Available online at www.sciencedirect.com
ScienceDirect
Forest Ecology and Management 254 (2008) 327–334
Forest Ecology and Management
www.elsevier.com/locate/foreco

Susceptibility of ponderosa pine, *Pinus ponderosa* (Dougl. ex Laws.), to mountain pine beetle, *Dendroctonus ponderosae* Hopkins, attack in uneven-aged stands in the Black Hills of South Dakota and Wyoming USA

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Received 6 April 2007; received in revised form 10 August 2007; accepted 14 August 2007

Abstract

Mountain pine beetle, *Dendroctonus ponderosae* Hopkins can cause extensive tree mortality in ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., forests in the Black Hills of South Dakota and Wyoming. Most studies that have examined stand susceptibility to mountain pine beetle have been conducted in even-aged stands. Land managers increasingly practice uneven-aged management. We established 84 clusters of four plots, one where bark beetle-caused mortality was present and three uninfested plots. For all plot trees we recorded species, tree diameter, and crown position and for ponderosa pine whether they were killed or infested by mountain pine beetle. Elevation, slope, and aspect were also recorded. We used classification trees to model the likelihood of bark beetle attack based on plot and site variables. The probability of individual tree attack within the infested plots was estimated using logistic regression. Basal area of ponderosa pine in trees $\geq$25.4 cm in diameter at breast height (dbh) and ponderosa pine stand density index were correlated with mountain pine beetle attack. Regression trees and linear regression indicated that the amount of observed tree mortality was associated with initial ponderosa pine basal area and ponderosa pine stand density index. Infested stands had higher total and ponderosa pine basal area, total and ponderosa pine stand density index, and ponderosa pine basal area in trees $\geq$25.4 cm dbh. The probability of individual tree attack within infested plots was positively correlated with tree diameter with ponderosa pine stand density index modifying the relationship. A tree of a given size was more likely to be attacked in a denser stand. We conclude that stands with higher ponderosa pine basal area in trees >25.4 cm and ponderosa pine stand density index are correlated with an increased likelihood of mountain pine beetle bark beetle attack. Information form this study will help forest managers in the identification of uneven-aged stands with a higher likelihood of bark beetle attack and expected levels of tree mortality.
Published by Elsevier B.V.

Keywords: Mountain pine beetle; Ponderosa pine; *Dendroctonus ponderosae*; Bark beetles

1. Introduction

Periodic elevated populations of mountain pine beetle, *Dendroctonus ponderosae* Hopkins, can cause significant mortality in ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., in the Black Hills of South Dakota and Wyoming. This tree mortality, although natural and caused by a native insect, can present challenges for managers and the public. Disruption of visual corridors devalues the recreational experience of visitors in areas where tourism is a major contributor to the local economy. Recreation sites, such as campgrounds and lake areas are also affected and require financial and human resources to remove hazard trees that may create unsafe conditions for visitors. Areas designated for timber production are also impacted, affecting forest planning processes and negating timber management investments. Moreover, high levels of tree mortality in stands managed for wildlife habitat, such as the northern goshawk, *Accipiter gentilis* (Linnaeus 1758) can compromise efforts.

Various studies have addressed different stand conditions and site characteristics associated with ponderosa pine susceptibility to mountain pine beetle (Fettig et al., 2007)

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0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2007.08.018

but most have focused on even-aged managed stands. Sartwell (1971) indicated that slow growth and crown ratios ≤30% were associated with nearly all ponderosa pines killed by mountain pine beetle in the Pacific Northwest in second-growth even-aged stands. This author also reported increased mortality levels caused by mountain pine beetle with increasing stand density and suggested that tree competition, primarily for soil moisture, fosters an increased likelihood of mountain pine beetle attack.

In the Black Hills, Sartwell and Stevens (1975) examined 44 groups of mountain pine beetle infestation in second-growth even-aged ponderosa pine stands and found that stands with basal area >34.4 m^2/ha were more susceptible to mountain pine beetle. Schmid and Mata (1992) established long-term plots to determine the relationship between stand density and occurrence of mountain pine beetle in partially cut even-aged ponderosa pine stands. Their results suggested a critical threshold for susceptibility to mountain pine beetle at a basal area of 27.5 m^2/ha. Their later work (Schmid and Mata, 2005) indicated that perhaps the threshold for high susceptibility may be closer to 22.3 m^2/ha. Also in the Black Hills, Olsen et al. (1996) examined spatial variation in even-aged ponderosa pine stands in the Black Hills and concluded that stocking was higher in areas prone to mountain pine beetle infestation. The authors suggested that variation in stand conditions resulted in clusters of trees with different probabilities of infestation.

Most of the knowledge from uneven-aged ponderosa pine stands comes from the Colorado Front Range, the eastern slope of the continental divide in north-central Colorado. McCambridge et al. (1982) examined the characteristics of ponderosa pine stands infested by mountain pine beetle in north-central Colorado. Basal area prior to infestation was significantly higher in areas that experienced large amounts of tree mortality. Negrón and Popp (2004) also reported that stands infested by mountain pine beetle had significantly higher total basal area, ponderosa pine basal area, stem density, and stand density index. The authors developed several classification models for estimating the probability of infestation by mountain pine beetle based on stocking levels. Increased likelihood of attack was observed with a ponderosa pine basal area >17.1 m^2/ha.

Based on these studies and many others (see Fettig et al., 2007) it is clear that stand density plays a major role in determining stand susceptibility to mountain pine beetle. As land managers increase the application of uneven-aged management, information on stand and tree susceptibility to mountain pine beetle in these stands will be essential. It is important to examine uneven-aged ponderosa pine susceptibility to mountain pine beetle across the range of the species as differences in forest structure are common. Growing conditions for ponderosa pine are much more favorable in the Black Hills compared to the poor sites typical of the Colorado Front Range (Mogren, 1956; Schubert, 1974; Shepperd and Battaglia, 2002). Sartwell (1971) and Sartwell and Stevens (1975) indicated that poor sites experienced higher levels of mountain pine beetle-caused tree mortality than did high quality sites of similar initial stocking. Ponderosa pine forests in the Black Hills are denser (Shepperd and Battaglia, 2002) with a rather even distribution of trees and are intensively managed. This contrasts with Colorado Front Range forests that are characterized by a clumpy tree distribution mixed with meadows (Peet, 1981) and are scantly managed.

In this study, our objective is to examine stand and tree conditions in uneven-aged ponderosa pine forests in the Black Hills stands to identify characteristics that may be conducive to mountain pine beetle infestation. This knowledge will be of benefit in managing uneven-aged ponderosa pine stands by providing guidelines for minimizing mountain pine beetle-caused mortality.

2. Methods

2.1. Study site

The Black Hills are located in the western part of South Dakota and northeastern Wyoming. Ponderosa pine is the dominant forest tree across the Black Hills, with quaking aspen, *Populus tremuloides* Michx, white spruce, *Picea glauca* (Moench) Voss, and bur oak, *Quercus macrocarpa* Michx, present to a lesser degree. Elevation ranges from 1219 m east of the Hills to 2164 m in the west. Precipitation increases with northing and in higher elevations. Mean annual precipitation is about 41 cm in the southern Hills and 49 cm in the northern Hills with November through February being the driest months and May and June the wettest. Temperatures are also generally cooler in the northern Hills and higher elevations. Mean annual temperatures range from about 9 to 2.9 °C, mean annual highs from 17.9 to 11.4 °C, and mean annual low temperatures from 2.1 to −5.6 °C, from south to north, respectively. Soils are quite variable across the area and include 107 different series (Shepperd and Battaglia, 2002).

2.2. Plot establishment and data collection

The study was conducted during the summer of 2004. We used aerial detection flight data collected by the USDA Forest Service, Forest Health Management, to identify areas where mountain pine beetle-caused pine mortality was present. Using Black Hills National Forest vegetation data we overlaid a map portraying uneven-aged stands over the aerial survey data. We then randomly selected areas for sampling and plot establishment.

As uneven-aged stands have an irregular stocking distribution (Smith, 1986) we used a cluster sampling approach to minimize the influence of irregular stocking. We established a total of 84 clusters of four plots. Each cluster included one infested plot and three uninfested plots. Infested plots included at least one ponderosa pine killed by mountain pine beetle. Uninfested plots included at least one ponderosa pine ≥15.2 cm in diameter at breast height (1.4 m) (dbh hereafter) and no trees killed by mountain pine beetle. To determine plot center for infested plots, we would approach a group of trees killed by mountain pine beetle and identify trees that were initially killed by the insect within these groups. Trees initially killed were determined by foliage discoloration and the presence or