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Pre-wildfire management treatments interact with fire severity to have lasting effects on post-wildfire vegetation response

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ABSTRACT

Land managers are routinely applying fuel reduction treatments to mitigate the risk of severe, stand-replacing fire in ponderosa pine communities of the southwestern US. When these treatments are burned by wildfire they generally reduce fire severity, but less is known about how they influence post-wildfire vegetation recovery, as compared to pre-fire untreated areas. We re-measured existing plots on the 2002 Rodeo–Chediski Fire 8 years after the wildfire to track plant community and exotic species response, as well as patterns of pine regeneration. We compared areas that experienced high- and low-severity burning, and also examined how pre-fire treatment (cutting in an uneven-aged harvesting system with prescribed fire) modified vegetation response. We detected persistent differences between low- and high-severity areas for nearly all variables measured. In high-severity areas overall understory plant cover was 40.6%, nearly three times that observed in low-severity areas; shrub cover was 18.4%, four and a half times greater than that observed in low-severity areas. We also detected significantly higher exotic forb cover in high-severity areas, although overall exotic response was generally quite low (<2%). Although this represents a slight decrease in exotic cover since the initial 2004/2005 measurements, the frequency of several exotic species did increase through time (particularly *Tragopogon dubius* and *Verbascum thapsus*). Pre-fire treatment resulted in significantly higher pine regeneration frequency in treated versus untreated areas. Within low severity areas, mean pine regeneration frequency was 0.17 in pre-fire untreated areas versus 0.06 in areas that were not treated before the fire. Within high severity burned areas, mean pine regeneration frequency was 0.67 in pre-fire treated areas, but was only 0.19 in pre-fire untreated areas. This treatment effect in high-severity areas may be linked to reduction in the overall patch size of high burn severity in pre-fire treated areas, which resulted in a more heterogeneous mixture of low and moderate severity burning in the neighborhood. This pattern decreased distance to seed source, which likely facilitated the more frequent pine regeneration observed. In addition to the well-documented benefits of fuel reduction treatments in reducing subsequent fire severity, these data suggest that even where treated areas do burn severely the size of severely burned patches is limited in extent, which is likely to have important ramifications for future reforestation and retention of foundation species.

1. Introduction

Severe large-scale fires in ponderosa pine (*Pinus ponderosa* P. & C. Lawson) forests of the southwestern US have been linked to uncharacteristically high fuels (Covington and Moore, 1994) and climate warming in recent decades (Westerling et al., 2006). These fire events have raised several important concerns about post-fire vegetation communities, three of which we examine here. First, extensive forest areas that have burned severely may result in persistent conversions to shrublands or grasslands, rather than regenerate as forest (Haire and McGarigal, 2008; Savage and Mast, 2005), particularly under a warmer and drier climate (Seager et al., 2007). The unprecedented size of high-severity burned areas necessarily means that post-fire pine regeneration in these areas is not well understood, because it is occurring in relatively novel conditions. In addition, high-severity fire may promote sprouting species over seeding species (such as ponderosa pine), where early site capture by sprouting species limits seeder species establishment through competition for resources (Barton, 2002; Fulé and Covington, 1998). Furthermore, ponderosa pine can be considered a foundation species in these communities because it defines community structure by creating locally stable conditions for other species, and modulates fundamental ecosystem processes. The loss of a foundation species over large, landscape-scale areas can create

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novel species assemblages and degrade native habitats (Ellison et al., 2005).

Second, numerous studies have documented exotic plant species invasions following high severity fire events in the Southwest (Barclay et al., 2004; Crawford et al., 2001; Dodge et al., 2008; Griffis et al., 2001). Such invasions can impact native plant communities, and also have the potential to alter future fire regimes via changes to the fuels properties of the native ecosystem (Brooks et al., 2004). These invasions are not entirely predictable, however, since other high severity fire studies in the Southwest have documented a low exotic species response (Foxx, 1996; Huisinga et al., 2005; Kuenzi et al., 2008).

Third, the extent to which pre-fire fuels treatments will influence post-fire vegetation response is of concern as land managers are routinely applying fuel reduction treatments (e.g., thinning and/or burning) to increase forest resilience and reduce high-severity fire risk (Baron et al., 2009). These treatments generally reduce fire severity by reducing surface fuels, and reducing tree density and canopy connectivity (Cochrane et al., 2012; Finney et al., 2005; Fulé et al., 2012; Pollet and Omi, 2002; Strom and Fulé, 2007), yet the influence of extreme fire weather conditions and topography can occasionally result in high-severity fire in treated areas. In both lesser- and more-severely burned sites, pre-fire treatments are likely to have long-term effects on post-fire recovery, yet these effects are not well known.

To investigate the longer-term effects of pre-wildfire treatments and fire severity on pine regeneration and native plant community recovery, we re-measured plots established after the 2002 Rodeo–Chediski Fire of northeastern Arizona that burned approximately 189,650 ha (Kuenzi et al., 2008; Strom, 2005). These plots were originally installed in 2004, when herbaceous understory, fuels, and forest structure response variables were measured in relation to fire severity and pre-fire treatment. Kuenzi et al. (2008) found that low- and high-severity areas had markedly different plant communities 2 and 3 years post-fire, which they primarily attributed to the near-complete loss of overstory trees in high-severity areas (Kuenzi et al., 2008). These early differences indicated two drastically different vegetation types on the landscape: in the absence of another high-severity fire event, low-severity areas are likely to remain pine-dominated systems, whereas high-severity areas have the potential to convert to other vegetation types (Haire and McGarigal, 2010; Savage and Mast, 2005; Strom and Fulé, 2007). They also detected a low exotic species response, contrary to expectations.

Eight years post-fire, we re-visited these plots to examine the influence of fire severity and pre-fire treatment on the post-fire vegetation community. We asked: (1) are the differences in low- versus high-severity areas persistent 8 years post-fire? And (2) do pre-fire treated and untreated areas differ within low severity or high severity areas? For each line of inquiry, we examined a suite of characteristics that pertain to forest recovery: understory plant community composition (with particular emphasis on exotic species response), overstory structure, and pine regeneration.

2. Materials and methods

2.1. Study area

The study area lies south of the Mogollon Rim in east-central Arizona on White Mountain Apache Tribal (WMAT) lands. For the 8 years of post-fire vegetation recovery, precipitation by water year was generally below the 60-year average of 45.0 cm. Total precipitation during 2010 was 35.2 cm, and 99.8 cm of snow accumulated over the winter of 2009/2010, which is only slightly below the 60-year average of 102.4 cm. Average maximum and minimum monthly temperatures were 29.2 °C in July and −8.7 °C in January. Weather data were recorded at the Heber Ranger Station by the Western Regional Climate Center (www.wrcc.dri.edu), which is located above the Rim at an elevation of 1984 m (16–311 m lower than the range of our study sites), approximately 12 km north of the study sites. It is on the edge of a ponderosa pine/pinyon-juniper transition zone and so may have recorded less precipitation and higher temperatures than our study sites experienced.

The study sites were randomly selected in 2004, ranging in elevation from 2000 to 2295 m, on slopes <45% (average slope was 17.6%) (Kuenzi et al., 2008; Strom, 2005). Study sites were stratified by fire severity classes (low and high), and by pre-wildfire management of (1) no treatment or (2) cut in an uneven-aged silvicultural system and subsequently burned under prescription (hereafter: untreated, treated) within 11 years prior to the fire. The specific cutting prescriptions were not uniform across the study area, but generally included uneven-aged forest management and noncommercial thinning followed by slash disposal. Uneven-aged managements followed a range of a *Q*-slope factor of 1.1–1.3, an SDI maximum of 1110 25.5-cm trees ha^{-1}, and maximum diameter of 46–76 cm (18–30 in). Out of the approximately 111,837 ha of the Rodeo–Chediski Fire that burned on WMAT lands, 13% were cut and burned during the time period used for this analysis (11 years) (Strom, 2005). Pre-fire treatment areas were identified using treatment history data provided by the tribe. Fire severity classes were determined by a combination of remotely sensed Differenced Normalized Burn Ratio (ΔNBR) maps and ground-truthing. Of the 111,837 ha WMAT fire area, nearly 20% was in the high-severity class and 29% in the low-severity class (with the remaining area classified as "moderate" severity) (Strom, 2005). The sites were randomly distributed throughout the treatment/severity combinations, resulting in distances between sites ranging from 0.55 to 9.37 km, and averaging 1.66 km.

The high-severity study areas were seeded immediately post-fire. The seed mix used on the WMAT lands included *Triticum aestivum* L. (common wheat), a sterile exotic species, which was applied at a rate of 16.8 kg ha^{-1}. The remainder of the seed mix included species native to the region, but the seed source is unknown and therefore may not represent locally native genotypes: *Elymus trachycaulus* (Link) Gould ex Shinners (slender wheatgrass), *Pascopyrum smithii* (Rydb.) A. Löve (western wheatgrass), *Panicum virgatum* L. (switchgrass), *Nassella viridula* (Trin.) Barkworth (green needlegrass), *Bromus marginatus* Nees ex Steud. (mountain brome) (*Bromus marginatus* = *Bromus carinatus* H. & A. (Welsh et al., 1993)), *Bouteloua curtipendula* (Michx.) Torr. (sideoats grama), *Sporobolus cryptandrus* (Torr.) Gray (sand dropseed), *Coreopsis tinctoria* Nutt. (plains coreopsis), *Dalea purpurea* Vent. (purple prairie clover), *Linum lewisii* Pursh (blue flax), and *Rudbeckia hirta* L. (black-eyed susan) (Kuenzi et al., 2008). The study area was not in an active cattle allotment, but we did observe a few horses, and evidence of deer and elk.

2.2. Measurement

Six sites were originally installed within each of four treatment and severity combinations (total $N = 24$), with three subsample plots at each site. In 2010 we re-located 70 of the 72 original plots, such that two sites had only two subsample plots. For consistency, all field protocols follow the original studies (Kuenzi et al., 2008; Strom, 2005). We used a variable-radius prism plot (basal area factor 2.3 m^2 ha^{-1}) for overstory trees using standard guidelines (Avery and Burkhart, 2001), in which we measured diameter at breast height (DBH, 1.37 m) and tree height. We tallied all pine regeneration shorter than breast height in a 3.1-m radius circle. Since smaller seedlings generally have high mortality rates (Smith et al., 1997), we were interested in separating the more established