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Limber pine in the central and southern Rocky Mountains: Stand conditions and interactions with blister rust, mistletoe, and bark beetles

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A B S T R A C T

Combined effects of the recent mountain pine beetle (*Dendroctonus ponderosae*) outbreak and white pine blister rust (caused by *Cronartium ribicola*) (WPBR) are causing extensive crown dieback and mortality in limber pine (*Pinus flexilis*) in the central and southern Rocky Mountains. Additional stressors such as climate change and limber pine dwarf mistletoe (*Aceuthobium cyanocarpum*) may significantly alter stand structure and biodiversity of these ecosystems. The objectives of this study were to: (1) assess site, stand, and tree health conditions in limber pine stands of northern Colorado, Wyoming, and southeastern Montana, (2) quantify impacts of WPBR, bark beetles, and dwarf mistletoe, and (3) determine biotic and abiotic factors that influence the occurrence and incidence of these damage agents.

We assessed 22,700 limber pines on 508 plots in limber pine-dominated stands in twenty-five study areas in northern Colorado, Wyoming, and southeastern Montana. Average live limber pine density was 311 stems ha^{-1}. Overall, 50% of limber pines were classified as healthy with over 50% of limber pine mortality attributed to bark beetle attacks. White pine blister rust damage was evident on over 60% of declining or dying limber pines. Blister rust was the primary damage agent, occurring on 73% of the plots and 26% of the trees. Bark beetle-caused mortality was found on 75% of plots and 18% of trees. Limber pine dwarf mistletoe was present on 29% of plots and 9% of trees. In study areas that were previously monitored, incidence of WPBR increased over 8–9 years by 6%, bark beetle-caused mortality by 17%, while dwarf mistletoe incidence remained the same. We used statistical modeling to determine meteorological, macro and micro site factors, and stand factors that influenced the occurrence and incidence of WPBR, bark beetles, and dwarf mistletoe on limber pines.

Declines in health and rise in mortality due to bark beetles and WPBR has left some study areas with low limber pine basal area and stand density. These stands may be at risk for localized extirpation if the minimum viable population thresholds are not maintained and are identified as areas of concern for restoration and conservation efforts. Current condition status and long-term monitoring of limber pine is needed for land manager decision making and facilitation of restoration goals.

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1. Introduction

Recent studies indicate the growing impact white pine blister rust (WPBR), caused by the introduced fungal pathogen, *Cronartium ribicola* (J.C. Fischer ex. Rabh.) has had on five-needle pine populations (Kearns and Jacobi, 2007; Maloney, 2011; Smith et al., 2008, 2013). Limber pine (*Pinus flexilis* James), a widely distributed five-needle white pine (subgenus *Strobus*) (Schoettle, 2004) is susceptible to dieback and mortality from WPBR, limber pine dwarf mistletoe (*Arceuthobium cyanocarpum* [A. Nelson ex Rydb.]), and bark beetles, including the recent outbreak of mountain pine beetle (*Dendroctonus ponderosae* Hopk.) (Gibson et al., 2008; Kearns and Jacobi, 2007; Taylor and Mathiasen, 1999). A 40% loss in basal area of limber pine is projected to occur by 2030 (Krist et al., 2014). Understanding abiotic and biotic factors that influence the occurrence of WPBR, bark beetles, and dwarf mistletoe will be critical in determining appropriate management actions to sustain limber pine populations.

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In the central and southern U.S. Rocky Mountains, limber pine is found from lower to upper tree line, occurring across a broad elevation range (1600 and 3400 m); differing from other five-needle pines in the region (Schoettle and Rochelle, 2000). The species is shade-intolerant and occurs in scattered, low-density stands that are often on rocky, xeric sites where cold temperatures, short growing seasons, and soil characteristics limit the growth of other conifer species (Schoettle, 2004; Schoettle and Rochelle, 2000). At lower elevations on mesic sites with deep soils, other conifer species are more competitive and white pines are often a seral component (Arno and Weaver, 1990; Kendall and Arno, 1990). As a beneficial component of forest ecosystems (Schoettle, 2004), limber pine is one of the first tree species to occupy burned sites (Donnegan and Rebertus, 1999; Rebertus et al., 1991) and may facilitate establishment of late successional species by ameliorating soil conditions, providing shade, and reducing wind (Baumeister and Callaway, 2006). Fire history is very limited, but limber pine likely experienced a variety of fire regimes (Brown and Schoettle, 2008). The pine also stabilizes soil and snowpack and provides a habitat and food source for animals (Schoettle, 2004). Limber pine seeds are wingless and rely on Clark's nutcrackers (*Nucifraga columbiana* Wilson) for long-distance dispersal.

C. ribicola is native to Asia but has been present in North America since the early 1900s. This pathogen is a heteroecious rust capable of infecting all North American five-needle pines and must use *Ribes* species (currants and gooseberries), *Pedicularus* species, or *Castilleja* species as alternate hosts to complete a complex life cycle requiring five spore stages (McDonald et al., 2006; Mulvey and Hansen, 2011; Zambino et al., 2006). Aeciospores, durable spores produced on the five-needle pine, can be wind dispersed for hundreds of kilometers to infect leaves of the alternate hosts (Frank et al., 2008). Basidiospores, fragile spores produced on leaves of alternate hosts in late summer to fall, are wind disseminated, traveling only a few hundred meters to five-needle pines (Zambino, 2010). Infection can lead to loss of vigor, death of cone-bearing branches (Maloney et al., 2012), and ultimately tree mortality, which can occur several years after infection depending on the size of the tree. Seedlings can die within three years of infection due to rapid girdling of the small diameter stems (Hoff and Hagle, 1990).

Since its introduction into western North America, WPBR has spread south and east into the Rocky Mountains during the last century. From its discovery in Montana in 1928 (Putnam, 1931), it has moved from western Wyoming (Brown, 1970; Krebill, 1964) to southeastern Wyoming (Brown, 1978), and was reported in Colorado in 1998 just south of the Wyoming border (Johnson and Jacobi, 2000). Previous assessments in 2002–2004 in the southern and central Rocky Mountains indicated that 55% of surveyed plots were infected with WPBR, with a mean overall incidence of 16% (Kearns and Jacobi, 2007). There is concern that this pathogen will continue to spread throughout the Rocky Mountain region (Johnson and Jacobi, 2000).

Until the recent massive mountain pine beetle outbreak, limber pine dwarf mistletoe was considered the second most damaging agent of limber pine behind WPBR (Kearns and Jacobi, 2007; Taylor and Mathiasen, 1999). *A. cyanocarpum* is an especially virulent dwarf mistletoe and known to cause widespread mortality of limber pine in the Rocky Mountains (Mathiasen and Hawksworth, 1988). Mountain pine beetle kills trees more rapidly than WPBR or dwarf mistletoe. Mountain pine beetle prefers larger diameter trees (Allen and Blodgett, 2012; Safranyik and Carroll, 2006) and can result in rapid and widespread mortality of cone-bearing trees important to regeneration during epidemic population levels. Another concern is that bark beetles can attack WPBR-resistant trees. Mountain pine beetle has recently caused extensive mortality of pines throughout the central and southern Rocky Mountain regions. From 1996 to 2013, USDA Forest Service aerial detection survey (ADS) data has indicated that in Wyoming (USFS Region 2) 806,000 cumulative hectares of all pines, of which almost half (396,000 ha) are five-needle pines, and in Colorado 1,363,000 cumulative hectares of all pines and 50,000 ha of five-needle pines have some mortality by mountain pine beetle, with peak years occurring in 2008 and 2009 (USDA Forest Service, Rocky Mountain Region, 2014). Smaller diameter trees and seedlings unaffected by mountain pine beetle are still at risk of mortality from WPBR, dwarf mistletoe, and other bark beetles including the limber pine engraver (*Ips woodi* Thatcher) and twig beetles (*Pityophthorus* spp. and *Pityogenes* spp.). Bark beetles and WPBR, which continue to spread and intensify in limber pine (Blodgett et al., 2005; Burns, 2006; Burns et al., 2011; Kearns and Jacobi, 2007; Maloney, 2011; Smith et al., 2013; Smith and Hoffman, 2001), may devastate or greatly alter some limber pine populations.

A better understanding of factors that influence recent widespread crown dieback and mortality of limber pine due to WPBR, dwarf mistletoe, and bark beetles is required so land managers can implement appropriate management actions to increase resilience of limber pine populations and maintain the species on the landscape. Previous work has shown how various site (e.g. slope, elevation), stand (e.g. density, basal area), and meteorological factors influence WPBR (Campbell and Antos, 2000; Duriscoe and Duriscoe, 2002; Kearns et al., 2014; Kearns and Jacobi, 2007; Larson, 2011; Smith and Hoffman, 2001), dwarf mistletoe (Barrett et al., 2012; Hawksworth and Wiens, 1996; Robinson and Geils, 2006; Taylor and Mathiasen, 1999), and bark beetles (Carroll et al., 2003; Larson, 2011) on various hosts, but few studies have looked at what impacts these disturbance agents have in limber pine, and no studies have addressed all three factors over an extensive geographic area in limber pine. While some prior knowledge exists of the extent of WPBR and limber pine dwarf mistletoe impacts (Brown, 1978; Kearns and Jacobi, 2007; Mathiasen and Hawksworth, 1988) in the southern and central Rocky Mountains, recent impact by mountain pine beetle in limber pine is largely unknown aside from ADS data which does not provide the precise quantification that would be given by ground surveys (USDA Forest Service, Rocky Mountain Region, 2014). The objectives of this study were to (1) assess site, stand, and tree health conditions in limber pine stands of northern Colorado, Wyoming, and southeastern Montana, (2) quantify the impact of WPBR, bark beetles, and dwarf mistletoe, and (3) determine biotic and abiotic factors that influence the occurrence and incidence of these damage agents.

2. Materials and methods

2.1. Study areas

The geographic range of the study included both central and southern Rocky Mountain ranges, specifically the eastern-most mountain range of the Rocky Mountains in northern Colorado (Front Range) and in Wyoming we included the eastern mountain ranges (Medicine Bow, Laramie, and Bighorn Mountains) and adjacent mountain ranges to the west (Sierra Madre, Wind River Range, Absaroka Range) with all minor mountains and basins in between and one mountain range in southern Montana (Pryor Mountains) and another area in eastern Montana (Terry Badlands) (Fig. 1). Surveys were conducted within twenty-five study areas in this geographic area that were defined by government proclamation boundaries and geographic sections of mountain ranges (Table 1; Fig. 1).