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Drought triggered tree mortality in mixed conifer forests in Yosemite National Park, California, USA

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Abstract

Tree mortality is an important process causing forest structural and compositional change. In this study, we investigate the influence of drought and topography on recent patterns of tree mortality in old-growth mixed conifer forests in Yosemite National Park, located in the Sierra Nevada Mountains of northern California, USA. The surveyed stands have experienced a century of fire exclusion and are dominated by associations of *Pinus ponderosa*, *Calocedrus decurrens* and *Abies concolor*. The average age of trees in the stands was 88 years. We sought answers to the following questions: (1) Do periods of high tree mortality correspond with drought? (2) Do spatial and temporal patterns of high tree mortality vary by slope aspect? and (3) Do different tree species exhibit similar temporal and spatial patterns of tree mortality? We identified temporal patterns of tree mortality on three north- and south-facing slopes by determining the death date of trees using dendrochronology. Tree death date frequency was then compared by slope aspect and to Palmer Drought Severity Index (PDSI), and April snowpack depth as measures of growing season water availability. The frequency of tree death dates was negatively correlated with annual and seasonal PDSI and April snowpack depth, and more trees died in years with below normal PDSI and snowpack. Correlations between tree mortality and drought were evident only for multi-year periods (2–5 years). Temporal patterns of tree death were similar on north- and south-facing slopes and among species, but the density of dead trees was higher on north than south slopes. Dense stand conditions caused by fire suppression, and the coincident outbreak of bark beetles during drought, may have limited any buffering effect of topography on tree mortality. Drought induced tree mortality in mixed conifer forests in Yosemite National Park highlights the importance of both historical legacies such as fire suppression and exogenous controls such as climate as drivers of vegetation change.

Keywords: Disturbance; Insect attack; Fire suppression; Tree mortality; Forest dynamics; *Pinus ponderosa*; *Abies concolor*; *Calocedrus decurrens*; Climate change

1. Introduction

Tree mortality plays a key role in the functional and structural dynamics of forest ecosystems, both as a mechanism for the release of carbon and nutrients, and

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as an agent of forest structural and compositional change (Franklin et al., 1987). While the causes of tree death related to discrete events such as fire or windthrow may be identified easily, longer periods of elevated tree mortality are usually associated with complex interactions between endogenous factors such as stand characteristics and genetics, and exogenous factors like site conditions, climate, insects and pathogens, which operate over a range of scales (Allen and Breshears, 1998; Mueller-Dombois, 1987, 1992; Savage, 1994).

Climate is an exogenous, regional-scale environmental control that influences vegetation development and establishes a context for local stand-level growth responses of trees (Lertzman and Fall, 1998). Climatic variation is thought to be an important factor influencing temporal and spatial patterns of tree death in forested ecosystems in both direct and indirect ways. For example, extended drought has been linked directly to tree death in tropical and temperate forests (Allen and Breshears, 1998; Villalba and Veblen, 1998; Fensham and Holman, 1999; Williamson et al., 2000). Indirectly, drought has been linked to tree death by acting as a trigger for insect or pathogen outbreaks (Ferrell et al., 1994; Ferrell, 1996; Speer et al., 2001). Extended periods of warm, dry conditions can induce a state of physiological stress, which reduces the ability of trees to withstand insect attacks. Consequently, drought often makes conifers more vulnerable to the attack of cambium-eating insects and this vulnerability may be expressed by an episode of high tree mortality (Mattson and Haack, 1987; Ferrell et al., 1994).

Montane forests in the western United States that once experienced frequent low and moderate severity fires have been dramatically altered by nearly a century of fire exclusion. For example, prior to Euro-American settlement, fires burned every 5–10 years in California's mixed conifer forests (Kilgore and Taylor, 1979; Caprio and Swetnam, 1995; Beaty and Taylor, 2001; Taylor and Skinner, 2003). Since the early 20th century a policy of excluding fires has been implemented in these forests (Skinner and Chang, 1996) and the reduction in the frequency and extent of fire has caused an increase in forest density, and a compositional shift to more fire sensitive species (Vankat and Major, 1978; Parsons and DeBenedetti, 1979; Minnich et al., 1995; Taylor, 2000; Taylor and Skinner, 2003). Unusually high forest densities caused by fire suppression are thought to exacerbate the effect of drought on tree mortality because of increased competition for soil moisture that increases water stress in trees (Innes, 1992; Dolph et al., 1995). Consequently, drought may trigger rapid vegetation change because mortality processes are quick and episodic compared to vegetation changes caused by new establishment which are slow and gradual (Franklin et al., 1987). Retrospective studies that examine the influence of climate on vegetation dynamics (e.g., Overpeck et al., 1990) provide an important basis for understanding how ecosystems respond to climatic variation, including climate changes predicted by models that incorporate increased greenhouse gas emissions from the combustion of fossil fuels (e.g., Leung and Ghan, 1999; Dettinger et al., 2004).

The regional-scale control of climate on temporal patterns of tree mortality may be mediated by local-scale controls, such as topographic variation, that influence site-level water availability (Stephenson, 1990). Topographic characteristics such as slope position and slope aspect are known to strongly influence site moisture conditions (Stephenson, 1990, 1998), and climatically triggered tree dieback may vary accordingly (Jane and Green, 1983; Allen and Breshears, 1998; Powers et al., 1999). Slope aspect, in particular, is a key topographic variable influencing site moisture availability in the mountainous western United States (Parker, 1982; Stephenson, 1990). South-facing slopes receive more solar radiation, experience greater evapotranspiration, and have less plant available soil moisture compared to north-facing slopes. Consequently, spatial and temporal variations in site moisture conditions may influence the spatial pattern and severity of drought induced tree mortality. Yet, few studies have evaluated the potential mediating effects of topography on widespread tree mortality (Akashi and Mueller-Dombois, 1995; Powers et al., 1999).

High interannual variability in precipitation is a hallmark of California's Mediterranean climate (Mittchell and Blier, 1997), and tree mortality in Californian mixed conifer forests in the San Bernardino Mountains and Sierra Nevada appear to be associated with prolonged drought and drought-related insect outbreaks (CFPC, 1970–1997; Macom-