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Vegetation change during 40 years of repeated managed wildfires in the Sierra Nevada, California

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ABSTRACT

Fire suppression has been reported to homogenize landscapes in regions that historically experienced frequent wildfire. The Illilouette Creek Basin in Yosemite National Park experienced nearly 100 years of fire suppression, but after a change in management strategy it is now one of the few areas in the United States that has experienced a frequent fire regime for the past half-century. This study quantifies changing landscape properties in the Basin from its fire-suppressed state to the present. These landscape properties range from the relative dominance of different vegetation types to the spatial distribution of vegetation patches. This is the first detailed study of watershed-scale changes in overstory vegetation within a landscape transitioning from a fire suppressed condition to frequent, mixed severity wildfires.

We mapped major vegetation types over time within Illilouette Creek Basin using high resolution aerial images from four different decades, starting with the final years of a fire-suppressed period and capturing multiple snapshots during forty years of repeated fires. We quantify landscape heterogeneity and vegetation patch shape properties using landscape metrics. From 1969 to 2012, conifer cover decreased by 24% while shrub area increased by 35%, sparse meadow area increased by 199% and dense meadows by 155%. The Shannon's Evenness Index based on these four vegetation types increased from 0.4 to 0.7, indicating increased landscape heterogeneity. This study demonstrates that wildfires can return diversity to a fire-suppressed landscape, even after protracted fire suppression. Management of forests to restore fire regimes has the potential to maintain healthy, resilient landscapes in frequent fire-adapted ecosystems.

1. Introduction

Landscape structure, as defined by the types and spatial organization of vegetation communities, is shaped by the interactions between disturbance events and succession following disturbance (Miller and Urban, 2000a). Succession trajectories vary depending on disturbance history, local site characteristics, and temporally varying conditions as young vegetation establishes in disturbed sites (Johnson and Miyanishi, 2010). Disturbance processes are also affected by the landscape structure, which can influence disturbance frequency, spatial extent, and severity (Turner, 1989; Turner et al., 1989). These two-way interactions allow landscape composition to be thought of as a non-equilibrium complex system, in which punctuated inputs of energy (in the form of disturbance) prevent the landscapes from achieving steady state conditions (Mori, 2011; Sousa, 1984). Removing these energy inputs, by suppressing disturbance events, would be expected to move landscapes towards a successional "steady state", which, for spatially uniform soil and climate conditions, could produce uniform vegetation cover (D'Odorico et al., 2006).

Homogenization of the landscape has been observed in response to the prevalence of fire suppression as a fire-management strategy in the Western USA during most of the 20th Century. In the Sierra Nevada, the homogeneity of both the landscape and individual forest stands has increased compared to pre-1900 baseline conditions (Scholl and Taylor, 2010; Stephens et al., 2015; Perry et al., 2011; Hessburg et al., 2005), and fire-suppressed forest stands have more than doubled in density since the early 1900s (Collins et al., 2011). In contrast, there are few opportunities to directly observe the response of landscape structure to increases in disturbance frequency due to fire. Simulations suggest that forest density and spatial autocorrelation of forest patches should decrease as fire disturbance rates increase (Miller and Urban, 2000b), with concomitant increases in the abundance of species that prefer open

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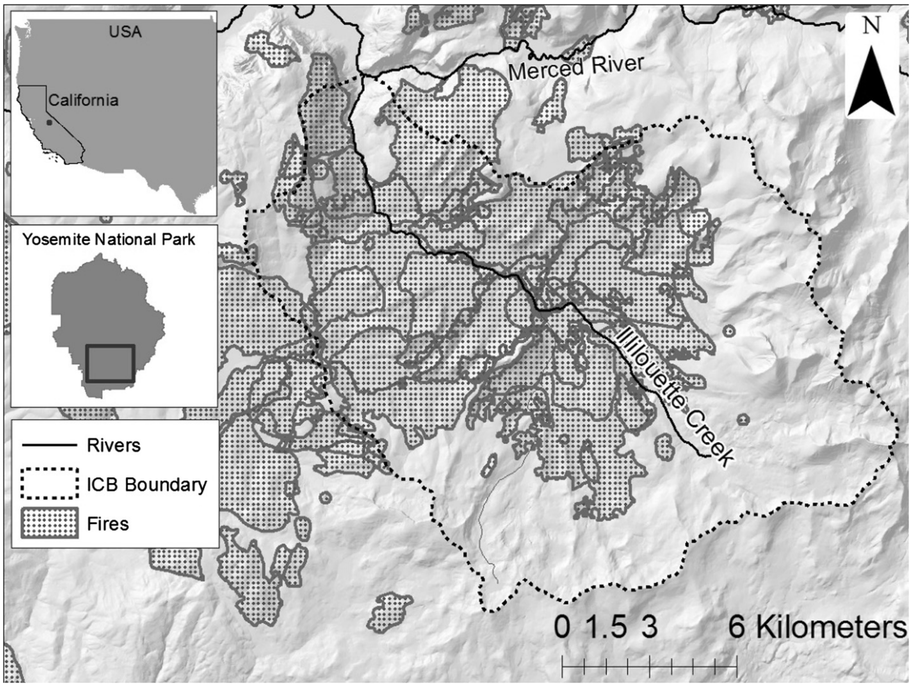

Fig. 1. Map of Yosemite National Park and ICB extent with all known fire perimeters from 1972 to 2012 (fire perimeter maps provided by the California Department of Forestry and Fire Protection).

habitat such as shade-intolerant flowering plants (Pausas, 2006), and in fire- or disturbance-adapted shrub species (Pausas and Lloret, 2007).

Opportunities to empirically evaluate such predictions have generally been limited to considering the immediate effects of isolated disturbance events such as individual stand-replacing fires, yet the conclusions to be drawn are not always clear. Large, stand-replacing fires can increase or decrease species richness, and can reduce beta diversity (the ratio of regional to local species diversity, measuring differentiation between habitats), particularly if the fire results in colonization by a small number of disturbance-tolerant species (Burkle et al., 2015). In contrast, mixed severity fires may increase beta diversity (Burkle et al., 2015; Perry et al., 2011). Such increases are theoretically consistent with increases in landscape heterogeneity in more frequently disturbed systems, since heterogeneity in natural landscapes is generally positively correlated with biodiversity (Seiferling et al., 2014).

However, drawing conclusions about landscape-scale effects of changing disturbance regimes from modeling or individual disturbance events alone is problematic. For example, fire return intervals can affect post-fire recruitment, even amongst fires with the same severity (Donato et al., 2009). Empirically evaluating the effects of increasing fire frequency on previously fire-suppressed landscapes is increasingly important. Forest and land management agencies are striving to find techniques to manage forested landscapes for resilience against the likely increases in fire and drought stress predicted to occur as consequences of climate change (Westerling et al., 2006; Westerling and Bryant, 2008; Stephens et al., 2016). The dense, homogeneous forests generated by decades of fire suppression are likely to exacerbate fire risks due to elevated fuel loads (Stephens et al., 2009; Collins and Skinner, 2014; Taylor et al., 2014) and drought risks due to increased water demand from dense forest stands and uniformly forested landscapes (Goulden and Bales, 2014; Grant et al., 2013). Indeed, high intensity wildfire and large-scale insect outbreaks are altering the Sierra Nevada landscapes faster than they did before fire suppression and logging (Hessburg et al., 2015), and drought-related tree mortality has been increasing throughout the Western US (Moore, 2015; Hicke et al., 2016).

In the Sierra Nevada, vegetation communities are adapted to a frequent, lightning-induced fire regime and Native American ignitions (Stephens et al., 2007; Hessburg et al., 2015). Consequently, "managed wildfire", a land management strategy in which such naturally ignited fires are allowed to burn without intervention (subject to an approved fire management plan) is attracting increased interest. Since 2016, three Californian National Forests (Inyo, Sequoia and Sierra National Forests) have been evaluating if more than 50% of their total area should support the use of managed wildfire (http://www.fs.usda.gov/detail/r5/landmanagement/planning/?cid = STELPRD3802842). Managed wildfire is anticipated to benefit landscapes by restoring a "natural" structure (Hessburg et al., 2015). Natural landscape structure is hypothesized to benefit local ecology (e.g. species abundance and dispersal responding to changes in patch size and shape; Turner, 1989), and hydrology (e.g. canopy interception; Andreadis et al., 2009, evaporative demand; Brown et al., 2005, and timing of snowmelt; Lundquist et al., 2013). Despite the increasing interest in managed wildfire and its effects on landscape structure, empirical evaluations of how landscape structure changes in response to such a management regime are rare, largely due to the paucity of landscapes managed under a natural fire regime.

Here we address this gap by providing a detailed description of how forty years of managed wildfire has altered a previously fire-suppressed landscape in the Illilouette Creek Basin (ICB) of Yosemite National Park in the Sierra Nevada, California. ICB has operated under a managed wildfire policy since 1972, one of only two such long-running managed wildfire regimes in forested areas of California (Van Wagtendonk, 2007). We evaluate changes in the ICB using historical aerial imagery spanning the final years of the fire-suppressed period through 2012. We present the results in terms of overall land cover compositional change, along with a range of metrics describing landscape patterns and vegetation patch structure (Turner, 1989). Results not only provide insight into possible trajectories of landscape structural change upon initiation of a natural wildfire regime, but also form a basis for managers to evaluate the effects of fire-induced landscape compositional changes on basin-scale ecosystem functions, such as water cycling and carbon storage.