University of Wyoming

Environment and Natural Resources

BARK BEETLES IN THE INTERMOUNTAIN WEST

Redefining Post-Disturbance Forests and Management Strategies for Minimizing Impacts

Proceedings of a Workshop held October 4–5, 2010, in Laramie, Wyoming

Haub School & Ruckelshaus Institute
of Environment and Natural Resources
University of Wyoming

Workshop Sponsors

Workshop Steering Committee

Jesse Logan, U.S. Forest Service (Retired)
Jim Neiman, Neiman Enterprises
Dick Taggart, Weyerhaeuser Company
Jim Thinnes, U.S. Forest Service
Steve Thomas, Sierra Club

Cover photo: The bark beetle epidemic has been compared to a "slow motion hurricane." Photo by Josh King.

Our Mission

The mission of the University of Wyoming Environment and Natural Resources (ENR) program is to advance the understanding and resolution of complex environment and natural resources challenges.

Through the work of the Helga Otto Haub School, William D. Ruckelshaus Institute, and Wyoming Conservation Corps, ENR:

- Educates undergraduate and graduate students through innovative and interdisciplinary teaching;
- Supports stakeholder-driven solutions to environmental challenges by communicating relevant research and promoting collaborative decision making; and,
- Inspires young adults to become stewards of our natural resources through leadership training and service-learning to benefit lands in Wyoming.

HAUB SCHOOL & RUCKELSHAUS INSTITUTE
OF ENVIRONMENT AND NATURAL RESOURCES
UNIVERSITY OF WYOMING

Suggested citation: Jakle, A., S. Brown, D. Tinker, J. Lovato, and N. Dobric. 2011. *Bark Beetles in the Intermountain West: Redefining Post-Disturbance Forests and Management Strategies for Minimizing Impacts.* Proceedings of a workshop held October 4–5, 2010, Laramie, Wyoming. Laramie, Wyoming: William D. Ruckelshaus Institute of Environment and Natural Resources.

Foreword

In October 2009, former Wyoming Governor Dave Freudenthal visited several sites in the Medicine Bow National Forest with University of Wyoming (UW) professors to get a firsthand look at some of the beetle-killed forests. UW students and professors researching aspects of the Medicine Bow have also observed the state of lodgepole pine forests that have been altered due to the ongoing mountain pine beetle epidemic. Both the Governor and UW faculty and students, as well as many citizens and stakeholders throughout the Intermountain West, were awed and a little unsettled by the state of the forest, the number of dead trees, and magnitude of the bark beetle epidemic, asking: What are the best ways to protect forests from beetle invasion? What can we do once a forest is infested? How will the swaths of dead trees impact future forest fire risk? What will our future forests look like?

The explosion of bark beetle populations in the Intermountain West is at the fore of natural resource management issues in the region. There are indeed many questions, none of which has a simple or straightforward answer. While scientists are continuing to tackle these questions through ongoing research, forest managers make decisions each day about how to manage our changing forests, and they often must prioritize activities given scarce funds and incomplete information. In our Bark Beetle Management Workshop, we sought to bring scientists and forest managers together—along with a variety of other interested stakeholders—to explore management options, share ideas, and define a vision for the future of the West's forests. Our proceedings report the key management and research ideas. In the future, providing managers with the most up-to-date scientific findings on bark beetles and their impacts on forests will be an important role for universities in the region. Clearly, partnerships and collaborative efforts with other stakeholder groups working on the issues related to future forests, and who are listed at the end of this document, will be critical to these efforts as well.

Indy Burke
Director,
Environment and Natural Resources Program

Dan Tinker
Professor,
Department of Botany

Table of Contents

Executive Summary

The current and ongoing bark beetle epidemics involve multiple species of bark beetles and tree hosts and are impacting millions of acres of forests in the Intermountain West. These epidemics are also killing trees on a scale that is unprecedented in the area's recorded history. It is unclear if existing management approaches will be appropriate and/or effective in post-disturbance forests to achieve desired future forest conditions. In fact, even identifying short-term desired future forest conditions remains a challenge, given the magnitude of changes to the forest landscape.

To address these issues, the Ruckelshaus Institute of Environment and Natural Resources at the University of Wyoming invited over 50 forest resource managers, economists, ecologists, and other stakeholders to identify desired future forest conditions and management strategies that could help shape sustainable future forests in the West. The workshop focused on four major coniferous forest types (and the associated bark beetle species) that occur in Wyoming and Colorado, as well as many other regions of the Intermountain West.

Four forest types the workshop considered:

- Lodgepole pine (*Pinus contorta* var. *latifolia*)
- Engelmann spruce/subalpine fir (*Picea engelmannii/Abies lasiocarpa*)
- Douglas-fir (*Pseudotsuga menziesii*)
- Ponderosa pine (*Pinus ponderosa*)

During the workshop, participants were asked to outline desired future forest conditions in four categories: 1) forest structure and biodiversity; 2) fire and fuels management; 3) timber management; and 4) roadless areas, trails, and recreation management. The participants then discussed current bark beetle management practices that have been effective and those that have been tried but have not proved to be successful. Lastly, the breakout groups brainstormed innovative and "outside-the-box" management approaches for forests impacted by bark beetle outbreaks. The workshop concluded with attendees outlining future research and knowledge gaps that would be useful to address.

Workshop participants identified a number of successful management strategies, including stand density management, prescribed fire, and single-tree intensive practices (such as pheromone patches) in high value areas. Innovative management approaches that were identified included developing Commu-

Figure 1. The "red stage," which occurs ~1–5 years after bark-beetle attack. Photo by Josh King.

nity Wildlife Protection Plans, better educating stakeholders on natural fire regimes, employing adaptive management based on changing forest and climate conditions, and creating advisory boards that include citizen input for all national forests. Future research ideas included intensifying efforts to study trees with genetic resistance to bark beetles, additional studies of past insect epidemics, and sophisticated modeling efforts to predict future forest structure.

Because bark beetles do not heed political boundaries, successful partnerships among cooperative groups and agencies from around the region will be critical to manage beetle epidemics and post-disturbance forests. There are a number of groups conducting research and outreach across the West (such as the Colorado Forest Restoration Institute and the Western Bark Beetle Research Group) that can benefit from each others' experiences and advance our understanding of and responses to the current epidemics. In addition, scientists and managers in British Columbia—where mountain pine beetle infestation is more severe and advanced than that in the western United States—may have insights into what the future forests of the western U.S. could look like. Bridging efforts and sharing information will facilitate the wise use of limited financial resources and can advance our knowledge of how to manage changing forests.

Introduction

The current and ongoing bark beetle epidemics in the Intermountain West are the largest in recorded history. In Colorado and southeastern Wyoming alone, the U.S. Forest Service (USFS) estimates that mountain pine beetles (only one of several species of beetle impacting western forests) have impacted more than 900 miles of trail, 3,200 miles of road, and 21,000 acres of developed recreation sites across 3.6 million acres (USFS n.d.). Though the beetles are native to forest ecosystems, conditions of drought, warmer winters, and a forested landscape that contains an abundance of suitable trees for the beetles have created very favorable conditions for beetles to thrive. Forest managers are finding it difficult to keep up with rapidly shifting forest dynamics and safety concerns posed by millions of dead trees.

In 2010, the USFS spent $40 million in the Rocky Mountain Region to address public safety concerns and other management needs arising from bark beetle infestations. These funds were primarily put toward removing hazard trees from areas where they posed imminent danger, including campgrounds, roads, trails, and along power line corridors. If new funds become available, it is important for forest managers to evaluate a diversity of beetle management approaches to determine which have or have not been effective, and to identify new strategies that could address current and future bark beetle epidemics in the Intermountain West.

There is a growing body of bark beetle management practices and science developed from experiences that range from British Columbia to the southeastern United States. The bark beetle management workshop hosted by the Ruckelshaus Institute of Environment and Natural Resources sought to pool knowledge of Rocky Mountain West beetle epidemics by bringing together forest managers from different backgrounds and regions to discuss lessons learned and a way forward. Ideas that emerged from the forum are included in these proceedings.

Background

Several species of bark beetles have affected more than 63 million acres of forests in the western United States over the past decade, roughly 33 million acres of which are in the Intermountain West (Bentz 2010; Figure 2). While bark beetles are native to western forests, the extent and severity of the current bark beetle epidemics are historically unprecedented. The ecological, social, and economic factors of these current epidemics are complex, and managing beetle epidemics creates difficult choices for policymakers, resource managers, and an area's residents.

Bark beetle species and life histories

Multiple species of bark beetle are contributing to forest mortality across the Intermountain West, including mountain pine beetle (*Dendroctonus ponderosae*), spruce beetle (*Dendroctonus rufipennis*), Douglas-fir beetle (*Dendroctonus pseudotsugae*), fir engraver (*Scolytus ventralis*), western balsam bark beetle (*Dryocoetes confusus*), pine engraver (*Ips* spp.), and western pine beetle (*Dendroctonus brevicomis*; Figure 3). The mountain pine beetle, however, has been responsible for the majority of tree mortality in the current epidemic and is estimated to be responsible for tree mortality in 31 million acres of the Intermountain West as of 2009 (Bentz 2010).

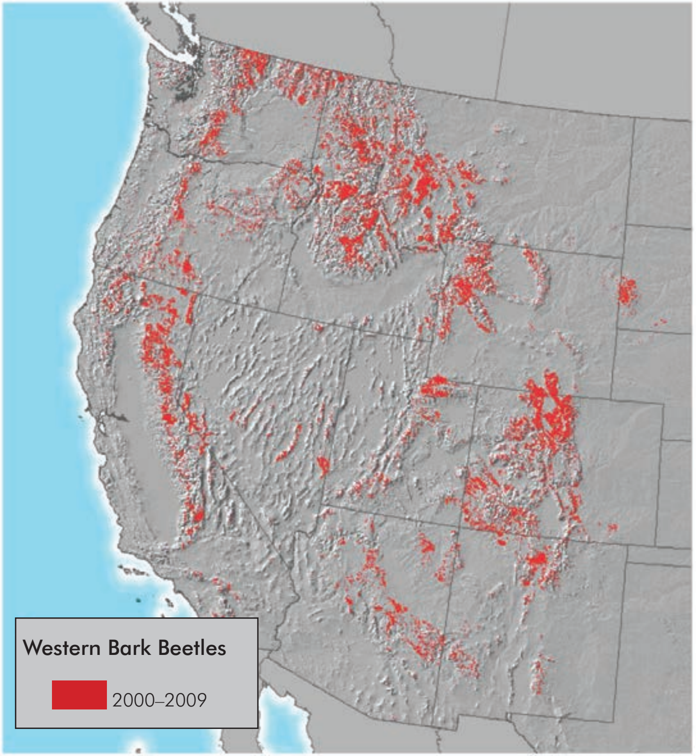

Figure 2. Bark beetle–impacted acres in the western U.S. (Bentz 2010; data from U.S. Forest Service Aerial Detection Surveys).

A snapshot of a bark beetle's lifecycle can be shown through following the mountain pine beetle. Mountain pine beetles begin their lifecycle by laying eggs beneath a tree's bark in late August. The eggs hatch within 7–10 days, becoming larvae. Larvae feed on the inner bark, or phloem, of a tree, forming galleries as they feed within the tree (Figure 4A). Between June and July the larvae reach full size and bore out a hollow room at the end of their feeding tunnel to pupate. The pupae reach adulthood around mid-August and will leave the tree in search of a new one. Adults seek out the strong smell of turpines (chemicals produced by trees) that indicate a forest of susceptible host trees. Female beetles release a pheromone when a suitable tree has been found, triggering other beetles to join them, causing a "mass attack" (Bentz et al. 2009). Mating occurs under the bark of the chosen tree, and the cycle begins again.

Except for emergence and dispersal, all phases of the mountain pine beetle's lifecycle occur beneath the bark of a tree. Though the length of reproductive cycle and other lifecycle details vary with beetle species and climate fluctuations, typically beetle eggs are laid and dispersal occurs in the late-summer/early-fall and the larval phase is during the winter. Some species of bark beetle complete reproductive cycles in less than one year, while others take up to two years (Halloin 2003).

Mountain pine beetles can occasionally overwhelm a tree by sheer number, particularly if the tree is weakened due to environmental conditions such as drought or disease. However, in most cases, tree mortality is caused by one of two species of fungi that the beetles carry and introduce into the tree. The two common fungal symbionts of the mountain pine beetle are *Grosmannia clavigera* and *Ophiostoma montium*. *Ophiostoma* spp., commonly called blue-stain fungus, leaves the gray-blue stain seen in beetle-killed wood (Figure 4B). Typically *G. clavigera* colonizes a disproportionately larger amount of phloem than the blue-stain fungus, but both species of fungi disrupt the water and nutrient transport ability of the tree (Halloin 2003; Nordahus 2009; Bleiker and Six 2009).

Most western forests have evolved with periodic bark beetle outbreaks and epidemics. Bark beetles help regulate nutrient cycling, ecological succession, forest structure, and distribution by altering size, age-class, and abundance of plant species (Fettig 2007). Historically, bark beetles and other disturbances created and maintained heterogeneous ecosystems that provided a measure of resistance and resiliency for forests. However, the relatively recent convergence of a warm and dry climate, forest succession, and management practices has created a forest structure conducive to bark beetle epidemics that fall outside historic ranges of variability.

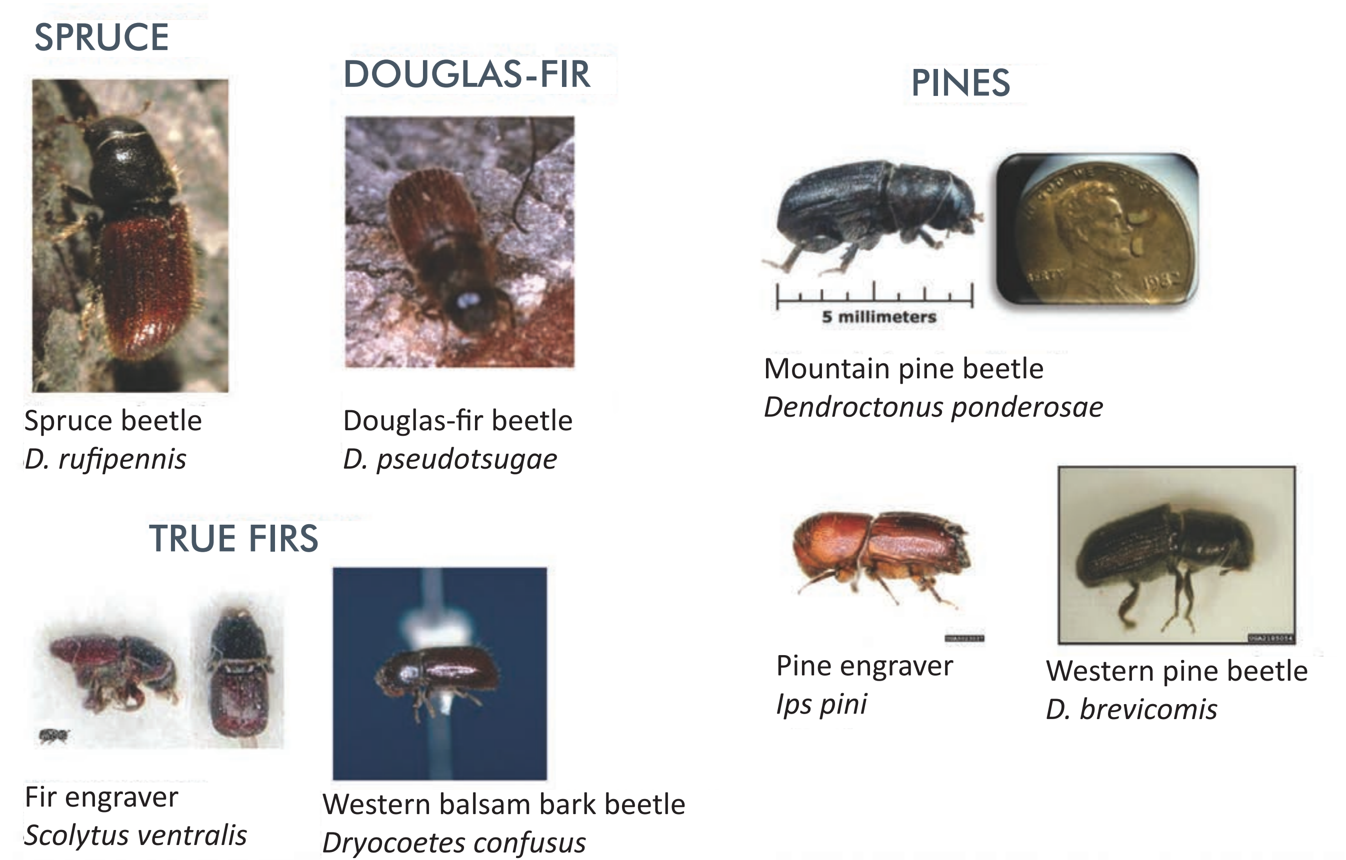

Figure 3. Bark beetles of the Intermountain West (Bentz 2010).

Contributing factors to the current epidemic

Forest composition and management

Multiple factors have influenced current forest structure and composition in the Intermountain West, and thus the recent beetle epidemic. Landscapes comprising large expanses of mature, homogenous forests with high tree density, basal area, and larger tree diameters are more susceptible to bark beetle attack, as they provide abundant inner bark (or phloem), which bark beetles use for food and breeding (see "Bark beetle species and life histories"; Fettig et al. 2007). For example, high-risk lodgepole pine tree stands are characterized as being 60–110 years old, greater than 7.5 inches diameter at breast height (DBH), and with a stand density of 750–1,500 trees per hectare (Fettig et al. 2007).

The current forest composition can be attributed to the past century (or more) of natural environmental conditions and disturbances, as well as past management decisions, including fire and timber policy. Many wildfires have been suppressed throughout the twentieth century, leading to denser stands of trees in a susceptible age category in some forest types, such as ponderosa pine, and leading to less diversity of age classes in other areas. Timber harvest practices of the late 1800s and early 1900s also contributed to more even-aged and even-sized stands that are now susceptible to beetles (Negron 1998; Fettig et al. 2007; Bentz et al. 2009).

Figure 4. A) Beetle galleries; B) Blue-stain fungus in lodgepole pine.

Climate conditions

Two climatic factors are likely interacting to facilitate the magnitude of the current epidemic: 1) drought-induced stress on host trees, which reduces defense mechanisms (Mattson and Haack 1987); and 2) warmer winter temperatures that increase overwinter survival of beetles and can speed up reproductive cycles in some species (Cole 1981; Bentz et al. 2009). Together, these two factors have created prime conditions that have resulted in the marked increase of bark beetle populations (Raffa et al. 2008). The bark beetles' tolerance to cold is dynamically dependent on the temperature regime experienced by a given species, so a simple low temperature threshold cannot fully explain the role of temperature in beetle survival (Bentz and Mullins 1999). However, when prolonged drought is coupled with increasingly shorter periods of severe cold and overall warmer winter temperatures, the likelihood of all bark beetle species' survival greatly increases (Bentz et al. 2010).

Consequences of the epidemic

Social and economic

Insect disturbances in forests can present serious complications for natural resource decision making and for relationships between stakeholders and managers (Flint et al. 2009). The current epidemics are causing considerable social and economic challenges for communities, businesses, and natural resource agencies throughout the Intermountain West. Thus far, forest managers have primarily focused resources on removing beetle-killed trees that pose immediate hazard from recreational areas and areas with infrastructure such as roads, campgrounds, and special-use areas. The increased resources needed to manage the affected sites can also strain agency budgets. In contrast to the conventional method of purchasers paying an agency to harvest trees on public land, the USFS has instead been issuing stewardship contracts to remove the trees. Stumpage value of beetle-killed trees currently is low in most areas, as U.S. lumber markets are depressed (Lipton 2010), with concomitant low demand from the ailing home construction industry. This low demand is compounded in areas of the Intermountain West that require long haul distances for beetle-killed trees to reach lumber markets.

Homeowners in affected forests have concerns about fire risk and declining property values resulting from loss of aesthetic value. The public's perception of the current epidemic varies from those who see it as an environmental disaster resulting in the complete loss of our forests, to those who see it as a natural process in forests and that they will eventually recover. The methods resource agencies use to respond to the epidemics can put considerable stress on relationships between managers and the public. Across the Intermountain West, public frustration has been expressed over what some see as government managers "not stopping the epidemic," implementing poor harvesting practices, and not replanting trees (Loomis 2011). However, such disturbances also create the potential for communities to work collectively and foster new relationships. This has happened in northcentral Colorado, where Summit and Routt Counties assembled beetle task forces with local residents, municipal governments, county commissioners, and state and federal agency representatives (Flint et al. 2009).

Forest ecology and species composition

Succession and disturbance are integral and natural processes of forest ecosystems, and they help shape forest composition, structure, and function (Progar et al. 2009). Indeed, the extent of tree mortality and disturbance caused by these beetle epidemics will likely create a new landscape that consists of a patchwork of forest with different ages, densities, species composition (Stone and Wolfe 1996), and successional stages (Progar et al. 2009). Healthy debate continues in the scientific community about forest recovery from beetle epidemics. Some research suggests that even with the severity and extent of current epidemics, beetle-killed forests will regenerate at a similar rate as other forests have in the past (Collins et al. 2010). Other research suggests that invasive species, the loss of dominant species, catastrophic fires, and other climatic changes produce much more severe consequences and will permanently alter the natural patterns of regeneration (Ellison et al. 2005). Regardless of regeneration patterns, the beetle-impacted forest systems will continue to face disturbances as they transition through beetle epidemics.

Wildfire

As a natural part of the disturbance regime in the forests of the Intermountain West, wildfire and bark beetles interact in many complicated ways. Because the current beetle epidemics are outside the range of historic variability in their size and severity, predictions related to future fire behavior in beetle-killed forests remain inconclusive. Scientists are continuing research projects to establish the impacts of beetle-killed trees on forest fires and to untangle how location, time since outbreak, and forest fuel structure will impact fire susceptibility and behavior (Jenkins et al. 2008).

While many people are concerned that forest fires will increase due to extensive stands of dead trees, some recent research has shown that in the short term, stands of mountain pine beetle–killed trees may actually reduce the likelihood of sustained active crown fires in lodgepole pine forests by reducing fuel loads in the canopy (Simard et al. 2011; Jenkins et al. 2008). It is also possible, however, that surface fires may increase as dead needles drop and dead trees start to fall to the ground and increase surface loads (Bentz 2010). Fires in these fuel structures are more resistant to control as fireline construction is slower. Both of these findings are related to the substantial change in fuel structure and amount due to beetle epidemics.

Figure 5. Wildfire in western Wyoming: recent research suggests lower risk of crown fire and higher risk of surface fire following a bark beetle epidemic. Photo courtesy of the Bureau of Land Management.

Hydrology

Bark beetle disturbances are expected to affect hydrologic processes across the Intermountain West; probable impacts include changes to snowpack levels, runoff rates, and evapotranspiration rates. Loss of forest canopy from beetle-killed trees can lead to greater ground accumulation of snow initially, but also impacts snowpack persistence and often ultimately leads to reduced snowpack (Bewley et al. 2010). With the loss of canopy, springtime snowmelt is likely to occur more quickly, as the snowpack has less shading from incoming solar radiation. This, in turn, can impact stream runoff characteristics (Bewley et al. 2010; Kaufmann et al. 2008). The extent that a watershed is impacted, however, depends on the type and composition of the forest, number of dead trees, and amount and type of precipitation the forest receives (Romme et al. 2006). More scientific research is needed to fully understand impacts to hydrologic processes that may occur during and after beetle outbreaks in a variety of forests (Kaufmann et al. 2008; Romme et al. 2006).

Workshop Objective and Organization

The primary objective of the two-day workshop was to define western forests with respect to current and desired future conditions and identify management strategies that reflect this new vision.

Because future forests will likely be very different from current forests for many decades to come, defining new desired future conditions is critical. The workshop's primary outcome was to develop a set of proposed desired future conditions that represented a broad range of forest management objectives, including, but not limited to, recreation, wildlife, fuels, and timber, and to couple these with an evaluation of current management practices and suggestions for new and novel approaches to forest stewardship.

The workshop was structured to have brief plenary sessions to introduce and summarize discussions and extensive breakout group discussions organized by forest type (lodgepole pine, Engelmann spruce/subalpine fir, Douglas-fir, and ponderosa pine). Each breakout group considered the same set of questions focused on desired future forest conditions, management approaches, and knowledge and research gaps for their assigned forest type.

See the workshop Web site (www.uwyo.edu/enr/ruckelshaus-institute/projects-and-events/bark-beetle-workshop-2010.html) for the full workshop agenda.

Desired Future Conditions

Participants in each breakout group were asked to identify a broad range of potential desired future forest conditions looking ahead to 2050 in four primary areas of forest management derived from the current Medicine Bow National Forest Plan: 1) forest structure and biodiversity; 2) fire and fuels; 3) timber management; and 4) roadless areas, trails, and recreation management. Each of the four groups developed an annotated set of reasonable and potentially achievable future forest conditions that follow current multiple-use forest management objectives and mandates. Common desired future conditions the groups identified were:

1. **Forest structure and biodiversity:** Forest structure should include a diversity of species composition and age-classes. Managing for biodiversity should provide conditions that promote species, genetic, and ecosystem diversity. Specific desired conditions in this category included:
    - **Landscape and stand diversity** with a mosaic of habitat types to boost resiliency. Based on the beetles' preference for mature trees and their pattern of spreading to surrounding trees, it is beneficial to maintain a variety of tree species and age-classes.
    - **Biodiversity**, which can be achieved by managing some areas for sensitive, threatened, and endangered species habitat, limiting invasive species, and maintaining habitat connectivity.
    - **Protection of ecosystem services,** or functions obtained from ecosystems that benefit society. Examples include: watershed services, wildlife habitat, carbon storage, erosion control, and cultural services such as recreational value.

2. **Fire and fuels:** Fires can help regenerate many forests and should be allowed to burn in appropriate areas, but managers typically need to most intensively manage forest fires in the wildland-urban interface (WUI). Specific desired conditions in this category included:

What are desired future conditions for Rocky Mountain forests in 2050?

- Forest structure and biodiversity
- Fire and fuels
- Timber management
- Roadless areas

- **Fuel conditions that provide for natural fire regimes.** Fire is a natural component of forest ecosystems and is essential for regeneration of some species. Lodgepole pine, ponderosa pine, and Douglas-fir forests typically experience a shorter fire return interval than spruce/fir forests.
- **Defensible space in the WUI.** Forests surrounding or adjacent to homes and communities need to be managed more intensively than other areas for wildfire prevention.

3. **Timber management:** Some areas should be managed with timber production as the highest priority for current and future timber economies. Specific desired conditions in this category included:
    - **An ecologically and economically sustainable timber supply** that benefits local economies and forest industries.
    - **Diverse species and size classes** that meet current and future timber demands and reduce the likelihood of future large-scale beetle epidemics.
    - **A variety of management methods** that meet site-specific and regional objectives. Each national forest develops its own forest plan based on management objectives and the landscape. As a result, different treatment methods need to be used to reach management goals.
4. **Roadless areas, trails, and recreation management:** Some areas should be managed to maintain roadless areas, trails, and recreation as the highest priority. These areas vary from motorized to non-motorized recreation, and from high- to low-use intensity. Specific desired conditions in this category included:
    - **Safety in developed recreation areas.** Falling beetle-killed trees create a safety concern, so priority should be given to hazard tree removal in those areas.
    - **A full spectrum of multiple-use recreation opportunities.** Public lands are managed for various recreational activities and each should be considered for resource allocation when considering the ongoing bark beetle epidemics.

Management Approaches

Workshop participants were then asked to create a list of management approaches that have been effective and appropriate during beetle epidemic conditions. They also created a similar list of approaches that have not been effective. Finally, the groups were asked to think creatively and discuss new and innovative management strategies that could maximize economic and ecological sustainability in post-disturbance forests and reduce bark beetle impacts at multiple scales.

For bark beetle management, what are:

- Existing, effective management approaches,
- Ineffective existing management approaches or potential concerns for management, and
- New, innovative, or untested management approaches?

Effective management approaches

Implementing prescribed burns and allowing wildfires to burn when feasible. Prescribed fires can reduce tree density and, in some cases, facilitate the regeneration of stands that are less susceptible to beetle infestation. Prescribed fires also can reduce fuel loads, specifically in the WUI. However, fires have the potential to weaken existing trees and increase probability of beetle attack.
Related literature: Jenkins et al. 2008; Elkin and Reid 2004; Schwik et al. 2006.

Managing for appropriate tree density. High tree density has been a critical factor for increased risk and severity of bark beetle attack. Thinning has been shown to reduce the risk of attack by increasing tree vigor from reduced competition for water and nutrients. Additionally, thinning can lead to greater air circulation that can disrupt beetle pheromone plumes by changing microclimates, such that beetles are more prone to freezing in the winter. However, caution needs to be given during thinning to minimize damage to residual trees, increasing risk of other insect/diseases, soil compaction, and potential for windthrow.
Related literature: Fettig et al. 2007; Thistle et al. 2004; Whitehead et al. 2004; Whitehead and Russo 2005; Hansen et al. 2010; Jonasova and Prach 2008.

Utilizing timber production methods with pre-commercial and commercial thinning for economic benefit. (See **Managing for appropriate tree density** above.) Additionally, pre-commercial thinning creates early monetary gains and increases tree growth rates.

Employing treatments to enhance age and tree species diversity. For instance, coniferous stands that include tree species such as aspen not only have more resilience but also enhance habitat for some wildlife species. Mechanical treatments can also provide suitable conditions for a variety of tree species of different age classes and in turn provide different types of habitat.

Allowing for natural processes to encourage tree age and species diversity. Forests have a natural level of diversity, with a mix of tree sizes, age, and species that could be more resistant and resilient to beetle attack.

Using intensive management—such as insecticide application, pheromone patches, and tree removal—in high value areas such as campgrounds, trailheads, and guard stations. Although costly, these treatments have proven successful in keeping some trees from being attacked.

Related literature: Haverty et al. 1998; Payne and Billings 1988; Billings and Upton 1993; Gillette and Munson 2009.

Figure 6. Forest thinning on Muddy Mountain, near Casper, Wyoming. Photo courtesy of the Bureau of Land Management.

Applying landscape-scale treatments, if possible. Although difficult to implement, management can be effective at the landscape level (as opposed to stand level), where appropriate, because of the way bark beetles disperse. This is easier to accomplish when one management agency has control over a large area.
Related literature: Fettig et al. 2007; Government of Alberta 2007.

Ensuring effective timing and coordination of treatments. Management treatments to reduce bark beetle impacts must be appropriate for the phenology of the bark beetles. Spraying should occur just prior to beetle flight.

Removing infested trees in high-risk stands early in the outbreak. Successful suppression of bark beetles has been recorded at small scales by removing infested trees, typically in spruce forests. This method has also proved to be effective in ponderosa pine forests in the Black Hills.
Related literature: Bentz and Munson 2000; Fettig et al. 2007.

Implementing post-disturbance, ecologically compatible salvage logging. Typically there is no ecological need to remove beetle-killed trees. However, if done for economic or social reasons, timber harvests executed with an eye toward ecological integrity can preserve snags for wildlife and reduce soil compaction and damage to residual trees.

Figure 7. Young lodgepole pine stands in the Medicine Bow National Forest infected with mountain pine beetle. Photo by Dan Tinker.

Considering road closures when and where appropriate. If costs or environmental factors such as erosion outweigh the need to reopen roads by removing hazard trees, closures may be appropriate.

Encouraging and facilitating place-based collaboration. Different forest types and geographic regions exhibit unique ecological processes, different management goals, and often involve multiple landowners, managers, and stakeholders. Focusing on a specific area as opposed to a broad area can be effective. Additionally, collaboration across property and political boundaries, such as private-public or multiple land agencies, increases the effectiveness of management approaches.

Utilizing published best management practices (BMPs), which include minimizing soil compaction and residual tree damage when salvage logging. BMPs provide information on the methods that can reduce environmental damage when implementing a management action. One example is guidelines on road planning, construction, drainage, maintenance, and closure for building forest access roads in a way that reduces nonpoint source pollution.

Ineffective management approaches/ potential concerns for management

Timber production in beetle-killed areas that are too wet, dry, or windy. Timber production in areas with these conditions can lead to soil damage, difficulties with tree regeneration or planting, and windthrow. Some of these effects can be mitigated by properly timing the harvest and designating skid trails.

Timber harvesting that creates high levels of site soil disturbance. Compaction of soils through timber harvest is of particular concern. These impacts can (and often are) mitigated by designating skid trails, following timing restrictions, and not using ground-based skidding in steep areas.

Management strategies that result in a lack of retention of understory, large woody debris, and snags. These forest traits provide for wildlife habitat, soil nutrients, hydrological benefits, biodiversity, and future trees.
Related literature: Klutsch et al. 2009.

Ineffective road closures. When roads are closed, proper and effective barricades need to be erected. Additionally, after timber harvests, some logging roads can be converted to cross-country ski trails or ATV trails. (See **Considering road closures when and where appropriate.)**

Inappropriate application of insecticides and pheromones. Overuse of insecticides has the potential to adversely affect aquatic ecosystems. If possible, application should be done just prior to beetle flight for the entire duration of a local epidemic, though insecticide application is usually effective for at least one year. Insecticide application is best done by licensed applicators following best practices.
Related literature: Grosman et al. 2010; Fettig et al. 2008.

Transport of beetle-infested wood from timber harvest, firewood, or other forest export activities. When needles are fading on infected trees, the trees most likely still host beetles.
Related literature: Halloin 2003.

Untimely or uncoordinated management responses. Ineffective management responses include not responding in a timely manner, perhaps because of a backlog in mandated processes, management that is fragmented among parties and agencies, and management that occurs only at the stand level.

Leaving dense stands in high-risk areas. (Refer to **Managing for appropriate tree density** above.)

Fire suppression resulting in dense stands and risk of increased fire intensity. Fire suppression may lead to denser stands, which are more susceptible to beetle attack. Further, when fires do ignite in dense stands, they could burn with higher intensity, which results in greater environmental and social consequences.

Management for even-age classes. A heterogeneous landscape is more resistant and resilient to bark beetle epidemics, and multiple tree species and age classes minimize the amount of beetle caused tree mortality. In contrast, managing for even-age classes can undermine trees' natural defenses.
Related literature: Taylor and Carroll 2004; Fettig et al. 2007.

New, innovative, or untested management approaches

Developing Community Wildfire Protection Plans (CWPP). The Healthy Forests Restoration Act provides incentives, such as funding for projects, and expedites USFS and Bureau of Land Management (BLM) fuel treatments for communities that have developed a CWPP, which identifies strategic sites and methods for fuel reduction.
Related literature: Communities Committee et al. 2004.

Creating advisory boards for every national forest. Assign public representatives and stakeholders to forest management planning boards to ensure meaningful public–private collaboration. This was done, among other places, in South Dakota with the Black Hills National Forest Advisory Board.

Creating opportunities for stakeholder-driven decision making and planning processes. Examples of this exist in Montana where a group of stakeholders worked to draft legislation for a national forest that includes restoration, timber harvest, wilderness protection, and other resources.
Related information: Tester 2011; www.owyheeinitiative.org; Flint et al. 2009.

Engaging in outreach to educate the public on insect outbreaks, natural fire regimes, disturbances, and desired forest conditions. There is broad public awareness about the current epidemic, yet there are a wide variety of views, ranging from accepting the epidemic as a natural process to believing it is an environmental disaster and fire hazard. Managers can do their jobs more effectively when there is community support that comes from an educated public. Outreach can include forums and social media or creation of citizen science programs.
Related literature: Flint et al. 2009.

Encouraging management decisions at the local and regional level. Forests vary among forest type, climate, public interests, and management objectives. As a result, broad management policies across large areas can fail. Decisions made at a local level can be more sustainable.

Facilitating better communication between managers and researchers. Agencies should make available a research "needs" list for more applied studies and invite scientific research to advance management projects and strategies.

Providing the best, most reliable science in a clear, comprehensive format for decision makers. The most current science is published in a broad array of peer-reviewed journals, targeted at specific audiences, and can differ in format, presenting challenges in locating all available resources. The Southern Rockies Fire Science Network is an example of an organization that facilitates collaboration and the dissemination of information among science practitioners and communities of science information users.

Recognizing and embracing new opportunities in management of dynamic, changing landscapes. With changing forest conditions, agencies have a great opportunity to shift management objectives such as stand-type conversion and road decommissioning and reclamation.

Remaining flexible to account for climate change in forest structure and biodiversity management strategies. Monitoring forest conditions and identifying thresholds of concern or trigger points will be important so that forest managers can utilize adaptive management techniques based on changing species composition and climate. It may also be beneficial for forest management strategies to incorporate projections of climate change on both forests and beetle population dynamics.

Identifying and protecting corridors between protected areas, areas with sensitive species, and other undeveloped backcountry areas where no action may be the preferred alternative.

Limiting management activities and resource expenditure in specific areas. Increased resource expenditure has already been required to deal with hazard trees in developed areas, such as the WUI, and additional money and human capital will be required in the future. Limiting focus to priority areas can be the most effective use of resources, while areas without development could be left to recover through natural processes.
Related literature: Shore et al. 2006.

Identifying areas where no action is a preferred alternative, accepting the effects of the beetle. This includes letting wildfires burn when they do not pose a threat to human life and property.

Creating incentives for the timber industry to develop and market post-disturbance products and help with forest restoration. The USFS is currently offering logging companies stewardship contracts to remove hazard trees. There could also be economic incentives for timber products, such as biomass material, wood pellets, or furniture lumber. In addition, there could be incentives or assistance for projects related to road improvements or removal, water culvert improvements, and biomass energy development or utilization.

Implementing disincentives for home development in WUI areas. Since more resources are required by land management agencies for protecting homes in the WUI, disincentives should be put in place to discourage people from building in areas with high fire risk.

Implementing firewood-cutting regulations and enforce them. Transportation of beetle-infested firewood can spread beetles to new areas.

Implementing treatments that emulate natural forest processes. Such treatments must be specific to forest type and region.

Focusing on regeneration. Smaller tree saplings and seedlings have been much less affected by beetle outbreaks, and all studies have shown some level of post-disturbance regeneration of seedlings and saplings, which at most sites will adequately provide for forest regeneration. However, differences occur by forest type, level of overstory mortality, and site and regional conditions.

Related literature: Nigh et al. 2008; Diskin et al. 2011; Aoki et al. 2011.

Figure 8. A pitch tube, a tree's main defense to repel bark beetles as they begin to bore into the bark. Photo by Josh King.

Research and Knowledge Gaps

Following the discussion on desired future conditions and management approaches, workshop participants created a list of research or knowledge gaps that were viewed as hindering the development of adaptive management strategies for the: 1) prevention and suppression of bark beetle epidemics at multiple scales, and 2) restoration of ecosystems following widespread forest disturbances in the Intermountain West caused by bark beetles. Research questions that arose from this discussion include:

> What are the research and knowledge gaps that are hindering the development of adaptive management strategies?

Which forest characteristics or other factors are best suited to minimize beetle spread and impact, and what are the outbreak patterns at different scales? Research has been done over short time periods and on small scales, in even-aged stands, and on tree species most valuable for timber. Information gaps exist outside of these parameters.
Related literature: Negron et al. 2008; Ayres and Lombardero 2000.

What are the long-term effects and effectiveness of various types of proactive management treatments to prevent bark beetle epidemics? Many past treatments have tried to reduce beetle attack at smaller scales, and thinning has been shown to be useful in some forest types. The current epidemic presents an opportunity to compare how forests respond to various treatments over larger scales.

What have we learned from past epidemics or epidemics that are more advanced than those in the Intermountain West? British Columbia's beetle epidemic predates that in the Intermountain West. What are some of the outcomes of the management decisions in Canadian forests?
Related literature: Brown et al. 2010; Yan et al. 2005; Romme et al. 1986.

What current technologies are available to address management issues and how can they be utilized fully? How accurate is remote sensing technology for monitoring the extent of bark beetle–caused tree mortality? How effective are applications to defend trees from beetle attacks, and what new technology can be used?

Do surviving trees possess genetic resistance to bark beetles? Why do some trees or pockets of trees survive outbreaks? Limited research has been done in this area, and the research that has been done shows some genetic resistance in lodgepole pine across different areas of British Columbia. The seeds of these trees can potentially be used for replanting efforts.
Related literature: Yanchuk et al. 2007.

How are genetic adaptations by bark beetles evolving over time and in different regions? How will bark beetles adapt to environmental changes such as climate, changing vegetation distribution patterns, and preventative treatments such as chemical applications?
Related literature: Monk et al. 2007.

How will climate change shift tree species' range, forest succession, beetle interactions, and fire patterns, and how can we best manage in response? Temperature increases and precipitation reduction during the growing season can reduce tree vigor, leaving trees more susceptible to beetle attack. Ranges for a wide variety of species, including subapline fir, ponderosa pine, lodgepole pine, and Douglas-fir, are predicted to change; some may actually shrink while others may move northward. Initial models have shown that mountain pine beetle and spruce beetle ranges are predicted to grow and the beetles may develop greater reproductive and survival rates.
Related literature: Mckenney et al. 2007; Bentz et al. 2010; Veblen et al. 1991.

What will future forest structure and composition look like? In order to make informed management decisions, managers must know what future forests will look like through predictive modeling and monitoring. Forecasting is needed for tree survival rates, advance regeneration, tree recruitment, and tree/snag fall. Predicting treefall rates will also assist in planning future hazard tree removal.
Related literature: Klutsch et al. 2009; Diskin et al. 2011.

How will fire behavior change during and after a beetle epidemic? While recent literature suggests decreases in active crown fires and increases in surface fires, fire behavior is complex and varies with weather conditions, region, and forest type. Many different factors also determine the severity of the fire and whether or not a crown or surface fire is more likely to occur.
Related literature: Jenkins et al. 2008; Simard et al. 2011; Ayres and Lombardero 2000.

How can managers balance the use of prescribed fires with "let it burn" strategies to maximize ecological integrity and socioeconomic vitality? And, **do prescribed fires alter stand**

susceptibility to bark beetle attacks? Wildfires are a natural and essential component to western forests, and small fires may reduce the risk of larger, catastrophic wildfires. As home construction in forested landscapes has increased, public acceptance for allowing wildfires to burn continues to be low. Managers need more information on how to most effectively manage fires while maximizing forest function and accounting for various forest uses and conditions, such as bark beetle outbreaks.

How are wildlife species going to respond to changing habitat? During and immediately after bark beetle outbreaks, some bird and small mammal populations are expected to increase or decrease. However, information on the long-term response of wildlife, included species of special conservation concern, is limited. Further, wildlife responses to post-disturbance salvage logging are largely unknown.
Related literature: Matsuoka and Handel 2007; Steventon and Daust 2009.

What stress will bark beetle epidemics have on ecological functions? Forests filtrate and regulate water, and the loss of live trees can impact hydrologic patterns. Impacts can include changes to evapotranspiration, snow accumulation and rate of melt-off, erosion control, and fish habitat. Questions that need to be addressed include: will more runoff occur in affected stands? How will water quality and quantity change in local areas? Will air quality be impacted?

What were the historic ranges of various forest types, their composition and structure, and disturbance regimes? Adding to our understanding of forest conditions at different historical time periods will continue to enhance resolution of baseline data and information on the changes that have occurred over time. This information can provide important data for management decisions.
Related literature: Tinker et al. 2003; Swetnam et al. 1999; Veblen 2003.

What are sustainable biomass utilization options? Feasibility studies are needed to better determine the potential for using dead trees as biomass to produce energy.

What are the social impacts of the beetle epidemic? How will forest recreation change after the current epidemic? Will forest use decrease if a forest is visually less attractive? Past epidemics have created tension between forest managers and the public. How can that be avoided in the future?
Related literature: Flint et al. 2009.

What funding outlets are available for management, research, monitoring, and related activities? Filling knowledge gaps and managing forests during and after the epidemic is expensive. Consistent and long-term funding will be needed.

How will current policies point us toward desired future conditions? Current federal, state, and local laws will, in part, determine what our future forests look like. Policies such as the Healthy Forest Restoration Act directly impact management of beetle-killed forests. Are these policies effectively working toward desired future forest conditions?

What are the most effective ways to make research accessible to the public? See **Engaging in outreach to educate the public** above. Are there additional, more effective ways that have not yet been tried?

What are the knowledge gaps identified by the public and policymakers? Public and political support is critical to successful management. Understanding what kinds of information the public wants and needs will provide a framework for communication between the public and forest managers.
Related literature: Flint et al. 2009.

Figure 9. University of Wyoming Environment and Natural Resources students on a field trip in the Medicine Bow National Forest.

Where Do We Go From Here?

Ongoing efforts of government agencies in the United States and Canada and other self-organizing entities have the possibility to advance scientific research, management practices, and public outreach for the bark beetle epidemic. Though many of these groups are making advances on their own, partnerships among cooperative groups and agencies will strengthen our knowledge base and be critical for managing beetle epidemics.

> Partnerships among cooperative groups and agencies will strengthen our knowledge base and be critical to more effectively manage beetle epidemics.

Collaboration among organizations

Collaboratives and organizations working to advance science and management of bark beetles that may have some overlap or synergistic potential include:

Colorado Forest Restoration Institute (CFRI)
Mission: To enhance the capacities of Colorado's land managers, landowners, collaborative forest health partnerships, and communities to mitigate forest wildfire risk to communities and improve forest resilience.

- Assists with collaborative monitoring and adaptive management, information synthesis and outreach, enhancing wood biomass utilization, and collaboration assistance and support.
- Produces reports and hosts conferences that advance knowledge of forest management.

Colorado Bark Beetle Cooperative (CBBC)
Mission: To address the environmental, social, and economic impacts of bark beetles on high-altitude forests through place-based collaboration.

- Steering committee is composed of federal, state, and local government representatives and representatives of utility and water providers, the wood products industry, conservation groups, and public interest groups.
- Focuses on high-altitude lodgepole pine forests in Colorado.
- Promotes public outreach, involvement of private industry, and pre-disaster mitigation and emergency preparedness.

Joint Fire Science Program (JFSP)
Mission: To provide credible research tailored to the needs of fire and fuel managers; develop focused, strategic lines of new research; solicit proposals from scientists; and focus on science delivery when research is completed.

- Promotes science discoveries that help fire and resource managers understand the complexities of wildland fire and fuels management.
- Delivers information to the public about forest and fire issues and specifically tailors information on wildland fire research to policy makers and fire managers.
- Convened by the U.S. Forest Service.

Northern Front Range Mountain Pine Beetle Working Group
Mission: To provide a centralized source for mountain pine beetle–related information to the public.

- Consists of local government agencies coordinating efforts during the mountain pine beetle epidemic in Colorado's Front Range.

Southern Rockies Fire Science Network (SRFSN)
Mission: To facilitate collaboration and the dissemination of information among science practitioners and communities of science information users. The SRFSN includes Colorado and south-central Wyoming.

- Brings together forest scientists and managers to educate the public primarily about fire science and management. It does this through field trips, Web site content and webinars, field visits, and science workshops.
- Funded by the Joint Fire Science Program.

USDA Forest Service (USFS) Rocky Mountain Region
Mission: To sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations.

- Provides information for the public on bark beetle science, safety in beetle-killed forests, and forest management for its region.
- Mitigates impacts of beetles in the Rocky Mountain Region, primarily in high-risk areas such as campgrounds or along roads.
- Partners with many other groups (including the Colorado Bark Beetle Cooperative and Northern Front Range Pine Beetle Working Group) on bark beetle education.

USDA Forest Service (USFS) Rocky Mountain Research Station (RMRS)
Mission: To develop and deliver scientific knowledge and technology that will help sustain forests, rangelands, and grasslands.

- Research priorities include understanding landscape-scale effects of bark beetles, sorting out the complicated interactions between bark beetles and forest fires, assessing the effects of climate change on beetle biology and outbreaks, and mitigating tree mortality.
- Primarily produces peer-reviewed, scientific publications on these topics.

Western Bark Beetle Research Group (WBBRG)
Mission: To serve as an umbrella organization that fosters communication and enriches scientific interactions among Forest Service bark beetle researchers in the western United States.

- Primary charge is to work with partners and stakeholders to identify western bark beetle research priorities and enhance communication and service to partners and stakeholders.
- Members produce scientific publications and give presentations across the United States.

Wyoming State Forestry Division
Mission: To manage, preserve, and enhance Wyoming's forested state lands to provide a sustainable forest resource base, quality recreation opportunities, and protection of state trust lands from insects, diseases, and wildfire.

- Plays an active role in addressing environmental and social concerns on state, private, federal, and municipal properties in Wyoming by participating in the USFS National Forest Health Monitoring (FHM) program.
- Engages in aerial surveys to document forest change events.
- Provides financial and technical assistance to rural fire departments and interagency cooperators for all aspects of fire management including prevention, preparedness, training, equipping, organizing, mobilization, reporting, detection, and prescribed fire.

Appendix A details the contact information for each of these organizations.

International collaboration

Canadian scientists and managers are also a good source for knowledge sharing and collaboration. The bark beetle epidemic in British Columbia is farther ahead than that in the western United States, and parts of Canada may provide a snapshot of what the West could look like in the future. A strategy that is undertaken in Canada not yet implemented in the United States, for example, is establishment of Emergency Bark Beetle Management Areas (EBBMAs) and associated strategic planning maps. EBBMA designation enables aggressive action in outbreak areas. British Columbia also has a regional regulation (B.C. Reg. 286/2001) that defines the parameters and guidelines for bark beetle management.

References

Aoki, C.F., W.H. Romme, and M.E. Rocca. 2011. Lodgepole pine seed germination following tree death from mountain pine beetle attack in Colorado, USA. *The American Midland Naturalist* 165: 446–451.

Arienti, M.C, S.G. Cumming, M.A. Krawchuk, and S. Boutin. 2009. Road network density correlated with increased lightning fire incidence in the Canadian western boreal forest. *International Journal of Wildland Fire* 18: 970–982.

Ayres, M.P., and M.J. Lombardero. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. *The Science of the Total Environment* 262: 263–286.

Bentz, B.J. 2010. Bark Beetles in the Intermountain West: Who, Where, and Why. Presentation at the Bark Beetles in the Intermountain West Workshop, October 4–5, Laramie, Wyoming.

Bentz, B.J., and D.E. Mullins. 1999. Ecology of mountain pine beetle (*Coleoptera scolytidae*) cold hardening in the Intermountain West. *Physiological and Chemical Ecology* 28: 577–587.

Bentz, B.J., and A.S. Munson. 2000. Spruce beetle population suppression in northern Utah. *Western Journal of Applied Forestry* 15: 122–128.

Bentz, B.J., J. Regniere, C.J. Fettig, E.M. Hansen, J.L. Hayes, J.A. Hicke, R.G. Kelsey, J.F. Negron, and S.J. Seybold. 2010. Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. *BioScience* 60: 602–613.

Bentz, B., J. Logan, J. MacMahon, C. Allen, et al. 2009. *Bark beetle outbreaks in Western North America: Causes and consequences.* Chicago, IL: University of Utah Press. 42 p.

Berg, E.E., J.D. Henry, C.L. Fastie, A.D. De Volder, and S.M. Matsuoka. 2006. Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to summer temperatures and regional differences in disturbance regimes. *Forest Ecology and Management* 227: 219–232.

Bewley, D., Y. Alila, and A. Varhola. 2010. Variability of snow water equivalent and snow energetics across a large catchment subject to mountain pine beetle infestation and rapid salvage logging. *Journal of Hydrology* 388: 464–479.

Billings, R.F., and W.W. Upton. 1993. Effectiveness of synthetic behavioral chemicals for manipulation and control of southern pine beetle infestations in east Texas. In *Proceedings of the Seventh Biennial Silvicultural Research Conference*, November 17–19, 1992, Mobile, Alabama: 555–563.

Bleiker, K.P., and D.L. Six. 2009. Competition and coexistence in a multi-partner mutualism: Interactions between two fungal symbionts of the mountain pine beetle in beetle-attacked trees. *Microbial Ecology* 57: 191–202.

Brown. M., T.A. Black, Z. Nesic, V.N. Foord, D.L. Spittlehouse, and A.L. Fredeen. 2010. Impact of mountain pine beetle on the net ecosystem production of lodgepole pine stands in British Columbia. *Agriculture and Forest Meteorology* 150: 254–264.

Cole, W.E. 1981. Some risks and causes of mortality in mountain pine beetle populations: a long-term analysis. *Researches on Population Ecology* 23: 114–116.
Collins, B.J., C.C. Rhoades, J. Underhill, and R.M. Hubbard. 2010. Post-harvest seedling recruitment following mountain pine beetle infestation of Colorado lodgepole pine stands: A comparison using historic survey records. *Canadian Journal of Forest Research* 40: 2452–2456.
Communities Committee, National Association of Counties, National Association of State Foresters, Society of American Foresters, and Western Governors' Association. 2004. Preparing a Community Wildlife Protection Plan: A handbook for wildland-urban interface communities (March). Online at: http://www.communitiescommittee.org/pdfs/cwpphandbook.pdf.
Davison, J. 1996. Livestock grazing in wildland fuel management programs. *Rangelands* 18: 242–245.
Diskin, M., M.E. Rocca, K.N. Nelson, C.F. Aoki, and W.H. Romme. 2011. Forest development trajectories in mountain pine beetle disturbed forests of Rocky Mountain National Park, Colorado. *Canadian Journal of Forest Research* 41: 782–792.
Dunn, D., and J.P. Crutchfield. 2009. Entomogenic climate change: Insect bioacoustics and future forest ecology. *Leonardo* 42: 239–244.
Elkin, C.E., and M.L. Reid. 2004. Attack and reproductive success of mountain pine beetles (Coleoptera: Scolytidae) in fire-damaged lodgepole pines. *Environmental Entomology* 33: 1070–1080.
Ellison, A.M., M.S. Bank, B.D. Clinton, E.A. Colburn, C.R. Ford, D.R. Foster, B.D. Kloeppel, J.D. Knoepp, G.M. Lovett, D.A. Orwig, N.L. Rodenhouse, W.V. Sobczak, K.A. Stinson, J.K. Stone, C.M. Swan, J.Thompson, B. Holle, and J.R. Webster. 2005. Loss of foundation species: Consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment* 3: 479–486.
Fettig, C.J., K.D. Klepzig, R.F. Billings, A.S. Munson, T.E. Nebeker, J.F. Negron, and J.T. Nowak. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. *Forest Ecology and Management* 238: 24–53.
Fettig, C.J., A.S. Munson, S.R. McKelvey, P.B. Bush, and R.R. Borys. 2008. Spray deposition from ground-based applications of carbaryl to protect individual trees from bark beetle attack. *Journal of Environmental Quality* 37(3): 1170–1179.
Flint, C., B. McFarlane, and M. Müller. 2009. Human dimensions of forest disturbance by insects: an international synthesis. *Environmental Management* 43: 1174–1186.
Gillette, N.E., and A.S. Munson. 2009. Semiochemical sabotage: Behavioral chemicals for protection of western conifers from bark beetles. *In* J.L. Hayes and J.E. Lundquist, eds. *The Western Bark Beetle Research Group: A Unique Collaboration with Forest Health Protection. Proceedings of a symposium at the 2007 Society of American Foresters Conference*, October 23–28, 2007, Portland, Oregon.

Government of Alberta. 2007. Mountain pine beetle management strategy. Edmonton, Alberta (December). Available at: http://www.mpb.alberta.ca/Files/MPB_man_strategy.pdf.

Grosman, D.M, C.J. Fettig, C.L. Jorgensen, and A.S. Munson. 2010. Effectiveness of two systematic insecticides for protecting western conifers from mortality due to bark beetle attack. *Western Journal of Applied Forestry* 25(4): 181–185.

Halloin, L. 2003. *Bark beetles of the Intermountain West.* Washington Department of Natural Resources (18 March).

Hansen, E.M., J.F. Negron, A.S. Munson, and J.A. Anhold. 2010. A retrospective assessment of partial cutting to reduce spruce beetle-caused mortality in the southern Rocky Mountains. *Western Journal of Applied Forestry* 25(2): 81–87.

Haverty, M.I., P.J. Shea, J.T. Hoffman, J.M. Wenz, and K.E. Gibson. 1998. Effectiveness of Esfenvalerate, Cyfluthrin, and Carbaryl in protecting individual lodgepole pines and ponderosa pines from attack by *Dendroctonus Spp.* RP-PSW-237. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, California, 12 p.

Jenkins, M.J., E. Hebertson, W. Page, and C.A. Jorgensen. 2008. Bark beetles, fuels, fires and implications for forest management in the Intermountain West. *Forest Ecology and Management* 254: 16–34.

Jonasova, M., and K. Prach. 2008. The influence of bark beetle outbreak vs. salvage logging on ground layer vegetation in Central European mountain spruce forests. *Biological Conservation* 141: 1525–1535.

Kaufmann, M.R., et al. 2008. The status of our scientific understanding of lodgepole pine and mountain pine beetles—a focus on forest ecology and fire behavior. The Nature Conservancy, Arlington, Virginia. GFI technical report 2008-2.

Klutsch, J.G., J.F. Negron, S.L. Costello, C.C. Rhoades, D.R. West, J. Popp, and R. Caissie. 2009. Stand characteristics and downed woody debris accumulations associated with a mountain pine beetle (*Dendroctonus ponderosae Hopkins*) outbreak in Colorado. *Forest Ecology and Management* 258: 641–649.

Lipton, J. 2010. What the timber market is telling us. *Minyanville*. Available online at: http://www.minyanville.com/businessmarkets/articles/commodities-lumber-homebuilders-housing-market-home/2/3/2010/id/26678.

Loomis, B. 2011. Beetles gnawing through Utah, West leaving trail of dying trees in their wake. *The Salt Lake Tribune* (28 September).

Matsuoka, S.M., and C.M. Handel. 2007. Nesting ecology of boreal forest birds following a massive outbreak of spruce beetles. *Journal of Wildlife Management* 71: 51–63.

Mattson, W.J., and R.A. Haack. 1987. The role of drought in outbreaks of plant-eating insects. *Bioscience* 37: 110–118.

McKenney D.W., J.H. Pedlar, K. Lawrence, K. Campbell, and M.F. Hutchinson. 2007. Potential impacts of climate change on the distribution of North American trees. *BioScience* 57: 939–948.

Negron, J. 1998. Probability of infestation and extent of mortality associated with the Douglas-fir beetle in the Colorado Front Range. *Forest Ecology Management* 107: 71–85.

Negron, J.F., B.J. Bentz, C.J. Fettig, N. Gillette, E.M. Hansen, J.L. Hays, R.G. Kelsey, J.E. Lundquist, A.M. Lynch, R.A. Progar, and S.J. Seybold. 2008. U.S. Forest Service bark beetle research in the western United States: Looking toward the future. *Journal of Forestry* 106: 325–331.

Nigh, G.D., J.A. Antos, and R. Parish. 2008. Density and distribution of advance regeneration in mountain pine beetle killed lodgepole pine stands of the Montane Spruce zone of southern British Columbia. *Canadian Journal of Forest Research* 38: 2826–2836.

Payne, T.L., and R.F. Billings. 1988. Effect of pheromone and pheromone plus tree cutting on suppression of southern pine beetle infestations. *In* T.L. Payne and H. Saarenmaa, eds. *Integrated Control of Scolytid Bark Beetles. Proceedings XVII International Congress of Entomology*, Canada, Vancouver, British Columbia: 267–273.

Progar, R.A., A. Eglitis, and J.E. Lundquist. 2009. Some ecological, economic, and social consequences of bark beetle infestations. *In* H.L Hayes and J.E. Lundquist, eds. *The Western Bark Beetle Research Group: A Unique Collaboration with Forest Health Protection.* USDA Pacific Northwest Research Station.

Raffa, K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner, and W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. *Bioscience* 58(6): 501–517.

Romme, W.H., J. Clement, J. Hicke, D. Kulakowski, L.H. MacDonald, T.L Schoennagel, and T.T. Veblen. 2006. Recent forest insect outbreaks and fire risk in Colorado forests: A brief synthesis of relevant research. Fort Collins, CO: Colorado Forest Restoration Institute.

Romme, W.H., D.H. Knight, and J.B. Yavitt. 1986. Mountain pine beetle outbreaks in the Rocky Mountains: Regulators of primary productivity? *The American Naturalist* 127: 484–494.

Schwik, D.W., E.E. Knapp, S.M. Ferrenberg, J.E. Keeley, and A.C. Caprio. 2006. Tree mortality from fire and bark beetles following early and late season prescribed fires in a Sierra Nevada mixed-conifer forest. *Forest Ecology Management* 232: 36–45.

Shore, T.L., L. Safranyik, B.C. Hawkes, and S.W. Taylor. 2006. Effects of the mountain pine beetle on lodgepole pine stand structure and dynamics. *In* L. Safranyik and B. Wilson, eds. *The Mountain Pine Beetle A Synthesis of Biology, Management, and Impacts on Lodgepole Pine.* Natural Resources Canada, Canadian Forest Service, Victoria, British Columbia: 95–114.

Simard, M., W.H. Romme, J.M. Griffin, and M.G. Turner. 2011. Do mountain pine beetle outbreaks change the probability of active crown fire in lodgepole pine forests? *Ecological Monographs* 81(1): 3–24.

Steventon J.D., and D.K. Daust. 2009. Management strategies for a large-scale mountain pine beetle outbreak: Modeling impacts on American martens. *Forest Ecology and Management* 257: 1976–1985.

Stone, W.E., and M. L. Wolfe. 1996. Response of understory vegetation to variable tree mortality following a mountain pine beetle epidemic in lodgepole pine stands in northern Utah. *Vegetatio* 122: 1–12.

Swetnam, T.W., C.D. Allen, and J.L. Betancourt. 1999. Applied historical ecology: Using the past to manage the future. *Ecological Applications* 9(4): 1189–1206.

Taylor, S., and A. Carroll. 2004. Disturbance, forest age, and mountain pine beetle outbreak dynamics in BC: A historical perspective. *In* T.L. Shore, J.E. Brooks, and J.E. Stone, eds., *Mountain Pine Beetle Symposium: Challenges and Solutions,* October 30–31, 2003, Kelowna, British Columbia, Canada, Report BC-X-399, Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia: 41–51.

Tester, J. 2011. Forest Jobs and Recreation Act. Online at: http://tester.senate.gov/Legislation/foresthome.cfm.

Tinker, D.B., W.H. Romme, and D.G. Despain. 2003. Historic range of variability in landscape structure in subalpine forests of the Greater Yellowstone Area, USA. *Landscape Ecology* 18(4): 427–439.

Thistle, H.W., H. Peterson, G. Allwine, B.K. Lamb, T. Strand, E.H. Holsten, and P.J. Shea. 2004. Surrogate pheromone plumes in three forest trunk spaces: composite statistics and case studies. *Forest Science* 50: 610–625.

U.S. Forest Service. n.d. Bark Beetle Management. Online at: http://www.fs.usda.gov/wps/portal/fsinternet/!ut/p/c4/04_SB8K8xLLM9MSSzPy8xBz9CP0os3gjAwhwtDDw9_AI8zPwhQoY6BdkOyoCAPkATlA!/?ss=110299&navtype=BROWSEBYSUBJECT&cid=null&navid=131000000000000&pnavid=null&position=BROWSEBYSUBJECT&ttype=main&pname=Rocky%20Mtn.%20Bark%20Beetle-%20Bark%20Beetle%20Management.

Veblen, T.T. 2003. Historic range of vulnerability of mountain forest ecosystems: Concepts and applications. *Forestry Chronicle* 79(2): 223–226.

Veblen, T.T., K.S. Hadley, M.S. Reid, and A.J. Rebertus. 1991. The response of subalpine forests to spruce beetle outbreak in Colorado. *Ecological Society of America* 72: 213–231.

Whitehead, R.J., and G.L. Russo. 2005. "Beetle-proofed" lodgepole pine stands in interior British Columbia have less damage from mountain pine beetle. Report BC-X-402. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia. 17 p.

Whitehead, R.J., L. Safranyik, G. Russo, T.L. Shore, and A.L. Carroll. 2004. Silviculture to reduce landscape and stand susceptibility to the mountain pine beetle. *In* T.L. Shore, J.E. Brooks, and J.E. Stone, eds. *Mountain Pine Beetle Symposium: Challenges and Solutions,* October 30–31, 2003, Kelowna, British Columbia, Canada, Report BC-X-399, Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia: 233–244.

Yan, Z., J. Sun, O. Don, and Z. Zhang. 2005. The red turpentine beetle, *Dendroctonus valens* LeConte (Scolytidae): An exotic invasive pest of pine in China. *Biodiversity and Conservation* 14: 1735–1760.

Yanchuk, A.D., J.C. Murphy, and K.F. Wallin. 2008. Evaluation of genetic variation of attack and resistance in lodgepole pine in the early stages of a mountain pine beetle outbreak. *Tree Genetics & Genomes* 4(2): 171–180.

Appendix A: Contact Information for Organizations Involved in Bark Beetle Science or Outreach

Organization	Contact	Web site
Colorado Forest Restoration Institute (CFRI)	(970) 491-1900 tony.cheng@colostate.edu	http://warnercnr.colostate.edu/cfri-home
Colorado Bark Beetle Cooperative (CBBC)	(970) 547-7121 acobbcbbc@gmail.com	www.nwccog.org/index.php/programs/rural-resort-region/cbbc
Joint Fire Science Program (JFSP)	(208) 387-5349 jcissel@blm.gov	www.firescience.gov
Northern Front Range Mountain Pine Beetle Working Group	(970) 295-6676 machambers@fs.fed.us	www.frontrangepinebeetle.org
Southern Rockies Fire Science Network (SRFSN)	(720) 974-7004 mkram@tnc.org	www.srmeconsortium.org
USDA Forest Service (USFS) Rocky Mountain Region	(303) 275-5350	www.fs.fed.us
USDA Forest Service (USFS) Rocky Mountain Research Station (RMRS)	(970) 498-1252 jnegron@fs.fed.us	www.fs.fed.us/rmrs/bark-beetle
Western Bark Beetle Research Group (WBBRG)	bbentz@fs.fed.us	www.usu.edu/beetle/wbbrg_bark_beetle.htm
Wyoming State Forestry Division	(307) 777-7586 forestry@wyo.gov	http://lands.state.wy.us/index.php?option=com_content&view=article&id=334&Itemid=58

Workshop Attendees

Cindy Allen	*Bureau of Land Management*
Mike Babler	*The Nature Conservancy*
Jerry Barker	*Walsh Environmental*
Barbara Bentz	*U.S. Forest Service*
Indy Burke	*University of Wyoming*
Gretchen Cross	*Private forester*
Phil Cruz	*U.S. Forest Service*
Steve Currey	*U.S. Forest Service*
Christopher Dahl	*National Park Service*
Joseph Duda	*Colorado State Forest Service*
Carson Engelskirger	*Black Hills Forest Resource Association*
Tom Florich	*U.S. Forest Service*
Lisa Gerloff	*University of Montana*
Jim Gibson	*U.S. Forest Service*
Timothy Gill	*U.S. Forest Service*
Jake Goheen	*University of Wyoming*
Bill Haagenson	*Wyoming State Forestry Division*
John Hart	*Hartwood Natural Resource Consultants*
Elizabeth Hebertson	*U.S. Forest Service*
George Jones	*University of Wyoming*
Lori Kayes	*University of Wyoming*
Les Koch	*Wyoming State Forestry Division*
Timothy Kramer	*Bureau of Land Management*
John Lundquist	*U.S. Forest Service*
Robert Means	*Bureau of Land Management*
David Morris	*University of Montana*
Kelly Mumm	*U.S. Forest Service*
Jim Myers	*U.S. Forest Service*
Nic Ondrejka	*U.S. Forest Service*
Emily Parsons	*TigerTree Land Management, Inc.*
Adrienne Pilmanis	*Bureau of Land Management*
Claudia Regan	*U.S. Forest Service*
Diane Ritschard	*U.S. Forest Service*
David Roberts	*Montana State University*
Frank Romero	*U.S. Forest Service*
Jeff Smith	*TigerTree Land Management, Inc.*
Jeff Swanson	*Fremont County Fire Protection District*
Jim Thinnes	*U.S. Forest Service*
Steve Thomas	*Sierra Club*
Dan Tinker	*University of Wyoming*
Kathy Tonnessen	*National Park Service*
Tom Troxel	*Intermountain Forest Association*
Jennifer Walker	*Bureau of Land Management*
Brenda Wilmore	*U.S. Forest Service*
Jeff Witcosky	*U.S. Forest Service*
Jamie Wolf	*Wyoming Outdoor Council*
Paul Wright	*Wyoming State Forestry Division*
Kristin Yannone	*Bureau of Land Management*

UNIVERSITY OF WYOMING

Environment and Natural Resources Program
University of Wyoming
Bim Kendall House
804 Fremont St.
Laramie, WY 82072
Phone: (307) 766-5080
Email: senr@uwyo.edu (School)
ienr@uwyo.edu (Institute)
wcc@uwyo.edu (WCC)
www.uwyo.edu/enr

Printed on
recycled paper