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Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA; a comparison of current and reconstructed conditions

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ABSTRACT

Fire plays an important role in shaping many Sierran coniferous forests, but longer fire return intervals and reductions in area burned have altered forest conditions. Productive, mesic riparian forests can accumulate high stem densities and fuel loads, making them susceptible to high-severity fire. Fuels treatments applied to upland forests, however, are often excluded from riparian areas due to concerns about degrading streamside and aquatic habitat and water quality. Objectives of this study were to compare stand structure, fuel loads, and potential fire behavior between adjacent riparian and upland forests under current and reconstructed active-fire regime conditions. Current fuel loads, tree diameters, heights, and height to live crown were measured in 36 paired riparian and upland plots. Historic estimates of these metrics were reconstructed using equations derived from fuel accumulation rates, current tree data, and increment cores. Fire behavior variables were modeled using Forest Vegetation Simulator Fire/Fuels Extension.

Riparian forests were significantly more fire prone under current than reconstructed conditions, with greater basal area (BA) (means are 87 vs. 29 m^2/ha), stand density (635 vs. 208 stems/ha), snag volume (37 vs. 2 m^3/ha), duff loads (69 vs. 3 Mg/ha), total fuel loads (93 vs. 28 Mg/ha), canopy bulk density (CBD) (0.12 vs. 0.04 kg/m^3), surface flame length (0.6 vs. 0.4 m), crown flame length (0.9 vs. 0.4 m), probability of torching (0.45 vs. 0.03), predicted mortality (31% vs. 17% BA), and lower torching (20 vs. 176 km/h) and crowning indices (28 vs. 62 km/h). Upland forests were also significantly more fire prone under current than reconstructed conditions, yet changes in fuels and potential fire behavior were not as large. Under current conditions, riparian forests were significantly more fire prone than upland forests, with greater stand density (635 vs. 401 stems/ha), probability of torching (0.45 vs. 0.22), predicted mortality (31% vs. 16% BA), and lower quadratic mean diameter (46 vs. 55 cm), canopy base height (6.7 vs. 9.4 m), and frequency of fire tolerant species (13% vs. 36% BA). Reconstructed riparian and upland forests were not significantly different. Our reconstruction results suggest that historic fuels and forest structure may not have differed significantly between many riparian and upland forests, consistent with earlier research suggesting similar historic fire return intervals. Under current conditions, however, modeled severity is much greater in riparian forests, suggesting forest habitat and ecosystem function may be more severely impacted by wildfire than in upland forests.

1. Introduction

Fire plays an important role in shaping stand structure, species composition, and fuel loads in many Sierran coniferous forest types. However, longer fire return intervals and reductions in annual area burned caused by fire suppression and changes in climate and grazing practices have altered forest conditions (Anderson and Moratto, 1996; Douglass and Bilbao, 1975; Dwire and Kauffman, 2003; Pyne, 1982; Skinner and Chang, 1996; Stephens et al., 2007). High densities of small trees and increased fuel loads are now present in many productive forest types that were historically maintained by frequent low- to moderate-intensity fires, resulting in increased risk of high-intensity fire (McKelvey and Busse, 1996; Stephens and Moghaddas, 2005). Development in wildland-urban interface areas with high fuel loads continues at an increasing rate, spurring land managers to suppress most wildfires despite policies that encourage reintroduction of fire as an ecosystem process (Jensen and McPherson, 2008).

Although fuel reduction is accomplished in strategic areas using treatments such as mechanical thinning and prescribed burning, treatment has historically been limited or excluded from riparian areas (FEMAT, 1993; USDA, 2004; McCaffery et al., 2008; Safford et al., 2009). While active management of fuels in riparian areas is becoming increasingly common (Stone et al., 2010), there is a lack

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of riparian stand structure and fuel load data that could support the perceived need for riparian fuels management. Riparian forests are often very productive due to greater moisture availability and have accumulated high stem densities and fuel loads, making them susceptible to high-severity fire and subsequent stream channel erosion, loss of wildlife habitat, and decreased ecosystem function (Camp et al., 1997; Olson and Agee, 2005; Segura and Snook, 1992; Skinner and Chang, 1996). High fuel loads and stem densities in riparian forests may allow them to act as a wick for high-intensity fire through a landscape of treated upland forest (e.g. the 2007 Angora Fire in the Tahoe Basin) under some conditions (Murphy et al., 2007; Pettit and Naiman, 2007). Although riparian areas are characterized by lower temperatures and higher humidity (Rambo and North, 2008, 2009) than adjacent upland areas, which may slow fire spread through the landscape under non-drought conditions (Skinner and Chang, 1996), they often burn at similar frequencies and may even propagate fire through the upland matrix during extreme weather conditions (Agee, 1998; Dwire and Kauffman, 2003; Pettit and Naiman, 2007; Van de Water and North, 2010). Despite increasing recognition of the importance of fire in some riparian forests, few studies have attempted to reconstruct historic riparian stand structure and fuel loads in the context of an active fire regime (Poage, 1994). Assessing the relationship between current and historic stand structure and fuel loads in adjacent riparian and upland forests could be useful in guiding efforts to restore forest ecosystems altered by fire exclusion and past timber harvesting.

Objectives of this study were to determine whether current riparian and upland forests have different stand structure, fuel loads, and potential fire behavior than historic riparian and upland forests, and whether riparian forests currently or historically had different stand structure, fuel loads, and potential fire behavior than upland forests. Because few studies of the linkages between fire and riparian stand dynamics have been conducted, additional objectives were to explore the relationships between historic stand conditions and fire regimes, as well as between riparian and upland forests under current vs. historic conditions. We hypothesized that: (1) current riparian and upland stands have stand structure and fuel loads more conducive to high-intensity fire than reconstructed riparian and upland stands; (2) current riparian stands have stand structure and fuel loads more conducive to high-intensity fire than current upland stands; and (3) reconstructed riparian stands have stand structure, fuel loads and potential fire behavior similar to reconstructed upland stands. Attributes suggesting that a stand is conducive to high-intensity fire include high basal area, stand density, snag volume, fuel loads, flame length, probability of torching, canopy bulk density, and potential mortality, and low quadratic mean diameter, canopy base height, fire-tolerant species composition, torching index, and crowning index. Additionally, we investigated the correlation between: (a) fire return intervals and reconstructed stand structure, fuel loads, and predicted fire behavior in riparian and upland forests; and (b) riparian and upland stand structure, fuel loads, and predicted fire behavior under current and reconstructed conditions.

2. Methods

2.1. Study area and site selection

Sampling occurred in four areas of the northern Sierra Nevada: the Almanor Ranger District of the Lassen National Forest (15 sites), the Onion Creek Experimental Forest (4 sites), and the east and west sides of Lake Tahoe Basin (6 and 11 sites, respectively) (Van de Water and North, 2010). Elevations ranged from 1519 m at Philbrook Creek on the Lassen National Forest to 2158 m at Tunnel Creek in the Lake Tahoe Basin. Longitudes ranged from 119° 55′ W to 121° 30′ W, and latitudes ranged from 38° 55′ N to 40° 20′ N. Most precipitation occurs during the winter as snow, and average annual totals (data from 1903 to 2009) varied from 460 mm on the east side of the Lake Tahoe Basin to 1340 mm on the Lassen National Forest (Beaty and Taylor, 2001; DRI, 2009). Forest composition varies widely with elevation, aspect and precipitation, and includes white fir (*Abies concolor*), red fir (*Abies magnifica*), Jeffrey pine (*Pinus jeffreyi*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), lodgepole pine (*Pinus contorta* ssp. *murrayana*), western white pine (*Pinus monticola*), incense-cedar (*Calocedrus decurrens*), Douglas-fir (*Pseudotsuga menziesii*), black oak (*Quercus kelloggii*), quaking aspen (*Populus tremuloides*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), mountain alder (*Alnus incana* ssp. *tenuifolia*), and willow (*Salix* spp.) in varying proportions. Jeffrey pine or ponderosa pine typically dominate on drier sites and south-facing slopes, while white fir or red fir typically dominate on wetter sites and north-facing slopes. Sampling was confined to Sierra Nevada forest types that were historically characterized by frequent (<30 year), low- to mixed-severity fire regimes.

Anthropogenic influence in all sampling areas has likely had a profound effect on stand structure and fuel loads. The Washoe Indians and their ancestors have inhabited the Lake Tahoe Basin for the last 8000–9000 years, and may have used fire to improve accessibility, wildlife habitat, hunting, and plant material quality. Major Euro-American settlement of the Tahoe Basin began when the first pack trail into the basin was completed in the 1850s. Logging began on the south shore of Lake Tahoe in 1859, and numerous settlements were established in the 1860s. Much of the Lake Tahoe Basin was heavily logged from the 1860s to 1890s to support the mining of Nevada's Comstock Lode. Accumulation of logging slash and introduction of new ignition sources such as sawmills, railroads, and logging equipment likely influenced fire frequency, residual stand structure, and fuel loads during this era (Lindstrom et al., 2000).

The Almanor Ranger District of the Lassen National Forest is located in Plumas County, which was also extensively logged beginning with the opening of the first sawmill in 1851 (Lawson and Elliot, 2008). The Onion Creek Experimental Forest was subject to considerably less human influence than the Tahoe Basin and Lassen areas, with only 20% of the area logged in the early 1900s (Berg, 1990). Because logging likely removed many of the larger trees with the longest tree ring records, sampling was concentrated on remnant late successional forest patches that would facilitate the best reconstruction of historic stand conditions.

Because data for this study was collected in conjunction with a study on historic riparian fire regimes (Van de Water and North, 2010), potential sites were identified by first consulting US Forest Service maps of late successional forest patches likely to contain a long fire record. Potential sites were then scouted to determine the prevalence of numerous fire-scarred trees, stumps, and logs. Sample sites were non-randomly chosen to provide a long record of fire history and to represent the variability of forest types and riparian area characteristics present in Sierra Nevada forests influenced by fire exclusion. Within these sample sites, plot locations were randomly selected for both the riparian and upland areas, with the stipulation that upland sites were located on the same side of the stream from which most historical fires likely approached, given local topography and regional wind patterns. This ensured that the effects of fire on stand structure and fuel loads measured in upland forests were not influenced by riparian microclimates. The riparian zone was determined by a combination of stream channel incision and understory plant community composition (i.e. riparian indicator species that were common throughout the study area, such as *Rubus parviflorus*, *Pteridium aquilinum*, *Alnus incana* spp. *tenuifolia*, *Salix* spp.). Riparian zone widths varied from 7 m on narrow ephemeral headwater streams to 420 m on wide alluvial flats of large perennial streams (Van de Water and North, 2010).