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

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11 **Abstract**

12 Wildland fires can cause shifts in understory species composition and production. Many
13 studies have examined short-term changes in understory vegetation following a wildfire;
14 however, very few long term studies are available. The objective of this study was to
15 examine changes in understory (herb and shrub) species composition and production
16 since the 1972 Rattle Burn wildfire on the Coconino National Forest near Flagstaff,
17 Arizona. Understory species composition and production were originally sampled in
18 1972, 1974, and 1980 and were re-sampled during July and August of 2002 and 2003 on
19 30 plots in each of four sites: high severity burn, low severity burn, unburned site
20 prescribed burned in 1977, and an unburned site. Repeated measures analysis was used
21 to test for the effects of fire and time on species production. The effects of fire and time
22 on species composition as well as species production were tested using Multi-Response
23 Permutation Procedures (MRPP). A lingering effect of the Rattle Burn wildfire on the

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

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

31 **Introduction**

32 Historically, the natural fire return interval in Arizona ponderosa pine
33 communities ranged from 5 to 12 years. This short fire return interval maintained an
34 open forest with an herbaceous understory (Covington and Moore 1994, Wright and
35 Bailey 1982). However, fire frequency has decreased since European settlement due to
36 fuel fragmentation from roads, decreased herbaceous fuels from livestock grazing, fire
37 suppression, and timber management activities (Mast et al. 1999, Cooper 1960). This
38 decrease in fire frequency has resulted in a decrease in herb and shrub productivity
39 (Covington 1994). The decrease in understory vegetation productivity is commonly
40 associated with an increase in tree density (Moore and Dieter 1992, Naumberg et al.
41 2001), crown closure, and an increase in the litter layer (Clary et al. 1968).

42 Fire alters understory species composition and production by removing non-
43 resistant plants, thereby reducing competition for moisture, light, and nutrients to the
44 remaining plants (Pyne et al. 1996, Wright and Bailey 1982). The nutrients released from
45 the dead plants are redistributed to the remaining individuals, which can increase their
46 growth rates (Goodwin and Sheley 2001). After a fire, plant species from adjacent

47 communities that are able to establish, grow, and regenerate, in addition to the fire-
48 resistant plant species, constitute the post-fire community. However, the degree of
49 change from pre-fire community to post-fire community is influenced by the intensity,
50 severity, and periodicity of the fire (Wright and Bailey 1982).

51 A number of studies have examined short-term changes in understory
52 vegetation following fire in ponderosa pine stands of northern Arizona. Pearson et al.
53 (1972) reported an increase in understory plant production the first year after a wildfire in
54 moderately and severely burned areas compared to an unburned area. Ffolliott et al.
55 (1977) reported an increase in herbage production for up to 11 years after a prescribed
56 burn compared to an unburned area. Lowe et al. (1979) reported a peak in forbs three
57 years after a fire. However, forbs production did not differ from an unburned area seven
58 years after the fire. Grass production declined the first year after the fire, peaked at year
59 seven, and remained twice the production of an unburned area at year twenty (Lowe et
60 al.1979). Two more recent studies (Griffis et al. 2001 and Crawford et al. 2001) reported
61 increased species richness and abundance of exotic plant species within five years on
62 wildfires that killed 90% or more of the trees, compared to both moderately burned sites
63 and thinned and burned sites.

64 These studies provide insights into short-term changes in understory species, but
65 provide little information regarding long-term changes. This study was built upon a
66 preexisting project that was developed in 1972 after a wildfire burned through a
67 ponderosa pine forest in the Coconino National Forest of northern Arizona. The original
68 studies reported the short-term response of understory plant species to fire in terms of
69 composition and production for the years of 1972, 1974, and 1980 (Beaulieu 1975,

70 Oswald 1981). The objective of this study was to examine changes in species
71 composition and production of understory vegetation since the 1972 Rattle Burn wildfire
72 on the Coconino National Forest near Flagstaff, Arizona. In addition, we attempted to
73 explore how overstory attributes contributed to patterns in understory composition and
74 production.

75 **2. Methods**

76 2.1. Study Area

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

87 In early May of 1972, 286 ha were burned by the Rattle Burn wildfire. A logging
88 operation, which removed an average of $16 \text{ m}^3 \text{ ha}^{-1}$ of timber, was conducted within the
89 Rattle Burn wildfire area during the spring of 1970 and the skid trails were seeded with a
90 mixture of hard fescue (most likely *Festuca trachyphylla* (Hack.) Krajina), orchard grass
91 (*Dactylis glomerata* L.), smooth brome (*Bromus inermis* Leyss.), timothy (*Phleum*
92 *pratense* L.), prairie burnet (*Sanguisorba annua* (Nutt. ex. Hook.) Torr. & Gray), and

93 small burnet (*S. minor* Scop.). During the summer and fall of 1972, a post-fire salvage
94 logging operation removed 4,366 m³ ha⁻¹ of timber and the skid trails were seeded with a
95 mixture of orchard grass, smooth brome, hard fescue, intermediate wheatgrass
96 (*Thinopyrum intermedium* (Host) Barkworth and D.R. Dewey), Russian wild-rye
97 (*Psathyrostachys juncea* (Fisch.) Nevski) and yellow sweet clover (*Melilotus officinalis*
98 (L.) Lam.). The study area has been grazed by livestock and elk (*Cervus elaphus*) since
99 the 1970's. According to Dr. James Rolf (personal communication), the high severity
100 burn site was planted with ponderosa pine seedlings in 1983.

101 2.2. Study Establishment

102 Plots were established in three watersheds in 1972 after the Rattle Burn wildfire: a
103 high severity burn site (HSWF), a low severity burn site (LSWF), and an unburned site
104 that was prescribed burned in 1977 (UBPB). In 1974, an additional unburned site (UB)
105 was established adjacent to the burned area. Within each research site, 30 plots, 404.7 m²
106 in area, were placed along transects, giving a total of 120 plots (4 research sites X 30
107 plots). Within each plot, four circular quadrats, 0.89 m² in area, were established at 90°
108 angles around each center point at a distance of 7.1 m from the center (Fig. 2).

109 2.3. Data Collection

110 In July of 2003, tree density and basal area were re-measured on each of the 120
111 plots (404.7 m²) by measuring diameter at breast height (DBH) of all trees whose base
112 fell at least halfway within the 404.7 m² plots. These overstory measurements were
113 originally collected in the summer of 1972 on the three original watershed sites. Tree
114 diameters were classified into 17 classes represented by the midpoint of each class. In
115 the center of two randomly selected quadrats in each plot, overstory canopy cover was

116 estimated using a spherical densiometer and mean canopy cover estimates per plot were
117 used for comparisons.

118 We measured two understory response variables: species composition and
119 production. In July and August of 2002 and 2003, understory vegetation within two
120 randomly selected circular quadrats in each plot per site was identified to the species
121 level and clipped. Production was estimated based on oven-dry weight. The samples
122 were dried for 48 hours at 69° C. Dry weights were recorded to the nearest 0.01 g.
123 Species production data were averaged by quadrat (n=2) for analysis. Total production
124 and species composition data were compared with previous data (Beaulieu 1975, Oswald
125 1981) collected from the same plots in July and August of 1972, 1974, and 1980.

126 2.4. Data Analysis

127 Semivariograms were produced using PROC VARIOGRAM and the graphs were
128 compared to spatial covariance models to determine if the response variable, production,
129 was spatially correlated (SAS Institute Inc. 1999). Plant production per plot by site for
130 the five years studied was analyzed using repeated measures procedure in PROC
131 MIXED. The compound symmetric covariance structure was specified for the analysis
132 based on the Akaike's and Bayesian's fit criteria (Little et al. 1996). The data were split
133 into two sets due to unequal treatment levels among the five years studied. Set one
134 included data from four years (1974, 1980, 2002, and 2003) with four levels of treatment
135 (HSWF, LSWF, UBPR, UB) within each year. Set two included data from five years
136 (1972, 1974, 1980, 2002, and 2003) with three levels of treatment (HSWF, LSWF,
137 UBPB) within each year. When a significant treatment by year interaction was found, the
138 random factor (time) was fixed and a one-way ANOVA was conducted on the fixed

139 factor (treatment) to determine the treatment effect on total plant production for the year
140 studied. Tukey's multiple comparison procedure was used to separate treatment means
141 whenever significant treatment effect was found. In addition, Bonferroni adjustment was
142 again used to control inflation of type I error that is associated with multiple analyses in
143 factorial designs (Lehman 1995).

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

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

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

162 **3. Results**

163 3.1. Understory plant production

164 Total plant production by plot within each site and year were not spatially
165 correlated. The time by treatment interaction was significant ($P < 0.001$) for the 5
166 sampling year and the 4 sampling year data sets. Therefore, each year was analyzed
167 separately for treatment effect using one-way ANOVAs with an alpha level of 0.01. In
168 1972, the first growing season following the Rattle wildfire, total plant production ranged
169 from 540.86 to 740.70 kg ha⁻¹ on the study sites, and did not differ among treatments ($P =$
170 0.60) (Fig. 3). By 1974, two years post-burn, plant production differed among treatments
171 ($P < 0.001$); with the LSWF site having significantly higher production than the UB site.
172 In 1980, production on the UB site and the UBPB sites did not differ, but was lower than
173 production on the HSWF site ($P < 0.001$). In 2002, production on the HSWF site was
174 significantly higher than that on the UBPB site ($P = 0.004$). In 2003, total understory
175 plant production on the HSWF site was significantly higher than production on the UB
176 site ($P = 0.003$).

177 3.2. Understory plant composition and production

178 In concordance with the one-way ANOVA, MRPP did not reveal differences
179 among treatments in production by species for 1972 ($\alpha=0.01$; $P = 0.017$), but did
180 indicate significant differences ($P < 0.001$) among treatments for 1974, 1980, 2002, and
181 2003. However, since MRPP takes into account composition and production, differences
182 were found between one-way ANOVA and MRPP in the pair-wise comparison results.
183 For 1974, 1980, and 2003, the HSWF and UBPB sites did not differ significantly from
184 each other in terms of species composition and production. However, species

185 composition and production on both of these sites for these three years did differ
186 significantly from the LSWF and UB sites. In addition, the LSWF differed significantly
187 from the UB site for these three years. In 2002, HSWF, LSWF, and UBPB were all
188 significantly different from each other in terms of production and composition.

189 3.3. Overstory – understory relationship

190 In 1972, based on the Mantel test, basal area and species composition and
191 production were not significantly correlated ($P = 0.132$; $r = 0.06$), but tree density and
192 species composition were negatively correlated ($P = 0.013$; $r = -0.13$). In 2003, basal
193 area ($P = 0.322$; $r = -0.03$), tree density ($P = 0.067$; $r = -0.07$), and canopy cover ($P =$
194 0.303 ; $r = -0.04$) were not correlated with species composition and production.

195 3.4 Summarization of species composition and production

196 Since the 1972 wildfire, 121 species have been identified on the sites. There were
197 33 species that were newly identified in 2002 and/or 2003 that were not previously
198 documented. Conversely, there were 30 species reported in 1972, 1974, and/or 1980 that
199 were not found in 2002 or 2003. In general, total understory production has decreased
200 over time, with peak production occurring in 1974 and lowest production occurring in
201 2002. Axis one of the ordination graph accounted for 39% of the variation among the
202 site-year combinations (Fig. 4). Common dandelion (*Taraxacum officinal* G.H. Weber
203 ex Wiggins) ($r = -0.80$), common mullein (*Verbascum thapsus* L.) ($r = -0.66$), and
204 western yarrow (*Achillea millefolium* var. *occidentalis* L.; D.C.) ($r = -0.71$), and
205 Johnston's ragweed (*Polygonum douglasii* spp. *johnstonii* Greene (Munz) Hickman) ($r =$
206 -0.66) were negatively correlated with axis one; whereas, Virginia strawberry (*Fragaria*

207 *virginiana* ssp. *glauca* Duchesne ; (S. Wats.) Staudt.) ($r = 0.72$) was positively correlated
208 with axis one.

209 **4. Discussion**

210 As with previous fire studies (Wienk et al. 2004, Andariese and Covington 1986,
211 Zimmerman et al. 1985), the understory vegetation did not respond to fire during the first
212 growing season following the fire. This delayed response is attributed to the time
213 required for colonization by pioneer species, since the species that responded the second
214 season was not previously found in the seed bank (Weink et al. 2004). However, the
215 delay might also be attributed to a delay in the increased nutrient availability (McPherson
216 and Weltzin 1998). The increases in production reported for the same sites in earlier
217 studies (Oswald and Covington 1983, 1984) follow other results (Ffolliott and Clary
218 1974, Pearson et al. 1972) but also can be attributed to the high (50% higher than long-
219 term mean) precipitation levels recorded in 1980.

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

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

240 The Mantel test revealed a significant, but weak negative relationship between
241 tree density and species composition and production for 1972. This is in agreement with
242 literature dealing with overstory-understory vegetation relationships. According to
243 Moore and Deiter (1992) and Naumberg et al. (2001), herbaceous biomass decreases and
244 species composition changes as tree density increases. Weink et al. (2004) reported that
245 two years following thinning and burning, understory production increased. Clary et al.
246 (1966) found a significant increase in herbage production for up to six years in a thinned
247 ($14 \text{ m}^2 \text{ ha}^{-1}$ of basal area) versus a non-thinned ponderosa pine stand. Cooper (1960)
248 reported that understory species need at least 25% of the sunlight to reach the forest floor
249 in order to grow. Naumberg and DeWald (1999) found a positive correlation between
250 abundance of graminoids and light received. However, the Mantel test failed to reveal a
251 significant relationship between any overstory attributes and understory species
252 composition and production for the year 2003. Griffis et al. (2001) found that stands that

253 are left unmanaged for at least 30 years with a canopy cover of 90% yields the greatest
254 diversity of native shrubs and cacti within northern Arizona. Moore and Deiter (1992)
255 failed to find a pattern between shrub production and overstory measurements. They
256 reported that other factors such as soil quality, precipitation, treatments, and history also
257 influence understory species production. According to Korb and Springer (2003),
258 response of understory production to thinning and burning can be confounded by plant
259 composition before treatment, the size and spacing of trees after treatment, timing of
260 treatment, time since treatment, and precipitation. Since there was a significant
261 relationship between the overstory and understory vegetation of 1972, maybe the time
262 since treatment could be confounding the relationship for 2003. Another plausible
263 confounding factor is precipitation, due to the drought of 2002, below average
264 precipitation for three years prior to 2002, and below average precipitation for 2003.
265 Clary et al. (1968) and Mitchell and Freeman (1993) both note that the accumulation of
266 pine needles in the litter layer negatively influences the production of understory
267 vegetation. Therefore, another plausible confounding factor could be the litter layer.

268 The negative correlation between common dandelion, common mullein, and
269 western yarrow with axis one and the positive correlation between Virginia strawberry
270 and axis one may be interpreted as a lack of disturbance, in the form of fire and thinning,
271 since the 1972 wildfire and 1977 prescribed burn. According to Lyon (1966), common
272 dandelion, the second most negatively correlated species to axis one, peaked in
273 production the first year following a fall prescribed burn and the first few years following
274 a spring prescribed burn and then declined in a Douglas-fir forest in south-central Idaho.
275 The decline of common dandelion in the 2002 and 2003 sites reflects the time lag since

276 the 1972 wildfire. Other negatively correlated species, such as common mullein, western
277 yarrow, and Johnston's ragweed, also increase with fire and then decrease with time since
278 the fire (Parker 1972, Snyder 1992, Humphrey 1984). According to Despain and Miller
279 (2000), Virginia strawberry is a fire sensitive species that declines in production
280 following a fire and then gradually increases in production.

281 (To be added somewhere if needed?!)

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

289 **5. Conclusions**

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

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445 Table 1. Mean overstory attributes (n=30) \pm SE by site and year for the Rattle Burn

446 HSWF = high severity wildfire site, LSWF = low severity wildfire site, UBPB =

447 unburned/prescribed burned site, and UB = unburned site.

448

449 Site	1972*	1972**	2003
450	Tree Density (no. ha ⁻¹)		
451 LSWF	1837.8 \pm 197.4	257.1 \pm 36.1	248.7 \pm 27.0
452 HSWF	1575.7 \pm 184.7	16.5 \pm 6.8	547.7 \pm 59.2
453 UBPB	1592.2 \pm 165.3	1519.7 \pm 165.9	524.7 \pm 60.3
454 UB***	NA	NA	401.1 \pm 30.7
455	Basal Area (m ² ha ⁻¹)****		
456	Basal Area (m ² ha ⁻¹)****		
457 LSWF	45	17	20.7 \pm 2.9
458 HSLF	44	2	9.5 \pm 1.5
459 UBPB	48	28	34.6 \pm 2.2
460 UB***	NA	NA	37.1 \pm 2.5

461 * Prelogging determined from stumps, burned trees (for LSWF and HSWF) and live
462 trees.

463 ** Postlogging for UBPB and post salvage for LSWF and HSWF determined from live
464 trees.

465 *** Overstory data was not collected for 1974 UB site in 1972.

466 **** SE are not available for 1972 basal areas.

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