997) reported that in patches dominated by postsettlement-origin trees, ground flora biomass in thinning only treatments was almost four times greater than in thin + prescribed burn treatments. In other studies such as in Andariese and Covington (1986), sporadic thinning that occurred before planned burning treatments makes it difficult to separate the effects of thinning only from burning and of prescribed burning under different stand densities. From an ecological restoration perspective, where burning may be reintroduced on sites with a variety of overstory characteristics (e.g., natural openings, formerly dense stands that are thinned to varying densities), future research could examine thin + burn interactions and the effects of mechanical thinning without prescribed burning.

In a retrospective study, Andariese and Covington (1986) is one of the few studies that has evaluated the effects of time since thinning or burning on ground flora biomass. These authors found that in mature stands ground flora biomass did not differ significantly between burn and control plots at sites burned 2 and 5 yr before sampling in 1981 but did differ at a site burned 7 yr previously. Additional retrospective studies combined with planned, long-term experiments are needed to ascertain how long the benefits of thinning or burning persist on ground flora biomass and how frequently burning should occur to optimize benefits for ground flora (Reynolds 1962). Ground flora biomass in Arizona ponderosa pine can vary seasonally and among years depending on precipitation (McLaughlin 1978), so long-term monitoring is needed to more carefully distinguish time from treatment effects (Ffolliott and Gottfried 1989).

In all studies reviewed, except for Covington et al. (1997) whose study area was excluded from large herbivore grazing, grazing either before or after treatment has apparently affected post-treatment standing crop biomass estimates. Available soil nutrients often increase following burning (Raison 1979, Covington and Sackett 1992), and this was expressed by greater concentrations of nutrients such as N and K in grass foliage after a northern Arizona burn (Harris and Covington 1983). Higher foliage nutrient concentrations can make plants more susceptible to grazing (Clary 1975). Landscape grazing influences on ground flora biomass and on species composition are not well quantified for Arizona ponderosa pine (Arnold 1953, Clary 1975, Rambo and Faeth 1999), and it is desirable to understand to what extent restoration sites in a matrix of denser forest containing little forage become targets for heavy grazing (Reynolds 1966, Ffolliott et al. 1977). Grazing use may have implications for restoration landscape planning of the size, dispersal, and spatial patterns of treated and untreated areas should restoration thinning and burning be applied at broad scales.

SPECIES DIVERSITY

Research published to date does not indicate that thinning or prescribed burning consistently increase ground flora diversity in Arizona ponderosa pine forests (Table 2). In northern Arizona, for example, Griffis et al. (2001) reported similar post-treatment mean native forb species richness (375 m^2) of 18 in control stands (mean basal area=32 m^2/ha), 17 in thinned stands (residual mean basal area=19 m^2/ha), and 19 in thinned and burned stands (residual basal area=15 m^2/ha). Abella and Covington (in press) found that total mean species richness/m^2 did not differ significantly among control, low-, and medium-intensity thinning treatments, but a richness of 4 species/m^2 in a high-intensity thin (reducing density 85% to 140 trees/ha) was twice as high as in the other treatments. This finding suggested that a lower-limit stand density threshold needed to be passed before species richness increased, but experimentation with a wider range of stand densities and on different soil types is needed to test this hypothesis. Near the Grand Canyon, Fulé et al. (2002) reported sharp post-

Table 2. *Summary of studies evaluating tree thinning and prescribed burning effects on ground flora diversity in Arizona ponderosa pine forests.*

Measure[a]		Thin/burn			Control			Reference
		Native	Exotic	Total	Native	Exotic	Total	
SR (375 m^2)	pre[b]	–	–	–	–	–	–	Griffis et al. 2001
	post (3)[b]	25.0[c]	3.0	28.0	25.0	2.0	27.0	
SR (1 m^2)	pre	–	–	–	–	–	–	Abella and Covington in press
	post (3)	2.7	0.3	3.0	2.0	0.0	2.0	
SDI	pre	–	–	5.8	–	–	7.1	Fulé et al. 2002
	post (1)	–	–	0.2	–	–	0.2	
SDI	pre	–	–	2.6	–	–	2.6	Korb et al. 2003
	post (1)	–	–	3.0	–	–	2.7	

[a] SR = species richness, SDI = Simpson's diversity index.
[b] Pre- and post-treatment, with the time since treatment that post-treatment means were measured indicated in parenthesis (no. years). Dashes indicate that data were not collected or were not published.
[c] All values in the table are means of thin and thin + burn treatments.

treatment declines in Simpson's diversity index both in control and thin/burn treatments. Precipitation only 61% of the average in the post-treatment year (2000) was hypothesized to have caused the decline, and counteracted any detectable treatment effects.

COMMUNITY COMPOSITION

By including both the species present and their abundances, composition is one of the best single measures for characterizing vegetation communities (McCune and Grace 2002). Community compositional change after thinning and burning has been rarely studied in Arizona ponderosa pine. Tables of species composition have been presented only in Oswald and Covington (1983), Vose and White (1987), and Abella and Covington (in press). Such tables are important for comparisons among study areas and for meta-analyses of regional species composition (Gurevitch et al. 2001). Abella and Covington (in press) is the only study that has statistically evaluated overall community compositional differences among treatments. They reported subtle but positive native species compositional differences between control plots and thin + burn plots 3 years after treatment, and concluded that multivariate methods were needed to detect these differences.

Increasing concern about exotic species in Arizona ponderosa pine forests (Sackett et al. 1996, Sieg et al. 2003) provides added incentive for detailed analyses of community compositional shifts after restoration treatments for early detection of exotics. Exotic species common at Abella and Covington's (in press) northern Arizona study area included common mullein (*Verbascum thapsus* L.), dalmatian toadflax (*Linaria dalmatica* (L.) P. Mill.), and bull thistle (*Cirsium vulgare* (Savi) Ten.). Sieg et al. (2003) provide a general list of potential exotic species of concern in Arizona ponderosa pine forests.

POPULATION PROCESSES

Vose and White (1987) found that soil seed banks averaged 8.4 viable seeds/m^2 in a northern Arizona prescribed burn area 1 year after the burn and concluded that seed banks contributed little to post-burn vegetation dynamics. In ponderosa pine forests near the Grand Canyon, Springer (1999) reported a much higher viable seed density of 3,152 seeds/m^2 in the seed bank in September after overstory thinning that summer. Maiden blue-eyed Mary (*Collinsia parviflora* Lindl.) comprised 45% of these seeds, redstem monkeyflower (*Mimulus rubellus* Gray) 17%, while the exotic common mullein comprised 30%. Of 14 species emerging in germination tests, 11 were annuals or biennials, three were perennials, and all species were forbs. Viable seed estimates in Arizona ponderosa pine seed banks are lower than estimates of 13,052 to 14,463/m^2 reported by Pratt et al. (1984) in an eastern Washington ponderosa pine forest. Research published to date suggests that seed banks may not be primary factors influencing post-thinning or burning vegetation dynamics in Arizona ponderosa pine forests.

During 1 year after a northern Arizona prescribed burn in open sawtimber, Vose and White (1987) reported a total seed rain of 244/m^2 for grasses, 303/m^2 for forbs, and none for shrubs. A main conclusion of this study was that pre-existing vegetation and vegetation surviving the burn most strongly controlled post-burn vegetation dynamics by producing seed or by expanding vegetatively (e.g., buckbrush [*Ceanothus fendleri* Gray]). At the same study area, White et al. (1991) found that

Arizona fescue (*Festuca arizonica* Vasey) and mountain muhly (*Muhlenbergia montana* [Nutt.] A.S. Hitchc.) did not flower the first year after a burn in sawtimber and pole patches. Both species resumed flowering the second year, while squirreltail (*Elymus elymoides* [Raf.] Swezey) and muttongrass (*Poa fendleriana* [Steud.] Vasey) exhibited no apparent phenological differences between burned and unburned areas. Community demographic studies (Vose and White 1987) over several years are needed in Arizona ponderosa pine to test hypotheses about fine-scale processes such as seed dispersal in burned areas from on- and off-site vegetation, phenological and seed production changes after burns, and the survival and growth of vegetation after fire (Harper 1977). These studies also could facilitate the reintroduction of native plant populations in treatment areas, which has been successful in longleaf pine savannas (Glitzenstein et al. 2001).

INDIVIDUAL SPECIES

As predicted from general ecological theory (Whelan 1995), thinning and burning in Arizona ponderosa pine increases some ground flora species, has no apparent impact on others, and negatively affects some species (Gaines et al. 1958, Phillips et al. 1993, Maschinski et al. 1997). In interpreting results, however, one should consider short- and possible long-term effects; most studies have evaluated only short-term effects. One year after burning in northern Arizona, squirreltail exhibited a mean biomass of 112 kg/ha in open sawtimber burned areas compared to 40 kg/ha in controls (Vose and White 1991). Biomass did not differ significantly between burned and control plots in below-canopy sawtimber, pole, or sapling patches. Research in other regions has generally found that squirreltail biomass and density increase after burning (Young and Miller 1985), probably partly because the species contains a low density of dead plant material that does not burn hot enough to appreciably damage the plant (Wright 1971). Mountain muhly, in contrast, exhibited significantly lower biomass in open sawtimber between burn (mean biomass=40 kg/ha) and control plots (mean biomass=58kg/ha) 1 year after fire (Vose and White 1991). Muttongrass and buckbrush biomass did not differ significantly between treatments, although resprouting of buckbrush was observed at the end of the study and may have resulted in long-term increases in buckbrush biomass (Vose and White 1991).

In a comprehensive study of Sunset Crater penstemon (*Penstemon clutei* A. Nels.), a species endemic to the Sunset Crater volcanic field of northern Arizona, Fulé et al. (2001) reported that prescribed burning resulted in a 75% decrease in penstemon density. Trenching to reduce root competition from overstory ponderosa pine, however, resulted in a 1200% increase in penstemon density. This is one of the few studies in Arizona ponderosa pine that has attempted to separate the effects of burning from overstory competition. Most other studies have variously had some type of mechanical tree thinning occur before prescribed burning (e.g., Andariese and Covington 1986), and Fulé et al. (2001) suggests that research distinguishing the effects of thinning only from thinning + burning might be insightful both ecologically and for applied management.

ECOSYSTEM PERSPECTIVE

Ground flora research as part of a multifactor ecosystem perspective might be the most rewarding because of the difficulty of separating treatment effects on ground flora from treatment effects on other interrelated ecosystem components. Examples include effects on ground flora of O-horizon thickness, soil nutrients and plant-mycorrhizae associations, and historical factors like seed-source limitations. Clary et al. (1968), for example, found that ground flora biomass was negatively correlated with O-horizon thickness. O-horizon thickness in ponderosa pine has increased during the past century because of fire suppression and increased tree densities, and prescribed burning might benefit ground flora only if O horizons are reduced (Covington and Sackett 1984). Korb et al. (2003) reported that arbuscular mycorrhizae were more abundant on thinned and burned plots than on control plots, and some plant species are associated with mycorrhizae for nutrient and water uptake. Since two studies in Arizona ponderosa pine suggest that perennial species are sparse in seed banks (Vose and White 1987, Springer 1999), seed source limitations might constrain ground flora responses to thinning and burning more than we realize. Seeding experiments could be used to better understand the relative roles of seed limitations from other limitations such as safe-site or light availability (Naumburg et al. 2001).

REGIONAL COMPARISONS

Most ground flora research in southwestern ponderosa pine forests has occurred in Arizona, so few comparisons to other southwestern states can be made (Lynch et al. 2000). In thinned Pacific Northwest ponderosa pine stands in central Oregon, Busse et al. (2000) concluded that prescribed burning had little influence on ground flora biomass and cover, with the exception that bitterbrush (*Purshia tridentata* (Pursh) DC.) declined significantly. In Montana ponderosa pine, Newland and DeLuca (2000) found that N-fixing plants were 195% more frequent in burned than in unburned plots and hypothesized that N-fixers were important in maintaining site productivity in these often N-limited forests. McConnell and Smith (1970) found that in eastern Washington, thinning ponderosa pine to >45% canopy cover caused higher forb than grass biomass, whereas thinning to <45% canopy cover resulted in greater grass than forb biomass. In Idaho ponderosa pine, Armour et al. (1984) reported that post-treatment graminoid cover was 5-10% lower on high-intensity than on low-intensity burn plots. Consistent with Vose and White (1987) in Arizona ponderosa pine, Armour et al. (1984) concluded that ground flora species occurring on plots before treatment most strongly affected post-burn vegetation dynamics, apparently by increasing reproduction. Similar to Fulé et al.'s (2001) study of Sunset Crater penstemon in northern Arizona, Riegel et al. (1995) found that trenching to reduce ponderosa pine root competition increased ground flora cover in Oregon.

FUTURE ARIZONA RESEARCH

Multivariate statistical methods need to be used more frequently in combination with univariate methods in Arizona ponderosa pine vegetation research. Unless part of a larger multivariate analysis, useful measures like total ground flora biomass and species richness are univariate approaches to the multivariate problem of plant communities and their relationships with other ecosystem components (Abella and Covington in press). It remains unclear how season of burn, burn intensity, and mechanical thinning + burning interactions differentially affect ponderosa pine ground flora. Ground flora responses to restoration treatments also have not been compared on different soil types, and replicating research sites across the landscape to evaluate the geographic consistency of research findings is one of the greatest research needs in Arizona ponderosa pine. In a nonmanipulative study, for example, Ffolliott and Clary (1975) reported generally greater ground flora biomass on sedimentary than on igneous soils. Differences in vegetation responses to restoration may also occur among different soil types.

Research published to date suggests that thinning and burning treatments have great potential to improve native ground flora communities, providing support for implementing monitored, broad-scale restoration experiments in Arizona ponderosa pine forests. These experiments should also test treatments additional to thinning and burning, such as seeding of native species and life-history specific control methods of exotic species. In an earlier review of fire effects in ponderosa pine forests, Wright (1978) noted that questions about specific responses of individual species and long-term, community-level transitions had been little studied. These specific questions remain little studied to date. Specific data about demographics and seed dispersal of individual species, the role of seeding native species, and detailed multivariate analyses of community dynamics could advance ecological restoration's ability to assist recovery of native ground flora vegetation in Arizona ponderosa pine forests.

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