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Delayed tree mortality, bark beetle activity, and regeneration dynamics five years following the Wallow Fire, Arizona, USA: Assessing trajectories towards resiliency

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ABSTRACT

Warm/dry mixed conifer forests have undergone changes in disturbance regimes, forest structure, species composition, and surface fuel accumulation which have led to increased susceptibility to large, uncharacteristically severe wildfires and pathogenic outbreaks. Ecosystems resilient to fire events return to a similar set of structures (e.g., forest and understory composition and density) or processes (e.g., fire, decomposition rates); however, when exposed to disturbances outside the evolutionary envelope, may transition to a different state (e.g., type conversion). We sampled warm/dry mixed conifer forest stands treated prior to the 2011 Wallow Fire and paired untreated sites five years following the fire. Our objective was to evaluate mid-term ecosystem resiliency in terms of forest structure, bark beetle activity, and tree regeneration. We hypothesized that treated units would have higher mid-term post-fire resiliency compared to untreated units. In 2016, average total tree density remained significantly lower in treated compared to paired untreated units; conifer density and BA decreased in both treated and untreated units. Diameter distributions in 2016 treated units remained similar to those observed in 2012 with the exception of increased density in the smallest diameter class. In untreated units, the majority of tree density reductions occurred in the 10–30 cm dbh classes. Post-fire tree mortality was stable across treated and untreated units, with no significant differences; however, abundant ingrowth of small hardwoods occurred throughout the study area. Large-tree density decreased by about 20% in both treated and untreated units between 2012 and 2016. Evidence of post-fire bark beetles was generally low and patchy throughout the study site; however, beetle activity was more widespread in untreated units. Twice as many trees were attacked by bark beetles in untreated versus treated units suggesting treatments may have reduced post-fire beetle activity. Following wildfire, observed conifer regeneration was lower and hardwood regeneration was higher with increasing burn severity; conifer regeneration was nearly three times higher in treated units. This study suggests that pre-fire fuel reduction treatments contribute less to mid-term resiliency than to short-term resiliency of forested ecosystems. We observed trends of higher resilience to insect outbreaks and potential implications for type change from conifer to deciduous forest. Furthermore, our study underscores the importance of understanding mid-term post-fire recovery, and while it provides insights regarding recovery of these ecosystems, additional monitoring and research is needed to fully understand the implications toward long-term resiliency.

1. Introduction

Larger fires, burning with higher severity (i.e., overstory loss), are occurring with increasing frequency in frequent-fire ecosystems throughout the world (Westerling et al., 2006; Climate Central, 2012; Attiwill and Binkley, 2013). Additionally, these larger, landscape-scale fires can result in contiguous, high-severity patches across larger areas than historically observed in these ecosystems (Pausas et al., 2008; Dennison et al., 2014). Ecosystems resilient to fire events return to a similar set of structures (e.g., forest and understory composition and density) or processes (e.g., fire, decomposition rates) (Holling, 1973); however, when exposed to disturbances outside the evolutionary

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envelope, may transition to a different state (e.g., type conversion). For example, uncharacteristically severe fire events in frequent-fire forests may result in an ecosystem transition from forests to grass-shrub communities (Beisner et al., 2003; Bowman et al., 2013; Stephens et al., 2013).

In the western U.S., warm/dry mixed conifer forests have undergone changes in disturbance regimes, forest structure, species composition, and surface fuel accumulation due to more than a century of fire exclusion and resource extraction (Fulé et al., 2009; Lydersen et al., 2013; Reynolds et al., 2013). These changes have increased ecosystem susceptibility to drought (Negrón et al., 2009), large, uncharacteristically severe fires (Stephens and Collins, 2004; Beaty and Taylor, 2008), and bark beetle attacks (McHugh et al., 2003; Hood and Bentz, 2007; Negrón et al., 2016). Recent landscape-scale fires (e.g., Rodeo-Chediski Fire [2002], Hayman Fire [2002], Rim Fire [2013]) have burned large landscapes with large, contiguous patches within warm/dry mixed conifer forest ecosystems. These fires have had adverse effects to ecological and human communities (Strom and Fulé, 2007; Graham, 2003; Lydersen et al., 2014). For example, the Wallow Fire, the largest fire recorded in Arizona, burned a total of 217,741 ha (538,050 ac) in Arizona and New Mexico during the summer of 2011 (Wadleigh, 2011), destroying 32 residences and sending a sustained smoke plume causing potential health impacts > 1500 km away (Weinhold, 2011).

Uncharacteristic disturbance events can also lead to increases in other disturbance agents, such as bark beetles (Coleoptera: Curculionidae, Scolytinae). For example, trees damaged, but not killed by fires, become more susceptible to bark beetle attacks resulting in additional tree mortality in stands impacted by fire (Rasmussen et al., 1996; Hood and Bentz, 2007; Lerch et al., 2016). The likelihood of beetle attacks and mortality has been correlated with various burn severity metrics including bole char height, crown damage, cambium injury, and diameter at breast height (dbh) (McHugh et al., 2003; Negrón et al., 2016), sometimes in a nonlinear fashion (Hood and Bentz, 2007).

To mitigate for high fire risk on federally-managed western forests, fuel reduction treatments including tree thinning and prescribed fire are implemented, but most often placed adjacent to high-value areas, such as communities and infrastructure. These locations provide anchor points for suppression activities, point protection for resources and values at risk, and can be effective at reducing fire severity and resulting post-fire damage (Pollet and Omi, 2002; Martinson and Omi, 2013). Pre-fire thinning treatments have been shown to reduce fire severity during wildfires (Waltz et al., 2014) and reduce beetle-caused mortality after prescribed fires (Fettig et al., 2010). In addition to reducing fire-injured trees, which could limit bark beetle-caused mortality, thinning has long been recognized as a method for increasing stand and individual tree resistance to beetle attacks because it reduces inter-tree competition, increases tree defense characteristics, and may change structural and olfactory characteristics, including influencing pheromone plume dispersal (Thistle et al., 2004), that beetles use for locating hosts and conspecifics (Bartos and Amman, 1989; Amman and Logan, 1998; Kolb et al., 1998; Fettig et al., 2007).

We examine the trajectory of frequent-fire forest responses to a large landscape fire, building off a one-year post-fire study (Waltz et al. 2014) that examined short-term metrics of forest resiliency to uncharacteristically severe wildfire. Using large-tree mortality, high-severity patch size, and burn severity (measured by tree mortality), they concluded that stands that had forest thinning treatments implemented prior to the wildfire had higher resiliency than untreated stands. Waltz et al., (2014) found treated areas had lower large-tree mortality, smaller high-severity patch sizes, and overall lower fire severity compared with adjacent untreated stands and recommended additional mid- and long-term assessments of metrics associated with resiliency were necessary to fully understand fuel reduction treatment effects on resiliency. In particular, the type changes predicted and observed from uncharacteristically severe events (Savage and Mast, 2005; Roccaforte et al., 2012; Buma et al., 2013) can only be assessed with regeneration studies through time. Understory responses, including invasive plant establishment or growth, also require years to decades to properly assess. Stand structure conditions one year following wildfire may have antecedent influence over observed recovery, especially in the case of fire-caused delayed tree mortality. Finally, little is known about the effects of fuel reduction treatments on beetle-caused tree mortality after wildfires.

Our objective in this study was to evaluate forest structure, bark beetle activity, and tree regeneration in terms of mid-term ecosystem resiliency and, with respect to the observed conditions five years following the Wallow Fire, to address the study constraints identified by Waltz et al. (2014). We re-examined the hypothesis that wildfire hazard reduction treatments increase ecological resiliency with respect to delayed large-tree mortality, bark beetle activity, and regeneration density and composition. We revisited the same study sites and used the same experimental design established in 2012 that paired areas that had fuels reduction treatments implemented prior to the fire with nearby untreated areas. Our specific questions in the warm/dry mixed conifer post-fire landscape were: (1) Do forest structure and post-fire delayed large-tree mortality differ among treated and untreated units? (2) Does bark beetle activity differ among treated and untreated units? and, (3) Does overstory regeneration density and composition differ among treated and untreated units?

2. Methods

2.1. Study area

We relocated study sites in the Wallow Fire footprint on the Apache-Sitgreaves National Forests in east-central Arizona near the communities of Greer, Alpine, and Nutrioso. We examined warm/dry mixed conifer forest ecosystems where multiple wildland-urban interface (WUI) fuels reduction treatments occurred prior to the Wallow Fire (Waltz et al., 2014). Elevation ranged between 2469 and 2838 m and slopes were < 45%. Overstory tree species present included: ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), Engelmann spruce (*Picea engelmannii*), southwestern white pine (*Pinus strobiformis*), quaking aspen (*Populus tremuloides*), Gambel oak (*Quercus gambelii*), New Mexico locust (*Robinia neomexicana*), and alligator juniper (*Juniperus deppeana*). The Wallow Fire burned 217,741 ha in east-central Arizona and west-central New Mexico between May 29 and July 8, 2011 (National Interagency Fire Center, https://www.nifc.gov/fireInfo/fireInfo_stats_lgFires.html, accessed 14 February 2018). Our study sites were located in the northern extent of the fire and burned from June 4–9, 2011; the fire burned 16,250–30,850 ha each of these days (Waltz et al. 2014). The two closest Remote Automated Weather Stations (RAWS http://www.raws.dri.edu) near Alpine and Greer, AZ recorded maximum air temperatures during this time period between 23.3 and 26.7 °C, daily minimum relative humidity of 5–15%, and maximum wind speeds of 38.5–67.7 km h^{-1} out of the south-southwest (Western Regional Climate Center, www.wrcc.dri.edu, accessed 3 May 2017; Waltz et al. 2014). Average total annual precipitation was 399 mm from 2001 to 2011. Total precipitation in 2011, the year of the Wallow Fire, was 90% of the pre-fire decadal average. Total annual precipitation at Alpine, AZ averaged 476 mm between 2012 and 2016. Most precipitation in the study area occurs in winter and during summer monsoon storms.

2.2. Experimental design

We replicated the same study design previously implemented in 2012 and described in detail in Waltz et al. (2014). In summary, we utilized a quasi-experimental design (Shadish et al., 2002) by remeasuring nine pairs of treated/untreated study units. We selected