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# Legacy effects of fire size and severity on forest regeneration, recruitment, and wildlife activity in aspen forests

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ABSTRACT

Human activities and climate change are increasing the size and severity of wildfires globally, creating a need for research that links changes in fire regimes with community-level responses. The objective of this study was to understand how variability in fire regimes influences forest regeneration and recruitment patterns and wildlife activity at large temporal and spatial scales. Across 25 fires in five National Forests (Uinta-Wasatch-Cache NF, Ashley NF, Fishlake NF, Dixie NF, and Manti-La Sal NF) in the state of Utah, we examined aspen regeneration and recruitment levels, and wildlife and livestock fecal group counts along belt transects that spanned gradients of fire size and severity. Forest cover change was assessed by comparing pre-fire and post-fire satellite images. The fires dated from 1992 to 2002 and were at least 10 years old when this study was conducted. Fire size and severity were positively related to aspen regeneration (density of saplings) and recruitment (saplings >2 m in height). There was a significant fire size and severity interaction effect on aspen regeneration, such that the positive influence of fire size increased with greater fire severity ($R^2$ = 0.40, $P$ < 0.001). Change in the extent of aspen cover was not correlated with fire size. Deer and cattle became more dispersed with increasing fire size and severity, but elk activity showed no difference. Deer preferred low severity burn patches in smaller fires, but appeared to avoid low severity patches as fires became larger. Our results suggest that fire size and severity are important ecological filters that can interact to affect forest development and the distribution and abundance of large herbivores. Effective management of forest systems in response to altered fire regimes will require an understanding of the legacy effects of fire size and severity at the landscape scale.



## 1. Introduction

Disturbance plays a principal role in shaping the development of biological communities. Human activities including exotic species introductions, logging, grazing, fire suppression, and human-induced climate change can modify the size, severity, frequency, and duration of natural disturbance regimes (Baker, 1995; Mack and D'Antonio, 1998; Turner et al., 1998; Liu et al., 2010). Altered disturbance regimes have the potential to reduce productivity, species abundance and diversity (Reich et al., 2001), and disrupt successional processes (Folke et al., 2004), all of which can decrease plant community resilience to biotic stresses (Wallin et al., 1994). Fire is among the most widespread and ecologically important disturbance types, and human activities are modifying fire regimes at a global scale (Bowman et al., 2011). There is a critical need to better understand the effects of changing fire regimes on community-level responses.

Fire influences terrestrial ecosystem patterns and processes, including vegetation distribution, structure, and composition. It strongly impacts successional patterns in many forest systems by replacing fire-sensitive species with fire-adapted species (Heinselman, 1981; Romme, 1982; Abrams, 1992). The extent of such impact is likely to increase with the size of area burned. Fire size alters ecological succession by influencing the diversity and abundance of seedling recruitment (Miller, 1982; Turner et al., 1997). Over the past few decades, there has been a rising trend in occurrence of large fires (Stephens, 2005; Westerling et al., 2006; Miller et al., 2009). We currently lack understanding of the effects of fire size on forest development, as well as how it influences the abundance and distribution of wildlife.

The impact of fire is often heterogeneous across landscapes due to variation in the distribution and quality of fuel loads, topography, and weather conditions. Consequently, a complex mosaic of burned conditions, or fire severity, is often created across post-fire forest landscapes. Plant functional processes such as growth

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(Chappell and Agee, 1996), nutrient uptake (Shenoy et al., 2013), and seedling establishment (Chappell and Agee, 1996; Turner et al., 2003) vary depending on fire severity. It has been recognized that the percentage of high-severity burned patches generally increases with burn size (Lutz et al., 2009; Miller et al., 2009). Fire severity can interact with disturbance size to affect biotic cover and richness of plant community (Turner et al., 1997). Most studies examining post-fire effects in forest systems have not considered both the individual and combined effects of fire size and severity on plant regeneration and recruitment. Moreover, few studies have examined the long-term or legacy effects that fire size and severity have on the ecological landscape.

Fire can affect the distribution and abundance of wildlife species by modifying habitat conditions (Klinger et al., 1989; Pearson et al., 1995). For instance, ungulate species are often attracted to burned patches for forage (Pearson et al., 1995; Archibald et al., 2005; Klop et al., 2007). Changes in habitat structure and quality due to variability in fire size and severity are likely to modify large mammal communities (Turner et al., 1994). Recent studies suggest that fire severity strongly modifies bottom-up and top-down interactions between plant and herbivore communities (Wan et al., in press). Ungulate herbivores can modify the extent, frequency, and intensity of fire disturbance by altering the quality and quantity of fuel load through browsing and grazing (Hobbs, 1996; Tremblay et al., 2006). Lengthened fire return intervals as a result of fuel load reductions from browsing can indirectly affect forest development (Johnstone and Chapin, 2006). It has been postulated that the habitat use of ungulate communities is likely influenced by the size of burned patches (Pastor et al., 1988; Smith et al., 2011; Endress et al., 2012; Wan et al., in press), but research that directly addresses the effect of fire severity on ungulate activity and forest regeneration pattern as a function of fire size is lacking.

We used quaking aspen (*Populus tremuloides*) forests across the state of Utah (USA) as a study system to examine the roles of fire size and severity on forest regeneration and ungulate activity. Aspen is an early successional species that is adapted to frequent disturbance regimes by rapidly regenerating new saplings from rootstocks following fire (Fraser et al., 2004; Smith et al., 2011). As aspen stands mature they support the development of a rich community of plant and animal species (St. Clair et al., 2013). In the presence of intensive ungulate herbivory, however, aspen regeneration can be adversely affected due in part to the high susceptibility of young aspen saplings to mammalian herbivores (Rogers and Mittanck, 2013; Seager et al., 2013). However, patterns of successful aspen regeneration and recruitment have been observed in forest landscapes with high ungulate densities that experienced large fires, providing anecdotal evidence that fire size may alter the distribution or behavior of ungulate herbivores (Smith et al., 2011).

The objective of this study was to characterize aspen regeneration, recruitment and cover change, and large herbivore community responses to fire size and severity. We integrated field and remotely sensed data to address the following questions: (i) What are the single and combined legacy effects of fire size and severity on aspen regeneration, recruitment and cover? (ii) Are there legacy effects of fire size and severity on the distribution and abundance of elk, deer, and livestock in these forest landscapes?

## 2. Methods

### 2.1. Study locations

This study included an analysis of 25 fires that occurred in pure aspen and mixed aspen-conifer forests throughout the state of Utah (Fig. 1). A map layer including polygons for all fires that have occurred since 1981 was obtained from the Utah Division of Natural Resources. We examined fires that were at least 10 years old (ranged from 1993 to 2002) at the time of data collection, and then selected fires that contained aspen prior to the disturbance for this study. We examined fires that were at least 10 years old to give regenerating aspen enough time to demonstrate recruitment. To ensure proper assessment of pre-fire stand conditions, we did not examine fires that were older than 20 years old as fallen trees become subject to weathering and decomposition. Presence of aspen was visually assessed by (1) post-fire aerial imagery (NAIP) for aspen stems that had not burned completely and had since fallen, which appeared white or grey in the images; or (2) pre- and post-fire satellite photos (Landsat 5) for aspen regeneration, which appeared as bright green patches in Summer or yellow patches in Fall. Elevation was also applied as another parameter in the selection process. Although aspen can survive at lower elevation, major aspen stands in Utah are usually found at 1800 m or above. Therefore, any fires below 1800 m were excluded from this study. Twenty-six fires were originally selected based on our selection criteria, but one of them was excluded from the study because aspen was not found upon ground-truthing in the field. Elevations of our sites ranged from 2170 m to 3301 m and stand slopes ranged from 1° to 39°.

### 2.2. Field measurements

Using satellite imagery, we randomly generated potential belt transect points across aspen patches within fires. Field measurements were taken using 50 m × 2 m belt transects. We had a total of 149 transects in this study. Our target was to census within each fire a minimum of 3, 6, and 10 transects based on fire sizes of <100 ha, 100–2000 ha, and >2000 ha respectively. In a few instances, we were unable to reach the target number of transects at some locations for reasons of safety, accessibility, or lack of permission on private land. Final transect points were selected based upon ground-truthing in the field for actual observance of aspen at the site. Transects were located at least 50 m from the fire burned edge, at least 50 m within an aspen stand, and were separated by at least 100 m. At each transect, the Universal Transverse Mercator (UTM) coordinates, elevation, aspect, slope, and cardinal direction from the starting point were recorded.

Field data were collected between June 3rd and August 30th in 2013. All post-fire aspen saplings were counted in the 50 m × 2 m belt transect and divided into three categories: live saplings <2 m tall, live saplings >2 m tall, and dead saplings of any height. In this study, we defined aspen recruitment as live saplings >2 m because aspen begin to escape upper level browsing at this height. We used the point-quarter method (Pollard, 1971) and took measurements every 5 m along the same belt transect for a total of 10 sampling points per transect line. The area around each sampling point was divided into 4 quadrants. In each quadrant, we identified the mortality status and species of the overstory tree nearest to the center quadrant point, and measured its diameter at breast height (if ⩾10 cm) and distance from the quadrant point to calculate overstory stand mortality, density, basal area and species composition as estimates for pre-fire stand characteristics (Smith et al., 2011). The percent of tree mortality was used as an estimate of fire severity. Based on field observation, tree mortality appeared to be primarily caused by fire. However, other agents such as disease or drought could have caused mortality, and some of the mortality may have occurred before the fire. We expect that large sample size and robust replication (i.e., multiple sampling points at the transect level and multiple transects at the fire level) should minimize the noise caused by other mortality agents.