Geographic Variation in Mixed-Conifer Forest Fire Regimes in California[1]

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Abstract
This paper reviews recent research from California on geographic variability in mixed conifer (MC) forest fire regimes. MC forests are typically described as having experienced primarily frequent, low to moderate severity burns prior to fire suppression that created a mosaic of vegetation patches with variable structure. Research throughout California generally supports this view, but recent research demonstrates that fire regimes and vegetation patterns in the MC zone were more complex and displayed significant spatial and temporal variability at landscape and regional scales. At the landscape scale, patterns of fire severity and fire return intervals varied with forest composition and environmental setting (e.g., fire frequency generally decreases from south to north facing slopes). There were also apparent regional differences in some fire regime parameters (e.g., season of burn, fire severity) and not in others (e.g., fire return interval). The degree of geographic variation in MC forest fire regimes suggests that researchers should be cautious when extrapolating relationships between fire regimes and forest structure that are observed in one area to other locations.

Introduction
The 1996 Sierra Nevada Ecosystem Project (SNEP) identified the lack of empirical data on the spatial and temporal variability of fire regime parameters as a key knowledge gap in understanding the dynamics of Sierran ecosystems (Skinner and Chang 1996). Geographical variation in disturbance regimes is known to contribute to regionally distinct vegetation patterns in several widespread forest types (e.g., Spies and Franklin 1989, Veblen and others 1992, Shinneman and Baker 1997, Taylor and Skinner 1998). Yet few studies from forests in California quantify spatial and temporal variability in disturbance regimes, identify the factors that control them, or describe how this variation influences vegetation patterns and dynamics. Determining how fire regime characteristics vary is important for understanding the role of fire in the long-term dynamics of forested ecosystems and is essential for developing strategies to manage and restore fire-prone landscapes. This paper focuses on recent research that begins to address these issues for mixed conifer forests in California. We begin by summarizing the literature on the fire history and ecology of mixed conifer forests and then review the results of recent research from the central Sierra Nevada, southern Cascades, and Klamath Mountains that addresses landscape and regional scale variation in mixed conifer forest fire regimes. We conclude with some of the implications of this recent research for the management of mixed conifer forests.

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Mixed conifer forests

Distribution and characteristics

Mixed conifer forests cover 1.6 million ha (Franklin and Fites-Kaufman 1996) of the mid-montane zone (900 to 2,200 m) in the Klamath, Sierra Nevada, Cascade, and Transverse Ranges of California (Barbour and Minnich 2000). Mixed conifer forests are compositionally and structurally diverse and may be dominated by up to six conifer species including ponderosa pine (*Pinus ponderosa* Dougl.), Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco), incense cedar (*Calocedrus decurrens* Torr.), sugar pine (*Pinus lambertiana* Dougl.), Jeffrey pine (*Pinus jeffreyi* Grev. & Balf. in A. Murr), and white fir (*Abies concolor* Gord. and Glend.). Species composition varies depending on site conditions, latitude, and stand history (Parker 1995, Barbour and Minnich 2000). Patches of montane chaparral often interrupt tree cover in mixed conifer forests and occupy sites that have experienced severe fire or are too poor to support trees (Wilken 1967, Weatherspoon 1987, Rundel and others 1988, Bolsinger 1989). Mixed conifer forests have undergone dramatic compositional and structural changes due to land-use changes (e.g., logging, livestock grazing, fire-suppression management) associated with EuroAmerican settlement.

Ecology and fire regimes

Much of our understanding of the role of fire in mixed conifer forests comes from stand level research conducted in the southern Sierras (Skinner and Chang 1996). These studies suggest that mixed conifer community dynamics prior to EuroAmerican settlement were controlled by feedbacks between vegetation structure, fuels production, and the frequency and severity of burns (e.g., Bonnicksen and Stone 1981, 1982). In these forests, low intensity surface fires occurred frequently (e.g., median fire return interval [MFI]=3 to 20 yr) and created a fine-grained mosaic of multi-aged stands (Kilgore and Taylor 1979, Swetnam 1993, Skinner and Chang 1996). The spatial pattern of burning was controlled by the time required for fuels to build up in a previously burned patch (e.g., van Wagtendonk 1995, Miller and Urban 1999, Minnich and others 2000), and the forest pattern resulting from this process has been described as a shifting mosaic steady-state (e.g., Bormann and Likens 1979) at the landscape scale (Bonnicksen and Stone 1981, 1982).

There is considerable spatial variability in forest composition and structure at landscape and regional scales in the mixed conifer zone that may not have resulted from feedbacks between fire regimes and forest structure. The relationship between fire and forest structure described for mixed conifer forests in the southern Sierras is based primarily on stand level data. At landscape and regional scales, fire regimes may also have been strongly influenced by topographic variation (e.g., Taylor and Skinner 1998, Taylor 2000, Beaty and Taylor 2001), extreme weather (e.g. Miller and Urban 1999, Bekker and Taylor 2001) or climate variability (e.g., Swetnam 1993). As a result, interactions between fire regimes and forest structure may have been more complex and less stable than previously described, and a non-equilibrium explanation (e.g., Botkin 1990, Sprugel 1991) of mixed conifer forest dynamics may be more appropriate. The remainder of this paper illustrates this point by describing some of the ways fire regime parameters varied historically at landscape and regional scales in relation to variation in environmental factors.

Variation within the mixed conifer zone

Landscape scale variation

Researchers are beginning to recognize and quantify the influence that topography has on disturbance regimes at the landscape scale (e.g., Harmon 1982, Foster and Boose 1992, Kulakowski and Veblen 2002). In mixed conifer forests, several studies have demonstrated that fire return intervals (FRI) varied with slope aspect and elevation (Kilgore and Taylor 1979, Caprio and Swetnam 1995, Fites-Kaufman 1997, Taylor 2000, Beaty and Taylor 2001, Bekker and Taylor 2001). There was a general pattern of lengthening fire return intervals from south to north facing slopes and from low to high elevations. This spatial variation in FRI may have been due to factors related to slope aspect and elevation that affect species composition and the flammability of fuels. In the Sierra Nevada and southern Cascades, species distribution and abundance patterns at the landscape scale are strongly controlled by elevation and slope aspect (Parker 1994, Parker 1995, Bekker and Taylor 2001). Generally, there is increased representation of fir versus pine along a gradient from south to north aspects and from low to high elevations. This variation in species composition has implications for landscape scale patterns of burning. Forest litter from long-needled species (i.e. ponderosa pine, sugar pine) is less dense than that from short-needled species (i.e. Douglas-fir, white fir, red fir) (e.g., Albini 1976, van Wagtendonk 1998), and fire intensity and spread are greater in lower density fuel beds (Albini 1976, Rothermel 1983, Fonda and others 1998). Additionally, on south facing slopes fuel moisture is lower for a longer period each year than on north facing slopes increasing the likelihood of an ignition developing into a fire (Agee 1993). Fires may also burn again sooner in pine dominated forests since the production of fine fuel is greater in pine versus fir dominated mixed conifer forests (e.g., Agee and others 1978, Stohlgren 1988).

Variation in fire severity has been identified as an important source of structural diversity in forested landscapes. In mixed conifer forests, fires have been described as being primarily low and moderate severity events (e.g., Kilgore and Taylor 1979, Bonnicksen and Stone 1982, Skinner and Chang 1996). Recent research from the southern Cascades (Beaty and Taylor 2001, Bekker and Taylor 2001), Klamath Mountains (Taylor and Skinner 1998), and central Sierra Nevada (Nagel 2002) demonstrates that high severity burns were an intrinsic part of the fire regime and that landscape scale fire severity patterns were also strongly influenced by topography. In these studies, the authors used fire scar dendrochronology, stand structural analysis, and repeat historical aerial photography to reconstruct cumulative patterns of fire severity. They found a gradient of increasing fire severity with increasing topographic position, and fire severity was generally high on upper slopes, low on lower slopes and intermediate on middle slopes (Taylor and Skinner 1998, Beaty and Taylor 2001). Higher fire induced tree mortality at mid and upper slope positions may have occurred due to higher fire line intensities at these positions. Higher fire line intensities are driven by the presence of fuels dried by greater exposure to wind and solar radiation and by the preheating of fuels that occurs when a fire moves up a slope (e.g., Rothermel 1983). This topographically controlled fire severity gradient indicates that interactions between topography and fire behavior can promote highly variable structures at landscape scales in mixed conifer forests.

Topography also influenced the timing of fire occurrence by promoting discontinuous fuels and limiting fire spread. In a study of a 2,325 ha mixed conifer forest in the Klamath Mountains, Taylor and Skinner (2003) found that patterns of fire occurrence were strongly influenced by riparian areas, changes in slope aspect, and rock outcrops that controlled fire spread. Fire occurrence groups had similar fire return intervals, but fires tended to occur in different years (Taylor and Skinner 2003). Differences between groups were not related to other factors such as species composition or differences in environmental parameters. The authors concluded that topographically controlled fire breaks act as filters that reduce the spread of fires, except in extremely dry years.

The previous examples emphasize the important influence of topography at the landscape scale on fire regime characteristics in forests on highly contrasting terrain. It is important to note that topographic controls may have been weaker on less contrasting terrain. For example, on flat terrain burn severity may have been more strongly associated with the strength and direction of prevailing winds than with variation in topography. Such differences may also have had important influences on compositional and structural patterns within mixed conifer forests at the landscape scale.

Regional scale variation

Within the mixed conifer zone, some fire regime parameters varied, while others were similar across stands. The range of values for fire return interval estimates was similar for the pre-fire suppression period in mixed conifer forests in the southern Cascades (Taylor 2000, Beaty and Taylor 2001, Bekker and Taylor 2001, Norman and Taylor 2002), the Klamath Mountains (Taylor and Skinner 1998, Taylor and Skinner 2003), the Sierra Nevada (Kilgore and Taylor 1979, Caprio and Swetnam 1995, Fites-Kaufman 1997), the San Bernardino range (McBride and Lavin 1976), and the Sierra San Pedro Mártir in Baja California (Burk unpublished in Savage 1997, Stephens and others 2003). These studies all indicate that frequent fire was important in the dynamics of mixed conifer forests, yet they also suggest that variation in fire return intervals may not have been as important as variation in other fire regime parameters in explaining compositional and structural differences across mixed conifer stands.

Fire history research throughout California suggests there may have been considerable variability in season of burn within mixed conifer forests. The season of fire occurrence has been reconstructed in dendroecological studies based on the position of fire scars in annual growth rings (e.g., Caprio and Swetnam 1995). In the Sierra San Pedro Mártir in Baja California nearly all fires in mixed conifer forests burned during the growing season (Stephens and others 2003), while in the central Sierra Nevada, 50 percent of the fires occurred near the end of the growing season and only 30 percent occurred in the dormant season (Caprio and Swetnam 1995). Fire seasonality in the Klamath Mountains (e.g., Taylor and Skinner 2003) and southern Cascades (e.g., Beaty and Taylor 2001, Norman and Taylor 2002) was different than that reported for the central Sierra Nevada. In these more northern forests, fires occurred mainly (75 to 90 percent) in the dormant season. These geographical differences may have been related to differences in the onset of summer drought along the Sierra Nevada-Cascade axis (e.g., Major 1977, Parker 1994, Skinner 2002). Drought may have occurred earlier in southern mixed conifer forests than in northern forests and this may have influenced the length of time fuels were dry enough to burn each year. The dominant season of burning has a strong influence on a species' response to fire (e.g., Kauffman and Martin 1989, Kauffman 1990), and regional variation in fire season may lead to distinct vegetation responses to fire.

There may also have been a regional gradient in fire severity between northern and southern mixed conifer forests. In the southern Cascades (Beaty and Taylor 2001, Bekker and Taylor 2001), Klamaths (Taylor and Skinner 1998), and central Sierra Nevada (Nagel 2002), topographically controlled (see previous section), high severity burns that generated coarse-grain patterns of even aged forest stands were an intrinsic part of mixed conifer forest fire regimes. This contrasts with typical descriptions of fires in mixed conifer forests as having been primarily low and moderate in severity (Kilgore and Taylor 1979, Bonnicksen and Stone 1982, Skinner and Chang 1996). Few landscape scale studies, however, reconstruct fire severity patterns. Thus, additional research is needed to evaluate whether high severity fires were indeed uncommon in southern mixed conifer forests.

Conclusions

Understanding spatial and temporal variability in fire regime parameters is essential for developing strategies for managing and restoring fire-prone landscapes (Skinner and Chang 1996). Recent research from mixed conifer forests in California demonstrates that there was significant variability in fire regime parameters at both landscape and regional scales. At landscape scales, patterns of fire occurrence, severity and timing were influenced by topography and climatic variability. At regional scales, some fire regime parameters were similar (e.g., fire return interval), while other parameters may have varied substantially (e.g., season of burn, fire severity). Variable disturbance regimes in mixed conifer forests highlight the importance of incorporating “site-specific” knowledge of past fire and vegetation dynamics into management plans and suggest that researchers should be cautious when extrapolating relationships between fire regimes and forest structure that are observed in one area to other locations.

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