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Research article

Management thresholds stemming from altered fire dynamics in present-day arid and semi-arid environments

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ABSTRACT

Changes in fire frequency, size, and severity are driving ecological transformations in many systems. In arid and semi-arid regions that are adapted to fire, long-term fire exclusion by managers leads to declines in fire frequency, altered fire size distribution, and increased proportion of high severity fires. In arid and semi-arid systems where fire was historically rare, factors such as invasion by highly combustible non-native plants elevate fire frequency and size, elevating mortality of native species. Altered temperature and precipitation regimes may exacerbate these changes by increasing biomass and flammability. Current transformation in fire dynamics carry social as well as ecological consequences. Human cultures, livelihoods, values, and management behaviors are attuned to fire dynamics. Changes can make it costly or impossible to maintain traditional landscape use and economic activities. We review the ecological and social science literature to examine drivers of altered fire dynamics in arid and semi-arid systems worldwide and the conditions representing fire dynamics thresholds—points at which altered conditions may make it difficult or impossible to achieve management objectives, even via traditional adaptive management focusing on alternative management activities to achieve objectives. Such thresholds could force a wholesale shift in management objectives and practices and a new approach to adaptive management that redefines objectives when no viable adaptive action can be undertaken.

1. Introduction

Fire frequency (i.e., fire return interval at any given point), size (i.e., extent of a burned area), and severity (i.e., degree to which a site has been altered by fire, a result of heat at the fireline combined with fire residence time at the site; NWCG, 2018) are actively changing in many systems (Dale et al., 2001; Keeley, 2009). Human management of any given landscape is influenced by the historical fire dynamics typical of that system (e.g., Cissel et al., 1999). Changes in fire dynamics can therefore force management changes, impacting land use activities as well as the achievement of management objectives (Baker, 1994; Brockway et al., 2002; Conedera et al., 2009; Noss et al., 2006a). For this article, we define *fire dynamics* as the combination of fire size, frequency, and severity typifying a particular system at a particular point in time.

The state of the art response to environmental change in managed systems is adaptive management (Briske et al., 2010), whereby managers implement sequential interventions accompanied by data collection to inform adaptive shifts in those interventions. Adaptive management permits flexibility and resilience, experimentation in management, and continuous learning in the face of rapidly changing conditions (Gunderson, 1999). However, adaptive management as normally practiced assumes consistent objectives guiding human activities at a particular location; those objectives are met via a shifting toolkit of actions. When fire dynamics depart sufficiently from the natural range of variation, systems may reach thresholds beyond which established land management objectives become unachievable even through traditional adaptive management. Such thresholds vary among systems and among objectives (Bowman et al., 2011; Groffman et al., 2006; Pausas and Fernández-Muñoz, 2011). In this manuscript, we discuss the combined social and ecological (*socioecological*) circumstances that may lead to such thresholds that necessitate a shift in how managers select, identify, and define management objectives themselves. This may compel a new form of adaptive management that focuses on shifts in objectives as well as activities. Although fire dynamics in many parts of the world have been influenced by human activities for

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thousands of years, for our purposes we focus on *modern shifts in fire dynamics* that are actively occurring in present-day managed environments, reviewing how fire size, frequency, and severity are currently and actively changing as a result of anthropogenic influences on arid and semi-arid ecosystems.

We focus on arid and semi-arid systems for tractability. Fire dynamics in these systems are affected by non-native species invasion, human-caused ignitions, climate-induced drought, and decades of anthropogenic fire suppression (Garfin, 2013). Arid and semi-arid systems include forested, woodland, shrubland, grassland, and desert zones and occur in patchy distribution in western North America, western South America, South Africa and northern Africa, interior Asia, and western and interior Australia (Scanlon et al., 2006).

2. Background: present-day changes in fire dynamics in arid systems

Fire dynamics are changing in arid and semi-arid systems across the globe as a result of anthropogenic drivers such as fire suppression and exclusion, livestock grazing, non-native plant invasions, intentional ignitions, and climate change (Bowman et al., 2011; Swetnam et al., 2016). Changes can include both increases and decreases in fire frequency and size, depending on whether a system is historically fire-adapted or non-fire-adapted. In fire-adapted systems, fire plays a fundamental role in the formation of vegetation patterns (Bowman et al., 2009), which can be affected by decreases in fire frequency and size. In a Swaziland savanna, for example, livestock grazing combined with fire suppression increased shrub cover from 2 to 31% between 1947 and 1990 (Roques et al., 2001). Suppression of fires in South African grasslands has led to similar growth in cover of woody species (Uys et al., 2004). The same pattern can be seen in native grasslands in the southwestern US, with encroachment of creosote (*Larrea tridentata*) and mesquite (*Prosopis glandulosa*) (Grover and Musick, 1990) (Fig. 1). Increased cover of western juniper (*Juniperus occidentalis*) in a south-central Oregon sagebrush steppe over the past century was driven by fire suppression and livestock grazing in combination with climate change (Miller et al., 2008). Woody encroachment resulting from fire suppression has occurred in Australia (Noble, 1998) and Venezuela (Silva et al., 2001), as well. Thus, in many parts of the world, vegetation patterns have been dramatically transformed as a result of fire suppression and exclusion in historically frequent-fire systems. By introducing woody vegetation, these changes transform rangelands and agricultural areas in working landscapes, as well, with consequences for regional economies (e.g., Moleele et al., 2002).

In the American West, long-term exclusion of fire by managers in woodland and forest ecosystems began in the late 1800s, leading to accumulation of fuels and increased fuel continuity in many historically frequent-fire regions (Littell et al., 2009; Romme and Despain, 1989; Stephens and Ruth, 2005). After a series of destructive fires, culminating in the Big Blowup of 1910, the US Forest Service was charged with wildland fire suppression to protect the nation's timber (as an economic resource) as well as human lives and property (Busenberg, 2004; Pyne, 2011). Suppression was highly effective; in a particularly dramatic example, fire frequency in ponderosa pine (*Pinus ponderosa*) forests in a southwestern study site decreased from one fire every 3.7 years before 1883 to only one fire event during the 112 years between 1883 and 1994, a 30-fold decrease in frequency (Fulé et al., 1997). Similar changes have occurred in other sites around the Southwest (Noss et al., 2006b). These rapid changes in fuel loads, structure and composition in many fire-adapted arid and semi-arid systems across the US paved the way for escalating fire intensity and fire severity (Pyne et al., 1996).

Fig. 1. Example of a socioecological threshold emerging from changing fire dynamics and leading to altered management objectives: ongoing shrub encroachment stemming from decades of combined fire suppression and grazing reduces the livestock carrying capacity of rangelands (Tobler et al., 2003; Anadón et al., 2014). Since this diminishes ranching profitability, it contributes to a widespread decadal trend of ranch sell-off for development in arid and semi-arid habitats (Sheridan, 2001). Photo by Emily Yurcich.