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Are density reduction treatments effective at managing for resistance or resilience to spruce beetle disturbance in the southern Rocky Mountains?

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ABSTRACT

While bark beetle disturbance is an inherent component of coniferous forest ecosystems throughout the northern hemisphere, associated tree mortality and ensuing changes in forest composition and structure may conflict with timber, wildlife, water and other resource management objectives. Therefore, host tree density reduction has been suggested as a management option to increase forest stand resistance to beetle infestation, protect remaining trees and maintain forest resources. However, little is known about the effectiveness of such treatments to mitigate spruce beetle (*Dendroctonus rufipennis*) infestation or their influence on the stand structural controls of beetle disturbance in subalpine spruce-fir forests in the Rocky Mountains. We addressed this research gap in a retrospective assessment of the impact of density reduction treatments on stand composition and structure and subsequent (ca. 5–20 years later) spruce beetle infestation in southwestern Colorado. The study area was located at the fringe of an ongoing spruce beetle outbreak and at the time of sampling was affected by endemic to incipient beetle pressure. Stand structural attributes and beetle infestation were measured in treated and untreated control stands at four sites. Classification tree analyses revealed spruce diameter and its interaction with spruce basal area percentage as the most important drivers of tree-level beetle infestation. The number, basal area and proportions of beetle-infested spruce were lower in treated stands at sites where treatments significantly reduced the abundance of large spruce trees and where the abundance of large spruce was relatively high prior to tree removal. However, spruce density reduction did not result in a reduction of infestation rates in the remaining large (>25 cm DBH) spruce during the ongoing beetle outbreak. While confirming previous assessments on the limited effectiveness of density reduction treatments for mitigating stand-level beetle infestation, this study provides further insights on the stand structural controls that mediate forest management effects on beetle disturbance dynamics. We conclude by suggesting that priority should be given to management practices that enhance resilience by increasing spruce advance regeneration in the understory as opposed to treatments aimed at achieving resistance to beetle disturbance.

1. Introduction

Bark beetle (Curculionidae: Scolytinae) disturbances are an inherent component of northern hemisphere conifer forests. Given suitable climatic conditions and susceptible forest states, beetle populations from the genus *Dendroctonus* may erupt to landscape or even regional-scale outbreaks (Bentz et al., 2010; Lundquist and Reich, 2014; Raffa et al., 2008). Tree mortality resulting from beetle outbreaks alters forest composition and structure (Hansen, 2014; Veblen et al., 1991), which may affect water quality and quantity and carbon and nutrient cycling, change wildfire fuels and shift habitat qualities for wildlife (Fayt et al., 2005; Hansen, 2014; Hicke et al., 2012; Jenkins et al., 2014a,b; Kurz et al., 2008; Price et al., 2010; Pugh and Gordon, 2013; Saab et al., 2014). Widespread beetle-induced tree mortality may create significant

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challenges for forest management with respect to public safety at recreation sites and along roads and where timber production, wildlife habitat and water quality and quantity depend on the maintenance of high timber volume, old-growth forest structures, and relatively closed forest canopies.

In southwestern Colorado a spruce beetle (*Dendroctonus rufipennis* Kirby) outbreak started in the early 2000s and was first detected by the Aerial Detection Survey (ADS) in 2003 (Colorado State Forest Service, 2003; USDA Forest Service, 2013a). In 2013, 87400 new hectares (ha) of subalpine spruce-fir (*Picea Engelmannii* Parry, *Abies lasiocarpa* [Hooker] Nuttall) forest were affected by spruce beetles compared to 74,100 ha in 2012, indicating that this outbreak is still progressing (Colorado State Forest Service, 2014). While warmer temperatures in the past two decades have contributed to increased spruce beetle developmental rates and lower over-winter mortality (Bentz et al., 2010; Hansen et al., 2001), a number of forest stand attributes are known to contribute to the susceptibility of spruce-fir forests in the Rocky Mountains. Spruce beetles preferentially select large diameter trees (>25 cm diameter at breast height; DBH) for attack, because thicker bark protects beetle larvae from cold winter temperatures, provides more nutritional phloem and thus increases the survival rates of the beetle larvae (Dymerski et al., 2001; Hart et al., 2014b; McCambridge and Knight, 1972). Stress-induced slow growth is likely to further predispose spruce trees to attack (Hard, 1985). Dry sites, long-term drought and dense stand conditions that lead to resource competition among trees may reduce tree vigor and result in slow tree growth (Berg et al., 2006; DeRose and Long, 2012; Hart et al., 2014a). At the stand-level the US Forest Service assesses susceptibility using Schmid and Frye's (1976) beetle hazard rating system, which was developed based on research on the large 1940s spruce beetle outbreak in Colorado (e.g. McMahon and Smith, 2002). Besides site quality, this system rates stands according to average DBH of spruce >25.4 cm DBH, stand basal area and percent spruce in the canopy. Stands exceeding 41 cm mean DBH, 34 m^2/ha basal area, and 65% canopy dominant spruce are rated as highly susceptible. However, recent research (Hart et al., 2014a,b) indicates that under current warmer and dry conditions in Colorado, even stands with low hazard ratings are being attacked. These findings call for a reevaluation of stand structural conditions that may be conducive to beetle infestation under current climate, in order to update recommendations for forest management planning.

In general, there are two basic approaches to managing bark beetle disturbances (Fettig et al., 2014). The first, often termed direct control, aims at suppressing the ongoing outbreak of a localized beetle population, slowing beetle spread or protecting individual trees or stands. Such direct control measures may involve sanitation felling and the subsequent burning or debarking of infested trees, the use of pheromone-baits and trap trees and insecticides. These direct control measures are resource intensive, protect only a few trees and the effect is short-lived at best (Carroll et al., 2006; DeRose and Long, in press; Fettig et al., 2014). The second approach, often termed indirect control aims to enhance the resistance and/or the resilience of a stand to bark beetle infestation (DeRose and Long, in press). DeRose and Long (in press) define stand resistance as the effect of stand composition and structure on the severity of spruce mortality due to bark beetles. In contrast, they define a stand's resilience to spruce beetle as the effects of spruce beetle infestation on the post-infestation stand composition and structure. These definitions imply that managing for more resistant (or less susceptible) stands aims at mitigating spruce beetle infestation, whereas managing for resilience manages for specific post-infestation stand composition and structure goals. These goals may include the retention of large spruce or maintaining the potential for future spruce-dominance by favoring abundant advanced reproduction of spruce (DeRose and Long, in press).

Stand manipulations that enhance the resistance and/or the resilience to beetles include density reduction treatments with varying prescriptions and goals (Eaton, 1941; Six et al., 2014). Individual-tree and group-selection harvests aim at regenerating a particular species and thinning from above and shelterwood preparatory cutting are intermediate treatments with the goal of enhancing the growth of commercially valued species such as Engelmann spruce by reducing resource competition (Smith et al., 1997). Direct beetle management through sanitation cutting aims at suppressing beetle population growth by removing infested and susceptible trees and may have the indirect effect of enhancing resistance and resilience to subsequent beetle disturbance through spruce density reduction, and salvage cutting that aims at recovering the potential value of beetle-killed trees can have a similar indirect effect on subsequent beetle disturbance (Alexander, 1986; Bentz and Munson, 2000; Fettig et al., 2014, 2007). In practice these sanitation and salvage cuttings are often conducted in conjunction as a consequence of detecting beetle infestations too late (USDA Forest Service, 2013b; Table 1). Whether intended or unintended, density reduction treatments reduce the density of large susceptible spruce, while increasing the proportion of non-host trees. These structural changes deprive the beetles of their breeding habitat, alter the stand's micro-climate by increasing solar radiation and within-stand wind speeds, which may decrease brood survival (Amman et al., 1988) and foster dilution of semiochemical cues used by the beetles in host location, selection and colonization (Thistle et al., 2004). Hence such treatments may enhance a stand's resistance to beetles by lowering its attractiveness for beetle colonization and by decreasing the chance for the development of an irruptive beetle population

Table 1
Elevation (meters above sea level), aspect and management activity at sampling sites as listed in the Rocky Mountain Management activity database (RMACT).

Site	Treatment	Elevation	Aspect	Management activity
Dunton	Treated	3150	NW	Shelterwood Preparatory Cut, 1989–1990 Sanitation (salvage), 1998
Dunton	Control	3200	N	–
Stoner Mesa	Treated	3150	N	Shelterwood Preparatory Cut, 1989 Salvage Cut (intermediate treatment, not regeneration), 1995
Stoner Mesa	Control	3100	N	–
Hermosa	Treated	3000	N	Sanitation (salvage), 1992–1995 Group Selection Cut, 1992–1995
Hermosa	Control	3000	N	–
Tuckerville	Treated	3350	NW	Improvement Cut, 1991 Sanitation (salvage), 1992
Tuckerville	Control	3400–3500	NW	–