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Comparison of riparian and upland forest stand structure and fuel loads in beetle infested watersheds, southern Rocky Mountains

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ABSTRACT

Extensive outbreaks of mountain pine beetle (MPB), spruce beetle (SB), and other insects are altering forest stand structure throughout western North America, and thereby contributing to the heterogeneity of fuel distribution. In forested watersheds, conifer-dominated riparian forests frequently occur as narrow linear features in the landscape mosaic and contribute to the spatial complexity of forest stands and fuel complexes. These streamside forests are valued for providing aquatic and terrestrial habitat, serving as sources of instream and floodplain large wood, and maintenance of streamside microclimates and stream water quality. Despite the ecological importance of riparian forests, few data exist on riparian stand attributes and fuel complexes in watersheds affected by recent beetle outbreaks. To address this need, we measured stand characteristics and fuel loads in riparian areas and adjacent uplands. Within beetle-infested watersheds in northern Colorado and southeastern Wyoming, we sampled 30 pairs of riparian and upland plots (0.05 ha). Our goal was to identify bark beetle induced differences in forest structure and fuel profiles between riparian and upland stands. Specific objectives were: (1) to quantify and compare riparian and upland forest characteristics, specifically structure, extent of insect-caused canopy mortality and understory regeneration; (2) to characterize and compare riparian and upland fuel profiles. Basal area did not differ significantly for live, dead, or total (live + dead) overstory trees ($\geqslant$10 cm diameter at breast height (DBH)) between upland and riparian stands, although variability was high between plot types and among plots. Although riparian and upland plots were both dominated by lodgepole pine, Engelmann spruce, and subalpine fir, they differed in relative proportions of lodgepole pine (higher in uplands) and Engelmann spruce (higher in riparian areas). For these two species, bark beetles caused greater than 80% mortality in diameter classes larger than 20 cm DBH across all plots. For subalpine fir, which is not directly affected by MBP or SB, live overstory basal area and stem densities were roughly similar in riparian and upland plots. The combination of MPB-and-SB-caused canopy mortality has diminished differences in overstory basal area composition of riparian and upland stands, making them more structurally similar than prior to the beetle outbreaks. Total understory stem densities of poles, saplings and seedlings were largely comparable across plot types. However, understory live subalpine fir densities were significantly higher in both riparian and upland plots compared to lodgepole pine and Engelmann spruce, suggesting that fir will play an increasingly important role in future forest development across the landscape. With the exception of 1-h fuels and herbaceous plant cover (higher in riparian plots), fuel complexes were also similar in riparian and upland plots, with total woody fuel loads of approximately 45 Mg ha^{-1}. Although current basal area, understory characteristics and surface fuel distribution are largely similar in riparian areas and uplands, fuel distribution and corresponding fire risk will likely change as the SB infestation progresses, stands respond to overstory mortality, and dead trees fall.

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1. Introduction

Throughout much of the western USA and Canada, conifer forests are undergoing bark beetle epidemics of unprecedented extent and severity (Raffa et al., 2008). Outbreaks of mountain pine beetle (MPB; *Dendroctonus ponderosae* Hopkins, Coleoptera: Curculionidae), spruce beetle (SB; *Dendroctonus rufipennis* Kirby, Coleoptera: Curculionidae), and other insects have affected millions of acres, altering forest stand composition and structure, the distribution, quality and quantity of fuels, and ecosystem processes (Raffa et al., 2008; Jenkins et al., 2008, 2012). The effects of MPB

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outbreaks on stand structure, notably basal area, species composition, and size class distribution, are reasonably well documented in the Rocky Mountain region in ponderosa (*Pinus ponderosa* C. Lawson) and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. ex S. Watson) dominated forests (Romme et al., 1986; Axelson et al., 2009). In some mixed-aged stands, MPB has caused nearly 70% tree mortality, while nearly 90% mortality has been observed in large trees (Cole and Amman, 1980; Romme et al., 1986; Collins et al., 2011; Pelz and Smith, 2012). Similarly, effects of SB on subalpine forests dominated by Engelmann spruce (*Picea engelmanii* (Parry) Engelm.) in the Intermountain West (Jenkins et al., 2008; Jorgensen and Jenkins, 2011; DeRose and Long, 2012a,b) and Colorado (Veblen et al., 1991; Eisenhart and Veblen, 2000) have been described for previous and current large-scale epidemics. Research on the recent beetle outbreaks has increased understanding of the spatial variation in canopy mortality, trajectories of forest recovery (Collins et al., 2011), and the influence on distribution of fuels and potential fire behaviour (Page and Jenkins, 2007; Hicke et al., 2012).

Riparian forests occupy only a small proportion of area within the landscape mosaic, generally occurring as narrow linear streamside features. In the Rocky Mountains, conifer-dominated riparian vegetation is frequently similar to surrounding uplands in overstory species composition, although it can have higher basal area, stem densities, plant diversity, and rates of production in the understory (Carsey et al., 2003; Romme and Knight, 1981). Streamside forests provide valued aquatic and terrestrial habitat, maintain riparian microclimates and stream water quality, and serve as sources of in-stream and floodplain large wood (NRC, 2002). Because of their ecological importance, riparian areas are afforded additional protection; they are administratively designated zones adjacent to stream channels with specific management objectives and regulations aimed at maintaining or improving valued ecosystems services, especially water quality (USDA Forest Service, 2012). Despite the valued functions of riparian ecosystems, few data exist on streamside forest stand attributes and fuel characteristics in watersheds affected by recent beetle outbreaks. Assessment and monitoring of forest condition, both plot-based and remotely sensed, have emphasized impacts on upland forests (Collins et al., 2012; Colorado State Forest Service, 2012). Comparable information on forest stand structure, extent of canopy mortality, composition of the residual overstory, and distribution of fuel loads in riparian areas is lacking. This limited knowledge, combined with administrative regulations for riparian management, presents additional challenges to resource specialists planning fuel treatment projects and other management actions in beetle infested watersheds.

To address this need, we measured stand characteristics and fuel loads in streamside and adjacent upland stands within selected beetle-infested watersheds in northern Colorado and southeastern Wyoming. Our objective was to compare bark beetle effects in riparian and upland forests with respect to species composition, structure, extent of insect-caused mortality, regeneration, and fuel profiles. Our broader objective is to provide basic ecological information about the condition of riparian forests in beetle-infested watersheds that could be useful for designing current and future conservation and management strategies.

2. Methods

2.1. Study area

The study was conducted in subalpine forests between 2500 and 3200 m in elevation in the Medicine Bow, Routt, Arapaho, and Roosevelt National Forests (Fig. 1), in southeastern Wyoming's Medicine Bow Mountains, and Colorado's Front Range (39°50′22″N, 105°55′3″W to 41°50′22″N, 106°12′14″W; Table 1). This elevation band was selected to sample effects of both MPB and SB. Within this elevation band, lodgepole pine generally comprises 45–55% of the tree cover, and Engelmann spruce and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) each contributes approximately 25–35% cover (Dillon et al., 2005; Alexander et al., 1986). Lodgepole pine usually dominates lower elevations and drier sites, whereas Engelmann spruce and subalpine fir tend to dominate at higher elevations, on north-facing slopes, and along riparian corridors, though lodgepole pine is frequently present. The study area has a temperate, continental climate with long, cold winters and short, cool summers (Kittel et al., 2002). Mean annual precipitation ranges from 450 mm to 660 mm across the study area (Fig. 1), with approximately 65% falling as snow between October and May. Air temperature ranges from an average low of −10 °C in January to an average high of 22.1 °C in July (PRISM Climate Group, 2012). The stream flow regime throughout the area is snowmelt dominated, and peak flow usually occurs in June (Jarrett, 1990).

The primary agents of natural disturbance in these subalpine forests are fire (Sherriff et al., 2001; Sibold and Veblen, 2006; Sibold et al., 2006), wind (Romme and Knight, 1981; Aplet et al., 1988), and bark beetle infestations (Kulakowski et al., 2003; Sibold et al., 2007; Jenkins et al., 2014). In the study area, mean fire intervals have been estimated based on age-class sampling, fire scars, historical records, and evaluation of stand structure and fuel accumulation. Estimated mean fire intervals for a given stand of subalpine forest range from 50 to 700 years, with most estimates between 200 and 500 years (Romme and Knight, 1981; Kipfmueller and Baker, 2000; Sibold and Veblen, 2006; Sibold et al., 2006). This large variation has been attributed to differences in site characteristics and species composition, with the longest fire-free intervals associated with mesic sites occurring on north-facing slopes, at high elevations or along streams (Dillon et al., 2005). Fire suppression was the dominant management policy from about 1920 until the early 1990s (Dillon et al., 2005; Sibold et al., 2006; Sibold and Veblen, 2006), and effectively managed wildfires during that period.

Throughout the study area, extensive lodgepole pine mortality from MPB became increasingly evident between 1998 and 2002, and the annual acreage affected peaked in 2008 (Colorado State Forest Service, 2010, 2012). The SB outbreak in north-central Colorado and southern Wyoming has been underway since 2005, and continues to spread. In 2012, the acreage impacted by SB surpassed that of MPB in Colorado for the first time since the MPB epidemic began in the late 1990s (Colorado State Forest Service, 2012).

2.2. Site selection

Potential study watersheds, i.e. those with >50% MPB beetle infestation, were selected using aerial detection survey maps of MPB beetle infestation compiled by US Forest Service Forest Health Monitoring program (USDA, 2011). Watersheds with previous clear-cuts were avoided. Potential riparian study locations were identified through examination of topographic maps, digital elevation models, forest vegetation maps for the selected watersheds, and suggestions from local land managers. Criteria were conifer-dominated riparian areas along gentle-to-moderate stream gradients, moderately confined stream segments with narrow floodplains, within the elevation range 2500–3200 m. Upland plots were located 200–400 m upslope from each riparian plot, on a randomly selected (coin-toss) side of the adjacent stream. Riparian study locations were selected first, followed by selection of a paired upland plot location. In cases where a road was present on one side of the channel, the upland plots were located on the non-roaded side.