Management of Lodgepole Pine Stand Density to Reduce Susceptibility to Mountain Pine Beetle Attack

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ABSTRACT. *Silvicultural strategies to reduce tree losses from mountain pine beetle attacks typically seek to reduce relative densities in order to increase tree resistance and thus lower potential beetle attacks. For lodgepole pine stands, however, the tree mortality/relative density relationship is nonlinear. We describe three relative density zones corresponding to different levels of resistance to beetle attack. In the density management of young lodgepole pine stands, we propose two alternative strategies to reduce future losses from mountain pine beetle attacks. The first density management regime involves a low density (i.e., SDI < 140) throughout the rotation. The second density management regime is designed to maintain relative density above a threshold level (i.e., SDI > 245). West. J. Appl. For. 11(2):50–53.*

Bark beetles in the genus *Dendroctonus* (Coleoptera: Scolytidae) are among the most damaging insects in western North American coniferous forests. The mountain pine beetle (MPB), *D. ponderosae*, is one of several aggressive species in the genus capable of sustaining outbreaks over large acreages, especially in lodgepole pine (*Pinus contorta*) forests. Silvicultural strategies designed to lower lodgepole pine stand susceptibility to beetles are effective prior to or in the early stages of outbreaks. Little can be done to reduce mortality once populations reach outbreak levels.

The mountain pine beetle plays an important ecological role in lodgepole pine forests. Endemic populations of beetles act as thinning agents, attacking large older trees, creating openings for regeneration, and contributing fuel for eventual stand-replacing fires. Such trees generally have thin phloem, thus limiting brood production and maintaining beetle populations at endemic levels (Amman 1972). It is not known how populations switch from endemic to epidemic levels. During short-term disturbances, otherwise healthy, thick phloemed trees may become susceptible to beetles, thereby allowing the population to increase (Berryman 1982). In an epidemic, most trees greater than about 6 in. in diameter may be attacked (Cole and Amman 1980).

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Amman et al. (1977) developed a system of rating susceptibility of lodgepole pine stands to beetle attack using stand age and diameter as the principal indicators along with elevation and latitude. Commonly accepted silvicultural strategies to lower stand susceptibility to mountain pine beetle were greatly influenced by the work of Cole and Cahill (1976) and Amman et al. (1977). Silvicultural strategies that alter tree species composition, age class distributions, and average stand diameter were summarized by Cole (1978) However, much of the basic research is based on mature unmanaged stands with high beetle populations and may not be germane to younger managed stands. A study by Anhold and Jenkins (1987) found that the tree mortality/relative density relationship for lodgepole pine stands is nonlinear Specifically, stands with either low or fairly high relative densities are resistant to beetle attacks. Conversely, stands with intermediate relative densities are susceptible to beetle attack. These results suggest alternative silvicultural strategies for "beetle-proofing" lodgepole pine stands. This paper describes two alternative density management regimes intended to reduce future losses from mountain pine beetle attacks in lodgepole pine stands.

Silviculturists use indexes of relative density to characterize stand structure. The most effective of these indexes combine some expression of mean size (e.g., mean volume, height, or diameter) and absolute density (i.e., trees per unit area). A commonly used index of relative density is SDI, based on the relationship between quadratic mean diameter and trees per unit area (Reineke 1933, Daniel and Sterba 1980). Size-density based indexes of relative density such as SDI are independent of site quality and stand age, and let silviculturists compare levels of growing stock, competitive stress, degree of site occupancy, and relative growth among stands, regardless of differences in site quality and age.

Density management regimes often are a compromise between maximizing volume production and maximizing the growth and vigor of individual trees (Figure 1). The nature of the trade-off depends on management objectives (Long 1985). For example, high volume production requires the maintenance of relative density within a fairly high range, i.e., greater than 35% of maximum SDI for the species. Alternatively, fostering individual tree growth and vigor means relative densities should generally not exceed about 25% of maximum SDI.

Silviculturists often assume that there is a monotonic relationship between a stand's relative density and its susceptibility to beetle attack (i.e., susceptibility plateaus), or even continues to increase beyond some critical threshold of relative density. Thus, silviculturists often recommend density management regimes that avoid self-thinning (e.g., Smith and Long 1987). Further, regimes intended to "beetle-proof" stands often implicitly assume that low relative densities confer greater protection than high relative densities, thus often leading to stands at less than full site occupancy

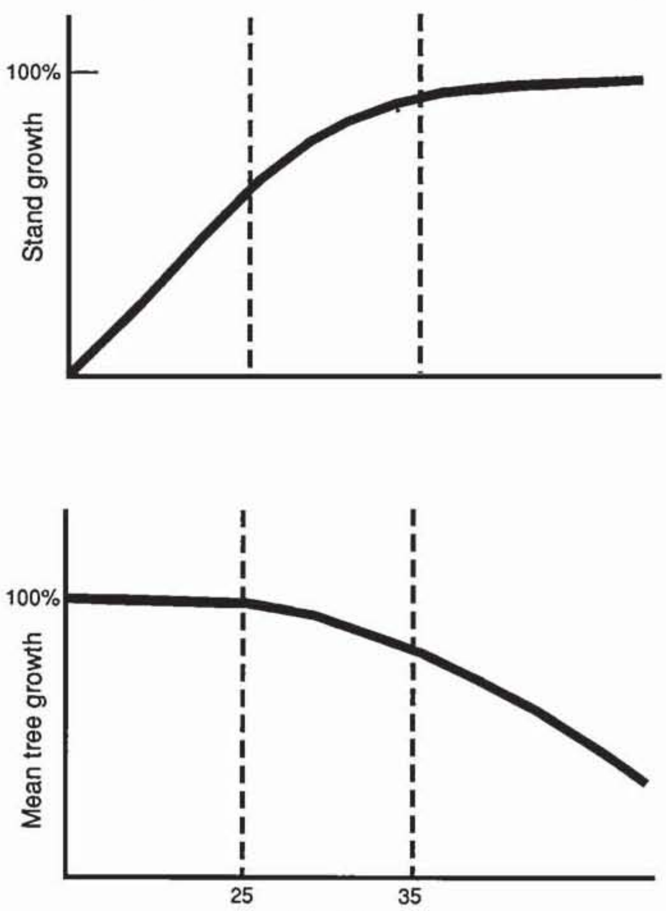

Figure 1. Relationship between stand and individual tree growth and relative density (after Long 1985).

(Cochran 1992). The loss of potential productivity (Long 1985) was assumed to provide the greatest resistance to beetle attack.

Anhold and Jenkins (1987) suggest a fundamentally different conceptual model in which the relationship clearly is not monotonic (Figure 2). We propose that there are three distinct zones. In Zone A, stands with SDIs of less than about 20% of maximum SDI experience few beetle attacks. In Zone B, between 20–35% of maximum SDI, stands experience much greater mortality. In Zone C, greater than 35% of maximum SDI, stands experience levels of mortality comparable to Zone A.

Zone A represents fast-growing, noncompeting, relatively vigorous trees. Resin production and flow are high, favoring beetle production, but the microclimates in these open stands are unfavorable for beetle attacks (Bartos and Amman 1989). The relative densities in Zone B reflect an increase in competition between trees, which leads to reduced tree vigor and resin flow (Figure 1). Canopy closure creates a microclimate more favorable for beetles, even though phloem is thinner than in Zone A. At the high relative densities represented by Zone C, tree vigor and defenses are further reduced, but phloem is so thin (Figure 3) that trees are largely unsuitable for bark beetle development and spread (Cabrera 1978).

While this interpretation appears to explain the data presented in Figure 2, during bark beetle outbreaks, trees can be successfully attacked regardless of phloem thickness, resin flow, tree vigor or beneath-canopy microclimate. Existing beetle populations and surrounding stand conditions must also be considered to predict potential tree mortality (Bentz et al. 1993).

Reducing Susceptibility with Density Management

These results suggest that relative density can be used to characterize the susceptibility of lodgepole pine stand structures to MPB outbreaks. The "zone" of high susceptibility includes stands with relative density from 20 to 35% of the

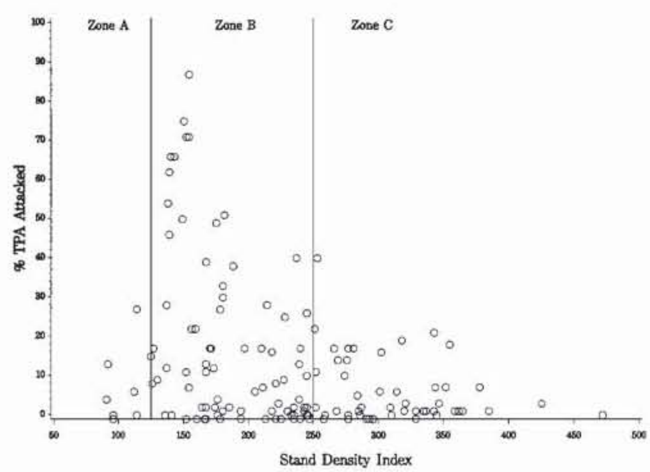

Figure 2. Potential for losses to MPB for different SDIs (after Anhold and Jenkins 1987).

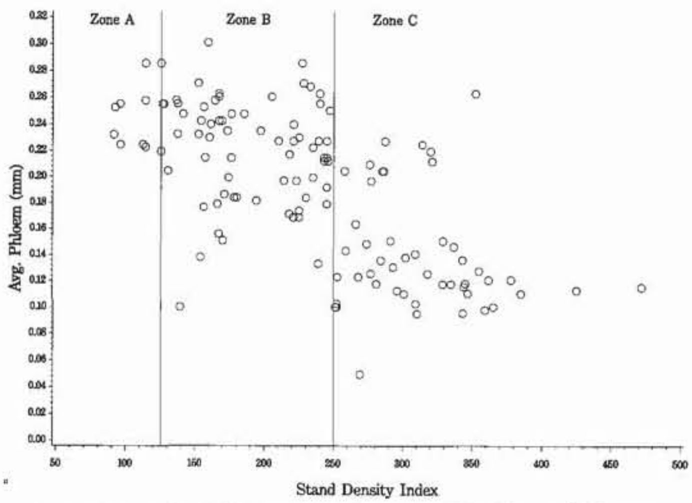

Figure 3. Relationship between SDI and LPP phloem thickness (after Anhold and Jenkins 1987).

maximum SDI (i.e., 140 to 245 for lodgepole pine) and a quadratic mean diameter (Dq) greater than 8 in. (Figure 4). Conversely, a lodgepole pine stand whose SDI is less than 140 or greater than 245 is assumed to have low susceptibility. A stand whose Dq is less than 8 in. is assumed to have low susceptibility, regardless of its relative density.

These assumptions were used to develop alternative density management strategies to reduce susceptibility to MPB. Density management regimes can be designed to "steer" stand development around the zone of highest susceptibility.

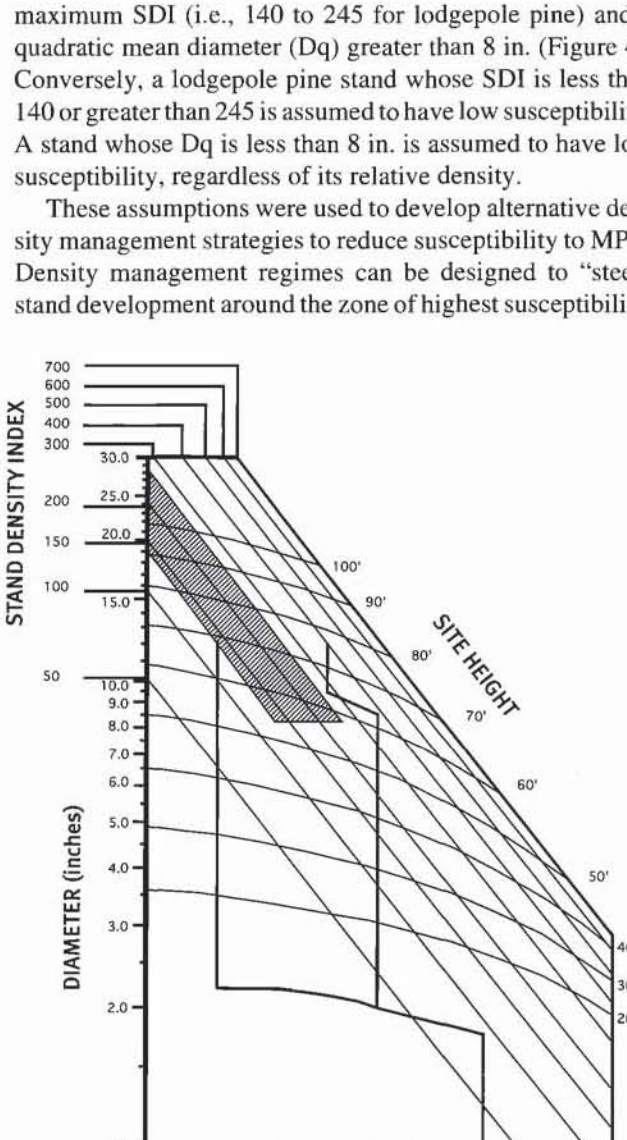

Figure 4. Alternative density management regimes intended to minimize hazard of mountain pine beetle attack. The cross-hatched area includes combinations of mean size and density reflecting high susceptibility.

To illustrate application of this strategy, we consider a young lodgepole pine stand with Dq of 1 in. and 1400 TPA that is managed to reduce susceptibility to MPB attack and for an end-of-rotation Dq of 12 in. A before-thinning Dq of at least 8 in. is required for thinning to be commercial.

The first alternative would be to maintain very low relative densities throughout the rotation (Figure 4); i e , following an early, heavy precommercial thinning the residual trees are essentially open-grown throughout the rotation. In principle, this could be accomplished by thinning the stand each time SDI approaches 140, but it is much more likely that a "PCT-only" regime would be used. This would involve a precommercial thinning to achieve the desired stand development trajectory. Density would be reduced to about 105 TPA, an average spacing of about 20 ft between residual trees.

As with any density management regime, this strategy has advantages and disadvantages. A principal advantage is maintaining stand density outside of the zone of high susceptibility throughout most of its development (Figure 4). Another advantage is that heavy precommercial thinning maintains the early successional shrub/forb stage for substantially longer than in stands managed at higher relative densities, which may also enhance species richness and biodiversity (Swanson and Franklin 1992). At very low relative densities there will be limited self-pruning, and the base of live crowns will remain near the ground for much of the rotation (Long 1985), thus providing ungulate hiding cover longer into the rotation (Smith and Long 1987).

The potential disadvantages include a generally poor log quality associated with open stands. Stem taper will be greater and knots will be considerably larger than in regimes of relatively high density. For example, the average diameter of the five largest branches on the first log (bottom 17 ft) will be about 2.2 in. at the end of the rotation (Ballard and Long 1988). Although this is in a relatively short technical rotation, it also results in a substantial loss of potential yield. Yields would only be about 25% of that of the high density regime, and its MAI will be only about 30% (Table 1).

An alternative strategy is a density management regime to maintain full site occupancy while avoiding density-related mortality. A light precommercial thinning reduces trees per acre to about 500, and a subsequent thinning, when Dq is about 8.5 in., is required in order to avoid self-thinning (Figure 4). This regime decreases susceptibility to beetle attack but produces greater yields than the low density regime

Table 1. Comparison of two lodgepole pine density management regimes. Estimates of site heights and yields are based on a lodgepole pine density management diagram (McCarter and Long 1986); ages are derived from site curves (Alexander et al 1967) assuming SI_{100} = 90.

	Low density regime	High density regime
TPA after PCT	105	300
Volume removed in CT	NA	1700 ft^3/ac
Volume (end-of-rotation)	2200 ft^3/ac	7000 ft^3/ac
Age (end-of-rotation)	64 yr	75 yr
MAI (total yield/age)	34 ft^3/ac/yr	116 ft^3/ac/yr

(Table 1). Log quality (i.e., reduced stem taper and knot sizes) will also be greater than with the first alternative. At the end of the rotation, average diameter of the five largest branches on the first log would be about 1.3 in. (Ballard and Long 1988). The low density regime may increase species diversity and some elements of wildlife habitat, such as ungulate hiding cover (Smith and Long 1987). The high density may better meet other specific habitat needs, such as the required structure for goshawk nest stands (Lilieholm et al. 1994). These density management regimes are applicable to young stands in which there is enough flexibility to design a system to reduce susceptibility to MPB attack. However, there is much less management flexibility in older stands, e.g., where Dq already exceeds 8 in. In these stands, the following guidelines may be applicable. When relative density is high, limit thinning so final relative density will be greater than 245 (i.e., 35% of maximum SDI). In stands whose relative density corresponds to the zone of susceptibility (i.e., 20–35% of maximum SDI) thinning should result in a relative density that does not exceed 20% at the next planned entry (i.e., another thinning or end-of-rotation harvest).

Susceptibility to serious MPB damage also depends on active bark beetle populations. A susceptible stand may not experience excessive MPB mortality if beetle populations in the area are low. Similarly, a less susceptible stand may experience considerable MPB damage if there are large, active bark beetle populations. This is evident in the data presented in Figure 2 in which 0 to 90% of the trees in Zone B were attacked. As proposed by Bentz et al. (1993), damage by MPB depends on susceptibility (a stand's ability to support or resist an outbreak) and risk (the size, activity, and location of the bark beetle population).

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