

Chapter 2: Forest Health and Bark Beetles

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Introduction

In recent years, bark beetles have caused significant tree mortality in the Sierra Nevada (<http://www.fs.fed.us/r5/spf/publications/pestconditions/index.shtml>), rivaling mortality caused by wildfire in some locations. This chapter addresses two important questions: How can managers prepare for and influence levels of bark beetle-caused tree mortality given current forest conditions and future climate uncertainties? and How would the variable forest conditions suggested by U.S. Forest Service General Technical Report PSW-GTR-220, “An Ecosystem Management Strategy for Sierran Mixed-Conifer Forests” (hereafter GTR 220) (North et al. 2009), influence these dynamics?

Host Tree and Bark Beetle Dynamics

Colonization of living hosts by bark beetles requires recruitment of a critical minimum number of beetles to initiate mass attack and overcome host tree defenses (Franceschi et al. 2005). This threshold differs with host tree vigor (i.e., the more “healthy” the tree, the more beetles required to overcome tree defenses) as beetles that initiate host selection are often killed by drowning or immobilization in resin, especially when adequate flow and oleoresin exudation pressure exist (Raffa and Berryman 1983, Vité and Wood 1961). Depending on the bark beetle species and numerous other factors (Fettig et al. 2007), levels of tree mortality attributed to bark beetle attack may be limited to small spatial scales (e.g., single

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Summary of Findings

1. **Bark beetles are an essential component of forest ecosystems and an important influence on stand dynamics.** Sierra Nevada forests are well recognized for the diversity of tree-killing bark beetle species inhabiting them (table 2-1).
2. **In the absence of frequent understory fire, increases in stand density and tree competition have made many forests more susceptible to bark beetle attack.** Microclimatic influences associated with dense stand conditions may increase beetle success in finding host trees and beetle fecundity and fitness. In addition, drought is one of the more important abiotic factors influencing tree susceptibility in the Sierra Nevada, suggesting changing climatic conditions could significantly alter the amount and distribution of bark beetle-caused tree mortality, particularly in dense stands.
3. **Reductions in stand density are the most effective treatment for reducing bark beetle-caused tree mortality.** Reducing competition improves tree growth and defensive mechanisms while often disrupting pheromone plumes, thus negatively affecting the beetle’s ability to locate and successfully mass attack host trees.
4. **Increases in stand- and landscape-level heterogeneity may reduce the occurrence of high levels of bark beetle-caused tree mortality while maintaining endemic (low) levels.** In contrast, forested landscapes that contain little heterogeneity promote the creation of large contiguous areas susceptible to bark beetle outbreaks.

Table 2-1—Bark beetle species that cause significant amounts of tree mortality in the Sierra Nevada

Common name	Scientific name	Primary hosts in the Sierra
California fivespined ips	<i>Ips paraconfusus</i>	Ponderosa pine (<i>Pinus ponderosa</i> Laws.), lodgepole pine (<i>Pinus contorta</i> Loud.), sugar pine (<i>Pinus lambertiana</i> Douglas), Jeffrey pine (<i>Pinus jeffreyi</i> Grev. & Balf.), and others
Fir engraver	<i>Scolytus ventralis</i>	White fir (<i>Abies concolor</i> (Gordon & Glend.) Lindl. ex Hildebr.), California red fir (<i>Abies magnifica</i> A. Murray bis)
Jeffrey pine beetle	<i>Dendroctonus jeffreyi</i>	Jeffrey pine
Mountain pine beetle	<i>Dendroctonus ponderosae</i>	Ponderosa pine, lodgepole pine, sugar pine, white bark pine (<i>Pinus albicaulis</i> Engelm.), limber pine (<i>Pinus flexilis</i> James), western white pine (<i>Pinus monticola</i> Douglas ex D. Don), and others
Pine engraver	<i>Ips pini</i>	Ponderosa pine, lodgepole pine, sugar pine, Jeffrey pine, and others
Piñon ips	<i>Ips confusus</i>	Singleleaf piñon (<i>Pinus monophylla</i> Torr. & Frem.) and others
Western pine beetle	<i>Dendroctonus brevicomis</i>	Ponderosa pine

trees or small groups of trees) or may affect large areas. When favorable stand and climatic conditions coincide, significant tree mortality may occur. While bark beetle infestations may affect timber and fiber production, water quality and quantity, fuel loadings, fish and wildlife habitat and populations, recreation, grazing capacity, real estate values, biodiversity, carbon storage, endangered species, cultural resources, and other resources (Coulson and Stephen 2006), bark beetles also play a critical role in the functioning of forests.

Factors Associated With Bark Beetle Infestations

After an indepth review of tree and stand factors associated with bark beetle infestations, Fettig et al. (2007) discussed the effectiveness of reducing stand density for preventing bark beetle infestations. Most work has concentrated on forests dominated by ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) or lodgepole pine (*Pinus contorta* Douglas ex Loud var.). Starting with the earliest research studies, factors such as stand density, tree diameter, and host density have been identified as primary attributes associated with bark beetle infestations. For example, Craighead (1925) and Miller (1926) were among the first to demonstrate that slower growing ponderosa pines were more susceptible to bark beetle attack, specifically by the western pine beetle, a species of primary importance in the Sierra Nevada. Working in the Pacific Northwest, Sartwell (1971) examined the relationship between radial growth and mountain pine beetle attack, another species of concern in the Sierra Nevada. He reported that nearly all trees killed by mountain pine beetle had crown

ratios (the ratio of crown length to total tree height) of ≤ 30 percent, suggesting that greater tree competition and slow growth rates increase the likelihood of mountain pine beetle attack. In general, less productive sites experienced higher levels of mountain pine beetle-caused tree mortality than did high-quality sites of similar stocking, a relationship that seems to hold for many bark beetle species.

Hayes et al. (2009) reported that stand density, measured as basal area or stand density index (SDI) (based on the number of trees per unit area and quadratic mean diameter [diameter at breast height of the tree of average basal area]), is the most important predictor of western pine beetle-caused tree mortality at large spatial scales in California. Areas with the highest stand densities experienced the highest levels of tree mortality on both an absolute (trees/ha) and proportion (percentage of mortality) basis. Surprisingly, host density had less predictive power than other measures of stand density, suggesting that tree competition is more important than host tree availability. Because SDI is an indicator of the amount of growing space available (Reineke 1933), and thus well correlated with tree growth, it is not surprising that SDI would be useful in predicting levels of bark beetle-caused tree mortality. Oliver (1995) reported that maximum SDI for even-aged ponderosa pine stands in northern California was regulated by mountain pine beetle and western pine beetle infestations. An SDI value of 230 defined a threshold for a zone of imminent bark beetle-caused tree mortality within which endemic populations kill a few trees but net growth is positive. Maximum (limiting) SDI was defined at 365. Modeling by Hayes et al. (2009) supports these observations and suggests that it might be appropriate to consider lower SDI thresholds under some conditions (e.g., during elevated bark beetle populations as associated with extended drought).

[Tree] host density had less predictive power than other measures of stand density, suggesting that tree competition is more important than host tree availability.

Managing Stand Density to Reduce Susceptibility to Bark Beetle Infestations

Thinning has long been advocated as a preventive measure to alleviate or reduce the amount of bark beetle-caused tree mortality (Fettig et al. 2007). However, thinning prescriptions differ widely, and much of the research concerning the effects of thinning on stand susceptibility to bark beetles has been conducted in stands thinned to achieve other specific objectives (e.g., to reduce wildfire severity). Thinning may have functionally different responses on the abundance and distribution of preferred hosts in the residual stand. Furthermore, thinnings conducted in a careless manner may also result in physical damage to residual trees. Although thinning may reduce stand susceptibility to bark beetle attack, there may be greater potential for increases in subcortical insects and root pathogens (Witcosky et al. 1986). In some cases, root diseases have been shown to increase the susceptibility of trees to bark

Posttreatment tree density may be the best predictor of subsequent levels of bark beetle-caused tree mortality.

beetle attack in the Sierra Nevada (Goheen and Cobb 1980). Furthermore, several bark beetle species (e.g., engraver beetles) are attracted to slash created during thinning operations. Effective guidelines, however, are available to reduce associated risks through proper slash management (DeGomez et al. 2008).

Research suggests that posttreatment tree density may be the best predictor of subsequent levels of bark beetle-caused tree mortality. For example, Fettig et al. (2010) reported significant positive correlations between the percentage of pines killed by bark beetles (several species) and trees/ha, basal area (ft²/ac), and SDI in the southern Cascades, California. Of these three metrics, trees/ha was the best predictor of levels of tree mortality following fuel reduction and forest restoration treatments (fig. 2-1). Thinning not only affects the vigor of residual trees influencing resin chemistry, flow, and oleoresin exudation pressure, but also the physical environment within treated stands. Increased windspeeds (Bigelow and North 2011) and temperatures are common within thinned stands, and these factors influence bark beetle fecundity, fitness, and survivorship in a variety of ways (Fettig et al. 2007). Thinning also increases wind turbulences that disrupt pheromone plumes used for recruiting conspecifics during initial phases of host tree colonization (Thistle et al. 2004). Low-density stands result in unstable layers and multi-directional traces that dilute pheromone concentrations and could result in reductions in beetle aggregation on individual trees.

Recent work conducted on the Tahoe National Forest, California to determine the impact of thinning on bark beetle infestations in Jeffrey pine (*Pinus jeffreyi* Balf.) forests provides further support for managing stand density to reduce stand susceptibility (Fettig et al. 2012). Treatments included thinning from below (i.e., initiating in the smallest diameter classes) to different residual target basal areas (80.1, 120.2, and 179.9 ft²/ac [18.4, 27.6, and 41.3 m²/ha], and an untreated control). Throughout the study, bark beetles killed no pines during the 10-year period in the lowest density treatment. Significantly fewer trees (ac/yr) were killed in the low-density thin than in the high-density thin or untreated control.

Bark beetle species indigenous to the Southwestern United States and Mexico have the potential to move northward with climate change.

Implications of Climate Change on Bark Beetle Dynamics

Climatic changes will significantly affect forest productivity and distribution. For example, Rehfeldt et al. (2006) estimated that by the end of this century, 48 percent of the Western U.S. landscape will have climate profiles incompatible with their current coniferous vegetation. These changes will likely have significant impacts on the frequency and severity of disturbances, such as bark beetle outbreaks, that shape these ecosystems. Bark beetle population success is influenced directly by

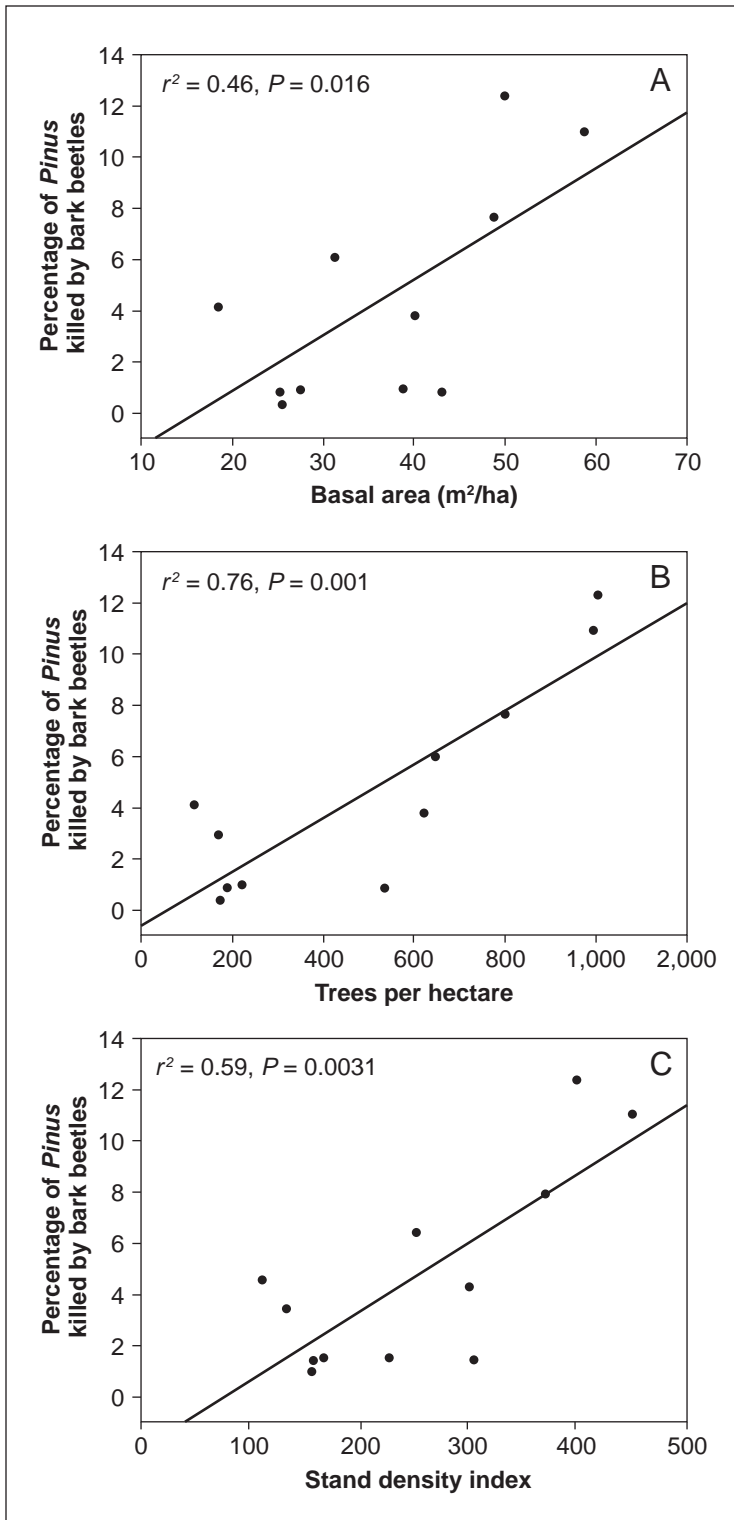


Figure 2-1—Relationship between (A) basal area (m²/ha) (multiply by 4.36 to get ft²/ac), (B) numbers of trees per hectare (trees/ha) (divide by 2.47 to get trees/ac), (C) stand density index and percentage of pines killed by bark beetles pooled across treatments on the Klamath National Forest, California. (Adapted from Fettig et al. 2010.)

temperature effects on developmental timing (Powell and Logan 2005) and mortality (Régnière and Bentz 2007). Warming may allow some species to complete extra generations per year, and adult emergence and flight activity could occur earlier and last longer. Cold-induced mortality during winter may also decrease. Effects of climate change on community associates and host tree vigor will also influence population success indirectly, although little information is available to quantify these relationships. Furthermore, climate-induced changes in carbon assimilation can alter the within-plant allocation of carbohydrates (Grulke et al. 2001) affecting the production of chemical defenses (Herms and Mattson 1992) and a tree’s ability to prevent bark beetle colonization.

Based on projected changes in climate, Bentz et al. (2010) suggested that future thermal regimes may be particularly favorable for mountain pine beetle populations, although considerable spatial and temporal variability was modeled. These predictions suggested a movement of temperature suitability to higher latitudes and elevations (e.g., as currently witnessed in whitebark pine (*Pinus albicaulis* Engelm.) in the Sierra Nevada) and identified regions with a high potential for bark beetle outbreaks and associated tree mortality in the coming century. Furthermore, Bentz et al. (2010) expressed a concern that bark beetle species indigenous to the Southwestern United States (e.g., Arizona) and Mexico have the potential to move northward with climate change following range expansions of their current hosts or adaptation to novel hosts.

Forest Heterogeneity and Bark Beetles

In the absence of frequent understory fire, bark beetles have become one of the principle agents of tree mortality in the Sierra Nevada and a strong influence on ecosystem processes. Although bark beetle infestations affect timber and fiber production, and indirectly a range of ecosystem services (Coulson and Stephen 2006), in the past, mortality of individual or small groups of overstory trees may have been a significant influence on the fine-scale spatial heterogeneity characteristic of mixed-conifer forests in California (Savage 1994). Beetles often inflict density-dependent mortality (Smith et al. 2005), and consequently maintain a mix of tree species, ages, sizes, and spatial heterogeneity in these forests. This is accomplished through the opening of canopy gaps that allow for differential reproduction of overstory species.

Tree mortality is often highly episodic (Franklin et al. 1987) making it difficult to determine when rates of beetle-induced tree mortality are uncharacteristically “high.” At the Teakettle Experimental Forest, California, cumulative levels of tree mortality (i.e., from all causes, not just bark beetles), as measured by standing dead trees ≥ 2 in (5 cm) d.b.h., was 8.7 percent, (range 5.3 to 13.1 percent) (Smith et al. 2005) compared to 14.0 percent (range 3 to 33 percent) in mixed-conifer, old-growth forests of the Lake Tahoe Basin (Barbour et al. 2002). In the Sierra San Pedro del Martir National Park of Baja, Mexico, where little fire suppression has occurred, cumulative tree mortality in mixed-conifer, old-growth forests was found to be 12.7 percent (range 4 to 15 percent) (Maloney and Rizzo 2002). Ansley and Battles (1998) reported an annual mortality rate of 0.6 percent per year in a Sierran old-growth, fire-suppressed forest, compared to only 0.162 percent per year in an active-fire, old-growth forest in the Sierra San Pedro del Martir (Maloney and Rizzo 2002). Rates in excess of the upper end of these ranges might be considered indicative of “high” levels of tree mortality in mixed-conifer forests.

The forest heterogeneity suggested in GTR 220 is likely to reduce beetle-caused tree mortality below current levels in most fire-suppressed forests. If treatments differ with topography, higher stem densities will be left in the most mesic (and presumably productive) sites that can support these conditions without incurring high levels of tree mortality. Heavier thinning on more xeric sites may be appropriate to reduce competition in areas most prone to drought stress and associated bark beetle attacks. Although measures of density and SDI are usually stand-level means, SDI and potential competitive stress should be assessed at a fine scale (see chapter 9) in areas where microtopography may create localized differences in productivity.

At the landscape scale, the maintenance of a mosaic of different stand structures, densities, and compositions, as suggested in GTR 220, may reduce the frequency and extent of bark beetle outbreaks. Larger scale beetle outbreaks are often associated with more homogeneous forest conditions (i.e., less species diversity and more uniform stem densities). Management that increases spatial diversity of forest conditions with variable tree density, species diversity and growth rates may retain the ecological benefits of chronic bark beetle impacts without facilitating episodic, large-scale tree mortality that historically may have been rare in much of the Sierra Nevada.

In general, bark beetle abundance is a good indicator of tree stress. As climate conditions change and high stem densities increase with fire suppression, beetle mortality can provide some measure of ecosystem response. If patterns change from low-level chronic mortality of scattered individual trees to persistently higher rates, particularly of large clusters, ecosystem resistance and resilience may be compromised.

As climate conditions change and high stem densities increase with fire suppression, beetle mortality can provide some measure of ecosystem response.

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