Forest Ecology and Management 258 (2009) 641–649

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Stand characteristics and downed woody debris accumulations associated with a mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreak in Colorado

Jennifer G. Klutsch[a,*], José F. Negrón[a], Sheryl L. Costello[b], Charles C. Rhoades[a], Daniel R. West[a], John Popp[a], Rick Caissie[c]

[a] USDA Forest Service, Rocky Mountain Research Station, 240 West Prospect, Fort Collins, CO 80526, United States
[b] USDA Forest Service, Forest Health Management, 740 Simms St., Golden, CO 80401, United States
[c] USDA Forest Service, Arapaho-Roosevelt National Forest, Sulphur Ranger District, PO Box 10, Granby, CO 80446, United States

ARTICLE INFO

Article history:
Received 15 February 2009
Received in revised form 23 April 2009
Accepted 29 April 2009

Keywords:
Pinus contorta
Lodgepole pine
Bark beetles
Coarse woody debris
Stand structure

ABSTRACT

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.)-dominated ecosystems in north-central Colorado are undergoing rapid and drastic changes associated with overstory tree mortality from a current mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreak. To characterize stand characteristics and downed woody debris loads during the first 7 years of the outbreak, 221 plots (0.02 ha) were randomly established in infested and uninfested stands distributed across the Arapaho National Forest, Colorado. Mountain pine beetle initially attacked stands with higher lodgepole pine basal area, and lower density and basal area of Engelmann spruce (*Picea engelmannii* [Parry]), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt. var. *lasiocarpa*) compared to uninfested plots. Mountain pine beetle-affected stands had reduced total and lodgepole pine stocking and quadratic mean diameter. The density and basal area of live overstory lodgepole declined by 62% and 71% in infested plots, respectively. The mean diameter of live lodgepole pine was 53% lower than pre-outbreak in infested plots. Downed woody debris loads did not differ between uninfested plots and plots currently infested at the time of sampling to 3 or 4–7 years after initial infestation, but the projected downed coarse wood accumulations when 80% of the mountain pine beetle-killed trees fall indicated a fourfold increase. Depth of the litter layer and maximum height of grass and herbaceous vegetation were greater 4–7 years after initial infestation compared to uninfested plots, though understory plant percent cover was not different. Seedling and sapling density of all species combined was higher in uninfested plots but there was no difference between infested and uninfested plots for lodgepole pine alone. For trees $\geq$2.5 cm in diameter at breast height, the density of live lodgepole pine trees in mountain pine beetle-affected stands was higher than Engelmann spruce, subalpine fir, and aspen, (*Populus tremuloides* Michx.), in diameter classes comprised of trees from 2.5 cm to 30 cm in diameter, suggesting that lodgepole pine will remain as a dominant overstory tree after the bark beetle outbreak.

Published by Elsevier B.V.

1. Introduction

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is among the most widely distributed conifers in the western USA, comprising about 6 million hectares (Lotan and Critchfield, 1990). From Alaska to south Baja California and from the Pacific coast east to the Black Hills of South Dakota, lodgepole pine exhibits great ecological variability (Lotan and Critchfield, 1990). Various disturbance agents shape the structure and composition of lodgepole pine forests including fire (Clements, 1910; Romme, 1982; Lotan and Perry, 1983), blowdown (Mason, 1915; Alexander, 1964, 1967; Veblen et al., 1989), mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreaks (Roe and Amman, 1970; Amman, 1977), and dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) infestations (Hawksworth and Graham, 1963; Hawksworth and Hinds, 1964).

Mountain pine beetle at endemic population levels utilize diseased, lightning-struck, and senescing trees, among others, as refugia. Under favorable climatic and stand conditions, population densities of this bark beetle can increase rapidly and cause extensive tree mortality in mature lodgepole pine forests (Fettig

* Corresponding author. Tel.: +1 970 498 1387; fax: +1 970 498 1010.
E-mail addresses: Jennifer.Klutsch@Colostate.edu, jklutsch@gmail.com (J.G. Klutsch).

0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2009.04.034

et al., 2007). The occurrence of favorable conditions for insect population growth or unfavorable conditions for trees, such as drought stress, or both, can cause eruptive bark beetle populations. It is well documented that lodgepole pine stand susceptibility to mountain pine beetle is related to factors such as stand density, basal area, and tree diameter (Amman, 1977; Amman and Logan, 1998). Larger diameter trees have thick phloem, which offers the insect a more suitable environment for population growth (Amman, 1972). In the late 1990s, increasing densities of mountain pine beetle-caused tree mortality were detected by Forest Health Management (USDA Forest Service) staff during aerials surveys in lodgepole pine forests of north-central Colorado (USDA Forest Service, 2005). From 2000 to 2008, mountain pine beetle killed large numbers of lodgepole pine trees in 770,000 ha of coniferous forests in Colorado (USDA Forest Service, http://www.fs.fed.us/r2/resources/fhm/aerialsurvey/download/).

Three major factors appear to have coincided to foster this outbreak in lodgepole pine of north-central Colorado of unprecedented severity and extent since written records have been available. First, a period of drought stress, which makes trees more susceptible to insect attack (Mattson and Haack, 1987), in north-central Colorado began around 1998 and became particularly intense from about 2000 to 2002, as characterized by the Palmer Drought Severity Index (National Climatic Data Center, http://www.ncdc.noaa.gov/oa/ncdc.html). Second, a major mortality agent for mountain pine beetle is cold winter temperatures (Safranyik, 1978; Cole, 1981). Temperature data from Fraser Experimental Forest (USDA Forest Service, unpublished data) in north-central Colorado indicates that since at least 1992, minimum winter temperatures have scarcely reached −30 °C, which is about the temperature where supercooling may begin in mid-winter causing insect mortality (Bentz and Mullings, 1999). These warmer temperatures may be fostering increased winter mountain pine beetle survival (Nordhaus, 2009). Third, a large landscape of continuous lodgepole pine forest is susceptible to mountain pine beetle due to the availability of large diameter trees in dense stands. About 100,000 ha of lodgepole pine in the Arapaho National Forest are over 80 years old (USDA Forest Service, unpublished data), the age at which lodgepole pine becomes most susceptible to mountain pine beetle (Amman, 1977). An abundance of suitable host type is an important factor in stand susceptibility to outbreak levels of bark beetles (Schmid and Frye, 1976; Furniss et al., 1981; Negrón, 1998; Fettig et al., 2007).

When mountain pine beetle population levels become extremely high, bark beetle-caused tree mortality can create forest management challenges for land managers. For example, the occurrence of mortality in high-value settings such as recreation areas, ski resorts, campgrounds, visual corridors, watersheds, and forest land designated for timber production can be disruptive and negate certain investments. Real estate values can decrease and private land owners are faced with the high cost of protecting high-value trees or the removal of killed trees, or both. Furthermore, dead trees are eventually transformed from live standing biomass and crown fuels to downed fine and coarse woody debris, which has the potential to change wildfire hazard (Jenkins et al., 2008).

Mountain pine beetle, however, is an integral part of the ecology of these forests and influences ecosystem dynamics and resources. The insects contribute to shaping forest structure and composition (Amman, 1977). While the trees are dying, insects and other organisms inside the tree become an important source of food for many animals, particularly woodpeckers (McCambridge and Knight, 1972; Bull et al., 1997). Beetle-killed trees become perching and nesting habitat for many avian species and when dead trees fall they provide habitat for many small mammals and invertebrates (Bull et al., 1997). Habitats are created for other insects and fungi which are responsible for decomposition of downed logs and returning nutrients to the soil (Edmonds and Eglitis, 1989; Apigian et al., 2006). Canopy structure, and water and nutrient demand by forest vegetation determine the amount, timing, and quality of water released from high-elevation watersheds (Troendle and King, 1985), and similar to forest harvesting or wildfire, extensive pine mortality will likely alter the delivery of clean water from areas affected by mountain pine beetle (Uunila et al., 2006). Previous research has documented increased streamflow following bark beetle outbreaks in western forests (Love, 1955; Bethlahmy, 1974; Potts, 1984; Troendle and Nanverkis, 2000).

Most research on the influence of mountain pine beetle on lodgepole pine ecosystems has been conducted in the Intermountain region of the western USA and western provinces in Canada. To address the lack of information about the influence of the current mountain pine beetle infestation on the structure of lodgepole pine forests in Colorado we conduced a study to: (1) identify structural and species composition similarities and differences between infested and uninfested stands; (2) characterize changes in stand characteristics caused by mountain pine beetle infestation; and (3) compare litter, duff, and fuel bed depths, downed woody debris loads, and understory vegetation characteristics in infested and uninfested stands.

2. Methods

2.1. Study site and plot selection

The study was conducted in the Sulphur Ranger District, Arapaho National Forest, Colorado (40°4′N, 106°0′W). Lodgepole pine covers about 45% of the 178,900 ha within the District, with an approximate elevational range of 2500–3500 m. Engelmann spruce (*Picea engelmannii* [Parry]), and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt. var. *lasiocarpa*) make up 25% of the tree cover and are the predominant trees at higher elevations, north slopes, and along streams; 30% of the area consists of valley bottom, alpine vegetation, or exposed rock.

During 2006 and 2007, a geographic information system was used to randomly select potential plot locations within the lodgepole pine forest type from USDA Forest Service vegetation cover maps. Plots were distributed throughout the study area at least 0.4 km from roads and at a minimum distance of 0.4 km from each other. Plots were 0.02 ha (8.0 m radius) which adequately represent the small scale at which bark beetles influence forest stands (Olsen et al., 1996; Negrón et al., 2001). We established a total of 221 plots that were in uninfested areas (51 plots) and in areas with lodgepole pine either initially infested between 2000 and 2003 (68 plots), hereafter referred to as plots 4–7 years after infestation, or between 2004 and 2007 (102 plots), hereafter referred to as plots 0–3 years after infestation (0 represents current infestation in 2007). In a plot, the tree with the earliest year of infestation by mountain pine beetle determined the time since infestation category for the plot. The year a tree was infested by mountain pine beetle was estimated by degradation status of the crown. For plots 4–7 years after infestation, all needles had been shed from the earliest infested lodgepole pine, whereas for the plots 0–3 years after infestation, most needles remained on the infested lodgepole pines.

2.2. Stand structure and downed woody debris sampling

Site, forest structure, understory, and downed woody debris characteristics were measured in each plot. Elevation, aspect, and percent slope were measured at plot center. For each tree ≥2.5 cm in diameter at breast height (DBH, 1.37 m above ground), species, DBH, and condition were recorded. Tree condition included: live,