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Plant community dynamics following hazardous fuel treatments and mega-wildfire in a warm-dry mixed-conifer forest of the USA

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ABSTRACT

The greater than 200,000 ha Wallow Fire of May-July 2011 burned through mixed-conifer and ponderosa pine forests in Arizona and New Mexico in the southwestern U.S. This "mega-fire" set the stage for an opportunistic study to examine understory plant community responses to pre-fire fuel reduction treatments in areas dominated by dry mixed-conifer forests. In 2016, five years after the fire, we remeasured nine pairs of treated and untreated sites that were installed in 2012 and compared understory characteristics including species cover, richness and community composition. Native plant cover was significantly higher (20% total cover) in areas that were treated for fuel reduction before the fire compared with untreated areas (17% cover), despite the variability in fire severity and tree mortality. Non-native plant cover was not significantly different between treated and untreated units. Herbaceous understory cover was negatively correlated ($p < 0.05$) with total tree basal area and tree canopy cover in treated as well as untreated units, and positively correlated with tree mortality and basal area mortality in the untreated units. In the treated units, species richness and diversity were negatively ($r = -0.62$ to -0.63) correlated with insolation and elevation. Non-metric multidimensional scaling ordinations along with univariate results suggested that community composition was driven by increased insolation following loss of tree canopy. Cover of species that benefit from high light and warmer temperatures, such as some shrubs and perennial graminoids, increased from 2012 to 2016. Overall, fuel reduction treatments led to persistent increases in cover of native species, lending weight to the usefulness of hazardous fuel reduction treatments in promoting native plant cover.

1. Introduction

Mega-fires are often defined by their size (e.g. > 10,000 ha) while also carrying "enormous and often lasting unwanted human, economic, and environmental consequences" and frequently result in wide ranging political actions (Williams, 2013). The heightened risk of unnaturally severe mega-fires in warm-dry mixed-conifer forests has led to ecological restoration and hazardous fuel reduction efforts across the southwestern USA. These endeavors generally involve tree thinning, prescribed burning and/or managed fire to restore forest structure and reduce hazardous fuel levels (Mason et al., 2007; Margolis et al., 2013; Abella and Springer, 2015). Strategic fuel treatments and managing low intensity wildfires for resource objectives are additional actions that may assist in conservation of mixed-conifer forest ecosystems (Wilkin et al., 2016). With expected increases in large wildfires in conjunction with climate change (Westerling et al., 2006; Littell et al., 2009; Schoennagel et al., 2017), determining the impact of pre-fire fuel treatments on understory plant communities is key for decision making. Wildfires that burn over treated areas provide important opportunities to examine effects of pre-fire treatments on ecosystem responses (Stevens-Rumann et al., 2013; Waltz et al., 2014).

The southwestern mixed-conifer forest habitat type covers ca 1 million ha in the states of Arizona and New Mexico (Dieterich, 1983). Occurring at approximately 2250–3000 m elevation, this forest type is situated between the ponderosa pine zone below and the spruce-alpine fir zone above (Pase and Brown, 1994; Grissino-Mayer et al., 1995). Southwestern mixed-conifer forests display wide variation in species composition and environmental characteristics and are further subdivided into cool/wet and warm/dry phases related to aspect, slope position, etc. (see Romme et al., 2009; Margolis et al., 2013; Reynolds et al., 2013). Differences between dry and wet types may have major impacts on fire behavior. Wetter and cooler forests generally occupy

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north-facing aspects, often contain fir and spruce species, and are mostly forb-dominated, while warm-dry forests tend toward more grass-dominated understories, lower elevations, and more southerly aspects (Romme et al., 2009). Research based on evidence from fire-scarred trees indicates warm-dry forests of this region have experienced a disruption of the natural frequent low-severity surface fire regime over the last century (Reynolds et al., 2013). In addition to *Pinus ponderosa* (ponderosa pine), which is often an indicator of the warm-dry type, dominant tree species include *Pseudotsuga menziesii* (Douglas-fir), *Abies concolor* (white fir), *Populus tremuloides* (quaking aspen), as well as *Pinus flexilis* (limber pine) and/or *P. strobiformis* (southwestern white pine) (Pase and Brown, 1994). Plant species richness and diversity in these forests is often high. Because of the complexity of these forests in terms of soils, slope, aspect, moisture and fire regimes and dominant overstory species, the effects of fuel treatments and fire on community responses can be correspondingly variable.

Fire scar records indicate that until roughly the beginning of the 20th century, southwestern warm-dry mixed-conifer forests displayed a low-severity, frequent-fire regime at roughly 2–30 year intervals with only small patches of high severity fire (Fulé et al., 2009; Margolis et al., 2013; Reynolds et al., 2013; Huffman et al., 2015). Recurring fire likely constrained conifer regeneration, limited the accumulation of woody surface fuels on the forest floor and may have created conditions for a greater abundance of herbaceous vegetation that contributed to fine fuel loading and surface fire spread. With increased grazing pressure and the active suppression of fire, concurrent with climate changes, there has since been an influx of tree species, some of which are shade-tolerant and fire-intolerant. These include white fir and Douglas-fir, which would have historically been limited by a frequent fire regime (Moir and Ludwig, 1979; Romme et al., 2009; Strahan et al., 2016). Fire exclusion in combination with selective logging have resulted in forests now dominated by a homogeneous structure of young, small, mostly shade-tolerant and fire-intolerant conifer species (Romme et al., 2009; Margolis et al., 2013). Whether these changes reflect similar changes in understory composition or among certain forest stand types is unknown (Korb et al., 2007), but the overall effect, not only in the Southwest but across western North America, appears to be a decrease in understory plant cover in mixed-conifer forests over the past century (Abella and Springer, 2015). Research from yellow pine and mixed-conifer montane forests on the west side of the central Sierra Nevada of California indicates that disturbances such as severe wildfire leading to canopy opening can further accelerate species compositional changes to favor those species that exhibit a more xeric or southern biogeographic affinity while disfavoring those with a more mesic or north-temperate affinity that may be less fire-adapted (Stevens et al., 2015). Although we don't yet know if this pattern also occurs following wildfire in Arizona mixed-conifer forests, it is worthy of further investigation.

In a systematic review of published literature, Abella and Springer (2015) reported that thinning and prescribed fire tended to reduce understory abundance in the first four years following hazardous fuels reduction treatments in mixed-conifer forests of western North America. Similarly, numerous other studies have investigated understory responses to fuel treatments in frequent-fire forests; however, results have been mixed in terms of cover, biomass and non-native species cover responses, likely due to factors other than treatment, such as soil type, treatment intensity, fire severity and time since fire (Strom and Fulé, 2007; Stevens-Rumann et al., 2012; Shive et al., 2013a, 2013b; Stevens-Rumann et al., 2013; Cram et al., 2015; Kalies and Yocom Kent, 2016). Stevens et al. (2015) found that community traits in Sierra Nevada mixed-conifer forests were altered after wildfire and thinning, shifting toward greater abundance of drought-tolerant species. Others have noted immediate increases in non-native species after wildfire in southwestern ponderosa pine and mixed-conifer forests (Kuenzi et al., 2008; Shive et al., 2013b; Fornwalt and Kaufmann, 2014). Few data are available that describe more than five years of understory responses to fuels treatments in mixed-conifer ecosystems (Abella and Springer, 2015), or that can be used to compare dynamics of pre-fire-treated sites with those of untreated sites following wildfire (but see Waltz et al., 2014). Lastly, little is understood concerning species composition shifts after fuels treatments and wildfire, and their implications with respect to climate change.

In 2004, a landscape-scale stewardship project, the White Mountain Stewardship Project, was implemented to reduce hazardous fuels and to protect human communities from severe fire in the White Mountains of eastern Arizona at the wildland-urban interface (WUI) (Sitko and Hurteau, 2010; Hurteau, 2016). Subsequent to the project, the human-caused Wallow Fire of May-July 2011 burned over 200,000 ha of mixed-conifer and ponderosa pine forest and set the stage for an opportunistic examination of longer-term understory plant community responses to pre-fire fuel reduction treatments in areas dominated by mixed-conifer forests. In 2016, we remeasured nine pairs of treated and untreated sites that were installed in 2012 to examine the connection between treatments and ecosystem resilience and to test plant community responses to fuel treatments, particularly in terms of differences in native cover and species richness between treated and untreated areas (Waltz et al., 2014). Our main research questions were the following: (1) Five years after wildfire, were there differences in native and non-native species cover, richness, and diversity between treated and untreated areas? (2) Was there a convergence in species composition between treated and untreated areas after five years? (3) What environmental factors, such as fire severity, tree mortality, slope, or aspect, affected species composition? (4) Were there shifts in composition toward drought- and/or heat-tolerant species over time?

2. Methods

2.1. Study sites

We located our study sites in warm-dry mixed-conifer forest ecosystems on the Apache-Sitgreaves National Forest (A-S NF) in eastern Arizona in areas that had been thinned prior to the Wallow Fire by the U.S. Forest Service as part of the White Mountain Stewardship Project (Sitko and Hurteau, 2010; Hurteau, 2016). In some areas, logging slash was piled and burned, and in others the slash was removed and processed off-site. This endeavor encompassed WUI-associated fuel reduction treatments near the human communities of Greer, Alpine and Nutrioso (Fig. 1). Elevations ranged from 2469 to 2838 m. Co-dominant tree species included *Pinus ponderosa*, *Pseudotsuga menziesii* and *Quercus gambelii* (Gambel oak) with dispersed patches of *Populus tremuloides* and *Robinia neomexicana* (New Mexico locust), particularly following the fire (Waltz et al., 2014). Characteristic understory species of more mesic microsites included *Maianthemum stellatum* (starry false Solomon's-seal), *Pyrola picta* (white-veined wintergreen), *Goodyera oblongifolia* (rattlesnake plantain), *Viola* spp. (violet), and *Valeriana acutiloba* (Cordilleran valerian) and various species of orchids and gentians. In drier and sunnier openings, common species included grasses such as *Agrostis* spp. (bentgrass), *Bromus* spp. (brome), *Festuca* spp. (fescue), *Poa fendleriana* (muttongrass), *Koeleria macrantha* (Junegrass) *Muhlenbergia montana* (mountain muhly) and *Carex geophila* (White Mountain sedge), and a wide variety of forbs, particularly members of the Asteraceae family. Common shrubs included *Symphoricarpos* spp. (snowberry), *Ribes* spp. (currant), and *Rubus* spp. (raspberry). The majority of the study site was on soils classified as Eutric Glossoboralfs (fine-loamy, mixed, and loamy-skeletal, mixed). These soils are moderately deep and well-drained and formed in residuum and/or colluvium from basalt and sandstone. They are on nearly level to moderately steep elevated plains and hills with slopes of 0–40%. Most of the remaining study area was on soils classified as Mollic Eutroboralfs which consist of moderately deep and deep, well-drained soils that formed in residuum, colluvium and alluvium derived from basalt, cinders and sandstone. They are formed on nearly level plains to steep slopes of 0–40% (Laing et al., 1989).