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Review

The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California

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ABSTRACT

Forests characterized by mixed-severity fires occupy a broad moisture gradient between lower elevation forests typified by low-severity fires and higher elevation forests in which high-severity, stand replacing fires are the norm. Mixed-severity forest types are poorly documented and little understood but likely occupy significant areas in the western United States. By definition, mixed-severity types have high beta diversity at meso-scales, encompassing patches of both high and low severity and gradients in between. Studies of mixed-severity types reveal complex landscapes in which patch sizes follow a power law distribution with many small and few large patches. Forest types characterized by mixed severity can be classified according to the modal proportion of high to low severity patches, which increases from relatively dry to relatively mesic site conditions. Mixed-severity regimes are produced by interactions between top-down forcing by climate and bottom-up shaping by topography and the flammability of vegetation, although specific effects may vary widely across the region, especially the relation between aspect and fire severity. History is important in shaping fire behavior in mixed-severity landscapes, as patterns laid down by previous fires can play a significant role in shaping future fires. Like low-severity forests in the western United States, many dry mixed-severity types experienced significant increases in stand density during the 20th century, threatening forest health and biodiversity, however not all understory development in mixed-severity forests increases the threat of severe wild fires. In general, current landscapes have been homogenized, reducing beta diversity and increasing the probability of large fires and insect outbreaks. Further loss of old, fire tolerant trees is of particular concern, but understory diversity has been reduced as well. High stand densities on relatively dry sites increase water use and therefore susceptibility to drought and insect outbreaks, exacerbating a trend of increasing regional drying. The need to restore beta diversity while protecting habitat for closed-forest specialists such as the northern spotted owl call for landscape-level approaches to ecological restoration.

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1. Introduction

In fire ecology, definitions of mixed severity fire arose from observations that many fires and fire regimes could not be neatly classified as either surface fire or stand replacement dominated disturbances. These fires occupied a middle zone in terms of first order effects leaving highly variable and mixed patterns of lethal and non-lethal outcomes. Definitions of mixed severity also arose from subtraction of more readily defined terms. Ecosystems with low severity fire were easily described as those where surface fire effects tended to dominate, and they were subsequently defined as those where less than 20% of the overstory trees or basal area is killed by the sum of all fire effects (Agee, 1990, 1993). In concept, low severity fires principally reduce the volume and distribution of the most flammable fuels via surface fire activity, and mortality effects are typically minimal (Stephens et al., 2008). At the opposite pole, high severity fires were also readily described as those where crown fire effects tended to dominate, defined by Agee (1990, 1993) as more than 70% of the overstory trees or basal area killed by the sum of all fire effects. High severity fires principally kill trees via torching and running crown fire and often significantly change the volume and distribution of surface and canopy fuels. Mixed severity fires formed the catch-all bin for what remained, by Agee's (1990, 1993) definition those where 20–70% of the overstory trees or basal area are killed by the sum of all fire effects. The broad bin of 20–70% masks a great deal of variability and would benefit from additional subdivisions. Progress toward a better scientific foundation for mixed severity fire will come by stratifying mixed severity regimes by ecological regions and proportion of high severity fire. Brown et al. (2008): stated the case for the latter "...simply to describe a historical fire regime as variable severity is by itself not useful either for characterizing fire as an ecological process or for fire management or ecological restoration purposes. For example, without reference to scale it is possible to conclude that recent variable-severity fires in ponderosa pine forests (i.e., that have included both surface burning as well as large areas of crown mortality) are within a historical range of variability even though areas of crown mortality are orders of magnitude larger than any area that occurred historically (e.g., Romme et al., 2003).We propose that future definitions of variable-severity fire regimes in ponderosa pine and related forests must be accompanied by descriptions of the maximum spatial extent and how often crown fire occurred over a defined period of time".

> It is important to note that canopy damage is not necessarily the same as soil damage and the two measures of severity can be independent of each other (Jain and Graham, 2007; Safford et al., 2009). In general, the severity of impacts cannot be generalized across different components of an ecosystem (e.g. soils, trees, understory vegetation, streams).

Mixed severity fire regimes are poorly understood and poorly documented but in all likelihood were widespread both in the western and eastern US. For example, Schoennagel et al. (2004) estimate that mixed severity regimes account for 17–50% of the major forest types of the Rocky Mountains.

Key ecological and management questions associated with historic[1] mixed-severity regimes center on implications of structurally diverse and temporally variable landscapes for habitats, animal movements, and propagation of disturbances. Consistent with the *intermediate disturbance hypothesis* (Connell, 1978; Petraitis et al., 1989), mixed severity regimes (by definition) produced rich intermediate scale beta diversity, providing a wide variety of habitats across landscapes. Forests in which mixed severity regimes were the norm were likely to support plant and animal species that prefer closed or nearly closed conditions for at least a part of their life history (Spies et al., 2006), as well as early successional and mid-successional specialists, and species that used both early and late-successional conditions [e.g. the California spotted owl (Bond et al., 2009) and the northern spotted owl in the Klamath Mountains (Franklin et al., 2000)].

In this paper we discuss: (i) the likely extent and location of historical forests of the mixed severity fire regime in Oregon, Washington and California, and variation in fire ecology within this large class (ii) the environmental factors that produce mixed-severity fires; (iii) changes to mixed severity landscapes during the 20th century and threats to biodiversity resulting with those changes; and (iv) uncertainties in the knowledge base and research needed to address those uncertainties. In a companion paper we discuss management approaches to reducing losses to remaining old trees and the habitat they represent; and to maintaining an appropriate mix of early, mid, and late successional habitats across landscapes.

2. Ecology and spatial geography of mixed severity disturbance

What exactly is a mixed severity disturbance? At a broad regional scale all wildfire is mixed severity, a fact that limits the usefulness of such scales for ecological interpretation. Moreover, all disturbance processes exhibit heterogeneity at one spatial scale or another, which may manifest within stands, across landscapes, or in some combination of the two. Within the spectrum of possible patterns mixed severity regimes grade into low and high severity regimes without distinct thresholds or patterns. To better understand the nature of mixed-severity regimes, we must look to the ecology, the spatial geography, and the variability of fires and their effects.

Mixed-severity fires create a patchiness of forest structure, composition, and seral status that can be observed and quantified at an intermediate or meso-scale, with patch sizes ranging from a few hundredths up to tens or hundreds of ha, depending on locale and climatic drivers (Fig. 1a). In forest types that were historically dominated by mixed severity regimes, surface and canopy fuels, topography, climatic conditions, and ignitions worked in concert to influence variation in fire frequency, severity, spatial extent, and seasonality. The result was a complex spatio-temporal mix of low, moderate, and high severity patches.

As we discuss in more detail later, the scale of patch sizes and the envelope of burn severity vary with forest type and across the region, however there are also widespread similarities. Studies in both Washington and California have found that patch sizes in mixed severity regimes followed a negative power law

[1] In the context of this paper, "historic" refers to the period prior to settlement by EuroAmericans.

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