

US Forest Service Bark Beetle Research in the Western United States: Looking Toward the Future

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ABSTRACT

Bark beetles cause extensive tree mortality in coniferous forests of western North America and play an important role in the disturbance ecology of these ecosystems. Recently, elevated populations of bark beetles have been observed in all conifer forest types across the western United States. This has heightened public awareness of the issue and triggered legislation for increased funding for state and federal agencies to address issues associated with bark beetle outbreaks. Recently, US Forest Service, Research and Development entomologists from the western research stations met with US Forest Service, State and Private Forestry, Forest Health Protection entomologists, our primary stakeholder, to identify bark beetle research priorities. These include vegetation management; ecological, economic, and social consequences of outbreaks; fire and bark beetle interactions; effects of climate change on bark beetle populations; and chemical ecology.

Keywords: bark beetles, western forest insects

Native bark beetles are important disturbance agents in western coniferous forests. Population levels of a number of species oscillate periodically, often reaching high densities and causing tree mortality on a landscape level when favorable stand and climatic conditions coincide. Bark beetles influence forest ecosystem structure and function by regulating certain aspects of primary production; nutrient cy-

cling; ecological succession; and size, distribution, and abundance of trees (Romme et al. 1986). These mortality events are part of the ecology of western forests and positively influence many ecological processes, but the economic and social implications can also be significant.

Recently, elevated bark beetle populations have caused extensive tree mortality across the western United States in forest types ranging from piñon-juniper woodlands to spruce-fir forests (US Forest Service 2005). In addition to the challenges presented by these disturbance agents to forest managers, public awareness of these outbreaks is high. The media regularly feature dramatic occurrences and effects of bark beetle-caused tree mortality in newspapers, television, and radio programs. Legislative

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bills have been introduced to the US Congress and state legislatures seeking funding and authorities to address the issue. These legislative bills follow the National Fire Plan and Healthy Forests Restoration Act of 2003 (US Public Law 108-148), which addressed private industry and public concerns about increased tree mortality due to fire and insect infestation in western forests.

For many years, US Forest Service research scientists in the West have studied the biology, ecology, and management of the principal species of tree-killing bark beetles. Some of the important species include the Douglas-fir beetle, *Dendroctonus pseudotsugae*, mountain pine beetle, *Dendroctonus ponderosae*, spruce beetle, *Dendroctonus rufipennis*, western pine beetle, *Dendroctonus brevicomis*, fir engraver, *Scolytus ventralis*, and pine engravers, *Ips* spp. Bark beetle research reflected the historical emphasis placed on western timber resources. Today, changes in societal values, global trading practices, and increased awareness of the importance of disturbances in the functioning of forest ecosystems present previously unexplored questions. Among others, these include the impacts on recreation, visual corridors, and high value areas such as ski areas; impacts to threatened, endangered, or sensitive wildlife species; the introduction of invasive species; and potential response of insects and their coniferous hosts to climate change.

To adequately address the present and future concerns of land managers and the general public, and to continue to explore basic ecological processes associated with bark beetles, the scientific community is compelled to examine research priorities. US Forest Service Research and Development (R&D) entomologists from the western United States (US Forest Service 2008b) [1] met in 2007 with entomologists from US Forest Service, State and Private Forestry, Forest Health Protection (US Forest



Figure 1. Impact of vegetation management on bark beetle infestations. Thinned lodgepole pine stand, Arapaho-Roosevelt National Forest, Colorado. Studies have shown that silvicultural treatments can reduce stand susceptibility to bark beetle infestations. However, there is a need to conduct studies at large spatial and temporal scales. Furthermore, data are lacking for some important cover types. (Photo courtesy of José Negrón, US Forest Service.)

Service 2008a) to discuss and identify research priorities on bark beetles. FHP specialists are responsible for technical assistance on forest insect and disease issues on all federal lands and work closely with state forest health cooperators, so feedback from FHP specialists reflected an efficient means of gathering stakeholder input. It should be noted that these research priorities were the primary issues identified by the group with stakeholder input and not a comprehensive list. In addition, stakeholder input did not include priorities that scientists with universities and state research agencies may consider important.

Bark Beetle Research Priorities, US Forest Service, Research and Development

Although much of the forest science community has been operating in resource-challenging times, we also find ourselves at the threshold of new and exciting avenues of research. In this section we discuss the primary research areas identified in conjunction with FHP, our primary stakeholder group.

Vegetation Management. In general, tree and stand conditions conducive to outbreaks of many bark beetles have been identified and thinning has been advocated as a preventive strategy to reduce the amount or

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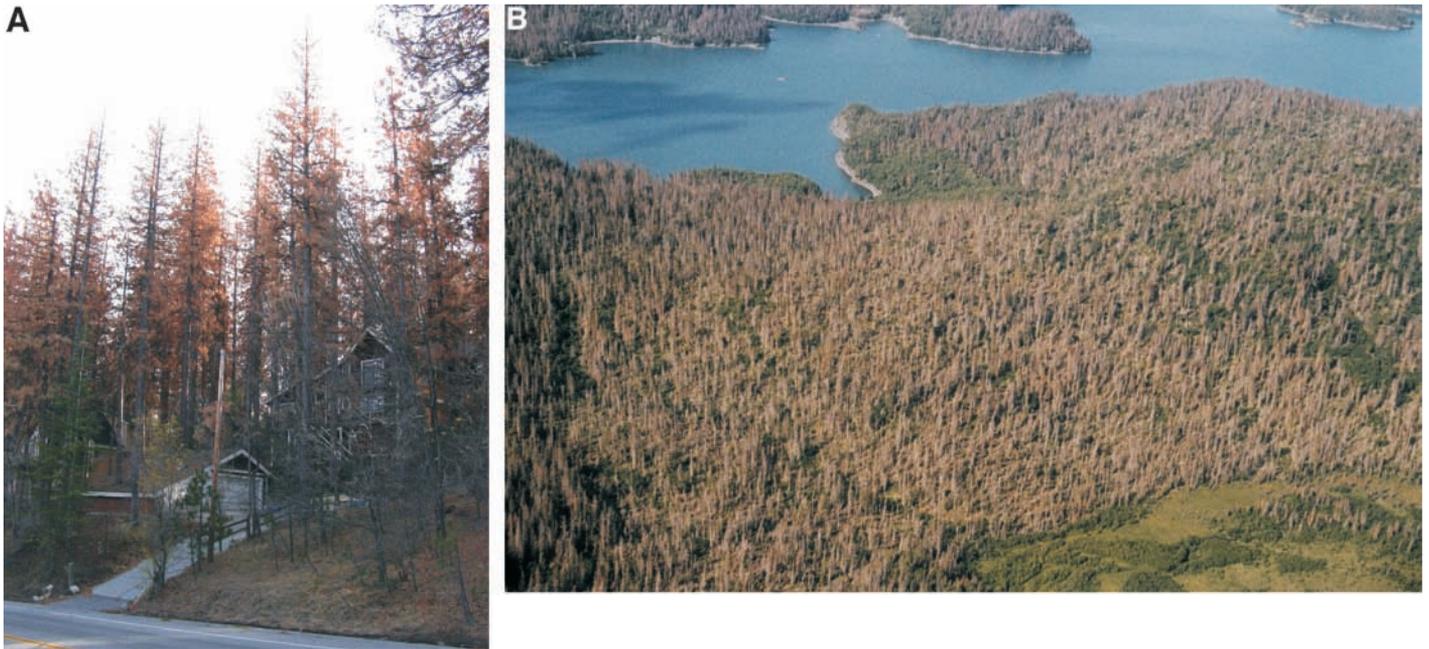


Figure 2. Ecological, economic, and social consequences of bark beetle outbreaks. Tree mortality caused by (A) western pine beetle, fir and pine engraver, and mountain pine beetle in a mixed conifer forest at the wildland–urban interface, San Bernardino National Forest, California, and (B) spruce beetle in a Sitka spruce forest, Kachemak Bay State Park, Kenai Peninsula, Alaska. The impacts of bark beetles on timber resources are well understood but little is known about other ecological and socioeconomic impacts. (Photos courtesy of Laura Merrill (panel A), US Forest Service, and Roger Burnside (panel B), Division of Forestry, State of Alaska.)

occurrence of bark beetle–caused tree mortality (Fettig et al. 2007). However, most studies on forest susceptibility to bark beetles and vegetation management were conducted on small plots, short temporal scales, even-aged stands, and few forest types such as lodgepole and ponderosa pine (Figure 1). We need to transfer this knowledge and expand our research to large landscapes, longer time frames, and uneven-aged stands, where land managers are increasingly practicing management, and examine understudied forest types (Fettig et al. 2007).

We have just begun to understand the effects of thinning on host finding and colonization by bark beetles at the tree and stand level (Fettig et al. 2007). Bark beetles are affected by spatial patterns of habitat patches within landscapes (Coulson et al. 1999), but how these processes influence the efficacy of vegetation management practices is unknown. Working in this area will provide managers with tools as they consider landscape-level processes in their management strategies.

Exploring the mechanisms of host susceptibility by which thinning and other disturbance agents such as drought, disease, and defoliation influence tree physiology, especially the production of stress-induced volatiles such as ethanol (Kelsey 2001) and tree responses to water deficit,

will strengthen the scientific basis for the application of vegetation management treatments to restore, maintain, and enhance ecosystem integrity and resiliency.

Fuel reduction projects, particularly in the wildland–urban interface, are being conducted using mechanical treatments. Fettig et al. (2006) showed that chipping slash in ponderosa pine stands resulted in a significant increase in bark beetle attacks on residual trees although no increases in tree mortality were observed in the short term. The effects of other treatments, such as mastication or delayed chipping of tree biomass or both, need to be explored if these fuel reduction practices are to be successful in leaving vigorous residual trees.

Ecological, Economic, and Social Consequences of Bark Beetle Outbreaks.

Because disturbances are important to the function of forest ecosystems, bark beetle outbreaks are ecologically beneficial. From the socioeconomic perspective, however, bark beetles are often considered detrimental, especially for economies supported by wood utilization, tourism, and outdoor recreation (Figure 2, A and B). Negative economic impacts of bark beetle–caused tree mortality have often been estimated in terms of timber production, but the beneficial ecological roles of this disturbance have received less attention. Bark beetles play important

roles in forest stand structure and net primary production (Romme et al. 1986), biogeochemical and hydrologic cycling (Edmonds and Eglitis 1989), and species diversity (Martin et al. 2006) among other processes. These topics have only been briefly addressed, but their consideration is essential for the successful delivery of ecosystem services.

Disturbance scale must be considered, because there are different ecological outcomes for stand-replacing versus canopy gap-producing events (Lundquist and Negrón 2000). At the landscape scale, insect infestations create a mosaic of forest patches of various ages, densities, species composition, and successional stages (Schowalter 2006). Spatial metrics have been developed to quantify landscape patterns (Gustafson 1998), but these need to be correlated to bark beetle activity. Geospatial analyses can be used to map relationships among ecosystem components and quantify the ecological roles of bark beetles.

Timber production metrics or single resource variables are inappropriate for characterizing nontimber impacts of bark beetles on forested ecosystems (Kline 2007). Methods developed to assess multiple variables offer alternatives for characterizing impacts affecting a variety of objectives (Lundquist and Beatty 1999). This work will result in



Figure 3. Fire and bark beetle interactions. The Left Hand Canyon fire occurred in a ponderosa pine stand where mountain pine beetle had previously caused tree mortality, Arapaho-Roosevelt National Forest, Colorado. Little is known about the relationship between bark beetle-caused tree mortality and the probability of occurrence or fire behavior of subsequent wildfires. (Photo courtesy of John Popp, US Forest Service.)

adequate valuation for complex systems associated with bark beetle outbreaks.

After outbreaks of spruce beetle in Alaska in the mid-1990s, Flint (2006) found that community perceptions of impacts ranged from (1) acknowledging that the insect is a natural component of the ecosystem to (2) considering that the outbreak was a socioeconomic and ecological disaster for the community. Others viewed it as an opportunity to generate income by processing dead trees. These results illustrate an exciting and important but unexplored avenue of research, which may lead to landscape-level quantification and modeling of outcomes of bark beetle activity. This will enhance forest management strategies that accommodate the full range of concerns of communities impacted by outbreaks.

Fire and Bark Beetle Interactions.

Interactions between bark beetles and fire can take two different forms. First, fire can cause tree injury and change the volatile emissions of conifers (Kelsey and Joseph 2003), thereby increasing susceptibility to bark beetles. Second, bark beetles can change the forest environment thereby influencing the probability, extent, or behavior of fire events. Authors cite examples of delayed tree mortality by what appear to be interactions between fire effects and large numbers of bark beetle attacks (Hood and

Bentz 2007). Further examination of these interactions may lead to the development of postfire salvage harvesting guidelines for forest sustainability within and adjacent to wildfire-impacted stands by identifying trees that survive fire, but may ultimately succumb to bark beetle attacks (Sieg et al. 2006).

Although it is widely believed by land managers and the public that bark beetle outbreaks set the stage for severe wildfires, few scientifically and statistically sound studies have been published on this topic (Figure 3). Bark beetles can influence the spatial distribution and conditions of fuels, which in turn may influence fire occurrence, behavior, and severity. By causing needles to dry and creating snags, bark beetles can change the composition, size, distribution, compactness, and arrangement of forest fuels. Page and Jenkins (2007) concluded the net result of a mountain pine beetle infestation in lodgepole pine forests was a highly altered fuels complex in which litter and fine fuels increase during current outbreaks and live surface fuels and large dead woody fuels dominate postoutbreak stands. A thorough examination of the fate of fuels after bark beetle outbreaks can shed light on the potential need for managing the downed wood.

Postoutbreak wildfire risk changes may depend on time since tree death and beetle-



Figure 4. Climate change effects on bark beetles. Whitebark pine killed by mountain pine beetle in Yellowstone National Park. Bark beetles are becoming more common in high elevation forests and at northern latitudes. Climate change may be a predisposing factor. (Photo courtesy of Ken Gibson, US Forest Service.)

caused changes in stand structure. Lynch et al. (2006) found a delayed interaction between beetles and fire and reported that the Yellowstone fires of the late 1980s were preceded by two mountain pine beetle outbreaks in 1972–1975 and 1980–1983. Only the former influenced fire behavior. The authors attributed the effect to changes in stand structure that resulted in increased fuel ladders. This relationship between bark beetle-caused tree mortality and wildfire may be cover-type specific, or may be site specific. For instance, in Yellowstone, studies suggest that the probability of burning increases 11% in beetle-affected lodgepole pine stands compared with unaffected stands (Lynch et al. 2006). In Colorado, Bigler et al. (2005) attributed a slight increase in probability of fire occurrence in a spruce forest after a spruce beetle outbreak partly to an increase in ladder fuels and Bebi et al. (2003) indicated that spruce beetle outbreaks had no effect on fire susceptibility. Berg and Anderson (2006) concluded that there was no relationship between spruce beetle-caused tree mortality and subsequent wildfire occurrence in Alaska. We need to better define the conditions, if any, where bark beetle outbreaks may influence fire oc-



Figure 5. Chemical ecology. Experimental application of behavioral chemical repellents to a ponderosa pine for individual tree protection, Lassen National Forest, California. Significant progress has been made in the identification of pheromones and other behavioral chemicals for many bark beetles. Critical work is needed to better incorporate their use into management programs. (Photo courtesy of Chris Fettig, US Forest Service.)

currence, behavior, or severity. This is of particular relevance as the wildlife–urban interface continues to expand into fire-

prone forests that are also susceptible to bark beetles.

Climate Change Effects on Bark Beetles. Important bark beetle life history strategies are directly influenced by temperature and are sensitive to climate change (Figure 4; Logan et al. 2003). Recent outbreaks of bark beetles in the western United States have coincided with increased temperatures and changes in precipitation patterns, suggesting a response to a changing climate (Shaw et al. 2005). Climate change influences bark beetles directly through effects on developmental timing, temperature-induced mortality, and disruption of host selection behavior and establishment. Because mortality from cold exposure is considered a key factor in bark beetle population dynamics (Bentz and Mullins 1999), increasing minimum temperatures associated with climate change can directly influence bark beetle population dynamics.

Conifers have evolved effective defensive response mechanisms against bark beetle attacks (Seybold et al. 2006), and many compounds used in defense reactions will be altered in a changing climate. For example, increases in carbon dioxide (CO₂) will generally stimulate tree growth and increase water use efficiency (Magnani et al. 2004), while tropospheric ozone (O₃) increases are inhibitory to trees, and both gases affect nutrient, secondary metabolite, and defense capacity (Saxe et al.

1998). Study of the effect of these tree-level changes on bark beetle population dynamics and defensive mechanisms of trees against bark beetles is needed to develop strategies for forest protection under a climate change scenario.

Our ability to predict bark beetle response to climate change is limited by a lack of data on species-specific temperature-dependent developmental processes. Currently, phenology models exist for mountain pine beetle (Gilbert et al. 2004) and spruce beetle (Hansen et al. 2001). Additional work is needed to parameterize these existing models to account for regional differences. For other bark beetle species, our current ability to forecast climate change effects on population dynamics is largely qualitative and not sufficient for the development of accurate predictions on the response of bark beetles to a changing climate. Discerning the effects of climate change on the relationship between trees and associated bark beetles may lead to practical tools and approaches to address and manage forests under these new interactions.

Chemical Ecology. Research on the behavior of western bark beetles has revealed the potential utility for semiochemical, rather than insecticidal, applications for manipulating levels of bark beetle–caused tree mortality (Borden 1997). Much of this research has focused on using beetle-produced

Table 1. Summary of research needs within five research priority areas for bark beetles in the western United States.

Vegetation management	
Examining vegetation management strategies in forest types lacking information such as Douglas-fir and spruce forests	
Transferring vegetation management information on bark beetle susceptibility to large landscapes, longer time frames, and uneven-aged stands	
Determine the impact of microclimate change on bark beetle populations and the role of landscape patchiness on the efficacy of vegetation management	
Exploring the mechanisms by which thinning and other disturbance agents such as drought, disease, and defoliation influence tree physiology and susceptibility to bark beetles	
Assessing the effect of mechanical fuel reduction treatments on residual tree susceptibility to bark beetles	
Ecological, economic, and social consequences of bark beetle outbreaks	
Examining the role of bark beetles on forest stand structure, biogeochemical and hydrological cycling, net primary production, and species diversity	
Using spatial metrics and multiple variables to characterize nontimber impacts of bark beetles on the landscape	
Quantifying and modeling of nontimber outcomes of bark beetle activity	
Fire and bark beetle interactions	
Characterizing insect-caused tree mortality after fires	
Examining the fate of fuels after bark beetle outbreaks	
Defining the conditions, if any, where bark beetle outbreaks may influence fire occurrence, behavior, or severity	
Climate change	
Developing regional models that will lead to adequate predictions about west-wide climate change affects on bark beetles	
Studying the effect of climate change on bark beetle population dynamics and on defensive mechanisms of trees against bark beetles	
Developing phenology models for many bark beetle species	
Discerning the effects of climate change on the relationship between trees and associated bark beetles	
Chemical ecology	
Developing and refining semiochemical-based management strategies for mitigating insect-caused tree mortality in high value areas	
Clarifying and refining the scientific foundation for use of behavioral chemicals for mitigating bark beetle-caused mortality in reactive forest environments under climate change and air quality degradation	
Examining the biosynthesis of bark beetle communication chemicals, bioproduction of large quantities of highly pure semiochemicals, and biochemical interactions between bark beetles and their host conifers	

antiaggregation pheromones such as methylcyclohexenone (Ross and Daterman 1995) and verbenone (Progar 2005) to protect trees (Figure 5). Others have begun studying the use of nonhost bark volatiles and green leaf volatiles that signal to beetles that the tree they are encountering is outside of their host range (Zhang and Schlyter 2004). Continuing studies in this field will lead to the refinement of semiochemical-based management strategies for mitigating insect-caused tree mortality, particularly in high value areas.

Forest ecosystems are reactive locations, both in terms of the chemistry on plant and physical surfaces and the chemistry of the fluid phase and aerosols in the airspace (Seybold et al. 2006). Our current fundamental understanding of host selection by bark beetles may be inaccurate because of the environmental oxidation of the classes of semiochemicals noted previously. A corollary of this is that the scientific foundation of the commercial and research use of these behavioral chemical tools may need significant refinement.

Additional research is merited on the bioproduction of large quantities of highly pure semiochemicals of western bark beetles and the interaction between bark beetles and conifers during pheromone synthesis. During the last 10 years, great strides have been made in understanding the biosynthesis of western bark beetle pheromones (Seybold and Tittiger 2003).

The key genes and enzymes from the *de novo* synthesis could be exploited commercially for the production of monoterpene alcohol and bicyclic acetal pheromones of high stereochemical purity for applications in management. Recently, the P450 genes that are the hallmark of the biochemical interactions between bark beetles and their host conifers were isolated and characterized from two species of western *Ips* bark beetles (Huber et al. 2007). These discoveries will perhaps mark a turning point in the biocommercialization of bark beetle pheromone synthesis and reveal new vulnerabilities in the physiology of bark beetles during host colonization.

Concluding Remarks

Forest Service R&D bark beetle research scientists in the western United States will continue to emphasize basic and application-motivated research to enhance our scientific understanding and solve problems faced by our diverse stakeholders (Table 1).

The areas of study discussed previously represent the five most fruitful lines of research identified with significant input from specialists in FHP. Cooperative work among US Forest Service research stations and FHP units, universities, and state forest health specialists will enhance the ability to adequately address these exciting areas of research. Interactions among these partners will synergize the work effort and foster creative approaches to solve research questions that can ultimately expand our knowledge base on the interactions between bark beetles and western forest ecosystems.

Endnotes

- [1] The Forest Service R&D Western Bark Beetle Research Group (WBBRG) was created in January 2007 in Stevenson, Washington. WBBRG includes scientists from the three western Forest Service R&D research stations with expertise in bark beetle research, development, and application in the West. (US Forest Service 2008c).

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