

The Western Bark Beetle Research Group: A Unique Collaboration With Forest Health Protection

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Bark Beetle Responses to Vegetation Management Treatments¹

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Abstract

Native tree-killing bark beetles (Coleoptera: Curculionidae, Scolytinae) are a natural component of forest ecosystems. Eradication is neither possible nor desirable and periodic outbreaks will occur as long as susceptible forests and favorable climatic conditions co-exist. Recent changes in forest structure and tree composition by natural processes and management practices have led to increased competition among trees for water, nutrients and growing space thereby increasing tree stress. As trees become stressed, their insect resistance mechanisms are compromised and thus they become more susceptible to bark beetle attack. In this presentation, we reviewed tree and stand factors associated with bark beetle infestations and analyzed the effectiveness of vegetation management practices for mitigating the negative impacts of bark beetles on forest ecosystems. We described the current state of our knowledge and practical application of this knowledge; identified future research needs required to make informed decisions on proposed silvicultural treatments; and discussed ongoing research efforts led by the Western Bark Beetle Research Group. Our discussion concentrated on pine-dominated systems in the western US.

Keywords: Silviculture, thinning, prescribed fire, bark beetles, ponderosa pine.

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Introduction

Bark beetles (Coleoptera: Curculionidae, Scolytinae), a large and diverse group of insects consisting of approximately 550 species in North America (Wood 1982), are commonly recognized as the most important mortality agent in coniferous forests (Furniss and Carolin 1977). Most bark beetles feed on the phloem tissue of woody plants and often directly kill the host influencing forest ecosystem structure and function by regulating certain aspects of primary production, nutrient cycling, ecological succession and the size, distribution and abundance of forest trees (Mattson 1977, Mattson and Addy 1975, Mattson et al. 1996). Attacks reduce tree growth and hasten decline, mortality and subsequent replacement by other tree species. Severe infestations may impact timber and fiber production, water quality and quantity, fish and wildlife populations, recreation, grazing capacity, biodiversity, endangered species, real estate values and cultural resources in a variety of ways.

Individual trees utilize growth factors until one or more factors become limiting (Oliver and Larson 1996). Therefore, a forest contains a certain amount of intangible growing space, which varies spatially and temporally. Disturbances can make growing space available to some tree species at the expense of others (e.g., selective herbivory), or alter the amount of growing space available to all trees (e.g., prolonged drought) (Fettig et al. 2007). As growing space diminishes, a tree's photosynthates are allocated to different uses in an order of priorities (Oliver and Larson 1996): (1) maintenance respiration (Kramer and Kozlowski 1979), (2) production of fine roots (Fogel and Hunt 1979), (3) reproduction (Eis et al. 1965), (4) primary (height) growth (Oliver and Larson 1996), (5) xylem (diameter) growth (Waring and Schlesinger 1985), and (6) insect and disease resistance mechanisms (Mitchell et al. 1983). This hierarchy is not absolute, but is often used to illustrate how production of insect resistance mechanisms may be compromised when growing space becomes limited by one or more factors (Fettig et al. 2007).

In order to reproduce, bark beetles must successfully locate and colonize suitable hosts. Once identified, using a variety of behavioral modalities, host colonization begins with the biting process. Given the cues received during this process and other factors, such as the beetle's internal physiology (Wallin and Raffa 2000), the host is either rejected or accepted. If the host is rejected, the beetle takes flight presumably in search of another host. If the host is accepted, colonization in the case of living hosts requires overcoming tree defenses that consist of anatomical and chemical components that are both constitutive and inducible (Franceschi et al. 2005). This can only be accomplished by recruitment of a critical minimum number of beetles, which varies with changes in host vigor (Berryman 1982). Most coniferous species, particularly pines, have a well-defined resin duct system, which is capable of mobilizing large amounts of oleoresin upon wounding and often drowns or encapsulates attacking beetles.

Factors such as stand density, basal area or stand density index, tree diameter and host density are consistently identified as primary attributes associated with bark beetle infestations. Therefore, efforts to prevent undesirable levels of bark beetle-caused tree

mortality must change stand susceptibility through reductions in tree competition and/or changes in tree species composition.

Bark Beetle Responses to Vegetation Management Treatments

Based on a comprehensive review of empirical and anecdotal evidence concerning the effects of thinning and other vegetation management practices on host susceptibility and subsequent bark beetle infestation, Fettig et al. (2007) developed seven primary conclusions. These are paraphrased below and supplemented with additional supporting information.

1. Bark beetles causing the majority of conifer mortality in the US are native insects and an integral component of forest ecosystems. As such, eradication is neither possible nor desirable. Although bark beetles are native to conifer forests of the western US, conditions of many forest types have changed substantially over the past century (Cocke et al. 2005), resulting in increased inter-tree competition and subsequent landscape level outbreaks (USDA Forest Service 2005). Changing forest stand and tree conditions through vegetation management would sensibly decrease susceptibility to bark beetle-caused impacts.

2. Forested landscapes that contain little heterogeneity promote the creation of large contiguous areas susceptible to insect outbreaks. For example, the extensive mountain pine beetle, *Dendroctonus ponderosae* Hopkins, outbreak in British Columbia, Canada may be due in part to homogenization of forest stands over large geographic areas. In the early 1900s, ~17 percent of lodgepole pine, *Pinus contorta* Dougl. ex Loud., forests were in age classes susceptible to mountain pine beetle infestation, while today >50 percent of forests meet this classification (Taylor and Carroll 2004). When developing vegetation management strategies for bark beetles, susceptibility needs to be considered at both stand and landscape levels. Typically, the later is often not adequately addressed.

3. Although an extensive body of research exists describing relationships among stand conditions, vegetation management practices, and host susceptibility for several bark beetle species (e.g., mountain pine beetle), we still have research gaps for some cover types and common bark beetle species (e.g., bark beetles attacking true fir species). McMillin et al. (2003) related the extent of subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., mortality caused by western balsam bark beetle, *Dryocoetes confusus* Swaine, to forest conditions in north-central Wyoming. Significant positive linear relationships were found between amount of fir mortality and percentage of subalpine fir trees, subalpine fir basal area, and subalpine fir stand density index. However, additional studies are required to more fully understand factors associated with bark beetle infestations in true fir forests, and to develop silvicultural prescriptions to minimize undesirable levels of western balsam bark beetle-caused tree mortality.

4. Bark beetle infestations are consistently associated with certain forest stand and site conditions, such as tree density, basal area, stand density index, and site quality index. These findings have implications for developing vegetation management strategies.

Although not all studies examining the effects of thinning have demonstrated significant treatment effects, no studies have shown that thinning resulted in significant increases in the amount of *Dendroctonus*-caused tree mortality. Furthermore, vegetation management treatments can have direct and indirect societal benefits in addition to reducing tree losses associated with bark beetle infestations. For example, thinning can redistribute growing space to desirable trees, utilize anticipated mortality resulting from stem exclusion, encourage regeneration, create early cash flows, and reduce risks associated with fire and diseases.

5. *Several bark beetles are attracted to thinning residues (slash), most notably several species in the genus Ips (Livingston 1979, Parker 1991).* The most damaging effects occur when fresh slash and weakened trees are present in an area for two or more years (Parker 1991). However, impacts caused by bark beetles infesting thinning residues can be minimized through the use of published guidelines (DeGomez et al. 2008, Kegley et al. 1997, Parker 1991), which include information regarding the timing of thinning, slash size, removal of thinning residues, and appropriate treatment of slash by burning, chipping, or burying (see “*Ips*-n-chips” section below for more on slash management and bark beetles).

6. *Sublethal heating of critical plant tissue can stress trees and increase their susceptibility to bark beetle attack.* Prescribed fires are increasingly being implemented to reduce the risk of catastrophic wildland fires (Agee and Skinner 2005); however, there is the potential for unintended increases in bark beetle activity to occur following relatively low-intensity prescribed fires (Parker et al. 2006). For example, Breece et al. (2008) found a significantly greater proportion of ponderosa pine, *P. ponderosa* Dougl. ex Laws., trees attacked by bark beetles in stands that were prescribed burned (13%) than in paired unburned stands (1.5%) at sites in Arizona and New Mexico. However, the authors stated that relatively small increases in tree mortality should be acceptable to many forest managers given the effects of such fuels management treatments on reducing surface fuel loads and the risk of severe wildfire.

7. *The effectiveness of direct control techniques varies among bark beetle species.* For example, direct control treatments (i.e., cut-and-remove, cut-and-leave) can be effective for managing southern pine beetle, *D. frontalis* Zimmermann, infestations because of its unique life cycle and attack behavior (Billings 1995). In general, these treatments are not as effective for management of bark beetle species in the western US, especially once an epidemic population phase has been reached. Most effective direct control treatments in the West are those that target increasing, but localized populations and those that are in response to discrete disturbance events (e.g., windthrow, mixed-severity fire).

Vegetation treatments currently implemented in southwestern ponderosa pine forests

In the Southwest, few silvicultural treatments are implemented for the sole objective of reducing stand risk or susceptibility to bark beetles. Exceptions include Forest Health Protection (FHP)-funded projects (State and Private Forestry, USDA Forest Service) in

high value settings such as developed recreation (e.g., campgrounds) and administrative sites. The majority of federal funding for vegetation management is geared towards fuels reduction and forest health restoration projects.

Fuels reduction treatments in the wildland urban interface (WUI)

Most funding for vegetation management in southwestern ponderosa pine forests is expended on fuels reduction treatments, such as thinning from below, particularly in the WUI. While the primary objective of these treatments is to reduce the risk of catastrophic wildland fires and damage to homes and other structures (National Fire Plan 2004), these treatments are also often advocated as a strategy to reduce the susceptibility of individual trees and forest stands to bark beetle attack. However, there has not been a critical examination of how these treatments actually affect the short- and long-term susceptibility of stands to bark beetles. As thinning and prescribed fire prescriptions to reduce fuels can vary widely, there is reason to believe their effects on bark beetles will also vary. Thinning treatments with diameter caps of less than 41–46 cm can result in residual basal areas that are still in the moderate to high stand susceptibility for bark beetles that typically attack ponderosa pine. These treatments can also result in the creation of even aged stands comprised of large-diameter, mature trees that may be highly susceptible to bark beetle species such as western pine beetle, *D. brevicornis* LeConte, particularly during periods of extended drought. It is recommended that land managers, in cooperation with forest health professionals, monitor how bark beetles respond to such treatments in both the short- and long-term with the intent that silvicultural prescriptions can be developed that successfully achieve multiple goals with limited additional cost.

Forest health restoration treatments

Prescriptions for improving overall forest ecosystem health and function are also being implemented in southwestern ponderosa pine forests. In general, these treatments work to restore historic patterns of stand structure, fire intensity and fire frequency (Fulé et al. 2007). The resulting stand structure is typically patchier, clumpier and comprised of more uneven-aged stands compared with stand structures produced as a result of fuels reduction projects. Being that many of the stand hazard rating systems for ponderosa pine were developed in even-aged stands, there is a question as to how bark beetle activity might vary in response to these silvicultural systems (Negrón et al. 2008). Mountain pine beetle-caused tree mortality in uneven-aged ponderosa pine stands in the Black Hills of South Dakota and Wyoming was found to be positively correlated with basal area and ponderosa pine stand density index, which is similar to previous findings in even-aged stands (Schmid and Mata 2005). However, in contrast to even-aged stands where it is the total contribution of ponderosa pine that affects stand susceptibility, Negrón et al. (2008) concluded that densities (basal area) comprised of mid- to large-sized trees make a stand more susceptible to bark beetle attack in uneven-aged stands. Thus, akin to the recommendation for short- and long-term monitoring of bark beetle activity following fuels reduction treatments, additional case history studies of bark beetle responses to forest health restoration treatments seem prudent.

Research and Development

In a research context, bark beetle responses to vegetation management treatments must be considered at three spatial scales (i.e., individual tree, stand and landscape) and at least two temporal scales (i.e., short-term and long-term). Typically, research and development (R&D) efforts have concentrated on short-term (e.g., 1–5 years post-treatment) responses using small scale plots (e.g., ≤ 4 ha) indicative of stand level conditions. Given today's resource constraints, this is most appropriate, but not without certain limitations. For example, Schmid and Mata (2005) suggested results obtained from 1-ha plots within their Black Hills thinning study may be confounded by the fact that plots were surrounded by extensive areas of unmanaged forest where bark beetle populations were epidemic. They stated that reductions in long-term tree mortality will be accomplished when an area of sufficient size is managed so that thinned stands are separated from unmanaged stands by natural buffers or those of lower tree density. Several studies are being conducted at larger spatial scales (e.g., 10–100 ha) that represent more realistic management scenarios, but while data from such studies are highly desirable they come at significant cost.

Forest health specialists recognize long-term reductions in stand susceptibility to bark beetle attack achieved through vegetation management practices often occur at the cost of short-term increases in bark beetle-caused tree mortality. For example, as previously indicated, several bark beetle species are attracted to slash and/or host volatiles produced during thinning operations. While describing short-term bark beetle responses to vegetation management treatments are important, more important is the determination of long-term impacts on the amount and distribution of bark beetle-caused tree mortality as this influences fuel reduction targets, forest productivity and forest sustainability. One caveat is that long-term studies require long-term commitments in funding and staffing generally with relatively few accolades over time (i.e., presentations and publications) for the individual scientists and sponsoring agents involved. While the tremendous value of long-term studies is fully recognized, few funding sources are available for maintaining them.

In preparation for this presentation, we polled several of our colleagues in FHP to determine what they considered to be primary needs for research. Among vegetation management treatments, responses concentrated on the application of mechanical thinning and prescribed fire and their effects on the amount and distribution of bark beetle-caused tree mortality at three spatial scales (Table 1).

Table 1—Examples of research needs identified by Forest Health Protection, 2007

Research Question	Spatial Scale	Temporal Scale
What are the benefits of “individual tree culturing” to reduce the risk of western pine beetle attack on large diameter ponderosa pine in the Pacific Northwest?	Tree	Short and long-term
What is the probability of bark beetle attack on individual trees following prescribed fire? What can be done to limit any negative impacts?	Tree	Short and long-term
How does the application of prescribed fire influence the amount and distribution of bark beetle-caused tree mortality?	Stand	Short and long-term
What specific thinning treatments best meet long-term bark beetle management objectives?	Stand and landscape	Long-term
Are thinning treatments implemented during a bark beetle outbreak effective in the short- and/or long-term?	Stand and landscape	Short and long-term
How much of a landscape needs to be treated? Where will treatments be most effective?	Landscape	Long-term
Are there combinations of treatments that also satisfy other resource objectives?	Landscape	Long-term

The tools and methods by which thinning is implemented are quite diverse, and their application can result in significantly different stand structures and compositions. Depending on the insect species of concern, each method would have a functionally different response on the abundance and distribution of preferred hosts as well as that of the insect herbivore. For example, Whitehead and Russo (2005) suggested that increases in resin production and tree vigor following thinning were not as important in reducing mountain pine beetle-caused tree mortality in lodgepole pine stands as reductions in the number of initiated attacks, which is more likely associated with inter-tree spacing. In western North America, 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).

Prescribed fire is often used to reduce the buildup of hazardous fuels, enhance wildlife habitat, improve grazing, thin overstocked stands, control some insects and diseases, prepare sites for regeneration and restore fire-adapted forest ecosystems. Forest managers must plan and execute prescribed burns carefully in order to minimize injury

to desirable residual trees while still fulfilling management objectives. Bark beetles are often considered the most important mortality agent following prescribed fires, and mixed-severity wildfires, in coniferous forests (Parker et al. 2006). It has been our experience that gross generalizations concerning bark beetle responses to prescribed fire at the stand level are misleading as the bark beetle assemblages present within and adjacent to treated areas are of primary importance.

The research question “Are there combinations of treatments that also satisfy other resource objectives?” (Table 1) is particularly important and worthy of further discussion. In recent years, relatively few resources have been available to conduct thinning specifically for bark beetle management (i.e., with consideration to residual tree distributions and densities within the context of lowering stand susceptibility to bark beetle attack). Therefore, it seems appropriate that forest health specialists should be working with fuel managers to determine if the application of SPLATs and SPOTs technology (i.e., Strategically Placed Landscape Area Treatments and Strategic Placement of Treatments as defined in fire-shed assessments) used in fuels management could be adjusted to meet other forest health concerns. To our knowledge, this is not currently being done in the western US.

We polled several of our colleagues in the Western Bark Beetle Research Group (WBBRG) to determine what studies were currently being conducted to identify bark beetle responses to vegetation management treatments (Table 2). It is encouraging that several studies will provide answers to questions posed in Table 1 and/or fill research gaps identified elsewhere (Fettig et al. 2007). For example, Massey and Wygant (1954) first reported the mean diameter of attacked Engelmann spruce, *Picea engelmannii* Parry ex Engelm., decreased during a spruce beetle, *D. rufipennis* (Kirby), outbreak thereby suggesting a preference by spruce beetle for larger diameter trees. Today, stands growing on well-drained sites and with a mean diameter at breast height (1.37 m) of live spruce > 25.4 cm being > 40.6 cm (i.e., large-diameter trees), basal areas > 34.3 m²/ha and proportions of spruce > 65% are considered more susceptible to spruce beetle attack (Schmid and Frye 1976). However, no experiments have specifically been conducted to determine the effects of thinning on spruce beetle activity in Engelmann spruce stands. To generate such data within a completely randomized or randomized complete block design would take years or perhaps decades to establish the scientific infrastructure and await spruce beetle populations to challenge the experiment in a manner sufficient to determine differences in susceptibility among treatments. Alternatively, to address this knowledge gap Matt Hansen and Jose Negrón of WBBRG have recently initiated a retrospective study to determine the efficacy of silvicultural treatments in reducing stand-level spruce beetle-caused tree mortality, and to quantify post-outbreak stand characteristics among a variety of treatment types including unmanaged stands. Twenty-six pairs of previously treated and untreated plots have been installed in Arizona, Utah and Wyoming.

Table 2—Examples of ongoing research led by the Western Bark Beetle Research Group, 2007

Research Projects	Primary Investigator(s)
Effects of silvicultural treatments on levels of spruce beetle-caused tree mortality in the Rocky Mountains	Hansen and Negrón
Tools for analyzing landscape-level fuels treatment scenarios and their effects on bark beetle-caused tree mortality	Hayes
Impacts of silvicultural treatments on defensive chemicals in stressed ponderosa and lodgepole pines and impacts on bark beetle host tree selection	Kelsey; Seybold
Factors associated with bark beetle-caused tree mortality at multiple spatial scales	Bentz; Fettig; Hansen; Negrón
Interactions among bark beetles and other disturbances to improve management approaches	Lundquist; Negrón; Seybold
Development of management guidelines to help reduce tree mortality due to bark beetle infestations after the application of prescribed fire	Bentz; Fettig; Hansen; Hayes; Kelsey; Lundquist; Negrón; Niwa
Thinning strategies for reducing the risk of bark beetle attack in Eastside pine and Sierra Nevada mixed conifer forests	Fettig

The “Ips-n-chips” Study

The *Ips-n-chips* study serves as a successful model for collaborative research between FHP and FS R&D (see Fettig et al. 2006). We share the genesis of this study as well as its results and impacts hoping that it serves as a model of success for similar studies conducted within the framework of WBBRG.

In recent years, unusually large and catastrophic wildfires have heightened public concern. Federal and state hazardous fuel reduction programs have increased accordingly to reduce the risk, extent and severity of these events, particularly in the WUI. Because sufficient markets have yet to be developed for small dimensional material in many locations, much of the tree biomass resulting from these treatments is not merchantable. In many areas, this material is cut and lopped (i.e., bole severed into short lengths and limbs removed) and/or chipped, and distributed on site. The amount of total biomass on the site may be unchanged, but the torching potential (i.e., the

initiation of crown fire activity) and rate of potential crown fire spread is significantly reduced. However, these actions result in increased amounts of host material (slash) and host volatiles (from slash and chips) that may concentrate certain bark beetle species in these areas.

In early 2002, Joel McMillin and John Anhold (Forest Health Protection, USDA Forest Service, Flagstaff, AZ) were contacted regarding what appeared to be excessive amounts of bark beetle-caused tree mortality resulting from the chipping of unmerchantable trees during fuel reduction treatments in the WUI surrounding Flagstaff, Arizona. Through several site visits and a preliminary study, they provided anecdotal evidence that several bark beetle species appeared to be attracted to stands where logging residues had recently been chipped (McMillin and Anhold, unpublished data). In 2003, FHP (McMillin and Anhold) and the Pacific Southwest Research Station (Fettig) joined forces to examine the effects of several mechanical fuel reduction treatments on the activity of bark beetles in ponderosa pine forests located in Arizona and California. Treatments were applied in both late spring (April-May) and late summer (August-September) and included: (1) thinned biomass chipped and randomly dispersed within each 0.4 ha plot; (2) thinned biomass chipped, randomly dispersed within each plot and raked 2 m from the base of residual trees; (3) thinned biomass lopped-and-scattered (thinned trees cut into 1–2 m lengths) within each plot; and (4) an untreated control. The mean percentage of residual trees attacked by bark beetles ranged from 2.0% (untreated control) to 30.2% (plots thinned in spring with all biomass chipped). A three-fold increase in the percentage of trees attacked by bark beetles was observed in chipped versus lopped-and-scattered plots. Bark beetle colonization of residual trees was higher during spring treatments, which corresponded with peak adult beetle flight periods as measured by funnel trap captures. Raking chips away from the base of residual trees did not significantly affect attack rates. In a laboratory study, the quantities of β -pinene, 3-carene, α -pinene and myrcene eluting from chips greatly exceeded those from lopped-and-piled slash during each of 15 sample periods. These laboratory results may, in part, explain the bark beetle responses observed in chipping treatments as many of these monoterpenes are attractive, or enhance attraction in the presence of aggregation pheromone components, for several bark beetles.

Despite higher levels of bark beetle attack in chipped plots, no significant differences in tree mortality were observed among treatments during the first two years of this study. However, the authors commented that negative effects of prolonged and large numbers of red turpentine beetle, *D. valens* LeConte, attacks, among others, on individual tree health may not be realized for some time (Fettig et al. 2006), and continued monitoring these plots for bark beetle-caused tree mortality on an annual basis. During 2005 and 2006, a significant treatment effect was observed with significantly higher levels of bark beetle-caused tree mortality observed in plots chipped in spring than plots chipped in fall or those lopped-and-scattered in fall. Cumulatively (2003–2006), a significant treatment effect was also observed with significantly higher levels of bark beetle-caused tree mortality occurring in plots chipped in spring (6.1 ± 1.7 percent) than those lopped-and-scattered in fall (1.4 ± 0.8 percent).

Based on this study, guidelines were developed for minimizing tree losses due to bark beetle infestation following chipping (DeGomez et al. 2008). Again, we feel this study serves as a fruitful framework in which to conduct research within the context of WBBRG. We hope it serves as an example of one of many productive partnerships to come as a result of formation of the WBBRG.

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