Preliminary Results from the Mineral Ecosystem Management Area (EMA) Experimental Block Study: One-Year Post-Treatment

May 2013

Report prepared for:
Apache-Sitgreaves National Forests

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Native Rocky Mountain irises (*Iris missouriensis*) bloom in Experimental Block 1 one year following a full restoration treatment. *Photo by John Paul Roccaforte, May 2009*

Abstract

Southwestern ponderosa pine (*Pinus ponderosa*) forest ecosystems have become uncharacteristically dense as a result of livestock grazing, logging, and fire exclusion, which has led to an increase in vulnerability to high-severity, landscape-scale crown fires. In 2002, the Ecological Restoration Institute (ERI) at Northern Arizona University (NAU) and the Apache-Sitgreaves (A-S) National Forests cooperatively implemented a replicated ecological restoration experiment to (1) determine site-specific reference conditions, (2) measure and evaluate contemporary (pre-treatment) forest structure variables, and (3) test responses to three treatments: control, full restoration, and burn only. The site is located in a ponderosa pine forest and spans an elevation gradient from the pinyon-juniper ecotone to the dry mixed conifer ecotone. Reconstructed total basal area (BA) averaged 40 ft^2/acre and total tree density averaged 35 trees/acre across all treatments indicating that a relatively open forest structure existed at the Mineral site in 1880. By 2002, prior to treatment, total BA had increased by more than 300% to an average of 125 ft^2/acre and total tree density increased by more than 1000% to an average of 376 trees/acre. In 2009, following treatment, the full restoration treatment reduced total BA by 53% from 135 ft^2/acre to 64 ft^2/acre and total tree density by 83% from 404 trees/acre to 67 trees/acre. In the burn only treatment, total BA increased by 3% from 120 ft^2/acre to 123 ft^2/acre and tree density was reduced by 18% from 339 trees/acre to 279 trees/acre between 2002 and 2009. In the control, little change in total BA and tree density occurred between 2002 and 2009. Post-treatment diameter distributions in the full restoration treatment closely matched the historical distribution. In contrast, the burn only treatment had only small reductions in the lower diameter classes. Following treatment, about 15% of the presettlement trees died or were cut in the full restoration treatment compared to 23% mortality of presettlement trees in the burn only treatment. Ten percent of presettlement trees died in the control during the same time without active treatment. One year after application, the full restoration treatment shifted forest structure and diameter distributions within the range of variability historically present at the Mineral site. In contrast, the burn only treatment did not shift forest structure and diameter distributions within the historical range of variability in the short term. The ERI will conduct a five-year remeasurement at the Mineral site in the summer of 2013 and will build upon the information provided in this report to evaluate five-year post-treatment responses on forest structure, regeneration, surface fuels, canopy cover, herbaceous understory, and potential fire behavior.

Introduction

Southwestern ponderosa pine (*Pinus ponderosa*) forest ecosystems have become uncharacteristically dense as a result of livestock grazing, logging, and fire exclusion (Cooper 1960, Covington et al. 1997) which has led to an increase in vulnerability to high-severity, landscape-scale crown fires (Allen et al. 2002). The two largest fires in Arizona history — the 2002 Rodeo-Chediski fire (468,638 acres) and the 2011 Wallow fire (538,049 acres total, 522,642 acres in Arizona) — occurred in the White Mountains of east-central Arizona (InciWeb.org). In addition to the loss of critical wildlife habitat and old-growth trees and the possibility that previously forested areas may experience type conversion (Savage and Mast 2005, Roccaforte et al. 2012), the fires have cost a combined $417 million to date including fire suppression, loss of property, and rehabilitation (Western Forestry Leadership Coalition 2010).

In recent decades, managers have implemented restoration and fuels treatments in altered forests to restore ecological integrity and increase resilience to disturbance events, such as high-severity crown fires and insect outbreaks (Covington et al. 1997, Stephens et al. 2009, Roccaforte et al. 2010) and associated research about these treatments has increased substantially (see Fulé et al. 2012). In 2002, the Ecological Restoration Institute (ERI) at Northern Arizona University (NAU) and the Apache-Sitgreaves (A-S) National Forests cooperatively implemented a replicated ecological restoration experiment on four replicated experimental blocks comprising approximately 400 acres in a ponderosa pine forest near Springerville, Arizona.

The goals of this study were to (1) determine site-specific reference conditions based on dendrochronological reconstructions of historical forest structure, (2) measure and evaluate contemporary (pre-treatment) forest structure variables, and (3) test responses to three treatments: control, full restoration, and burn only.

Methods

Study Area

The study site is located within the Mineral Ecosystem Management Area (EMA) in east-central Arizona on the Apache-Sitgreaves National Forests. The site has a north aspect with slopes ranging between 0 – 27%. Elevations range from approximately 7,700 – 8,400 feet. The site is located in a ponderosa pine forest and spans an elevation gradient from the pinyon-juniper ecotone to the dry mixed conifer ecotone. Overstory tree species present at the site include: ponderosa pine, Gambel oak, juniper, pinyon, southwestern white pine, Douglas-fir, white fir, and aspen (see Table 1 for scientific names of species). Shrub species present include: wax current (*Ribes cereum*), Woods' rose (*Rosa woodsii*), and Fendler's ceanothus (*Ceanothus fendleri*). The understory herbaceous plant community is characterized by a mix of mostly native perennial graminoids and forbs. Common perennial grasses include squirreltail (*Elymus elymoides*), Arizona fescue (*Festuca arizonica*), mountain muhly (*Muhlenbergia montana*), muttongrass (*Poa fendleriana*), Junegrass (*Koeleria macrantha*), and there is also a dominant component of sedge species (*Carex* spp.). Common forbs include ragworts (*Packera* spp.), fleabanes (*Erigeron* spp.),

Table 1. Species names and codes for trees occurring at the Mineral site.

Common name	Species	Code
White fir	*Abies concolor* (Gord. & Glend.) Lindl. Ex Hildebr	ABCO
Alligator juniper	*Juniperus deppeana* Steud.	JUDE
Oneseed juniper	*Juniperus monosperma* (Engelm.) Sarg	JUMO
Utah juniper	*Juniperus osteosperma* (Torr.) Little	JUOS
Twoneedle pinyon	*Pinus edulis* Engelm.	PIED
Ponderosa pine	*Pinus ponderosa* C. Lawson var. *scopulorum* Engelm.	PIPO
Southwestern white pine	*Pinus strobiformis* Engelm.	PIST
Quaking aspen	*Populus tremuloides* Michx.	POTR
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	PSME
Gambel oak	*Quercus gambelii* Nutt.	QUGA

Note: Nomenclature follows USDA plants database (USDA 2013).

Wheeler's thistle (*Cirsium wheeleri*), pineywoods geranium (*Geranium caespitosum*), alpine false parsley (*Pseudocymopterus montanus*), groundcover milkvetch (*Astragalus humistratus*), yellow hawkweed (*Hieracium fendleri*), and yarrow (*Achillea millefolium*). Soils are classified as a complex of Mollic Eutroboralfs, Lithic Argiborolls, and Eutric Glossoboralfs, of fine to cobbly clay loam texture, derived from volcanic parent material (USDA Forest Service 1987). Between 1979 and 2009, annual precipitation at Greer, Arizona (elevation 8,200 feet, approximately 14 miles southeast of the study site) averaged 21.28 inches with an average January temperature of 30.8 degrees Fahrenheit and an average July temperature of 64.4 degrees Fahrenheit (Western Regional Climate Center, www.wrcc.dri.edu, accessed 5/8/13). Most precipitation occurs in winter and during summer monsoon storms. Land use history at the site includes grazing beginning in the late 1800s and fire suppression since the early 20th century.

Experimental Design

We established four experimental blocks of approximately 100 acres each, each representing one complete replicate (Figure 1). Each block was divided into treatment units of about 33 acres. One of three treatments, untreated control, full restoration, and burn-only was randomly assigned to each unit. The thinning design in the full restoration treatment was developed according to the site-specific historical (pre-1880) pattern of tree species composition and spatial arrangement (Covington et al. 1997). We chose the year 1880 because it represented disruption of the historical frequent fire regime and Euro-American settlement of the Southwest (Moore et al. 1999). All living ponderosa pines older than 1880 (i.e., presettlement trees) or > 16 inches diameter at breast height (dbh) were retained. Presettlement ponderosa pines of any size were identified in the field based on yellow bark coloration and other tree characteristics (White 1985). In addition, wherever evidence of presettlement conifer material was encountered (i.e., snags, logs, stumps, stump holes), an average of 1.5 postsettlement (i.e., trees established after 1880) ponderosa pine "replacement" trees (if > 16 inches dbh) or three ponderosa pine replacement trees (if ≤ 16 inches) were retained within a 60-foot radius of the dead structure. The purpose of leaving more trees when they were ≤ 16 inches was to account for the smaller amount of biomass contributed by smaller diameter replacement trees, possible loss of presettlement evidence due to fire or decomposition,

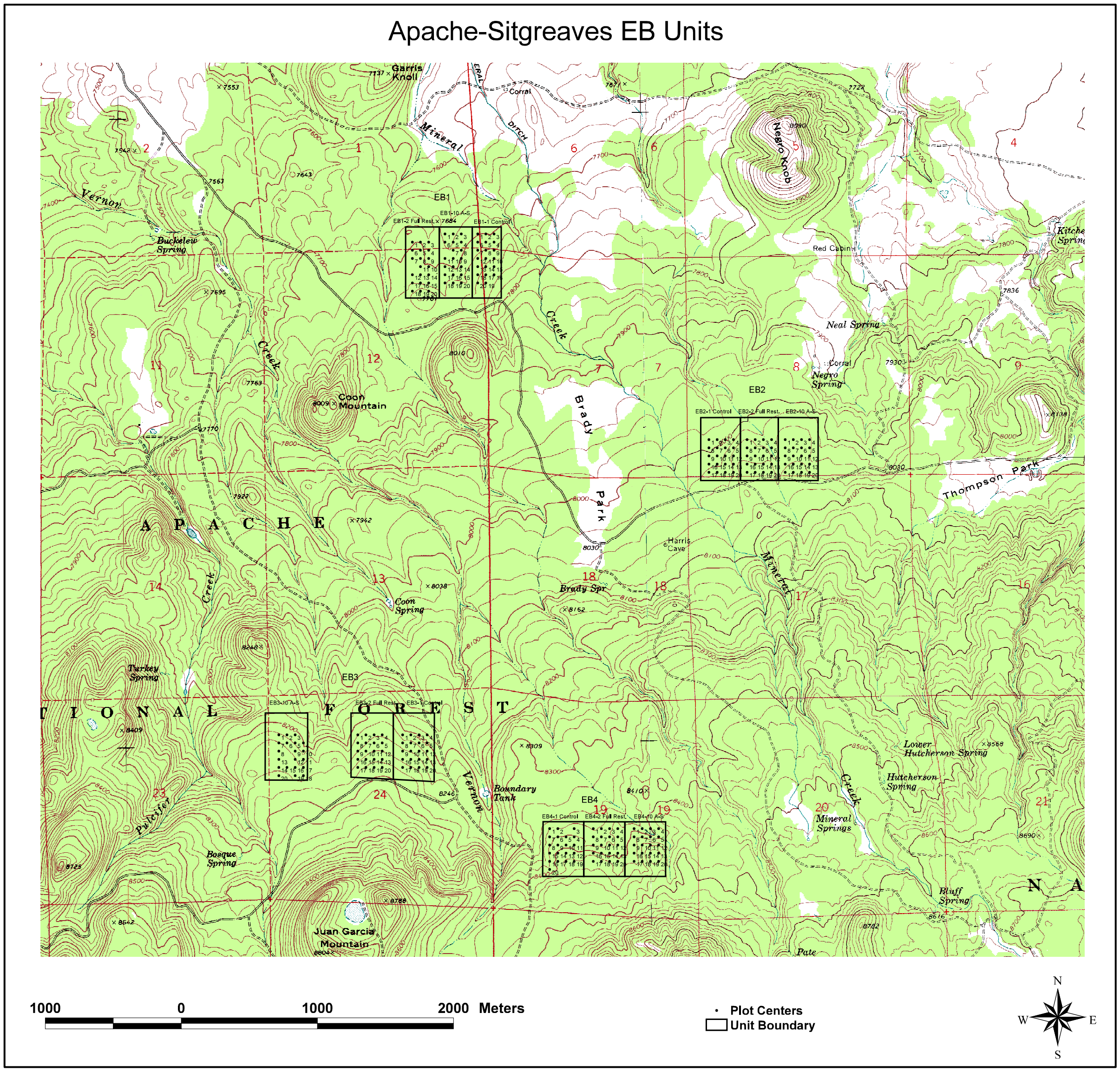

Figure 1. Three treatments were implemented across four experimental blocks which were located on an elevation gradient ranging between 7,700–8,400 feet.

and to allow for unintended mortality resulting from prescribed fire (Covington et al. 1997). Oak and aspen were not thinned. Slash was lopped and scattered. Accumulated forest floor material was raked away from living presettlement trees to prevent cambial girdling (Sackett et al. 1996) and away from large snags to limit ignition during prescribed fires. Treatment units were broadcast burned in October of 2008 (Figure 2).

Field Methods

We installed 20 permanent sample plots on a 197-foot grid in each unit to characterize forest structure and fuels (n = 4 experimental blocks; 4 blocks x 3 treatments x 20 plots = 240 plots). We collected pre-

Figure 2. A prescribed broadcast burn was implemented in October of 2008. *Photo by Rusty Bigelow, Apache-Sitgreaves National Forests*

treatment data in the summer of 2002 and post-treatment data in the summer of 2009. We measured all trees taller than breast height (4.5 feet) within a 1/10th acre (37 foot radius) circular plot. We recorded species, condition (living or snag/log classes from Thomas et al. 1979), dbh, total height, crown base height, and a preliminary field classification of pre- or post-settlement origin for each tree located within the plot. We identified potentially presettlement ponderosa pine trees based on size (> 16 inch diameter at stump height [dsh], 16 inches above ground level) or yellow bark (White 1985). We identified other conifers as potentially presettlement if dsh > 16 inches and aspen were noted as potentially presettlement if dsh > 8 inches. We collected increment cores for all potentially presettlement trees and a 10% subsample of all postsettlement trees to determine age and past size.

We collected regeneration and surface fuels data before and after treatment; however, these data are not presented in this report due to high variability in the first year following treatment. Regeneration and fuels results will be collected and analyzed following the five-year post-treatment remeasurement in the summer of 2013.

Analysis

We mounted and surfaced tree increment cores and visually cross-dated (Stokes and Smiley 1968) them with local tree-ring chronologies. We counted rings on cores that could not be cross-dated, usually junipers or young trees. We estimated additional years to the center ring using a pith locator (concentric circles which were matched to the curvature and density of the inner rings) for cores that missed the pith (Applequist 1958).

We reconstructed historical forest structure (tree density, basal area [BA], and diameter distribution by species) using dendroecological methods (Fulé et al. 1997; Mast et al. 1999, Bakker et al. 2008). We reconstructed diameter for all living trees by subtracting the radial growth since 1880 measured on increment cores and estimated death date of dead trees on the basis of tree condition class using diameter-dependent snag decomposition rates (Thomas et al. 1979; Rogers et al. 1984).

Forest structure reconstruction methods were based on the assumption that evidence of trees (i.e., snags, logs, stumps, stump holes) present in 1880 was intact and correctly identified during pre-treatment inventory. The probability that this occurred was relatively high given the absence of fire since 1880 combined with the semiarid environment limiting the decomposition of conifer wood (Fulé et al. 1997, Mast et al. 1999, Huffman et al. 2001) and because field crews were trained to identify the presence and species of presettlement structures. Moore et al. (2004) found that reconstruction techniques in a similar environment and forest type were reliable within ±10% for tree density over approximately 90 years.

We analyzed differences of total BA and total tree density among treatments using analysis of variance (ANOVA). If a significant effect was found, the ANOVA was followed by Tukey's honestly significant difference (HSD) post-hoc multiple comparisons test. All data met the assumptions of normality and homogeneity of variance based on the Shapiro-Wilk test and Levine test. Treatment differences were assessed at $\alpha = 0.05$.

Results

Forest Structure

Total BA and tree density were lowest in 1880, highest in 2002, and variable in 2009 depending on treatment. Reconstructed total BA averaged 40 ft²/acre and ranged between 38 – 44 ft²/acre and total tree density averaged 35 trees/acre and ranged between 30–37 trees/acre across all treatments (Table 2) indicating that relatively open forest structure existed at the Mineral site in 1880. There were no differences in total BA ($F = 0.1$, $p = 0.9$) or total tree density ($F = 0.2$, $p = 0.8$) among treatments in 1880 (Table 2). Ponderosa pine was the dominant tree species at the Mineral site in 1880, making up about 95% of total BA and total tree density. Overstory composition differed between blocks in 1880. Block 1 was comprised of ponderosa pine, juniper, and Gambel oak; block 2 was comprised of ponderosa pine only; block 3 was comprised of ponderosa pine, Douglas-fir, and aspen; and block 4 was comprised of

Table 2. Forest structure (average basal area [BA] and tree density) by treatment (all blocks combined) in 1880 (reconstructed), 2002 (pre-treatment), and 2009 (post-treatment). Standard errors are shown in parentheses. Species codes are shown in Table 1. N = 4 Statistical testing was performed for total BA and total density across treatments for each time period; different lower case letters, oriented vertically (columns), denote significant differences at α = 0.05.

Treatment	Basal Area 1880 (ft^2/ac)	Basal Area 2002 (ft^2/ac)	Basal Area 2009 (ft^2/ac)	Density 1880 (tpa)	Density 2002 (tpa)	Density 2009 (tpa)
Control						
ABCO	0	0.3 (0.2)	0.3 (0.2)	0	1.4 (0.5)	1.5 (0.5)
JUDE	0.4 (0.4)	2.2 (0.9)	1.3 (0.1)	0.9 (0.6)	6 (2.1)	6.6 (2.3)
JUMO	0.9 (0.4)	0.9 (0.4)	0.2 (0.09)	.65 (0.3)	1 (0.5)	1 (0.5)
JUOS	0.9 (0.9)	1.3 (0.9)	0.1 (0.09)	0.9 (0.7)	1.7 (0.8)	1.4 (0.7)
PIED	0	0.001 (0.001)	0.001 (0.001)	0	0.4 (0.4)	0.4 (0.4)
PIPO	34 (4.3)	114.5 (4.8)	123.2 (5.2)	34.5 (4)	362 (27.5)	347.1 (25.5)
PIST	0	1.3 (0.3)	1.3 (0.4)	0	8 (2.1)	9.0 (2.3)
POTR	0.04 (0.04)	0.4 (0.4)	0.4 (0.4)	0.2 (0.2)	1.2 (1.1)	0.9 (0.8)
PSME	1.3 (1.3)	0.4 (0.2)	0.4 (0.3)	0.4 (0.3)	2.3 (1.0)	2.3 (0.9)
QUGA	0.13 (0.13)	0.001 (0.001)	0.008 (0.008)	0.1 (0.1)	0.5 (0.5)	0.6 (0.6)
Total	38.2 (4.3) a	121.1 (4.3) a	128 (5.2) a	37.2 (3.5) a	383.7 (27.3) a	371 (25.3) a
Full						
ABCO	0.002 (0.002)	0.3 (0.2)	0.3 (0.2)	0.1 (0.1)	0.6 (0.3)	0.2 (0.2)
JUDE	0.02 (0.02)	0.02 (0.02)	0.004 (0.004)	0.4 (0.4)	0.5 (0.2)	0.1 (0.1)
JUMO	0	0.003 (0.003)	0	0	0.1 (0.1)	0
JUOS	0	0.009 (0.009)	0	0	0.2 (0.2)	0
PIED	0	0	0	0	0	0
PIPO	43.1 (4.8)	126 (5.7)	57.5 (3.9)	35.2 (3.7)	383.8 (26.7)	60.2 (4.9)
PIST	0	2.6 (1.3)	2.2 (1.3)	0	10.5 (2.7)	2.4 (1.1)
POTR	0.4 (0.4)	6.5 (3)	3.9 (1.7)	0.4 (0.8)	6.2 (2.8)	3.1 (1.5)
PSME	0	0.4 (0.3)	0.4 (0.4)	0	1.8 (0.6)	0.4 (0.3)
QUGA	0.02 (0.02)	0.001 (0.001)	0	0.1 (0.1)	0.2 (0.2)	0
Total	43.5 (4.8) a	135.4 (5.7) a	64 (4.3) b	37.4 (3.7) a	404.4 (28.3) a	66.5 (6) a
Burn Only						
ABCO	0	0.04 (0.04)	0.09 (0.04)	0	0.6 (0.3)	0.5 (0.2)
JUDE	0.9 (0.9)	1.7 (1.3)	0.9 (0.9)	1 (0.6)	1.2 (0.5)	0.6 (0.4)
JUMO	0.4 (0.4)	0.2 (0.2)	0.04 (0.04)	0.4 (0.2)	0.6 (0.3)	0.4 (0.3)
JUOS	0.04 (0.04)	0	0	0.1 (0.1)	0	0
PIED	0	0	0	0	0	0
PIPO	37.4 (4.3)	117 (5.7)	121.1 (5.7)	28.6 (3.1)	328.6 (31.7)	273.5 (25.8)
PIST	0	0.9 (0.2)	0.9 (0.3)	0	5.4 (1.4)	3.3 (0.8)
POTR	0.02 (0.02)	0.4 (0.4)	0.09 (0.09)	0.2 (0.2)	1.2 (0.8)	0.4 (0.7)
PSME	0	0.2 (0.2)	0.2 (0.2)	0	0.6 (0.3)	0.6 (0.3)
QUGA	0	0.003 (0.003)	0	0	0.4 (0.4)	0
Total	39.1 (4.3) a	120 (5.7) a	123.2 (0.04) a	30.3 (3.1) a	339 (32.1) a	279 (26) a b

ponderosa pine, aspen, Douglas-fir, and white fir. Pinyon and southwestern white pine were not detected at the Mineral site in 1880.

In 2002, prior to treatment, total BA averaged 125 ft^2/acre and ranged between 120 – 135 ft^2/acre and total tree density averaged 376 trees/acre and ranged between 175 – 470 trees/acre. There were no differences in total BA (F = 0.5, $p = 0.6$) or total tree density (F = 0.2, $p = 0.9$) among treatments (Table2). Between 1880 and 2002, total BA and total tree density increased by more than 300% and more than 1000%, respectively. Ponderosa pine was the dominant tree species at the Mineral site prior to treatment, making up about 95% of tree density and BA in 2002.

In 2009, following treatment, forest structure was variable depending on treatment. In the control, total BA increased from 121 ft^2/acre in 2002 to 128 ft^2/acre in 2009 and total tree density decreased from 384 trees/acre in 2002 to 371 trees/acre in 2009 (Table 2). Full restoration treatments reduced total BA by 53% from 135 ft^2/acre to 64 ft^2/acre and total tree density by 83% from 404 trees/acre to 67 trees/acre between 2002 and 2009. In the burn only treatment, BA increased by 3% from 120 ft^2/acre to 123 ft^2/acre and tree density was reduced by 18% from 339 trees/acre to 279 trees/acre between 2002 and 2009. In 2009, the full restoration treatment was significantly different in total BA (F = 6.6, $p = 0.02$) compared to both the control and the burn only treatment. For total tree density (F = 7.3, $p = 0.01$), the full restoration was significantly different compared to the control but not significantly different compared to the burn only treatment and the burn only was not significantly different compared to the control (Table 2). There was no significant difference between the control and burn only in 2009. Ponderosa pine was the dominant tree species at the Mineral site following treatment, making up ≥ 90% of tree density and > 95% of BA across all treatments. In 2002 and 2009, overstory composition differed between blocks. Block 1 was comprised of ponderosa pine, Gambel oak, pinyon, and juniper; block 2 was comprised of ponderosa pine only; and blocks 3 and 4 were comprised of ponderosa pine, Douglas-fir, white fir, southwestern white pine, and aspen.

Reconstructed (1880) diameter distributions for each treatment were unimodal (Figure 3, A-C). Two-thirds of the trees in 1880 had a dbh between 8 — 20 inches and only 16% — 27% of the trees had dbh < 8 inches. By 2002, the diameter distribution had shifted from a unimodal to a reverse J-shaped distribution with 62% – 69% of the trees having a dbh < 8 inches (Figure 3, D-F). Trees > 24 inches decreased from 2.3 trees/acre in 1880 to 1.5 trees/acre by 2002. By 2009, the diameter distribution in the control remained reverse J-shaped with only a slight decrease from 2002 in total tree density (Figure 3, G). Although total tree density in the full restoration treatment was nearly double the historical mean, the diameter distribution shifted from a reverse J-shape back to a unimodal distribution with only 15% of the trees having a dbh < 8 inches (Figure 3, H [Note scale differences]). The post-treatment diameter distribution in the burn only treatment remained dominated by the lower dbh classes (Figure 3, I).

Tree Mortality

Tree mortality varied with treatment. In the control, 15% of the trees alive in 2002 died by 2009 (Figure 4). Ten percent of the presettlement trees alive in 2002 died by 2009 in the control. In the full restoration treatment, 80% of the trees alive prior to treatment were thinned and an additional 3.5% died from

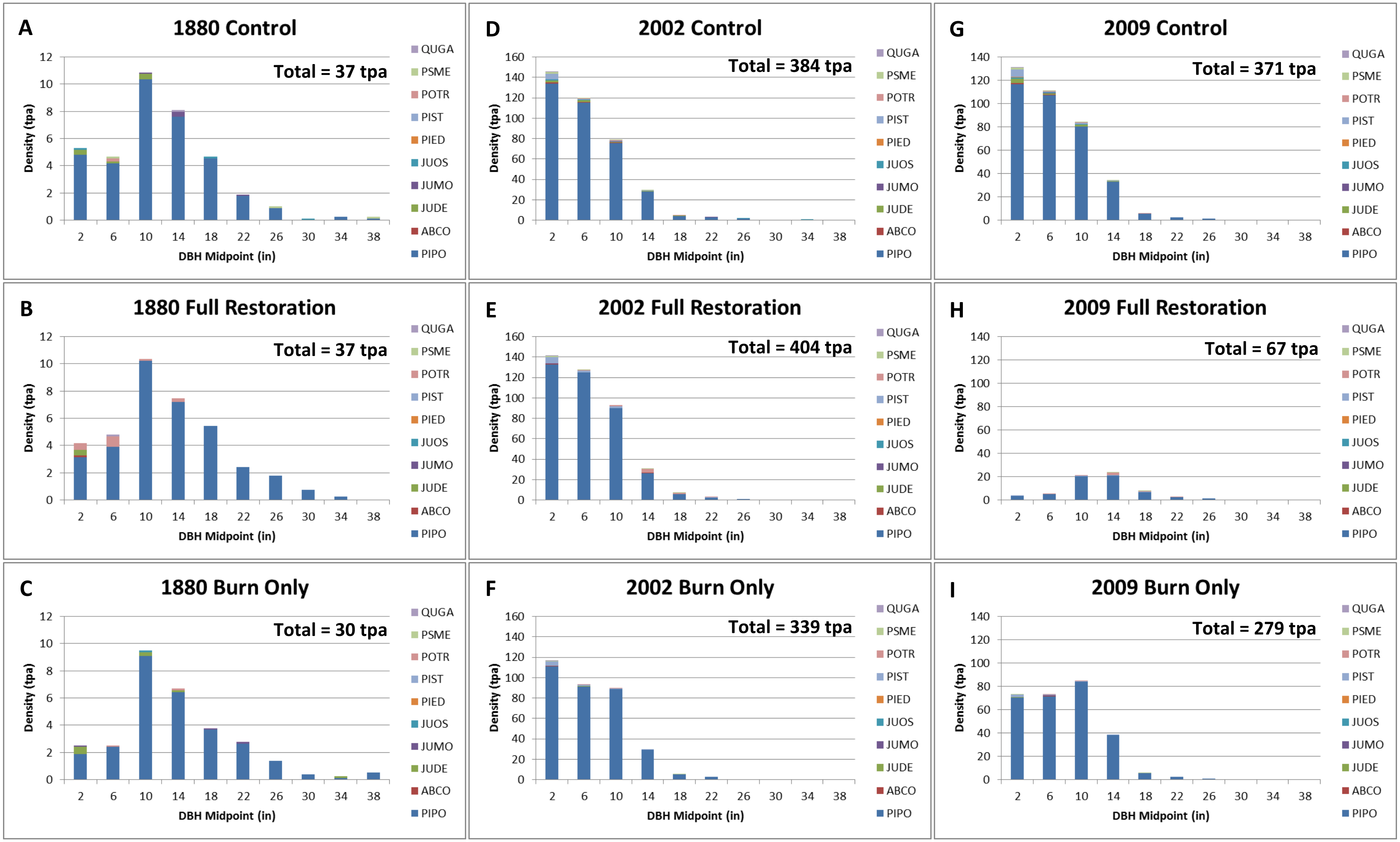

Figure 3. Diameter at breast height (dbh) distributions by treatment at the Mineral site for 1880 (reconstructed at dbh) (A, B, and C), 2002 (pre-treatment) (D, E, and F), and 2009 (post-treatment) (G, H, and I). Note scale differences between time periods.

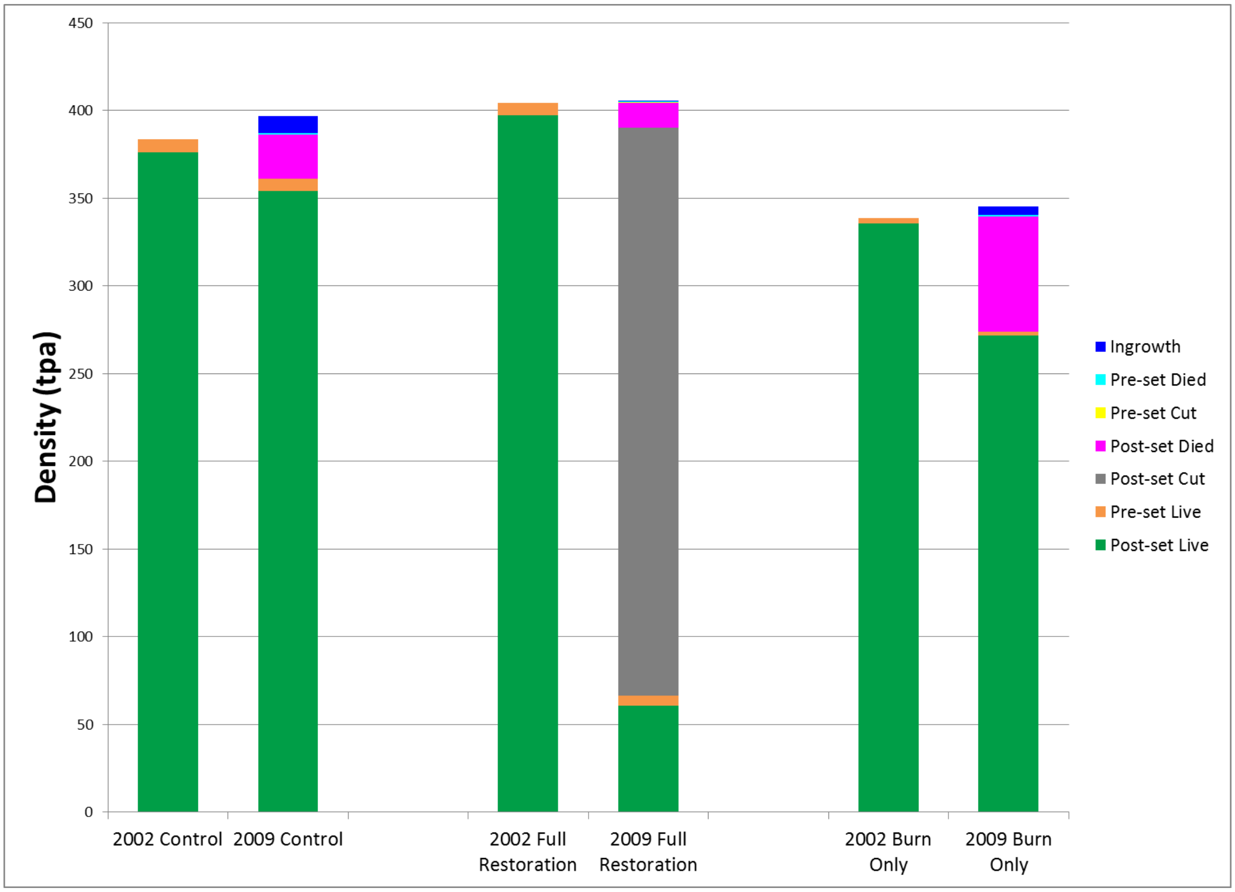

Figure 4. Pre- and post-settlement tree mortality at the Mineral site before (2002) and after (2009) treatment.

other causes between 2002 and 2009. Three presettlement trees (all ponderosa pine), or 5.6% of the presettlement trees alive prior to treatment, were cut in the full restoration treatment. Five presettlement trees (one ponderosa pine, four aspen), or 9% of the presettlement trees alive prior to treatment, died in the full restoration treatment. In the burn only treatment, 18% of the trees alive in 2002 died by 2009. Six presettlement trees (four ponderosa pine, two juniper), or 23% of the presettlement trees alive prior to treatment, died in the burn only treatment (Figure 4).

Discussion

This experiment is part of the ERI's Long-term Ecological Assessment and Restoration Network (LEARN) which is designed to test treatment alternatives and long-term responses using a robust replicated study design. Other sites within the network are located in Arizona at Mt. Trumbull, Kaibab National Forest/Grand Canyon National Park, and the Centennial Forest; and the San Juan National Forest in Colorado. The addition of the Mineral site to this network fills an important gap by providing information about restoration and burn- only treatments in the White Mountains in the heart of the largest contiguous ponderosa pine ecosystem in the world. Furthermore, results from this study will inform planners and land managers involved in the upcoming landscape-scale (2.4 million acres) restoration project known as the Four Forests Restoration Initiative (4FRI).

Forest Structural and Compositional Changes

Prior to Euro-American settlement, the forest at Mineral had a relatively open forest structure and was heavily dominated by ponderosa pine. The average BA values/tree density (40 ft^2/acre, 35 trees/acre) as well as their range (13-70 ft^2/acre , 13-59 trees/acre) was similar to that found at other LEARN ponderosa pine sites, including Fort Valley (average 49 ft^2/acre, 39 trees/acre, range 27-80 ft^2/acre, 24–50 trees/acre) and Mt. Trumbull (average 32 ft^2/acre, 25 trees/acre, range 20-60 ft^2/acre, 14-33 trees/acre) (Stoddard 2011).

Between 1880 and 2002, both average BA and average tree density increased substantially in all units at Mineral. Similar increases in BA and tree density were also observed at the Fort Valley (Fulé et al. 2001) and Mt. Trumbull (Waltz et al. 2003) LEARN sites. While ponderosa pine was the tree species exhibiting the greatest increases at Mineral, there were also increases in several mesic species, including southwestern white pine, white fir, and Douglas-fir — all of which either had limited presence or were absent historically.

After treatment, in 2009, the full restoration treatment produced statistically significant differences in BA and tree density compared to the control. Although total BA in the full restoration was about 1.5 times greater and total tree density was nearly double the 1880 values, BA was reduced by more than 50% and density was reduced by more than 80% compared to pre-treatment levels, moving these areas close to the historical reference condition. A before/after photo series visually illustrates the reduction of tree density and BA following the full restoration treatment (Figure 5). Similar reductions in BA and tree density following full restoration treatments were also observed at the Fort Valley (Fulé et al. 2001) and Mt. Trumbull (Waltz et al. 2003) LEARN sites. It is important to note that the higher BA and density values in the full restoration treatment (compared to 1880 values) were intentional. The thinning prescription was designed to leave excess replacement trees, indicating that the treatments were implemented effectively.

In contrast, the burn only treatment produced only slight reductions in BA and tree density by 2009. Although the reductions primarily occurred in the lowest diameter classes, forest structure in burn only treatments was moved only slightly toward the historical reference condition. Fulé et al. (2006) found similar reductions in BA and tree density following burn only treatments at the Grand Canyon LEARN site.

Treatment effectiveness is also captured by evaluating post-treatment diameter distributions relative to historical distributions. The diameter distribution in areas that were thinned and burned closely matched the historical distribution indicating that the full restoration treatment effectively addressed the project goals. Studies at Mt. Trumbull (Roccaforte et al. 2010, Waltz et al. 2003) and in northeast Oregon (Youngblood et al. 2006) have also documented a change from a reverse J-shaped to a unimodal

Figure 5. Plot EB2-2-19 prior to treatment in 2002 (left) and one year after thinning and burning in 2009 (right).

diameter distribution for ponderosa pine following thinning and burning treatments. In contrast, the distribution remained virtually unchanged in the control and slightly shifted towards the historical distribution in areas that were burned but not thinned, similar to the findings at Grand Canyon (Fulé et al. 2006).

Tree Mortality

The overall goal of implementing restoration and burn only treatments is to restore open forest structure conditions, thus allowing the reintroduction of low-severity surface fire. As expected, the majority (80%) of the tree reductions in the full restoration treatment were due to thinning of small diameter trees and < 5% of trees died from other causes (e.g., fire, natural mortality). Tree cutting did not occur in the burn only treatment, thus the majority of the 20% reduction in tree density was presumably due to the effects from fire.

By definition, presettlement trees are irreplaceable (DellaSalla et al. 2004) and were not intended to be cut in this project. In addition, the goal of the treatments was to limit mortality of these “legacy” trees because they provide genetic and structural diversity to the ecosystem, and take centuries to replace (Moore et al. 1999, DellaSalla et al. 2004). In the full restoration treatment, 15% of presettlement trees were cut or died between 2002 and 2009, an intermediate value compared to presettlement tree mortality in the control (10%) and the burn only treatment (23%). Roccaforte et al. (2010) reported similar percentages of presettlement trees that died or were cut as a result of thinning and burning treatments on a landscape-scale restoration project at Mt. Trumbull. Fulé et al. (2007) reported delayed mortality that disproportionally affected large trees at the Mt. Trumbull LEARN site five years after full restoration treatment.

Conclusions

Results from previous studies indicate that responses to restoration treatments may include improved ecosystem function (Covington et al. 1997, Kaye et al. 2005), increased vigor in old trees (Feeney et al. 1998), improved resistance to disturbance agents, such as bark beetles (Wallin et al. 2004) and fire (Fulé et al. 2001, Roccaforte et al. 2008), and increases in native herbaceous understory vegetation (Stoddard et al. 2011).This study at the Mineral site tested the responses of restoration and burn only treatments on forest structure in a ponderosa pine forest in the White Mountains, Arizona.

Of the three treatments tested in this experiment, the full restoration treatment was the only one that, after one year, shifted forest structure conditions and diameter distributions to levels within the range of variability historically present at the Mineral site. Although the restoration treatment had higher presettlement tree mortality than the control, presettlement trees had a higher probability of surviving thinning and burning treatments when compared to the burn only treatment.

The results from this experiment will provide information about ecological responses to such treatments and are likely to affect management decisions on the Apache-Sitgreaves National Forests. For example, it is commonly argued that burning without thinning may be an appropriate management alternative in some cases because burn only treatments usually cost less and are less likely to be litigated than restoration treatments that involve tree cutting. However, results from this study indicate that burn only treatments will not shift forest structure conditions to levels within the historical range of variability in the short term. Moreover, while burn only treatments may be appropriate in areas with limited access to mechanized thinning, repeated entries may be necessary to shift the ecosystem to historical levels. Finally, the study results indicate that burn only treatments have the potential to increase presettlement tree mortality at rates higher than other restoration treatments. Thus, managers will have to consider the tradeoffs between the full restoration and burn only treatments and increasingly make those decisions in the context of climate-induced, landscape-scale forest fires (Fried et al. 2004, Saeger and Vecchi 2010).

Both full restoration and burn only treatments will require frequent maintenance burns and continued monitoring to evaluate long-term responses. To that end, the ERI will conduct the five-year post-treatment re-measurement at the Mineral site during the summer of 2013. Following the measurements, we will build upon the information provided in this report and evaluate five-year post-treatment responses on forest structure, regeneration, surface fuels, canopy cover, herbaceous understory, and potential fire behavior. In addition, we plan to collect fire scar samples to provide a detailed fire history for the Mineral site. The ERI will continue to collaborate with Forest Service staff and encourage feedback regarding the Mineral project.

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NAU is an equal opportunity provider.
This research was funded by a grant from the USDA Forest Service.