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Changes in understory vegetation of a ponderosa pine forest in northern Arizona 30 years after the Rattle Burn Wildfire

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Abstract

Wildland fires can cause shifts in understory species composition and production. Many studies have examined short-term changes in understory vegetation following a wildfire; however, very few long term studies are available. The objective of this study was to examine changes in understory (herb and shrub) species composition and production since the 1972 Rattle Burn wildfire on the Coconino National Forest near Flagstaff, Arizona. Understory species composition and production were originally sampled in 1972, 1974, and 1980 and were re-sampled during July and August of 2002 and 2003 on 30 plots in each of four sites: high severity burn, low severity burn, unburned site prescribed burned in 1977, and an unburned site. Repeated measures analysis was used to test for the effects of fire and time on species production. The effects of fire and time on species composition as well as species production were tested using Multi-Response Permutation Procedures (MRPP). A lingering effect of the Rattle Burn wildfire on the

understory plant production and composition was revealed. Burned sites may have greater understory production as compared to unburned sites up to 30 years after a wildfire. However, species composition on burned sites is altered. A significant relationship between tree density and understory species composition and production was found for 1972, but no relationship was found for overstory parameters and understory species production and composition for 2003.

Key words: understory vegetation, wildfire, ponderosa pine, Coconino National Forest

Introduction

Historically, the natural fire return interval in Arizona ponderosa pine communities ranged from 5 to 12 years. This short fire return interval maintained an open forest with an herbaceous understory (Covington and Moore 1994, Wright and Bailey 1982). However, fire frequency has decreased since European settlement due to fuel fragmentation from roads, decreased herbaceous fuels from livestock grazing, fire suppression, and timber management activities (Mast et al. 1999, Cooper 1960). This decrease in fire frequency has resulted in a decrease in herb and shrub productivity (Covington 1994). The decrease in understory vegetation productivity is commonly associated with an increase in tree density (Moore and Dieter 1992, Naumberg et al. 2001), crown closure, and an increase in the litter layer (Clary et al. 1968).

Fire alters understory species composition and production by removing non-resistant plants, thereby reducing competition for moisture, light, and nutrients to the remaining plants (Pyne et al. 1996, Wright and Bailey 1982). The nutrients released from the dead plants are redistributed to the remaining individuals, which can increase their growth rates (Goodwin and Sheley 2001). After a fire, plant species from adjacent communities that are able to establish, grow, and regenerate, in addition to the fire-resistant plant species, constitute the post-fire community. However, the degree of change from pre-fire community to post-fire community is influenced by the intensity, severity, and periodicity of the fire (Wright and Bailey 1982).

A number of studies have examined short-term changes in understory vegetation following fire in ponderosa pine stands of northern Arizona. Pearson et al. (1972) reported an increase in understory plant production the first year after a wildfire in moderately and severely burned areas compared to an unburned area. Ffolliott et al. (1977) reported an increase in herbage production for up to 11 years after a prescribed burn compared to an unburned area. Lowe et al. (1979) reported a peak in forbs three years after a fire. However, forbs production did not differ from an unburned area seven years after the fire. Grass production declined the first year after the fire, peaked at year seven, and remained twice the production of an unburned area at year twenty (Lowe et al.1979). Two more recent studies (Griffis et al. 2001 and Crawford et al. 2001) reported increased species richness and abundance of exotic plant species within five years on wildfires that killed 90% or more of the trees, compared to both moderately burned sites and thinned and burned sites.

These studies provide insights into short-term changes in understory species, but provide little information regarding long-term changes. This study was built upon a preexisting project that was developed in 1972 after a wildfire burned through a ponderosa pine forest in the Coconino National Forest of northern Arizona. The original studies reported the short-term response of understory plant species to fire in terms of composition and production for the years of 1972, 1974, and 1980 (Beaulieu 1975, Oswald 1981). The objective of this study was to examine changes in species composition and production of understory vegetation since the 1972 Rattle Burn wildfire on the Coconino National Forest near Flagstaff, Arizona. In addition, we attempted to explore how overstory attributes contributed to patterns in understory composition and production.

2. Methods

2.1. Study Area

The study area was located in the Coconino National Forest 30 km southwest of Flagstaff, Arizona. Soils are of the Kaibab limestone formation with interbedded Coconino sandstone. Forty percent of the soils is comprised of the Soldier and McVickers series, both classified as Alfisols, while 50% is an unnamed extremely stony, limestone outcrop complex. The overall climate is described as cold winters, mild summers, and moderate humidity. Most of the precipitation falls in the form of snow during the winter; the remainder occurs as rain showers in the months of July and August (Campbell et al. 1977). Annual precipitation ranged from 28.5 cm to 90.4 cm and averaged 56.7 cm during the 33-year period of 1970 to 2003 (Fig. 1) (Western Regional Climate Center, Desert Research Institute 2004).

In early May of 1972, 286 ha were burned by the Rattle Burn wildfire. A logging operation, which removed an average of 16 m^3 ha^{-1} of timber, was conducted within the Rattle Burn wildfire area during the spring of 1970 and the skid trails were seeded with a mixture of hard fescue (most likely *Festuca trachyphylla* (Hack.) Krajina), orchard grass (*Dactylis glomerata* L.), smooth brome (*Bromus inermis* Leyss.), timothy (*Phleum pratense* L.), prairie burnet (*Sanguisorba annua* (Nutt. ex. Hook.) Torr. & Gray), and small burnet (*S. minor* Scop.). During the summer and fall of 1972, a post-fire salvage logging operation removed 4,366 m^3 ha^{-1} of timber and the skid trails were seeded with a mixture of orchard grass, smooth brome, hard fescue, intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkworth and D.R. Dewey), Russian wild-rye (*Psathyrostachys juncea* (Fisch.) Nevski) and yellow sweet clover (*Melilotus officinalis* (L.) Lam.). The study area has been grazed by livestock and elk (*Cervus elaphus*) since the 1970's. According to Dr. James Rolf (personal communication), the high severity burn site was planted with ponderosa pine seedlings in 1983.

2.2. Study Establishment

Plots were established in three watersheds in 1972 after the Rattle Burn wildfire: a high severity burn site (HSWF), a low severity burn site (LSWF), and an unburned site that was prescribed burned in 1977 (UBPB). In 1974, an additional unburned site (UB) was established adjacent to the burned area. Within each research site, 30 plots, 404.7 m^2 in area, were placed along transects, giving a total of 120 plots (4 research sites X 30 plots). Within each plot, four circular quadrats, 0.89 m^2 in area, were established at 90º angles around each center point at a distance of 7.1 m from the center (Fig. 2).

2.3. Data Collection

In July of 2003, tree density and basal area were re-measured on each of the 120 plots (404.7 m^2) by measuring diameter at breast height (DBH) of all trees whose base fell at least halfway within the 404.7 m^2 plots. These overstory measurements were originally collected in the summer of 1972 on the three original watershed sites. Tree diameters were classified into 17 classes represented by the midpoint of each class. In the center of two randomly selected quadrats in each plot, overstory canopy cover was estimated using a spherical densiometer and mean canopy cover estimates per plot were used for comparisons.

We measured two understory response variables: species composition and production. In July and August of 2002 and 2003, understory vegetation within two randomly selected circular quadrats in each plot per site was identified to the species level and clipped. Production was estimated based on oven-dry weight. The samples were dried for 48 hours at 69° C. Dry weights were recorded to the nearest 0.01 g. Species production data were averaged by quadrat (n=2) for analysis. Total production and species composition data were compared with previous data (Beaulieu 1975, Oswald 1981) collected from the same plots in July and August of 1972, 1974, and 1980.

2.4. Data Analysis

Semivariograms were produced using PROC VARIOGRAM and the graphs were compared to spatial covariance models to determine if the response variable, production, was spatially correlated (SAS Institute Inc. 1999). Plant production per plot by site for the five years studied was analyzed using repeated measures procedure in PROC MIXED. The compound symmetric covariance structure was specified for the analysis based on the Akaike's and Bayesian's fit criteria (Little et al. 1996). The data were split into two sets due to unequal treatment levels among the five years studied. Set one included data from four years (1974, 1980, 2002, and 2003) with four levels of treatment (HSWF, LSWF, UBPR, UB) within each year. Set two included data from five years (1972, 1974, 1980, 2002, and 2003) with three levels of treatment (HSWF, LSWF, UBPB) within each year. When a significant treatment by year interaction was found, the random factor (time) was fixed and a one-way ANOVA was conducted on the fixed factor (treatment) to determine the treatment effect on total plant production for the year studied. Tukey's multiple comparison procedure was used to separate treatment means whenever significant treatment effect was found. In addition, Bonferroni adjustment was again used to control inflation of type I error that is associated with multiple analyses in factorial designs (Lehman 1995).

In order to incorporate species composition into the analysis, Multi-Response Permutation Procedures (MRPP) was utilized to test the hypotheses of no difference in production by species between treatments within each year. Euclidean distance was chosen as the distance measure (Zimmerman et al. 1985). In addition, Bonferroni adjustment was used to control inflation of type I error that is associated with multiple analyses on the same dataset (Lehman 1995).

To determine if there was a relationship between the overstory attributes (basal area, canopy cover, and tree density) and understory attributes (species composition and production) of 1972 and 2003, the Mantel test was used to test the hypothesis of no relationship between the overstory matrix and the understory matrix. Euclidean distance was chosen as the distance measure (McCune and Mefford 1999).

Understory species composition and production data were summarized with Detrended Correspondence Analysis (DCA) using PC-ORD software (McCune and Mefford 1999). The data were transformed using square-root transformation in order to give equal weight to all species (Romesburg 1984). To determine what factor(s) is(are) may be contributing to the differences in species composition among the site-year combinations, the most correlated species (Pearson's correlation coefficient, r) to axis one were examined.

3. Results

3.1. Understory plant production

Total plant production by plot within each site and year were not spatially correlated. The time by treatment interaction was significant ($P < 0.001$) for the 5 sampling year and the 4 sampling year data sets. Therefore, each year was analyzed separately for treatment effect using one-way ANOVAs with an alpha level of 0.01. In 1972, the first growing season following the Rattle wildfire, total plant production ranged from 540.86 to 740.70 kg ha^{-1} on the study sites, and did not differ among treatments ($P = 0.60$) (Fig. 3). By 1974, two years post-burn, plant production differed among treatments ($P < 0.001$); with the LSWF site having significantly higher production than the UB site. In 1980, production on the UB site and the UBPB sites did not differ, but was lower than production on the HSWF site ($P < 0.001$). In 2002, production on the HSWF site was significantly higher than that on the UBPB site ($P = 0.004$). In 2003, total understory plant production on the HSWF site was significantly higher than production on the UB site ($P = 0.003$).

3.2. Understory plant composition and production

In concordance with the one-way ANOVA, MRPP did not reveal differences among treatments in production by species for 1972 (alpha=0.01; $P = 0.017$), but did indicate significant differences ($P < 0.001$) among treatments for 1974, 1980, 2002, and 2003. However, since MRPP takes into account composition and production, differences were found between one-way ANOVA and MRPP in the pair-wise comparison results. For 1974, 1980, and 2003, the HSWF and UBPB sites did not differ significantly from each other in terms of species composition and production. However, species composition and production on both of these sites for these three years did differ significantly from the LSWF and UB sites. In addition, the LSWF differed significantly from the UB site for these three years. In 2002, HSWF, LSWF, and UBPB were all significantly different from each other in terms of production and composition.

3.3. Overstory – understory relationship

In 1972, based on the Mantel test, basal area and species composition and production were not significantly correlated (P = 0.132; r = 0.06), but tree density and species composition were negatively correlated (P = 0.013; r = -0.13). In 2003, basal area (P = 0.322; r = -0.03), tree density (P = 0.067; r = -0.07), and canopy cover (P = 0.303; r = -0.04) were not correlated with species composition and production.

3.4 Summarization of species composition and production

Since the 1972 wildfire, 121 species have been identified on the sites. There were 33 species that were newly identified in 2002 and/or 2003 that were not previously documented. Conversely, there were 30 species reported in 1972, 1974, and/or 1980 that were not found in 2002 or 2003. In general, total understory production has decreased over time, with peak production occurring in 1974 and lowest production occurring in 2002. Axis one of the ordination graph accounted for 39% of the variation among the site-year combinations (Fig. 4). Common dandelion (*Taraxacum officinal* G.H. Weber ex Wiggins) (r = -0.80), common mullein (*Verbascum thapsus* L.) (r = -0.66), and western yarrow (*Achillea millefolium* var. *occidentalis* L.; D.C.) (r = -0.71), and Johnston's ragweed (*Polygonum douglasii* spp. *johnstonii* Greene (Munz) Hickman) (r = -0.66) were negatively correlated with axis one; whereas, Virginia strawberry (*Fragaria* *virginiana* ssp. *glauca* Duchesne ; (S. Wats.) Staudt.) (r = 0.72)was positively correlated with axis one.

4. Discussion

As with previous fire studies (Wienk et al. 2004, Andariese and Covington 1986, Zimmerman et al. 1985), the understory vegetation did not respond to fire during the first growing season following the fire. This delayed response is attributed to the time required for colonization by pioneer species, since the species that responded the second season was not previously found in the seed bank (Weink et al. 2004). However, the delay might also be attributed to a delay in the increased nutrient availability (McPherson and Weltzin 1998). The increases in production reported for the same sites in earlier studies (Oswald and Covington 1983, 1984) follow other results (Ffolliott and Clary 1974, Pearson et al. 1972) but also can be attributed to the high (50% higher than long-term mean) precipitation levels recorded in 1980.

The species composition and production of the sites for 2002 was severely affected by the lower than average rainfall for several years in a row prior to 2002. The plant production of the LSWF site of 1974 and the HSWF site of 1980 and 2003 was significantly greater due to the effect of fire in comparison with the unburned sites of the corresponding years. According to Ffolliott et al. (1977), production on burned areas was significantly greater than unburned areas for at least 11 years. Lowe et al. (1978) reported that grass production remained double the amount on burned areas versus unburned areas for at least 20 years following a fire. Therefore, a lingering effect of fire upon the species production of the HSWF site is present for at least 30 years following the wildfire.

With the use of a multivariate procedure (MRPP), species composition and production could be analyzed simultaneously as response variables to fire. This technique indicated that all the sites starting in 1974 (2 years after the wildfire) are significantly different from one another in terms of species composition and production due to the effects of fire with the exception of the HSWF site to the UBPB site. These results from the MRPP analysis differ from the one-way ANOVA, Tukey's multiple-comparison procedure due to the addition of species composition as a response variable. This indicates that fire intensity plays a significant role in species presence and abundance for at least 30 years following the wildfire and 23 years following the prescribed burn.

The Mantel test revealed a significant, but weak negative relationship between tree density and species composition and production for 1972. This is in agreement with literature dealing with overstory-understory vegetation relationships. According to Moore and Deiter (1992) and Naumberg et al. (2001), herbaceous biomass decreases and species composition changes as tree density increases. Weink et al. (2004) reported that two years following thinning and burning, understory production increased. Clary et al. (1966) found a significant increase in herbage production for up to six years in a thinned (14 m^2 ha^{-1} of basal area) versus a non-thinned ponderosa pine stand. Cooper (1960) reported that understory species need at least 25% of the sunlight to reach the forest floor in order to grow. Naumberg and DeWald (1999) found a positive correlation between abundance of graminoids and light received. However, the Mantel test failed to reveal a significant relationship between any overstory attributes and understory species composition and production for the year 2003. Griffis et al. (2001) found that stands that are left unmanaged for at least 30 years with a canopy cover of 90% yields the greatest diversity of native shrubs and cacti within northern Arizona. Moore and Deiter (1992) failed to find a pattern between shrub production and overstory measurements. They reported that other factors such as soil quality, precipitation, treatments, and history also influence understory species production. According to Korb and Springer (2003), response of understory production to thinning and burning can be confounded by plant composition before treatment, the size and spacing of trees after treatment, timing of treatment, time since treatment, and precipitation. Since there was a significant relationship between the overstory and understory vegetation of 1972, maybe the time since treatment could be confounding the relationship for 2003. Another plausible confounding factor is precipitation, due to the drought of 2002, below average precipitation for three years prior to 2002, and below average precipitation for 2003. Clary et al. (1968) and Mitchell and Freeman (1993) both note that the accumulation of pine needles in the litter layer negatively influences the production of understory vegetation. Therefore, another plausible confounding factor could be the litter layer.

The negative correlation between common dandelion, common mullein, and western yarrow with axis one and the positive correlation between Virginia strawberry and axis one may be interpreted as a lack of disturbance, in the form of fire and thinning, since the 1972 wildfire and 1977 prescribed burn. According to Lyon (1966), common dandelion, the second most negatively correlated species to axis one, peaked in production the first year following a fall prescribed burn and the first few years following a spring prescribed burn and then declined in a Douglas-fir forest in south-central Idaho. The decline of common dandelion in the 2002 and 2003 sites reflects the time lag since the 1972 wildfire. Other negatively correlated species, such as common mullein, western yarrow, and Johnston's ragweed, also increase with fire and then decrease with time since the fire (Parker 1972, Snyder 1992, Humphrey 1984). According to Despain and Miller (2000), Virginia strawberry is a fire sensitive species that declines in production following a fire and then gradually increases in production.

(To be added somewhere if needed?!)

None of the sites used in this study represent the historic fire return intervals associated with Ponderosa pine forests of the southwestern United States, but do represent conditions where the historic disturbance vector (fire) has been removed since the early and mid 1970's. The impact of grazing by both domestigated and wild animals, while not quantified in this study, wascobserved to have had a tremendous impact on the understory community, and has been noted in other studies (Pearson et al. 1972, Mitchell and Freeman 1993)

5. Conclusions

In this study, the effects from the high severity wildfire are still lingering on the understory plant production. In addition, the wildfire and the prescribed burn are still an influencing factor upon the species composition found in those sites. Therefore, the burn history of the site has affected the species composition and production for those sites until another disturbance occurs.

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Table 1. Mean overstory attributes (n=30) ±SE by site and year for the Rattle Burn HSWF = high severity wildfire site, LSWF = low severity wildfire site, UBPB = unburned/prescribed burned site, and UB = unburned site.

Site	1972*	1972**	2003
		Tree Density (no. ha^{-1})	
LSWF	1837.8 ± 197.4	257.1±36.1	248.7 ±27.0
HSWF	1575.7 ± 184.7	16.5 ±6.8	547.7 ±59.2
UBPB	1592.2 ± 165.3	1519.7 ±165.9	524.7 ±60.3
UB***	NA	NA	401.1 ±30.7
		Basal Area (m^2 ha^{-1})****	
LSWF	45	17	20.7 ±2.9
HSLF	44	2	9.5 ±1.5
UBPB	48	28	34.6 ±2.2
UB***	NA	NA	37.1 +2.5

* Prelogging determined from stumps, burned trees (for LSWF and HSWF) and live trees.
** Postlogging for UBPB and post salvage for LSWF and HSWF determined from live trees.
*** Overstory data was not collected for 1974 UB site in 1972.
**** SE are not available for 1972 basal areas.