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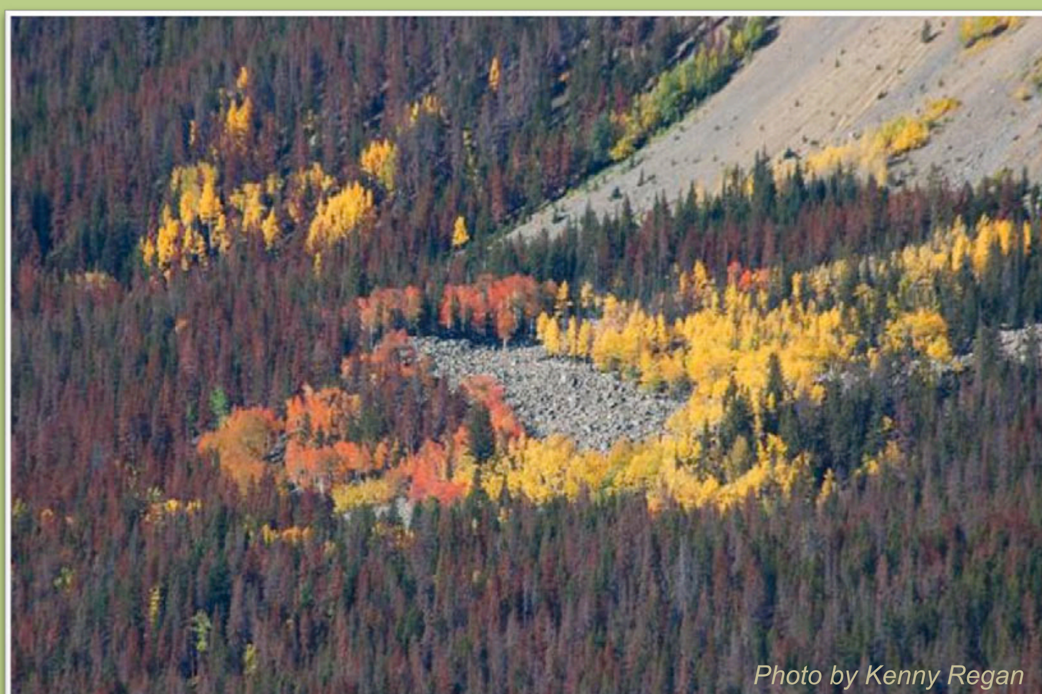
Future Forests Webinar Series

October 2011 – December 2012

Webinar proceedings and summary:

Ongoing research and management responses to the mountain pine beetle outbreak



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Technical coordinators: *Megan Matonis, Rob Hubbard, Krista Gebert, Beth Hahn, Sue Miller, and Claudia Regan*

Webinar series hosted by:

USDA Forest Service
Rocky Mountain Research Station,
Rocky Mountain Region, &
Northern Region

Colorado Forest Restoration Institute
Warner College of Natural Resources,
Colorado State University

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Abstract

The Future Forest Webinar Series facilitated dialogue between scientists and managers about the challenges and opportunities created by the mountain pine beetle (MPB) epidemic. The series consisted of six webinar facilitated by the USFS Rocky Mountain Research Station, the Northern and Rocky Mountain Regions, and the Colorado Forest Restoration Institute. The series ran from October 2011 to December 2012 and covered a variety of topics related to the MPB epidemic: potential fire risk and behavior, current and future vegetation conditions, wildlife habitats and populations, social and economic considerations, ecosystem- and watershed-level changes, and management responses. The purpose of these proceedings is to relate information shared during the webinar series (rather than to summarize all available research on implications of the MPB epidemic). These proceedings represent a snapshot of relevant scientific and management concerns related to this epidemic. In the coming decades, additional research and lessons learned by managers will continue to deepen and broaden our understanding of the future of post-epidemic forests.

Keywords: Mountain pine beetle, Lodgepole pine, Forest change, Socio-economic impacts, Wildlife habitat

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Future Forest Webinar Series

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Chapter 1—Overview of the Future Forest Webinar Series

Authors: Sarah Hines and Megan Matonis

Background of the Future Forest Webinar Series Proceedings

The Future Forest Webinar Series was created to facilitate dialogue between scientists and managers about the challenges and opportunities created by the mountain pine beetle[1] (MPB) epidemic. A core team of scientists and managers from the USFS Rocky Mountain Research Station and the Northern and Rocky Mountain Regions worked together to develop the format and content of the series and written proceedings. The core team facilitated six webinars (from October 2011 to December 2012) covering the ecological and social dimensions of the MPB epidemic. Webinar recordings are available online through the Rocky Mountain Research Station (http://www.fs.fed.us/rmrs/presentations/).

These written proceedings represent a synthesis of material presented during the webinar series. Many webinar participants indicated that written proceedings would add value to the series by providing a reference document and resource for informing future management decisions. Each chapter was authored by webinar presenters and members of the webinar core team, and the entire document was reviewed by independent experts from the Rocky Mountain Region of the Forest Service, Colorado Forest Restoration Institute, and University of Wyoming. The purpose of the proceedings is to relate information shared during the webinar series rather than to summarize all available research on implications of the MPB epidemic. These proceedings represent a snapshot of relevant scientific and management concerns related to this epidemic. In the coming decades, additional research and lessons learned by managers will continue to deepen and broaden our understanding of the future of post-epidemic forests.

Goals of the Future Forest Webinar Series

The concept for the Future Forest Webinar Series grew out of the work of the Rocky Mountain Research Station, Colorado Forest Restoration Institute, and other partners in 2009 and 2010. The goal was to assess the general information needs of managers regarding the MPB epidemic[2] (Colorado Forest Restoration Institute 2010). At that point in time, the MPB epidemic was already well underway throughout the Intermountain West. Scientists and managers recognized that relatively little could be done to stem the beetles' progression, but there was still a clear and pressing need to understand implications of this disturbance for post-epidemic forests. RMRS research scientists and others had been conducting research on the ecological and social consequences of the extensive tree

[1] See appendix A for scientific names of insect, plant, animal, and fungi species referenced in this document.

[2] The term epidemic refers to the continental-scale MPB event, and the terms infestation or outbreak refer to local-scale events.

Table 1.1. The Future Forest Webinar Series consisted of six webinars spearheaded by a member of the webinar core team, a group of researchers and managers from the Rocky Mountain Research Station (RMRS) and Northern and Rocky Mountain Regions of the Forest Service tasked with designing the webinar series.

Webinar date	Title	Core team lead
October 18, 2011	Post-epidemic fire risk and behavior	Kevin Ryan (RMRS, Fire, Fuel and Smoke Program Area)
January 10, 2012	Forests in transition: Post-epidemic vegetation conditions	Mike Battaglia (RMRS, Forest and Woodland Ecosystems Program Area)
March 6, 2012	Ecological consequences of the mountain pine beetle epidemic for wildlife habitats and populations	Vicki Saab (RMRS, Wildlife and Terrestrial Ecosystems Program Area)
August 28, 2012	Beetles among us: Social and economic impacts of the mountain pine beetle epidemic	Megan Matonis and Jan Engert (RMRS, Science Application & Integration)
October 30, 2012	Small bugs with large-scale impacts: Ecosystem and watershed-level responses to the mountain pine beetle epidemic	Rob Hubbard (RMRS, Air, Water and Aquatic Environments Program Area)
December 11, 2012	Moving forward: Responding to and mitigating effects of the mountain pine beetle epidemic	Claudia Regan (USFS Rocky Mountain Region) and Barry Bollenbacher (USFS Northern Region)

mortality, and managers were eager for preliminary findings and peer-reviewed results.

The Rocky Mountain Research Station convened a group of scientists and managers from the Northern and Rocky Mountain Regions of the Forest Service to develop a webinar series about the MPB epidemic. An overarching goal of the webinar series was to bring research scientists and resource managers together to exchange information about post-epidemic forests.

The series consisted of six webinars from October 2011 through December 2012 (Table 1.1) with presentations by well-known managers and scientists from the USFS Rocky Mountain Region, Northern Region, Southwestern Region, and Rocky Mountain Research Station. Partners from Colorado State University and the University of Wyoming, who have first-hand experience in beetle-killed forests, were also included. The webinar series served as an avenue for informing managers of peer-reviewed research, and an opportunity for dialogue between scientists and managers about applications of the scientific information. It also allowed scientists to share research information with managers in the interim between data collection and publication, and created the opportunity for managers to influence future research questions and approaches.

Context of the MPB epidemic

The current MPB epidemic began in 1996, and as of 2012 had affected approximately 23 million acres of forestland across the western United States, severely impacting forests in Colorado, Wyoming, South Dakota, Montana, Idaho, and beyond (USDA Forest Service 2013). The MPB primarily attacks lodgepole pine, but also affects ponderosa, whitebark, Scots, and limber pine, and occasionally foxtail, bristlecone and pinyon pines. The MPB is native to the forests of western North America, and many smaller (endemic) outbreaks have occurred in the

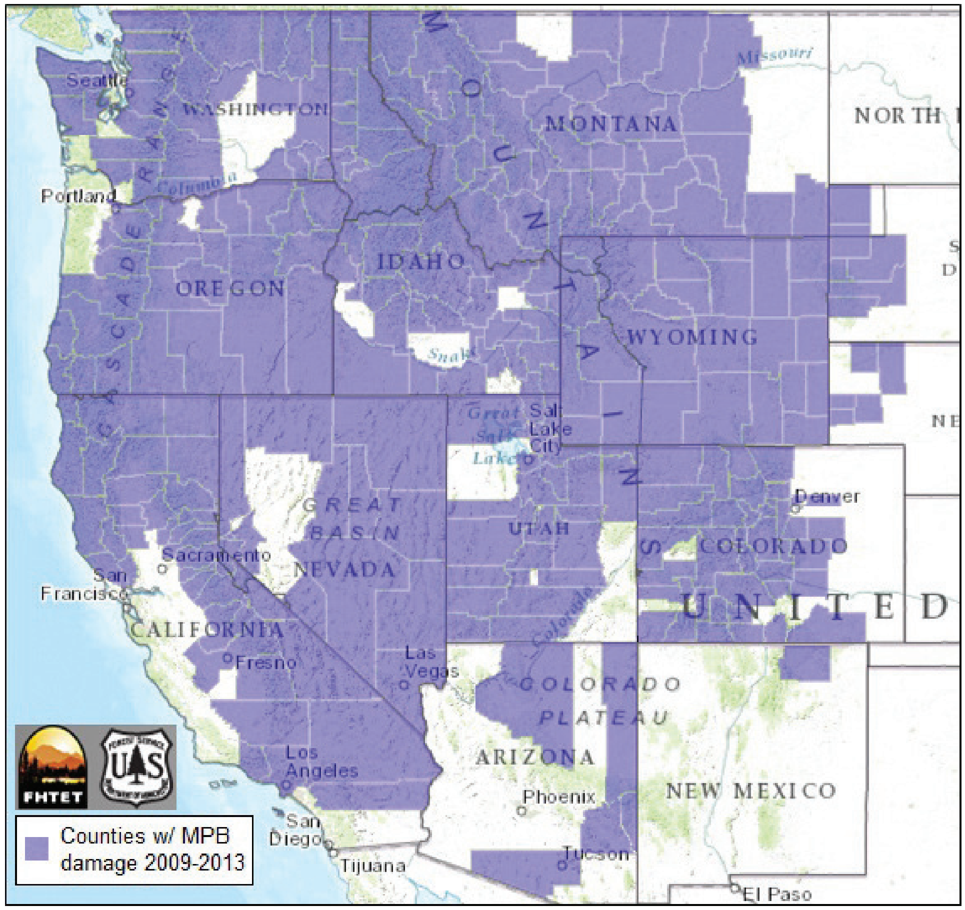

Figure 1.1. Counties reporting MPB activity from 2009 to 2013 (USDA Forest Service, Forest Health Technology Enterprise Team).

past. However, the scale of the current epidemic is historically unprecedented (Fig. 1.1). There is no clear consensus on exactly why the recent epidmic has grown to such an epidemic scale, but it is hypothesized that contributing factors include: (1) a severe drought in the mid-1990s to early 2000s that stressed forests, leading to increased vulnerability (Bentz and others 2010); (2) warmer temperatures, especially in November and April, that decreased beetle mortality and increased MPB populations (Bentz and others 2010); and (3) previous management practices, including a history of fire suppression, which led to large swaths of dense forests (Fettig and others 2007).

The MPB typically has a one-year developmental life cycle at lower elevations and a two-year life cycle at higher and colder elevations. However, milder winter temperatures at higher elevation attributed to a shortened one-year life cycle for beetles during the current epidemic. This phenomenon has led to faster population growth rates and contributed to the rapid expansion of the epidemic, especially between 2004 and 2008 (**Chapter 5**).

The primary mode of tree death is not directly through the burrowing activity of the MPB, but rather via the introduction of a blue-stain fungus that it carries (**Chapter 7)**. The MPB burrows into the inner bark of trees, laying its eggs and carrying the fungal spores directly into the tree. The fungus then grows and blocks the xylem cells, eliminating the tree's ability to transport water. A healthy tree may be able to resist a MPB attack by releasing large quantities of resin to push burrowing beetles out of the bark. A clear sign of a tree undergoing attack

Figure 1.2. Pine trees produce large quantities of resin and terpenes as their natural defense against MPBs. Trees can occasionally survive a MPB attack by pitching the bugs in their galleries or pushing them out entry holes in the bark (photo courtesy of the National Park Service).

is the appearance of "pitch tubes," or small popcorn-like areas of sap, on the trunk of a tree (Fig. 1.2).

If trees are drought-stressed and/or MPB populations are particularly large, a tree's typical defense mechanisms may be insufficient to resist infestation. Within days of being infested, transpiration halts and affected trees begin to die (**Chapter 4**). Foliar moisture content immediately decreases, leading to increased needle flammability (**Chapter 3**), but the tree typically does not show visible signs of mortality (*i.e.*, green needles turning red) until several months to

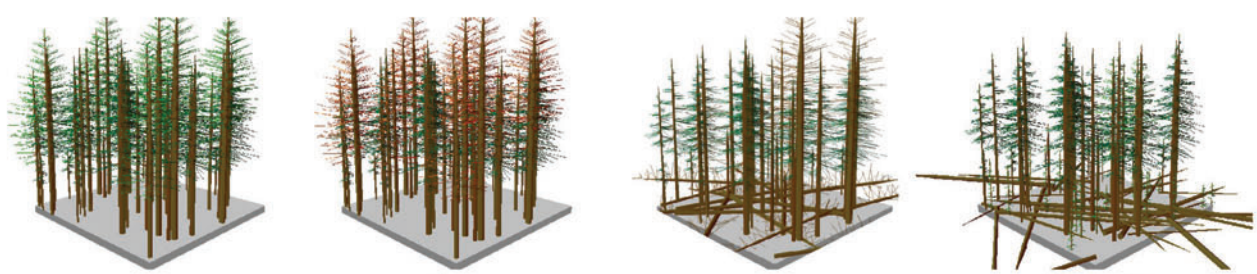

Figure 1.3. Trees succumbing to MPB attack go through four stages that have different physical characteristics and implications for fire hazards, wildlife habitat, and human safety. (1) Dying trees with green needles are in the "green stage"; (2) dead trees with dry, red needles are in the "red stage"; (3) standing snags that have lost their needles are in the "gray stage"; and (4) snags that have fallen to the ground are in the "dead and downed stage" (adapted from Schoennagel and others 2012).

about a year later. Within several years after this “red phase,” the tree will drop all its needles and enter the needleless “gray phase.” These dead snags will fall to the ground over the course of years to decades (Fig. 1.3).

The epidemic has slowed in recent years. According to the Forest Health Protection unit of the USFS, the MPB epidemic only affected an additional 2.4 million acres across the western U.S. in 2012. This is down from 3.8 million acres in 2011 and 8.8 million acres in 2009 (USDA Forest Service 2013). Decreased levels of infestation suggest that the MPBs are running out of new pine forests to infect.

Management challenges introduced by the MPB

Resource specialists and managers are struggling with challenges presented by the extensive tree mortality caused by the MBP. Conversations have turned to moving forward and managing for future forest conditions. Resource managers are especially concerned with:

- identifying issues of concern that may affect public safety or hamper agency response to safety concerns;
- developing management approaches that will develop a more resilient forest; and
- providing for the sustainability of wildlife and fish habitat.

Post-epidemic forests have different fuel loads and fire hazards than unaffected forests. This increases concern for the safety of firefighters, water supply facilities, interstate electricity transmission lines, and communities at the wildland-urban interface (WUI). Falling of beetle-killed trees presents a hazard to natural resource managers, recreation visitors, permittees, and contractors. Wildlife populations have also been affected by the MPB epidemic. Post-forest conditions have improved habitats for some species, such as woodpeckers, but reduced habitat suitability for others.

Managers are addressing these changes by reducing fuel loads and removing hazardous trees in some locations. They are also exploring methods to increase forest resilience. Managers and the public alike are aiming for adequate forests regeneration. The nature of management responses is influenced by timing of disturbance events, risk management objectives, organizational inertia, and pre-existing management goals across the landscape. A suite of management options are possible in areas where managers anticipated MPB-related issues (Fettig and others 2014). Research can help managers understand social and ecological consequences of the MPB epidemic and inform management activities in post-epidemic forests.

Outcomes of the webinar series

The webinar series was widely attended and well received by managers and researchers alike. Participation ranged from 70 to over 180 people, with the entire series reaching about 500. Roughly half of the webinar attendees were affiliated

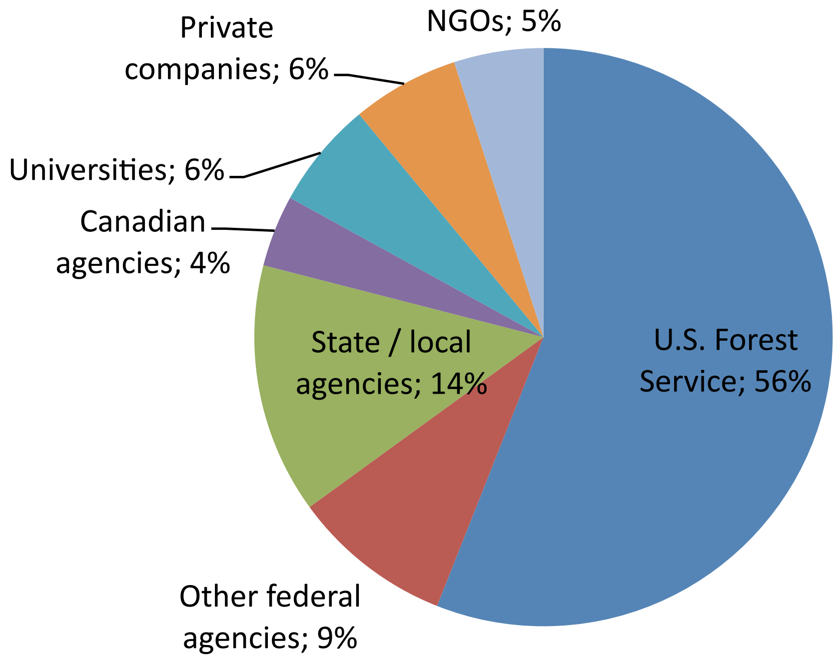

Figure 1.4. The Future Forest Webinar Series was attended by 500 different individuals representing a variety of governmental agencies, universities, non-governmental organizations, and private companies.

with the Forest Service, and about a quarter worked for other federal, state, and local agencies. The remaining participants represented 15 different universities, 25 private companies, and 14 non-government organizations (Fig. 1.4).

The core team solicited feedback from webinar attendees by distributing a survey at the end of the series. About 40 participants submitted responses, most of which were positive about the format and outcomes of the series. About 90 percent of respondents agreed or strongly agreed that the Future Forest Webinar Series was a useful forum for discussing research findings and management implications. In addition, over three-fourths of respondents agreed or strongly agreed that information from the series has better prepared them for future management decisions regarding the MPB epidemic. Respondents were generally satisfied with the level of detail provided by researchers and the amount of time allocated to questions and discussions.

Over half of the respondents thought that the series should have included more "take home" messages from researchers and on-the-ground observation from managers. To address this, **Chapter 2** summarizes the entire webinar with an emphasis on management, and the chapters that follow pair research findings with management implications wherever possible.

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Meet the chapter authors

Sarah Hines is a Science Delivery Specialist with the Rocky Mountain Research Station of the Forest Service. She joined the agency as a Presidential Management Fellow after graduating from the University of Michigan with a master’s in natural resources. Sarah provides assistance to the Climate Change Resource Center and helps make forest science more accessible to land managers. She created the ‘Science You Can Use’ Bulletin, a publication sent to almost 2,500 managers across the Intermountain West summarizing research findings and their management implications. Reach Sarah at shines@fs.fed.us; 970-498-1135.

Megan Matonis is a Graduate Student Cooperator with the Rocky Mountain Research Station and a PhD student at Colorado State University. Her dissertation research focuses on the development and use of locally-relevant ecological information to empower collaborative forest restoration. Megan worked for the Forest Service Policy Analysis staff in Washington, DC after receiving a master’s in forestry from Michigan State University. Megan can be reached at megan.matonis@colostate.edu; 970-498-1342.

Chapter 2—Webinar summary: Important findings for managers

Author: Claudia Regan

Introduction

This chapter summarizes key findings and offers take-home messages of the Future Forest Webinar Series with regard to resource management planning, analyses, and project design. In the wake of the mountain pine beetle (MPB) epidemic, resource managers are especially concerned with developing more resilient forests, providing for the sustainability of wildlife and fish habitat, public safety, and managing our water resources. We attempted to provide information to support these management goals via the series of webinars. More details on the findings of each webinar are presented in the subsequent chapters of these proceedings.

Resilient forests

Resource managers are interested in developing management approaches that contribute to resilient forests in the future.[3] They want to ensure that forests regenerate after a disturbance and maintain their structure and function over the long term. They are also concerned about invasive species and soil erosion that may be exacerbated by beetle-caused tree mortality and subsequent disturbances, including post-epidemic salvage operations.

Figure 2.1. Subalpine forests have recovered from disturbances in the past, including massive MPB epidemics, wildfires, and windfall events (photo by J.M. Miller in 1924 of the Tenaya Ghost Forest in Yosemite National Park showing lodgepole pine regeneration a decade after the MPB and lodgepole needle miner killed overstory trees; Furniss 2007).

Managing for resilience requires knowledge about potential changes in forest conditions with and without management treatments. Subalpine forests evolved with widespread and severe disturbances, and the species dominating these ecosystems are adapted to these conditions (Fig. 2.1). The composition and structure of subalpine forests vary across the

[3] Resilience is the ability of an ecosystem to recover from disturbance (natural or anthropogenic) without shifting to an alternative state (i.e., substantially different structure, composition, and function) (SER 2004).

West. How does this variability contribute to their resilience in the wake of the epidemic? The recent MPB epidemic is unprecedented in terms of its extent, geographic distribution, and longevity, but managers want to know if recovering subalpine forests are on a different trajectory than they might following more characteristic disturbances.

Managing for fire hazards and risks

Resource managers are concerned about the possibility of increased wildfire hazards, especially in the WUI, following the MPB epidemic. They recognize that the widespread death of trees dramatically changes fuel conditions over time, but they are uncertain about potential impacts on fire hazard and behavior. There is an interest in ameliorating short-term effects through fuel treatments and in planning for treatments that might have positive resource outcomes in the future. The webinar *Post-epidemic fire risk and behavior* focused on the fire behavior research of Forest Service researchers and their collaborators (**Chapter 3**), and additional research on MPB and fire interactions were presented during the webinar *Forests in transition: Vegetation structure and composition* (**Chapter 4**).

This research suggests that fire behavior in beetle-killed forests may be more complex than initially expected. Larger safety zones may be required for fire operations during the red stage of the MPB attack due to greater heat release (Fig. 2.2). This may also be true for fire operations in cut areas due to greater surface fuel loads and in uncut stands following massive windthrow events. Firefighters might decline assignments on wildland fires burning in beetle-killed stands given the high hazards involved.

Information on fuel loads and fire behavior in the gray stage is more limited. Predicting fire behaviors under gray stage or future conditions remains an area of uncertainty with conflicting findings. Public safety concerns may call for conservative approaches that would favor management to mitigate future fire concerns.

Management Implications

- The potential for crown fire and fire intensity (heat release) increases as the proportion of red-stage trees in a forest increases.
- Stand structure and the nature of MPB outbreaks in space and time *(i.e.*, low and slow mortality pulses vs. high and fast mortality pulses) affect how MPB outbreaks influence the risk of crown fires.
- Tree removal in post-epidemic forests can result in a three-fold increase in surface fuels for several years after treatment. Higher fuel loads can result in greater flame lengths, potentially decreasing our ability to suppress fires with ground tactics.
- However, uncut stands could have higher fuels loads in the long-term as dead trees fall to the ground.

Figure 2.2. Fire behavior in beetle-killed forests is complex and difficult to predict. Research shows that forests with many red-stage trees have a greater potential for crown fires. Fires in red-stage forests also burn with a higher intensity (greater heat release) than fires in green forests (photo from 2009 Kelly Creek Fire in British Columbia, photo courtesy of B.C. Wildfire Management Branch).

Figure 2.3. Advanced regeneration and new recruitment of tree species are abundant in most post-epidemic stands (photo by Chuck Rhoades, USDA Forest Service).

Current and future stand conditions

The webinar *Forests in transition: Vegetation structure and composition* covered research that is addressing uncertainties about how changing fuel profiles after the MPB epidemic might influence future fire behavior and/or impair fire suppression efforts (**Chapter 4**). We learned that forested landscapes in the future may have different structures and compositions than before the MPB epidemic. Management decisions regarding the removal of beetle-killed trees will influence the types of forests that develop.

We also learned that forests are responding positively to the increased availability of resources (light, nutrients, etc.) with rapid growth of residual trees and new tree recruitment (Fig. 2.3). Simulations of stand development using the Forest Vegetation Simulator suggested that increased growth of residual trees, as well as new recruitment, might return stands to pre-outbreak basal areas

Management Implications

- Post-epidemic forests are undergoing extensive regeneration. Tree planting is largely unnecessary to ensure forested conditions in the future.
- Recovery of post-epidemic forests will depend on species composition of surviving trees and advanced regeneration.
  - The abundance of subalpine fir and Engelmann spruce will increase in some stands, especially if the abundance of lodgepole pine declined substantially during the beetle epidemic.
  - Lodgepole pine will continue to dominant some stands, especially those where pre-epidemic densities of subalpine fir and Engelmann spruce were low.
  - Aspen abundance is increasing in stands without substantial competition from subalpine fir.
- Harvesting beetle-killed trees can promote the recruitment of lodgepole pine or aspen, while subalpine fir recruitment more likely in uncut stands.

within a century. The simulations reveal that lodgepole pine may continue to dominate harvested stands over the next century, while some uncut stands may have larger proportions of subalpine fir.

Sustainability of wildlife habitat

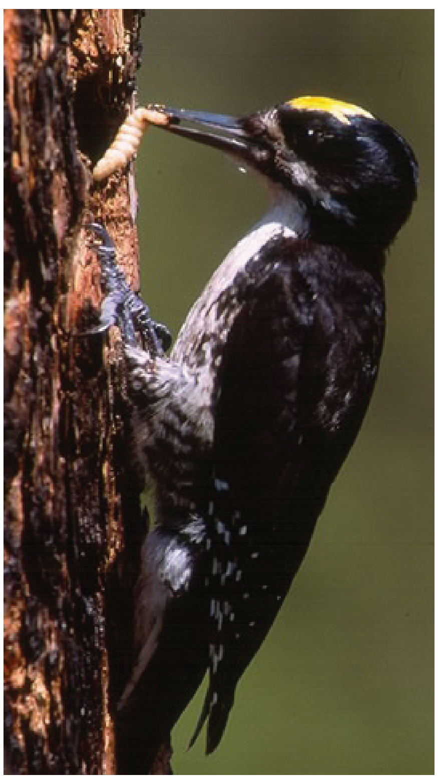

Figure 2.4. Several woodpecker species, including the black-backed woodpecker, forage for MPBs and other bugs under the bark of dead snags (photo courtesy of USDA Forest Service).

Resource managers need information on the consequences of the MPB epidemic for wildlife habitat and wildlife populations. This information will support conservation and recovery efforts and help in prioritizing treatment sites. A team of researchers and resource specialists addressed some of these information needs in the webinar *Ecological consequences of beetle outbreaks for habitats and populations of wildlife* (**Chapter 5**).

A wildlife biologist with the Rocky Mountain Research Station illustrated how life history traits provide clues about the impact of disturbances on different bird species. Cavity-nesting birds, beetle foragers, and bark insectivores (*e.g.*, hairy woodpeckers and American three-toed woodpeckers) often respond positively to MPB outbreaks and fire (Fig. 2.4). This is due to increased availability of snags for nesting and food resources. In contrast, foliage gleaners and canopy-nesting birds (*e.g.*, golden-crowned kinglet) are likely to respond negatively because they prefer dense forest canopies.

Impacts of the MPB epidemic on wildlife habitat will change over time as the forests regrow and snags fall down. Wood-boring insects that colonize MPB-killed trees can serve as a foraging resource for woodpeckers even 4-5 years following a MPB attack.

Management Implications

- Animal species respond differently to disturbances like the MPB epidemic based on their life history traits.
  - Species that utilize snags for feeding and/or nesting (*e.g.,* woodpecker species) often benefit from MPB outbreaks and fires. Habitat suitability for these species can decline over time as snags fall down.
  - Species preferring dense forest overstories (*e.g.,* foliage-gleaning and canopy-nesting birds) often decline following a MPB outbreak, but populations might rebound as forest stands recover.
- Retention of snags for wildlife habitat is an important project consideration for some large-scale salvage operations. Managers should also remember that snag fall rates are highly variable.
  - Research shows that woodpeckers preferentially forage on large-diameter snags.
  - Anywhere from 70-90 percent of snags fall within 5 years of a MPB outbreak. Higher fall rates are generally associated with warmer and wetter conditions.

Webinar presenters also discussed the use of models to evaluate changes in wildlife habitat over time. They found that models are useful tools for predicting habitat suitability under different climate conditions and disturbance regimes. Some models can examine interactions among disturbances (*e.g.,* climate change, wildfires, and MPB outbreaks). Researchers suggested several best practices for using models:

- Determine the appropriate spatial and temporal scale for projections. Projections at landscape scales are necessary for species that have large home ranges or migrate from season to season. If snags are important habitat for the focal species, annual or decadal projections at the stand scale are more appropriate.
- Try linking site-specific research projects with broader monitoring programs to develop multi-scale inferences about habitat suitability.
- The future is not set in stone, so models can help assess the impact of different management decisions under a range of potential conditions (*e.g.,* climate scenarios).
- Understand the assumptions and limitations of models. For example, some datasets are less reliable than others, and this can greatly influence the reasonableness of model predictions.
- Qualitative modeling approaches, such as scenario planning, are often helpful when future conditions are dynamic and largely unknown and/or when quantitative data is not available.

Public safety

Resource managers continue to be concerned about the direct consequences of forest insect epidemics to human safety. They are interested in understanding issues that relate to agency responses to safety concerns. Once the extent and severity of the MPB epidemic became apparent, managers worked to address

Figure 2.5. Trees killed by MPB attacks eventually weaken and fall, posing a serious safety concern for forest users (photo courtesy of USDA Forest Service).

current and future safety of employees, recreation visitors, permittees, and contractors who use the National Forests. In addition, the agency has an interest in addressing the safety of communities in the wildland urban interface (WUI). Dead and dying trees eventually fall, creating imminent and future risks to people and structures (Fig. 2.5). Resulting changes in fuel profiles are seen as potentially influencing fire potential and behavior and impacting suppression responses (**Chapter 3,** discussed earlier).

Management Implications

- Respondents generally support the management of forest conditions to decrease the effects of wildfire that may potentially be influenced by changes in fuel profiles associated with dying, dead, and falling trees.
- Respondents are generally willing to accept the risks of recreating in beetle-killed forests, and they accept that certain activities are restricted or no longer possible.
- There is less agreement among respondents that managers are doing everything they can to respond to tree mortality from MPBs.

Knowing the perceptions, beliefs, and preferences of the public can help land managers identify the issues, communicate better with the public, and improve collaborative efforts. The webinar *Beetles among us: Social and economic impacts of the mountain pine beetle epidemic* drew largely on a survey of public perceptions by researchers at Colorado State University (**Chapter 6**).

Managing water resources

The webinar *Ecosystem and watershed level responses to the mountain pine beetle epidemic* summarized research by forest ecologists and hydrologists at the Rocky Mountain Research Station (**Chapter 7**). Research shows that water yield and quality has not changed in the first years following the MPB epidemic. Stream nitrogen levels remain below those expected to cause problems for human health. Uptake by residual vegetation and new recruits has dampened the loss of nutrients to surface water.

Managers should be aware of how treatments in post-epidemic forests can alter water yields and soil resources. Treatment of slash can have particularly

Figure 2.6. Slash management techniques can impact snow retention, soil nutrient availability, and seedling development. Lop and scatter approaches increase snow retention, often leading to greater soil moisture and enhanced seedling recruitment and growth (photo by Byron Collins, USDA Forest Service).

Management Implications

- Snow retention and associated spring runoff are impacted by post-epidemic management decisions.
  - Removal of trees in large groups can decrease snow retention due to wind scour.
  - Retaining slash in post-epidemic forests increases surface roughness and will help to keep snow on the ground.
- Different methods of treating slash in post-epidemic forests can impact future stand development.
  - Slash retention (*i.e.*, lop and scatter) has positive effects on soil resources and seedling recruitment and growth relative to other options.
  - Burning the very large and numerous slash piles resulting from post-epidemic management can have long-lasting negative impacts (*i.e.*, overs 50 years) on soil nutrients and seedling recruitment.
- Riparian ecosystems are particularly sensitive to management approaches that emphasize hazard tree removal and pile burning.

pronounced effects on snow retention and soil nutrients in forest ecosystems (Fig. 2.6). Additional research is needed to understand impacts of post-epidemic management to riparian ecosystems, but preliminary findings suggest these ecosystems are especially sensitive to mechanical disturbances and pile burning.

Economic feasibility of management actions

The amount of mitigation and hazard removal that managers can undertake in post-epidemic forests is limited by funding and the availability of forest-industry infrastructure. States with robust forest-products infrastructure, such as Montana, can finance at least some of their management costs by selling some or all of the material. In places where such infrastructure is sparser, like in Colorado, the material is often piled and burned in the woods, offsetting none of the costs of treatment. Utilizing woody material for bioenergy, rather than piling and burning it in the forest, also offsets carbon emissions.

There are significant challenges to developing the capacity of private industries to utilize woody biomass. These include:

- Uncertainty in the amount of timber available to investors in the coming decades.
- High transportation costs to haul timber or biomass from infested forests to far-away mills.
- The price that the woody material receives on the market, as well as the price of alternatives. For example, the lower the cost of natural gas, the lower the price purchasers are willing to pay for biomass.

Conclusions

The MPB epidemic has greatly altered the future of forests across the West. The conditions across post-epidemic landscapes are complex and the future is largely uncertain. Implications of the epidemic for public safety, fire hazards, forest vegetation, and wildlife populations are variable across the landscape and will change over time. Management decisions have the potential to steer forests away from an undesirable future, but guidance is needed on how this might be accomplished (Fettig and others 2014).

Navigating through this complex and dynamic situation calls for continual interaction among managers, resource specialists, and scientists (Fig. 2.7). The process of developing, delivering, and implementing scientific information is most effective when it incorporates diverse perspectives, training, and expertise. For example, entomologists understand environmental controls of MPB outbreaks, forest ecologists have insights about forest development over time, and wildlife biologists know which variables are important for habitat suitability. Discussions among scientists and managers can also ensure that research is relevant and focused on the right questions.

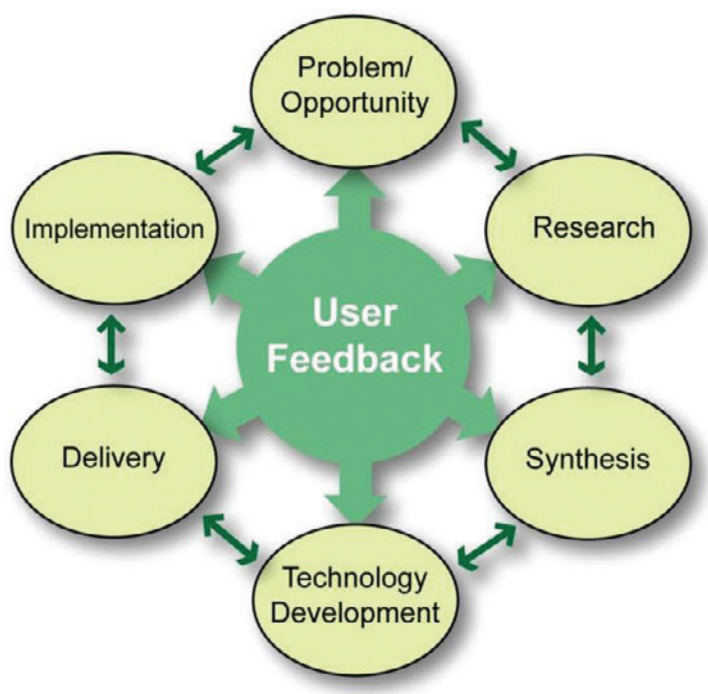

Figure 2.7. A fully collaborative science cycle involves continual interactions among researchers, managers, and other science users. Interactions can familiarize non-scientists with research methods, make researchers aware of information needs, and improve the usability of research results (USDA Forest Service 2009).

The Future Forest Webinar Series helped to kick-start these interactions. Our hope is that the webinar coordinators, presenters, and participants continue working together; there is still much to learn about the future of post-epidemic forests.

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Meet the chapter author

Claudia Regan is the Regional Ecologist with the Rocky Mountain Region of the Forest Service. She has worked with the agency as a full-time employee for 18 years and in temporary or seasonal capacities for 6 years. Regional Ecologists serve as applied scientists who bridge scientific research with resource management issues and work toward information synthesis, delivery, and application. Claudia has Bachelor's and Master's degrees in Forest Science from Southern Illinois University and a Ph.D. in Ecology from Colorado State University. Reach Claudia at cregan@fs.fed.us; 303-275-5004.

Chapter 3—Post-epidemic fire risk and behavior

Authors: Russ Parsons, Matt Jolly, Paul Langowski, Megan Matonis, and Sue Miller

Presenters: Russ Parsons, Matt Jolly, and Paul Langowski

Introduction

Citizens, government officials, and natural resource managers are greatly concerned about potential impacts of the mountain pine beetle (MPB) epidemic on fire hazards and risk. Some mountain towns are surrounded by dead and dying trees. In the Rocky Mountain Region of the Forest Service, the MPB epidemic threatens over 250,000 acres of the wildland-urban interface (WUI; USDA Forest Service 2011). This post-epidemic landscape also poses hazards for firefighter safety due to heavy fuel loads and unpredictable fire behavior. Abundant snags are especially dangerous for firefighters working in beetle-killed forests.

Changes in fuel and microclimate conditions caused by the MPB epidemic (Fig. 3.1) add another dimension of complexity to wildfire concerns across the West. Many forested landscapes have not burned in nearly a century, leading to an abundance of trees and accumulation of fuels, setting the stage for large and severe wildfires. The death of trees due to the MPB has exacerbated this situation and created a need for extensive fuel reductions in many areas. Hotter and/or drier climates in the future might further worsen the situation. Lodgepole pine forests evolved with an infrequent and severe fire regime, but many people find this type of fire behavior unacceptable, especially in the WUI.

Researchers and managers are working together to understand the interaction between MPB outbreaks and wildfires and to develop the appropriate responses.

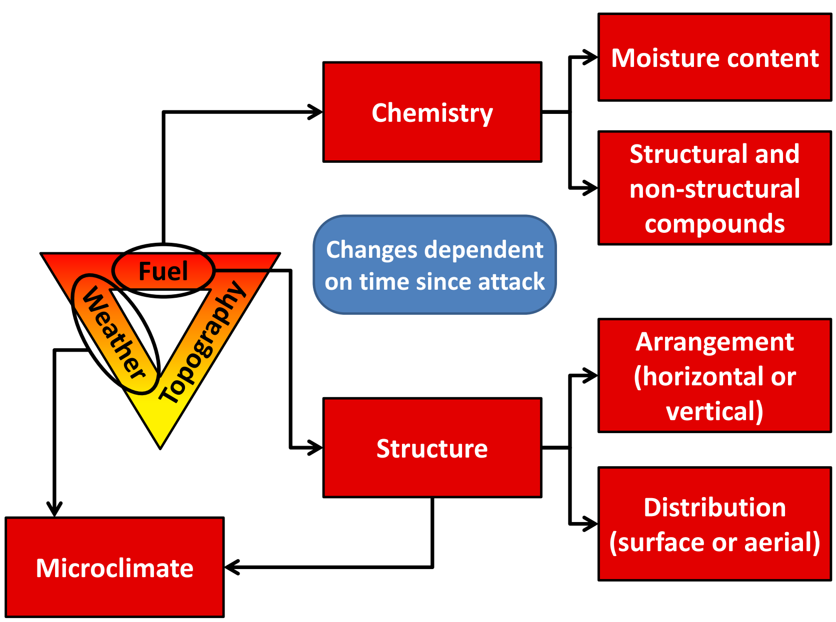

Figure 3.1. The MPB epidemic has altered fuel and microclimate conditions in forest stands. Fuel loads and microclimates will change over time due to management decisions and forest regrowth. These changes can result in unexpected fire behavior, with serious implications for fire operations (diagram by Matt Jolly, USDA Forest Service).

Many potential impacts of the MPB epidemic on fire hazards and behavior are still a matter of debate, and some questions remain unanswered. Some researchers suggested that post-beetle landscapes have a lower potential for crown fires, while others suggested risk of crown fires may increase in these forests. Others found that generalizations could not be made, since fuel loads and microclimates differ substantially between beetle-killed stands and will change considerably over time. Adding to the difficulty in understanding the situation is the fact that many fire behavior models used to analyze potential effects of the MPB epidemic on fuel loads were not designed for exploring such interactions.

Research findings

Research finding #1: Current operational models are greatly limited in their ability to accurately predict fire risk and behavior in post-epidemic forests.

Management Implications

- Predictions from standard fire behavior models (e.g., BEHAVE, FlamMap, and NEXUS) are highly unreliable for stands affected by the MPB epidemic.
- Consider using short-term fixes to improve predictions of current operational models, such as reducing crown base height in Van Wagner crown fire model to compensate for lower foliar moisture contents.

Assumptions of fuel homogeneity and other simplifications within operational fire behavior models used in the United States make it difficult to realistically represent impacts of MPB outbreaks on fuels and fire behavior. This significantly limits their application in modeling fire behavior for stands with beetle-killed trees (Jolly and others 2012b; Jenkins and others 2014). MPB outbreaks typically result in stands with complex arrangements of trees in all different stages of mortality. Operational fire behavior models cannot currently account for this type of variability in fuel structures. In addition, they cannot incorporate changes in wind dynamics as trees transition between stages (*e.g.,* from gray to down). Unrealistic predictions from these models have contributed to confusion among researchers, managers, and the public (Hoffman and others 2012, Jenkins and others 2014).

Physics-based models, such as FIRETEC and the Wildland-Urban Interface Fire Dynamics Simulator (WFDS), show great promise for overcoming inadequacies presented by operational fire behavior models (Hoffman and others 2013). These models can represent mixes of green and red trees typical of beetle-attacked stands because they represent the forest as a collection of individual trees, rather than as a homogeneous block. They also capture critical interactions between fuel, fire, and the atmosphere (Fig. 3.2).

At this time, physics-based models are used primarily in research, but work is underway to make them operationally useful for fire and fuel managers. A limitation of physics-based models is their data-intensive nature. Use of these models requires knowledge about the location of individual trees and detailed measurements of surface and canopy fuels.

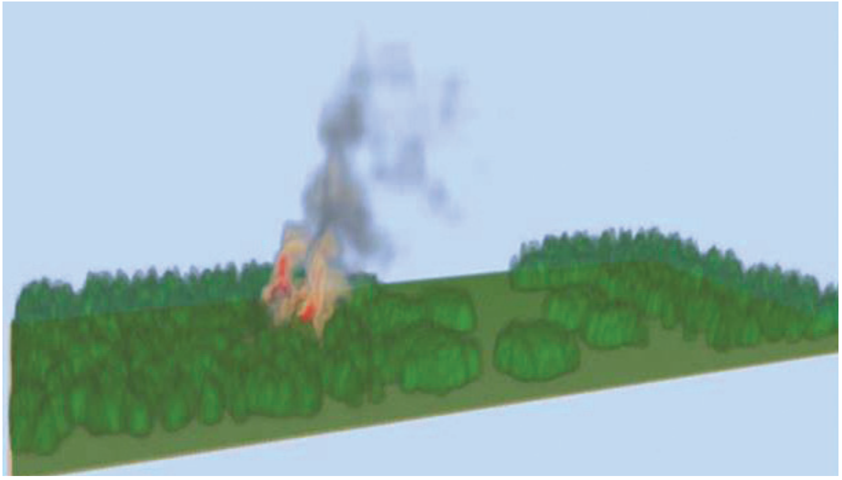

Figure 3.2. Physics-based fire models such as FIRETEC (pictured here) simulate fire spread in three dimensions and at much higher resolution than standard fire models. These detailed models are useful for exploring how disturbances, such as MPB outbreaks, affect fuel loads and fire behavior (figure by Russ Parsons, USDA Forest Service).

Research finding #2: Fire hazards are greater and fire behavior more severe when trees are in the red stage of a beetle attack.[4]

Management Implications	
	• Larger safety zones may be required for fire operations in red-stage forests due to the larger heat release. • Ground operations might not be feasible due to longer flame lengths. • Spotting distances can be greater than usual during fires in red-stage forests.

The flammability of pine branches and needles increases between the green and red stages of a beetle attack. In a replicated laboratory study, scientists with the Rocky Mountain Research Station determined that the greater flammability of red needles is due to their lower foliar moisture and altered chemistry. Ignition rates are about three times faster for red needles than healthy green needles (13 vs. 35 seconds) (Jolly and others 2012a). When considered at the scale of whole trees, such changes in flammability can be significant. Forest Service researchers compared fire behavior between a green healthy tree and a red stage tree using a physics-based fire model, WFDS. They found that heat was released twice as fast from the combustion of red needles as from green needles (Fig. 3.3). These differences are partially explained by changes in the chemical composition of needles after a beetle attack. Red needles have about one-tenth the water content of healthy green needles, and they contain about 1.5 times more fiber (Jolly and others 2012a).

Changes in the composition and flammability of pine needles in red-stage forests translate into different fire behavior. Crews on the 2012 Halsted Fire in southwestern Idaho observed unusual fire behavior, including passive, active, and independent crown fire. Fire spots even ignited canopy fuels in the absence of surface fire. They also noted rapid transition of surface to crown fires where needles of green and red-stage trees comingled in the canopy (Jenkins and others 2014).

Fire managers both in Canada and the United States have observed rapid crown fire ignition in red-stage forests and spot fires up to a quarter-mile away from

[4] *This research finding reinforces material presented in Research Finding 4 of Chapter 4.*

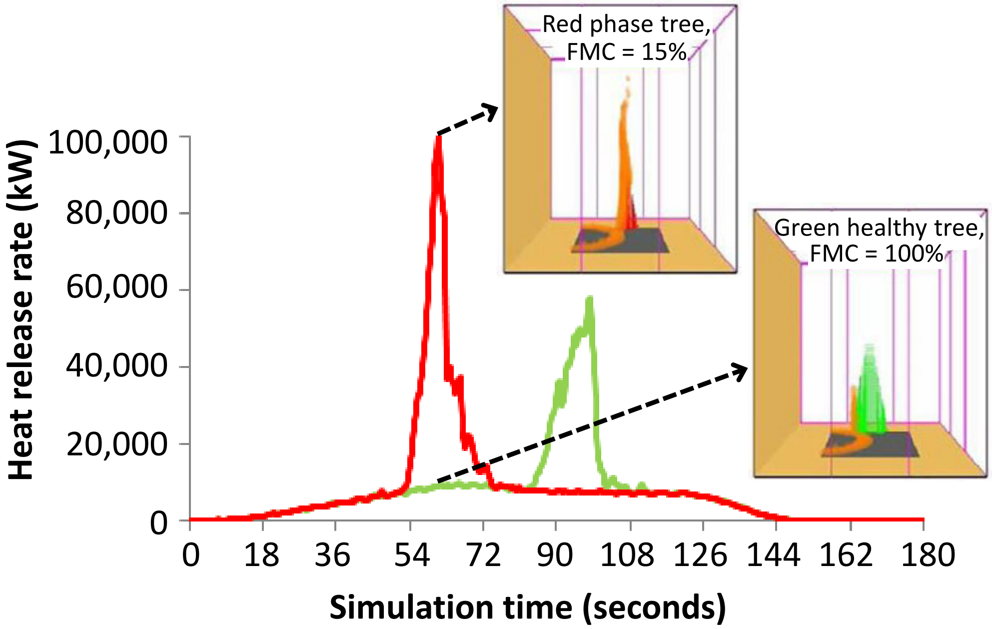

Figure 3.3. Comparison of heat released by consumption of a red-stage tree and a healthy, green tree as modeled with the Wildland-Urban Interface Fire Dynamics Simulator (WFDS). Both trees have identical fuel properties except that the red-stage tree has lower foliar moisture content (FMC). The maximum rate of heat release is greater and occurs sooner for the red-stage tree. This rapid, intense heat release has important implications for crown fire dynamics (figure by Russ Parsons, USDA Forest Service, unpublished data).

torching red-stage trees (Schroeder and Mooney 2012). For example, the 2011 Saddle Complex Fire made a sustained crown fire run of 17,000 acres along the Montana-Idaho border in a relatively short time, mostly through beetle-kill fuels. Spotting distances were likely greater than 1 mile (Matt Jolly, USDA Forest Service, *pers. obs.*). One game-changing effect is that embers from red-stage tree crowns might potentially ignite other red-stage trees. This mechanism has the potential to dramatically increase crown fire spread rates.

Research finding #3: Fire hazards and behavior are more uncertain when trees turn gray and fall down.[5]

Management Implications	
	• Fire behavior is less predictable in gray-stage forests, calling for more cautious and judicious deployment of ground resources during fire operations. • In the absence of fuels reduction treatment, windthrown snags will cause a >5-fold increase in the coarse surface fuels after the gray stage. • Falling snags and abundant logs during the "dead and downed stage" pose serious hazards to firefighters and slow fire line production rates.

Beetle-attacked fuels can alter transitions from surface to crown fire in unpredictable ways, especially during the "gray stage." Trees have dropped their needles but they are still vertical during this relatively persistent stage (≥10 years). Green and red trees are often intermixed throughout forests in the gray stage.

Very few researchers have explored fire behavior in gray-stage forests and forests with fallen snags. A common assumption at the beginning of the MPB epidemic was that the flammability of trees would decrease after their needles fall off. However, fire managers in Canada reported that standing gray-stage trees shed bark that could

[5] *This research finding reinforces material presented in Research Finding 4 of Chapter 4.*

generate embers and increase spot fire occurrence (Schroeder and Mooney 2012). Spot fires from gray-stage stands have been recorded as far as a half-mile away (Dana Hicks, British Columbia Forests, Lands and Natural Resource Operations, *pers. obs.*)

Research suggests that fire hazards and behavior will change after the gray-stage as snags drop to the ground. Collins and others (2012) estimated that windthrown snags will cause a >5-fold increase in the coarse surface fuels in beetle-killed stands with no fuels reduction treatment. Wind speeds are likely to increase throughout the forest, fanning fast fires through accumulations of dry fuels (Linn et. al 2013). A higher prevalence of open canopies and coarse surface fuel loads are likely to increase surface fireline intensities. These changes could facilitate active crown fires at lower wind speeds across all moisture scenarios in gray-stage or dead-and-downed stands, even 30 years after a MPB attack (Schoennagel and others 2012). Falling snags and jack-straw logs are serious hazards for firefighters. In addition, fire line production rates drop when more logs need cutting (Page 2013). Fires in these forests may grow exceptionally large due to an unwillingness to put firefighters at risk.

Research finding #4: The intensity and rate of MPB attacks influence the risk of crown fires.

Management Implications

- Expect more intense fire behavior (*e.g.*, greater fireline intensities, more rapid transitions from surface to crown fires, and longer spotting distances) in stands with a greater portion of beetle-killed trees, especially of those in the red-stage.
- Forests experiencing low-level and prolonged (“low and slow”) tree mortality might burn less intensely than forests with “high and fast” mortality. However, fire hazards are likely to remain elevated for a longer period of time following “low and slow” MPB outbreaks.
- Fuel treatments in the near term should focus on reducing hazards around priority infrastructure. Beetle-altered fire behavior and the scale of the epidemic make it less likely that ground operations can defend critical infrastructure during future wildfires.

Scientists at the Rocky Mountain Research Station and their partners are using physics-based models to explore how the trajectory of MPB outbreaks might impact fire spread. They developed a simple probabilistic model of MPB spread, in which beetles spread from an initial start location to adjacent trees over time. Two factors affect the success of MPB attacks in this simple model: distance between trees and tree diameter. Beetles are known to preferentially attack larger host trees as they provide greater food value (**Chapter 5**).

The researchers compared two outbreak trajectories: (1) “low and slow” outbreaks, where successful attacks start with a small number of trees dispersed throughout the stand, and (2) “high and fast” outbreaks, where successful attacks start with a larger number of trees and spreads more rapidly among trees (Fig. 3.4). The “low and slow” case is similar in many ways to an endemic MPB outbreak, while the “high and fast” case is more representative of a MPB epidemic.

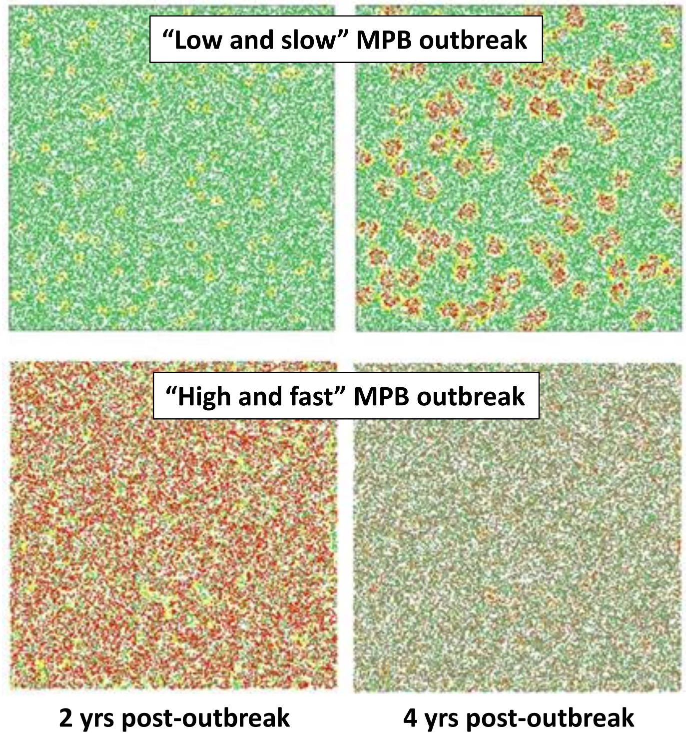

Figure 3.4. Forest Service researchers developed a simple model to examine how the rate and intensity of MPB outbreaks might change fuels and fire behavior over time. The “low and slow” scenario involved a slower rise in the proportion of red-stage trees, peaking below 20 percent of trees around year 7. The rapid mortality pulse in the “high and fast” scenario resulted in 40 percent of red-stage trees by year two, with most of these trees entering the gray stage by year 4. Each dot represents a tree and the color corresponds to the stage of MPB-induced mortality (green, yellow, red, and grey stages). (Figure by Russ Parsons, USDA Forest Service, unpublished research).

The two outbreak trajectories resulted in different spatial patterns of tree mortality and had different implications for fire behavior. The “high and fast” case resulted in higher rates of spread (Fig. 3.5) and more intense fire behavior due to the higher proportion of red-stage trees. These findings are consistent with other researchers who found that crown fire intensity and canopy fuel consumption are strongly related to the percentage of red-stage trees in a stand (Hoffman and others 2012).

More intense fires might be possible in stands experiencing “high and fast” MPB outbreaks, but fire hazards are likely to decline sooner than in stands experiencing “low and slow” outbreaks. This is due to disrupted continuity of canopy fuels as trees lose their needles during the gray stage. More rapid rates of tree mortality for the “high and fast” scenario result in a relatively synchronous loss of needles and fine branches. In contrast, the red-stage persists over a longer period of time for “low and slow” outbreaks (Russ Parsons, USDA Forest Service, *unpublished data*).

As time continued in the model and canopy fuels dropped to the surface, wind speeds increased in both the “low and slow” and “high and fast” simulations due to less resistance from tree canopies (Fig. 3.5; Schoennagel and others 2012; Jenkins and others 2014). This change may result in faster surface fires. More work is needed to understand these interacting factors.

Research finding #5: Many questions remain about potential impacts of the MPB epidemic on forest fuels and fire behavior.

Despite two review papers (Hicke and others 2012; Jenkins and others 2014), our understanding of post-epidemic fire behaviors continues to be fraught with

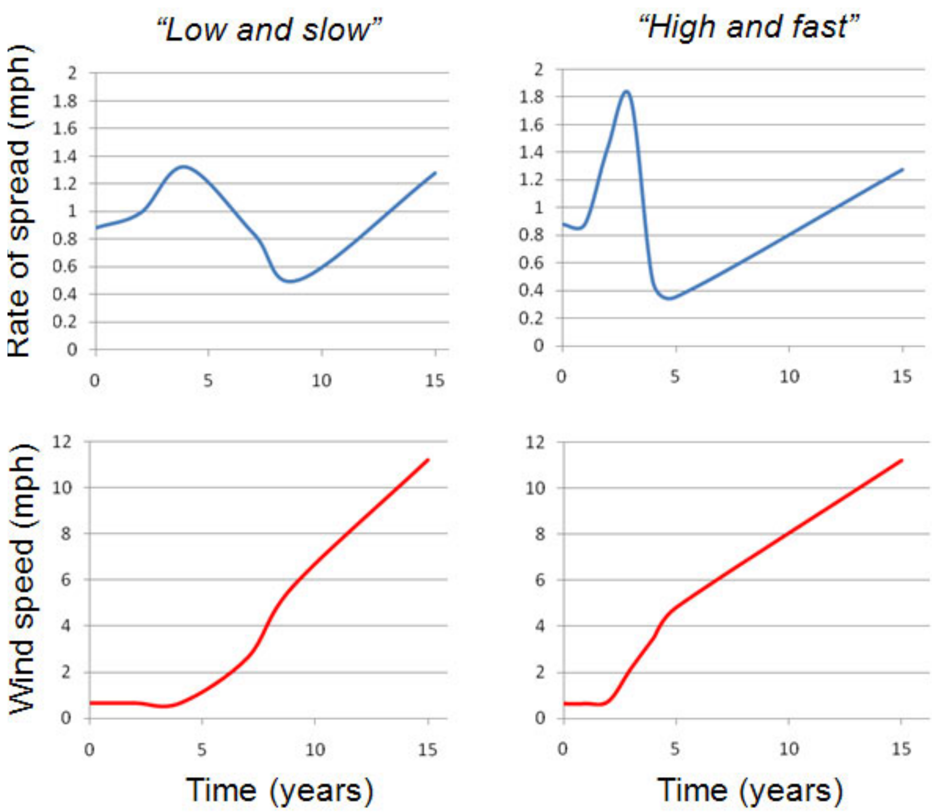

Figure 3.5. Potential effects of "low and slow" versus "high and fast" MPB outbreaks as modeled with the Wildland-Urban Interface Fire Dynamics Simulator (WFDS). Peak rates of spread are potentially greater for "high and fast" outbreaks due to the abundance of red-stage trees. As trees fall to the ground, potential wind speeds increase over time (Russ Parsons, USDA Forest Service, unpublished research).

contradictions. For example, one finding is that MPB outbreaks do not necessarily lead to an increased risk of active crown fire (Simard and others 2012). This seems counter-intuitive given the large amounts of dry fuels in these forests. Contradictory research findings arise because many interacting factors influence post-epidemic fire behavior. These factors include:

- *The rate and intensity of a MPB outbreak over space and time* (see Research finding #4). MPB-affected stands are often mixtures of green, red, and gray trees. Mixing causes greater variability in the continuity of canopy fuels, which might reduce the potential of active crown fires (Hicke and others 2012; Jenkins and others 2014).
- *Different pre-outbreak compositions and structures.* Fuel loads and distributions are less affected in stands with a lower proportion of pines and/or a lower proportion of beetle-killed pines (Schoennagel and others 2012).
- *Lower canopy bulk densities of trees killed by the MPB.* This factor might moderate hazards from more abundant fine surface fuels, leading to less intense crown fire behavior (Hicke and others 2012). Alternatively, greater wind speeds in gray-stage forests might promote active crown fires (Research finding #4; Schoennagel and others 2012; Jenkins and others 2014).
- *Specific weather conditions largely impact post-outbreak fire potentials.* The risk of severe wildfire is likely high during a drought in dense pine forests, regardless of outbreak status (Schoennagel and others 2012).

Remaining Questions & Knowledge Gaps	
Remaining Questions & Knowledge Gaps	• How do vertical snags during the gray-stage influence rates of spread and fire line intensity? • What is the timing and rate of snag-fall, and how does this affect changes in fuel loads over time? • To what degree do changes in microclimate during different post-epidemic stages influence fire behavior? • What impacts will heavy accumulations of dead and downed woody fuels have on fire line construction, holding operations, and safety zone adequacy?

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Meet the chapter presenters and authors

Matt Jolly works for the Rocky Mountain Research Station as a Research Ecologist with the Missoula Fire Sciences Lab. Matt served six years in the United States Air Force as a Satellite Communications Technician, and he earned a Ph.D. in Forestry from the University of Montana in 2004. Matt focuses his research on linking plant physiological processes with combustion and fire behavior characteristics and understanding the roles that live fuels play in current, operational fire behavior prediction systems. He can be reached at mjolly@fs.fed.us; 406-329-4848.

Paul Langowski is the Branch Chief for Fuels and Fire Ecology with the Rocky Mountain Region of the Forest Service. He has program leadership responsibility for fuels management and fire use programs on National Forests and Grasslands lands in Colorado, Wyoming, South Dakota, Nebraska and Kansas. Paul also serves as the Forest Service representative to the Fuels Management Committee and Fire Use Sub-Committee of the National Wildfire Coordinating Group, and he is vice-chair of the Governing Board for the Joint Fire Science Program. Paul can be reached at plangowski@fs.fed.us; 303-275-5307.

Megan Matonis is a Ph.D. student at Colorado State University and a graduate student cooperator with the Science Application & Integration staff at the Rocky Mountain Research Station. Reach Megan at mmatonis@fs.fed.us; 970-498-1342.

Sue Miller is a contract science writer for the Rocky Mountain Research Station. She received her Ph.D. in ecology from the University of Georgia. Sue can be reached at millroad@comcast.net.

Russ Parsons works for the Rocky Mountain Research Station as a Research Ecologist with the Missoula Fire Sciences Lab. He specializes in simulation modeling and spatial analysis, with a focus on the impact of fuel loads and arrangements on fire behavior. Russ received his Ph.D. in Forestry from the University of Montana in 2007. Reach Russ at rparsons@fs.fed.us; 406-329-4872.

Chapter 4—Forests in transition: Post-epidemic vegetation conditions

Authors: Rob Hubbard, Michael Battaglia, Chuck Rhoades, Jim Thinnes, Tom Martin, Jeff Underhill, and Mark Westfahl

Presenters: Michael Battaglia, Chuck Rhoades, Jim Thinnes, Tom Martin, Jeff Underhill, and Mark Westfahl

Introduction

More than 23 million acres of lodgepole pine forests across the western U.S. have experienced overstory mortality following the recent mountain pine beetle (MPB) epidemic (USDA Forest Service 2013). Unknowns regarding the immediate and long-term consequences of the epidemic challenge the ability of managers to make informed decisions aimed at sustaining forest health and delivery of ecosystem services. There is a large body of research regarding the recovery of lodgepole pine forest following fire and logging; however, the trajectory of stand development in beetle-killed forests is poorly understood. Research presented in this webinar aims to better understand forest recovery following the MPB epidemic, including the impacts of management options on regeneration, fuel loads, and potential fire behavior.

Lodgepole pine forests in the central and southern Rocky Mountains can be broadly classified into two main types: pure lodgepole pine and mixed-species lodgepole pine stands (Fig. 4.1). Pure lodgepole stands are those where the majority of the overstory is composed of lodgepole pine, and understory vegetation and advanced regeneration is sparse. Pure lodgepole pine forests generally exist on drier and warmer landscape positions and are also found in frost pockets. Mixed-species lodgepole pine stands generally exist on wetter sites and have a mixture of overstory species including lodgepole pine, Engelmann spruce, subalpine fir, and/or quaking aspen. The relative percentage of these species depends on a variety of factors, including site conditions and disturbance history. Mixed-species lodgepole pine stands usually have significant advance regeneration that reflects overstory composition.

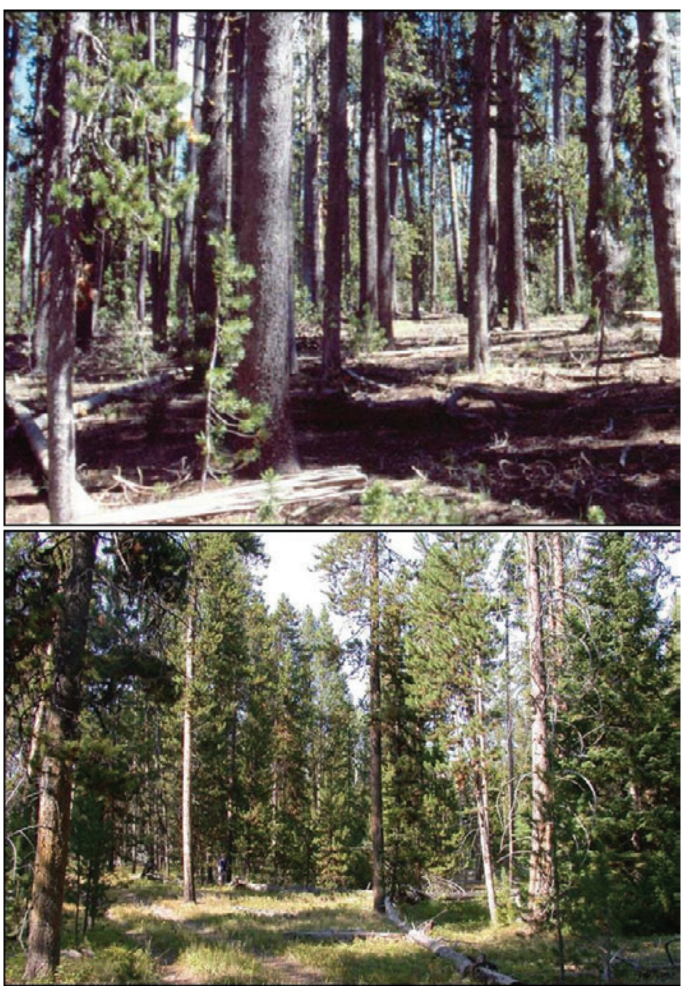

Figure 4.1. Lodgepole pine forests in the central and southern Rocky Mountains can be broadly classified into two main types: pure lodgepole pine (top), typically occurring on drier sites, and mixed-species lodgepole pine stands (bottom), often found on wetter sites (photos courtesy of USDA Forest Service).

The MPB has caused significant overstory mortality in both pure and mixed-species lodgepole pine stands. The original stand structure, species composition, and management treatments will influence the post-beetle trajectory of forest recovery in these ecosystems.

Research findings

Research finding #1: Research and management observations in Colorado and Wyoming suggests there is adequate regeneration in beetle-affected forests to ensure forest recovery.

Management Implications

- Tree planting is unnecessary in many stands impacted by the MPB. Advanced regeneration and seedling recruitment are adequate to ensure recovery to pre-epidemic basal areas.
- Some mixed-species lodgepole pine forests may experience a shift in their dominant tree species from lodgepole pine to subalpine fir and aspen.

Future forest growth trajectories in MPB affected forests may differ substantially from stands that have experienced disturbance from wildfire or logging. In beetle-killed lodgepole pine forests, pine establishment can be inhibited by limited seed source and/or the absence of exposed mineral soil. The uncertainty of forest growth trajectories has led to a strong research effort to evaluate the role of seedling recruitment and advance regeneration in the recovery of beetle-killed forests.

Multiple studies suggest that forests will recover in the wake of this MPB epidemic:

- Pelz and Smith (2012) re-sampled pure and mixed species lodgepole pine stands that had experienced a MPB outbreak in the 1980's. Thirty years following the outbreak, pure lodgepole pine stands had recovered 91 percent of pre-mortality basal area and 93 percent of overstory tree density. In many stands, the dominant species in the understory switched from pine to subalpine fir and aspen. In mixed-species stands, basal area and overstory tree density remained significantly reduced, and subalpine fir and Engelmann spruce continued to dominate the understory.
- Collins and others (2011) sampled 24 mixed-species lodgepole pine forests in northern Colorado that had been impacted by the recent MPB epidemic. They found that average seedling recruitment and advance regeneration exceeded regional stocking requirements of 150 trees/acre (Fig. 4.2).
- Research in Rocky Mountain National Park suggests that remaining live trees and understory saplings are sufficient to ensure forest recovery, in spite of an average reduction in overstory basal area of 64 percent. Residual live trees, saplings, and seedlings averaged 1,600 stems/acre in both pure and mixed-species stands, with a slight increase in the abundance of subalpine fir, Engelmann spruce, and aspen (Diskin and others 2011).
- Across the Medicine Bow Range in Wyoming, advance regeneration of lodgepole pine exceeded acceptable stocking levels (780 stems/acre) in 19 of 20 pure and mixed lodgepole pine stands following the current MPB epidemic (Kayes and Tinker 2012).

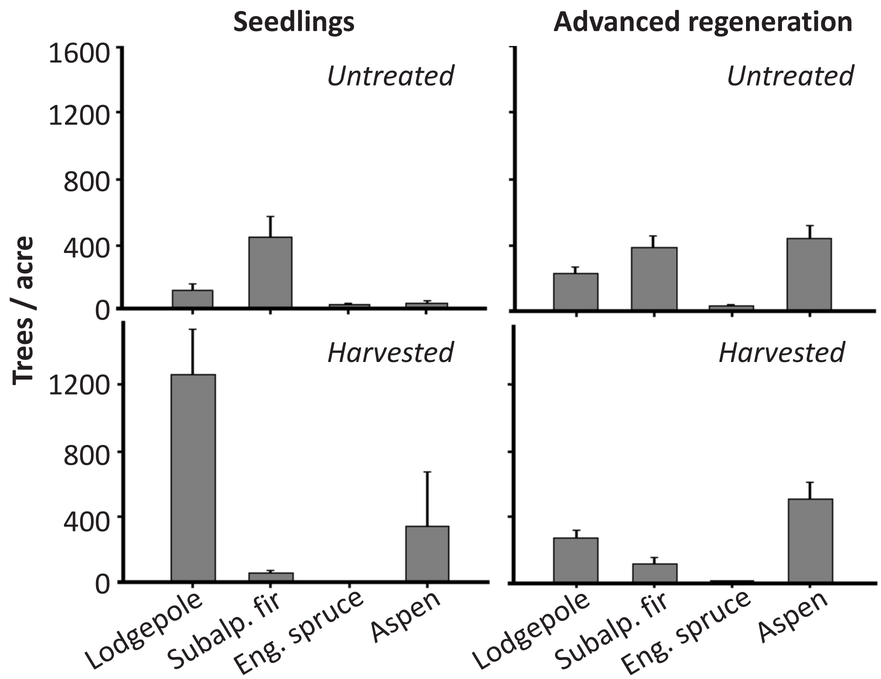

Figure 4.2. Density of seedlings and advance regeneration in harvested versus untreated forests across four MPB management areas in northern Colorado (figure adapted from Collins and others 2011).

Research finding #2: Residual overstory and understory trees are growing faster following the MPB epidemic.

The MPB caused a significant loss of lodgepole pine overstory, resulting in increased availability of light, water, and nutrients for surviving vegetation. Increased resource availability can facilitate growth and recovery of residual vegetation. Surviving trees increased growth by a factor of two to three following a MPB outbreak in the late 1960's and early 1970's in Yellowstone National Park (Romme and others 1986).

Preliminary research at the Fraser Experimental Forest in northern Colorado found increased growth in residual overstory subalpine fir and Engelmann spruce after the most recent MPB epidemic. In a three-year period following the epidemic, more than 35 percent of sampled overstory trees showed an increase in growth relative to ten years prior to the epidemic, and 16 percent grew faster than any other time during their life span. In addition, advanced regeneration of lodgepole pine and subalpine fir more than doubled their height growth since the beginning of the MPB epidemic (Collins and others 2011).

Research finding #3: Alternative management practices create a range of regeneration scenarios.

The current MPB epidemic has raised concern about wildfire and threats to public safety from falling trees, prompting an unprecedented management response in MPB impacted areas. Rates of post-epidemic timber harvesting are greater than at any other time since the 1970's. However, the epidemic is so extensive that only about 15 percent of the landscape will be treated (Collins and others 2010).

Management Implications

- Decisions about slash retention and soil disturbance create tradeoffs between water delivery and seedling establishment.
  - Greater slash retention can enhance water delivery by promoting snow accumulation. This can enhance seedling growth, but the absence of bare mineral soil can inhibit seedling establishment.
  - Removal of slash and exposure of mineral soil can enhance seedling establishment, but it reduces surface roughness and snow accumulation.
- Fuels reduction treatments in mixed-species lodgepole pine stands might result in future forests dominated by lodgepole pine, whereas untreated stands might be dominated by subalpine fir.

Forest managers have a suite of management alternatives available for treating beetle-killed stands. These alternatives result in different amounts of aboveground structure (*i.e.,* snags), surface roughness, and soil disturbance:

- "No action" option retains standing snags, downed wood, and maximum surface roughness.
- Watershed protection / delivery treatments maximize water delivery by retaining logging residue on site. Slash maintains surface roughness, increasing snow accumulation, and helps avoid soil disturbance.
- Fuel reduction treatments focus on removing snags and slash.
- Forest regeneration treatments combine slash reduction and mechanical scarification to enhance seedling establishment.

All four of these management options are likely to impact soil resources and seedling recruitment and growth. Research across four MPB management areas in northern Colorado found that watershed protection and water delivery treatments increased seedling height growth by approximately 20 percent relative to the other treatments (Chuck Rhoades and others, USDA Forest Service, *unpublished data*). This is possibly due to increased water availability. Survival of seedlings experimentally planted by researchers was generally greater in the forest regeneration treatments, but natural seedling recruitment was greater in fuel reduction treatments.

Treatments can also result in different species compositions in mixed-species lodgepole pine stands. Research in northern Colorado found that about 75 percent of new seedlings in cut areas were lodgepole pine, where about 70 percent of new seedlings in untreated stands were subalpine fir (Fig. 4.2; Collins and others 2011). Cut areas had about ten times more new pine seedlings and seven times more aspen sprouts than untreated stands.

Stand development projections using the Forest Vegetation Simulator (FVS) suggest that significant aspen sprouting will increase the proportion of aspen in both untreated and harvested areas. Lodgepole pine will become the dominant species in harvested areas after aspen declines, while subalpine fir and lodgepole pine will dominate in untreated areas a century after the MPB epidemic (Fig. 4.3).

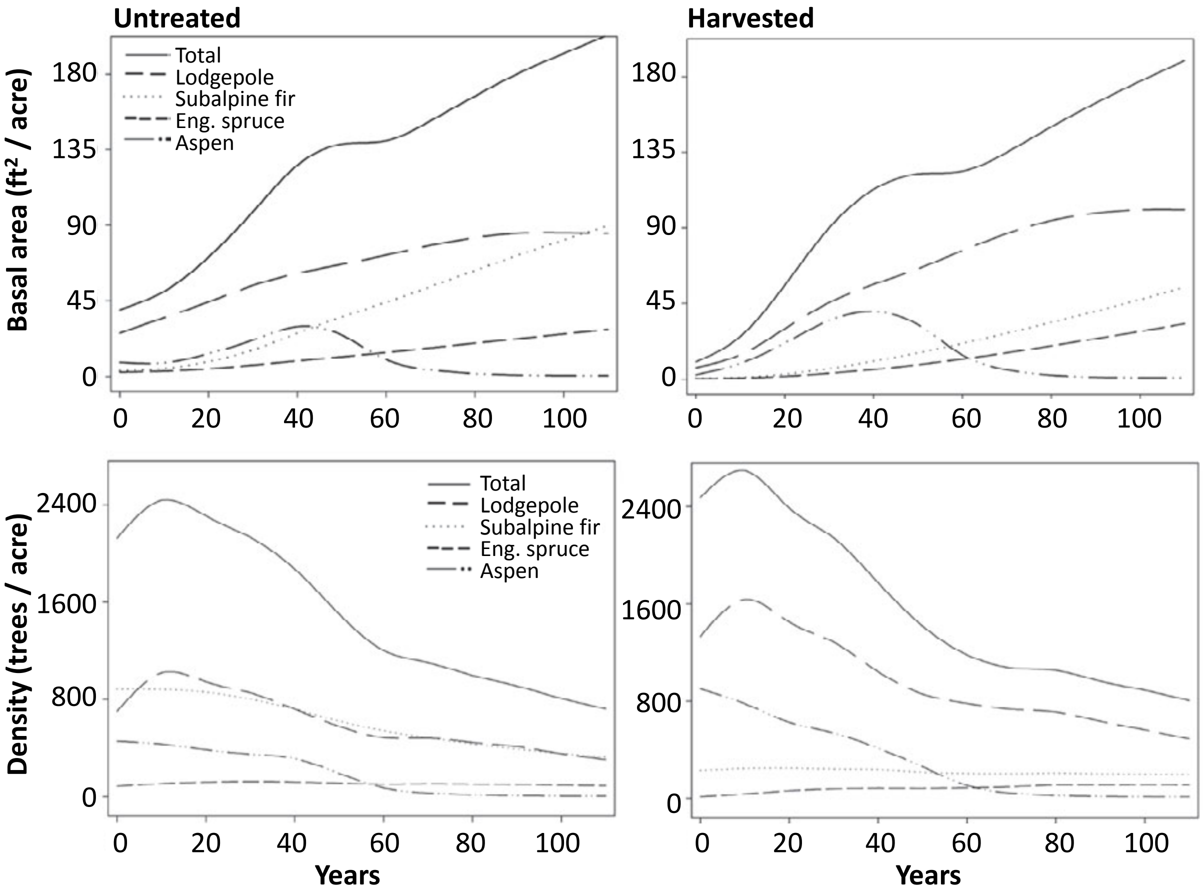

Figure 4.3. Projected stand development based on initial observations in harvested (n = 24) and untreated stands (n = 24) across northern Colorado. Growth was simulated using the Forest Vegetation Simulator. Projections were based on observed regeneration, overstory conditions, and site index (reprinted from Collins and others 2011).

Research finding #4: Tree mortality from the MPB epidemic and post-epidemic harvesting will influence fuel loads and fire behavior for many decades to come.[6]

The MPB epidemic and subsequent harvesting substantially alter fuel loads with potential implications for fire behavior. Salvage logging in beetle-infested Colorado forests is expected to affect future fires by favoring regeneration of pine and aspen over subalpine fir, a species with a dense crown and branches that extend to the ground. Abundant subalpine fir in untreated, beetle-killed stands could act as ladder fuels that allow fires burning on the surface to spread into the forest canopy.

Researchers at the Rocky Mountain Research Station explored this possibility using FVS and its Fire and Fuels Extension. They compared forest composition and fuel loads in 24 paired treated and untreated stands in northern Colorado and projected stand structure characteristics and potential fire behavior over the next 100 years (Collins and others 2012a,b). They found that:

[6] *This research finding reinforces material presented in Research Findings 2 and 3 of Chapter 3.*

Management Implications	• Fuel loads are initially greater in harvested stands, but research suggests this does not increase the potential for crown fires. • Untreated stands will accumulate greater coarse fuel loads (≥3 inches in diameter) over time, increasing the potential for larger and more severe wildfires across beetle-killed landscapes. • Abundant subalpine fir regeneration in untreated, beetle-killed stands could act as ladder fuels that facilitate the transition from surface fires to crown fires.

- Surface fuel loads (1, 10, 100, and 1000-hr size classes) were about 3 times greater in harvest units compared to untreated stands.
- Coarse fuel loads (≥3 inches in diameter) will accumulate over time, increasing the potential for larger and more severe wildfires. Higher coarse fuel loads increase soil heating, increase the production of airborne embers, and hinder fire suppression.

Differences in tree species composition and the higher fuel loads in untreated, beetle-killed stands create the potential for more extreme fire behavior compared with harvested areas (Fig. 4.4). Fire behavior might become more similar between untreated and harvested areas when trees lose their needles and transition into the gray-stage. However, as the forest overstory develops, abundant subalpine fir will increase the canopy bulk density and lower canopy base height of untreated stands. These crown conditions allow for torching at lower wind speeds and increase active crown fire potential during extreme weather (Fig. 4.5). As a result, passive crown fires (*i.e.,* fires that ignite individual tree crowns but do not spread between canopies) are expected to occur in untreated stands under average weather conditions (*i.e.,* 50th percentile weather). In contrast, surface fires are predicted for harvested areas under similar weather conditions (Collins and others 2012a).

Remaining Questions & Knowledge Gaps	• How adequate are forest growth projections from the Forest Vegetation Simulator, given that it was developed for stands that had not experienced significant bark beetle disturbances? • How do standing dead snags and subsequent tree fall impact stand development over time? • To what degree can an abundance of herbaceous vegetation in some post-epidemic understories impact seedling recruitment and establishment? • How will future disturbances from insects, diseases, and fire influence stand development in treated and untreated pure and mixed-species lodgepole pine forests?

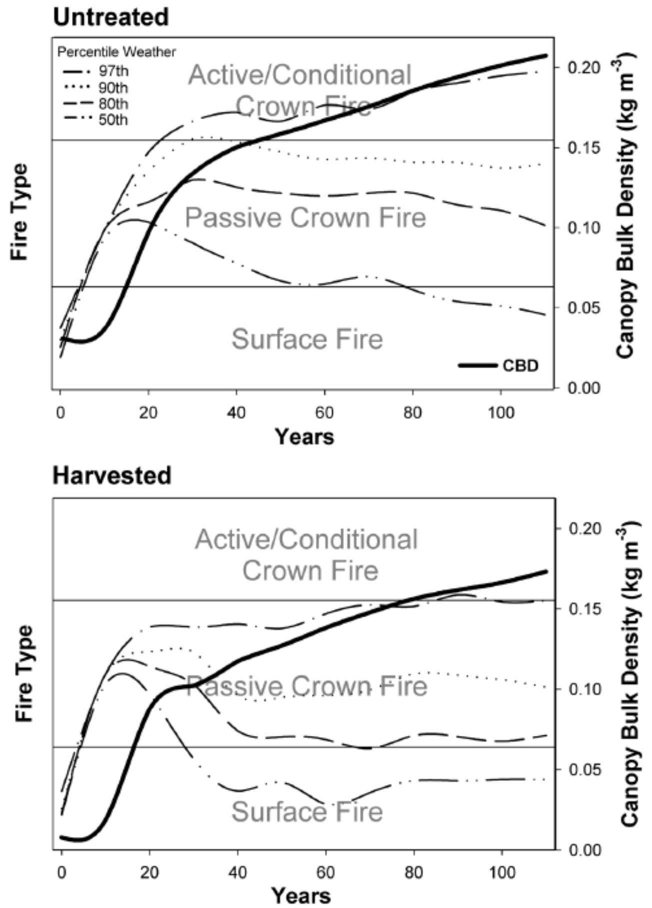

Figure 4.4. Changes in surface fuel loads in harvested and untreated MPB management areas as estimated by the Forest Vegetation Simulator Fire and Fuels Extension. Projected changes based on initial observations of fuel loads in 24 untreated and 24 harvested areas across northern Colorado (reprinted from Collins and others 2012a).

Figure 4.5. Removing beetle-killed trees can increase surface fuel loads for several years following treatments, but over time, coarse woody fuel loads will be greater and ladder fuels more abundant in untreated forests. Untreated forests might have greater potential for crown fires in the future, increasing safety concerns for firefighters during fire operations (image of the 2010 Church's Park Fire near Fraser, CO, courtesy of InciWeb).

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Meet the chapter presenters and authors

Michael Battaglia is a Research Silviculturist and has been a scientist with the USFS Rocky Mountain Research Station since 2011. He received his Ph.D. in Forest Sciences from Colorado State University in 2007. Mike's research interests focus on forest restoration, fuels mitigation, and forest resilience across multiple spatial scales. He can be reached at mbattaglia@fs.fed.us; 970-498-1286.

Rob Hubbard has worked as a Research Ecologist with the Rocky Mountain Research Station since 2005. He worked as a Research Ecologist for the Coweeta Hydrologic Lab in North Carolina after graduating with his Ph.D. in forest ecology from Colorado State University. Rob's research explores how forests respond to disturbances and the role that plants play in regulating hydrologic processes. Reach Rob at rhubbard@fs.fed.us; 970-498-1260.

Tom Martin is the Assistant Director Renewable Resource Management for the Northern Region of the Forest Service. Tom has worked with the Forest Service for over 35 years in timber management, silviculture, environmental analysis, and forest planning. He has dedicated most of his career to developing forest conditions that meet resource objectives, including the use of timber harvests as a tool to meet resource, social, and economic needs. Tom graduated in 1978 with a B.S. in Forest Management, and he is a certified silviculturist. Reach Tom at thmartin@fs.fed.us; 406-329-3608.

Chuck Rhoades is a watershed biogeochemist and has been with the Rocky Mountain Research Station since 2003. He earned his Ph.D. in forest biogeochemistry and soil ecology from the University of Georgia in 1998. Chuck's research interests focus on forest biogeochemical processes that regulate the delivery of clean water and sustain productive soils and forests. He can be reached at crhoades@fs.fed.us; 970-498-1250.

Jim Thinnes has been the Regional Silviculturist for the Rocky Mountain Region of the Forest Service since 2005. He has 30 years of experience with the Forest Service in environmental planning, silviculture, timber management, hydrology, and wildland fire suppression. He is an SAF Certified Forester and received his degree in natural resource management from Ohio State University. He has much on-the-ground experience with the MPB epidemic owing to his time on the Pike & San Isabel National Forest and the White River National Forest. He can be reached at jthinnes@fs.fed.us; 303-275-5016.

Jeff Underhill is the Forest Timber Program Manager and Forest Silviculturist for the Pike & San Isabel National Forests. Jeff has five years of experience addressing the effects of the MPB epidemic through his work on the Pike & San Isabel National Forests and Arapaho & Roosevelt National Forests. Jeff received his M.S. in Forestry from the University of Tennessee and his B.A. in History from Virginia Tech. He can be reached at junderhill@fs.fed.us; 719-553-1513.

Mark Westfahl is the Timber Program Manager and Forest Silviculturist for the Medicine Bow-Routt National Forests. At the time of the Future Forest Webinar Series, he was a Silviculturist and Safety Coordinator for the Medicine Bow-Routt National Forests. Mark has worked in timber management for the Forest Service for over 25 years, spending three seasons on the Arapaho & Roosevelt National Forests before starting on the Parks Ranger District of the Medicine Bow-Routt National Forests. He is a certified silviculturist and graduated from the University of Montana with a B.S. is Forest Resource Management. Reach Mark at mwestfahl@fs.fed.us; 970-723-8204.

Chapter 5—Ecological consequences of the MPB epidemic for habitats and populations of wildlife

Authors: Beth Hahn, Vicki Saab, Barbara Bentz, Rachel Loehman, and Bob Keane

Presenters: Beth Hahn, Vicki Saab, Barbara Bentz, Rachel Loehman, and Bob Keane

Introduction

Wildlife biologists must balance a diverse array of ecological and social considerations in managing species and habitats. The challenges of managing species and habitats in dynamic landscapes are influenced by diverse factors, including natural disturbances, vegetation development, and anthropogenic-mediated changes, such as climate change, management activities, and land use. Mountain pine beetles (MPBs) can be viewed as an ecosystem engineer—a species that both directly and indirectly shapes landscapes by altering the composition, structure, and function of ecosystems. Although native wildlife species co-evolved with natural disturbances such as MPB outbreaks, in the shorter term these changes simultaneously create and eliminate certain habitats. Additionally, changes to ecosystems from MPB outbreaks interact with other processes such as fire, nutrient cycling, and sedimentation to further alter habitats.

Species-specific responses are expected to vary as a function of outbreak severity, time since the peak of tree mortality, and characteristics of the species, including life history traits, habitat associations, and foraging requirements (Saab and others 2014). MPB outbreaks cause both short- and long-term changes in the pattern, extent, and structure of habitats, with major implications for wildlife populations. For example, MPBs provide an extended food resource for some bird species, while reducing habitat in the short term for other species, such as the pine squirrel.

Managing forests to anticipate or mitigate the effects of the MPB epidemic on wildlife species is challenging. For instance, there are critical differences in the operative scales for responding to MPB outbreaks and managing forest resources and wildlife populations. Beetle-induced tree mortality may be high at the stand scale (Fig. 5.1), but most vertebrate populations exist across areas with magnitudes much larger than a single stand or watershed. Moreover, the "footprint" of interacting natural disturbances such as the MPB epidemic and fire is enormous compared to the footprint of most land management actions (see **Chapter 8**).

Wildlife management does not proceed in isolation from other considerations such as timber or recreation. Projects are designed and analyzed by interdisciplinary teams, and wildlife biologists contribute to this process by adding elements that either improve habitat or mitigate adverse impacts. Project design and analysis must comply with relevant law, regulation and policy (*e.g.*, National Forest Management Act, National Environmental Policy Act, and Endangered

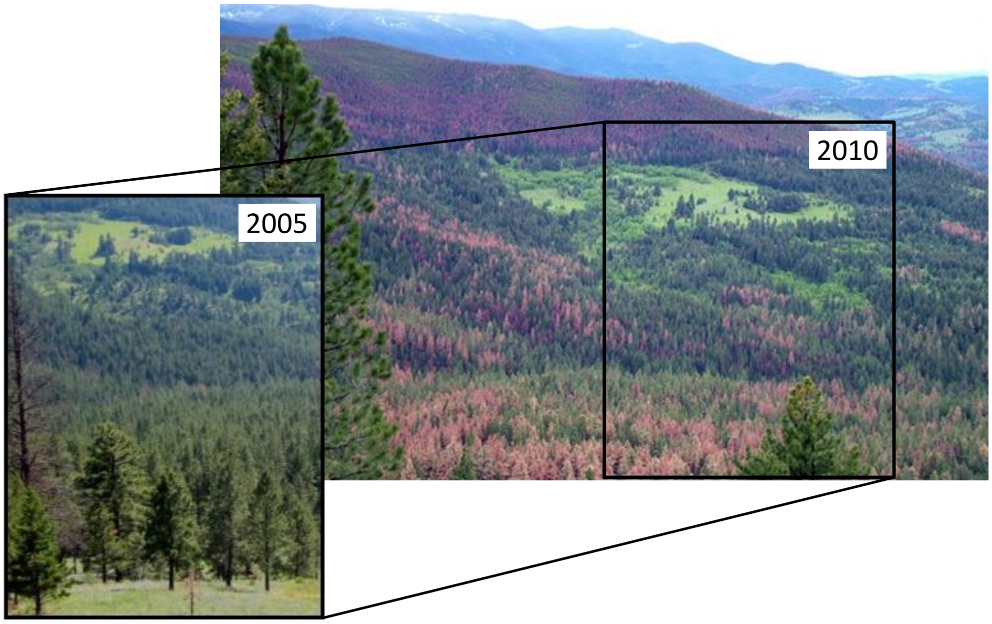

Figure 5.1. Tree mortality from the current MPB epidemic in the Elkhorn Mountains, Helena National Forest. Left photo shows pre-epidemic conditions in 2005; right photo shows the same site in 2010 (photos by V. Saab and Barbara Bentz, USDA Forest Service).

Species Act). Analysis requirements imposed by laws or regulations frequently differ from ecologically-relevant spatial and temporal scales (Ruggiero and others 1994; Block and others 2012). For instance, a Forest Service biologist will need to evaluate whether a 1,000-acre salvage harvest within a 15,000-acre project area will affect the persistence of sensitive species (*e.g.*, black-backed woodpecker) at the scale of the entire National Forest. An entire National Forest is much larger than the home ranges for different populations of black-backed woodpeckers (*cf.* Pierson and others 2010).

In this webinar, we used a case study approach to examine the ecological consequences of the MPB epidemic for wildlife habitats and species. We presented different methods for comparing spatial and temporal patterns of bird diversity, reproduction, habitat use, persistence, and foraging in relation to the MPB epidemic. We also presented modeling techniques for investigating wildlife responses to large-scale disturbance.

Research findings

Research finding #1: Life history traits can help predict the impact of disturbances on populations and habitats of wildlife species.

Management Implications

- The MPB epidemic created habitat for some species and eliminated habitat for others. Birds that eat beetles and/or build nests in snags will likely benefit for several years following the epidemic, whereas foliage gleaners may have lower occupancy levels relative to pre-epidemic conditions.
- Responses of bird guilds to disturbance change over time as vegetation recovers and alters habitat suitability.
- Areas with low, medium, and high levels of beetle-induced tree mortality provide habitat for different types of species.

Scientists with the Rocky Mountain Research Station are examining implications of the MPB epidemic for habitats and populations of small land birds. Birds make an ideal model for evaluating wildlife responses to the MPB epidemic because of their high sensitivity to disturbances (Saab and Powell 2005; Saab and others 2014). Guilds—groups of ecologically similar species—can be useful categories for predicting and examing bird responses to disturbance. Cavity-nesting birds that feed on larvae, and bark- and wood-boring insects are one guild (*e.g.*, woodpeckers), while foliage-gleaning birds that nest in open cup structures are another guild (*e.g.*, golden-crowned kinglet).

Responses of bird guilds to disturbance change over time as vegetation recovers and alters habitat suitability (Fig. 5.2). The first years after a disturbance are more favorable for cavity-nesting species because of the high abundance of snags for nesting. Populations of beetle-foraging specialists also peak four to five years after fire or MPB outbreaks due to elevated populations of bark and wood-boring insects (Saab and others 2007b; Davis and others 2012). Ground and aerial insectivores continue to increase for at least 12 years following a wildfire, particularly when there is a pulse of arthropods due to nutrient release after fire (Saab and others 2007b). Omnivorous, shrub-nesting species select habitats that form as snags begin to fall and shrubs establish. Canopy-nesting species and foliage gleaners are the last to colonize forests after disturbance because they depend on dense forest overstories.

Disturbance severity also influences the habitat of different bird guilds. Most foliage-gleaning (*e.g.*, chickadees) and log-foraging species (*e.g.*, pileated woodpecker) are abundant in unburned habitats. Sites experiencing low- and

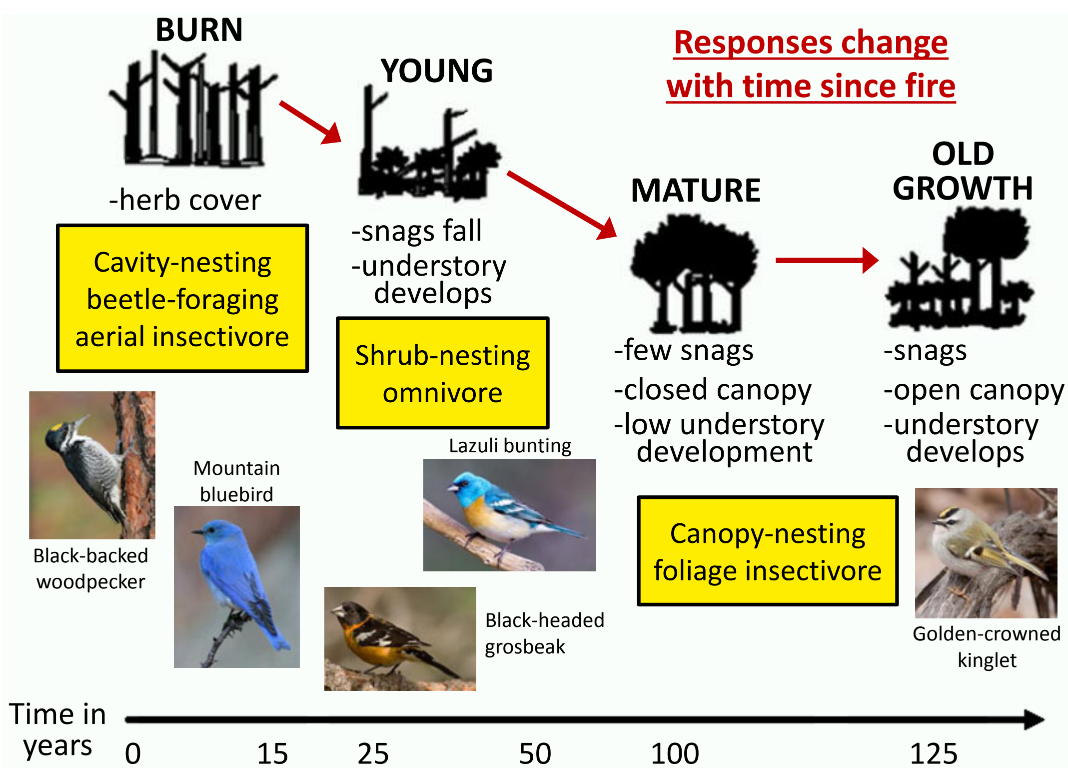

Figure 5.2. Generalized response of bird guilds to post-fire habitat conditions (figure from Saab and others 2007a, modified from Hannon and Drapeau 2005).

mixed-severity fires provide habitat for species benefiting from snag creation and the retention of some live trees for foraging. These species include cavity-nesters that feed on pine seeds (*e.g.*, white-headed woodpecker) and species that glean insects from bark of living trees. At locations subject to moderate and high severity fires, wood drillers (*e.g.*, black-backed woodpeckers) and aerial insectivores (*e.g.*, mountain bluebird) predominate.

Compared to post-fire conditions, data on species and guild responses to insect outbreaks are relatively sparse. Research in the Elkhorn Mountains on the Helena National Forest assessed changes in bird occupancy, nest density, and habitat suitability using data collected before and during the MPB epidemic (Mosher 2011; Saab and others 2014). Occupancy levels were substantially different before and during the MPB epidemic for 30 percent of the species measured. Bark insectivores had a strong positive response, while foliage gleaners had a weak negative response to the epidemic (Mosher 2011). Nest densities for cavity-nesting birds increased, primarily for beetle-foraging species (American three-toed woodpecker, hairy woodpecker, and downy woodpecker). In contrast, nest densities of species that do not forage on beetles remained similar to pre-epidemic levels (Saab and others 2014).

Researchers also modeled nesting habitat suitability for American three-toed woodpeckers. This species responded most favorably to the MPB epidemic in terms of increased occupancy and nest density. Highly-suitable habitat was abundant across the study area following the MPB epidemic (Vicki Saab, USDA Forest Service, *unpublished data*). With more research, habitat suitability models could be developed for additional species to inform management decisions that balance multiple objectives.

Research finding #2: Beetle-killed trees provide an important foraging resource for some bird species immediately following MPB outbreaks.

Management Implications

- Bird species that eat beetles can actually lower the local density of MPB in years with endemic and post-endemic population sizes.
- Large diameter snags are particularly important foraging resources for woodpeckers, with the greatest foraging value occurring 4-5 years after MPB outbreaks.
- Anywhere from 70-90 percent of snags fall within 5 years of a MPB outbreak. Higher fall rates are generally associated with warmer and wetter conditions.

One of the research objectives at the Elkhorn Mountain sites was to estimate how long trees killed by MPBs are a foraging resource for birds. After initial tree attack, MPB larvae and adults develop within a tree for one year before emerging to attack another live tree. A large number of wood-boring insects subsequently infest beetle-killed trees. A single tree can provide a food resource for woodpeckers over several years. At the Elkhorn sites, preliminary results show that woodpeckers preferentially foraged on beetle-attacked trees with large diameters (>9” dbh). These trees are of greatest foraging value in the first 4-5 years following an attack, although infested trees can provide forage up to

14 years after their death (Barbara Bentz, USDA Forest Service, *unpublished data*). Beetle-foraging bird species can actually influence the local density of some MPB populations during endemic and post-epidemic population phases (Fayt and others 2005).

The snag-fall rate will influence the time that a tree is a foraging resource for birds. There is high variability in snag persistence following beetle-induced tree death. Anywhere from 70-90 percent of snags fall within 5 years of a MPB outbreak. The rate that trees fall may be related to climate, soil moisture, tree species, and the speed of bole decay. Higher fall rates are generally associated with warmer and wetter conditions, as well more open forest structures due to lower wind resistance (Mitchell and Preisler 1998; Lewis and Hartley 2006).

Research finding #3: Models can help project changes in wildlife habitat over time and at different spatial scales.

Management Implications

- Model projections at landscape scales are necessary for species that have large home ranges or migrate throughout the year. Smaller-scale projections are more appropriate for species that depend on specific within-stand structures and composition.
- The future is not set in stone, so models can help assess the impact of different management decisions under a range of potential conditions (*e.g.*, climate scenarios).
- Linking site-specific research projects with broader-scale monitoring programs will be essential to derive robust, multi-scale inferences while also leveraging limited resources.
- Understand the assumptions and limitations of models. For example, some datasets are less reliable than others, and this can greatly influence the reasonableness of model predictions.
- Qualitative modeling approaches, such as scenario planning, are often helpful when future conditions are dynamic and largely unknown and/or when quantitative data is not available.

Wildlife managers rely on empirical data and model predictions to estimate wildlife population sizes and habitat suitability. Setting wildlife management priorities for a particular landscape, such as recovery efforts for federally-listed species, requires information at different spatial and temporal scales. Research on implications of the MPB for wildlife can help managers prioritize critical restoration projects, inform project design criteria (*i.e.,* retention, thinning, salvage, and replanting), and identify sites and habitats that should be left in an "unmanaged" state.

Modeling allows managers and researchers to examine interactions among ecological processes (*e.g.*, the MPB epidemic, climate change, and wildfire) and other landscape influences (*e.g.*, management actions and land use changes), and the effect of these dynamic interactions on wildlife habitat. The FireBGCv2 model is useful to exploring long-term trends in landscape conditions, such as the quality of bull trout habitat under different disturbance regimes (Keane and others 2011; Holsinger and others *in review*).

Models are useful for projecting wildlife habitat at sites or times for which there are no empirical observations, and for exploring different landscape configurations (*e.g.*, connectivity and management treatments) over large spatial and long temporal scales. For example, researchers used an extensive stream network database to develop a model of suitable stream habitat for bull trout, a threatened species under the Endangered Species Act, under current and projected climate changes (Rieman and others 2007; Isaak and others 2010). This model is especially helpful to managers because it provides robust inference at both watershed and landscape scales.

Modeling efforts can describe a range of potential future conditions, such as multiple climate scenarios. For example, researchers can couple models of MPB survival with projections of temperatures in future decades to predict future MPB populations across the western United States (Bentz and others 2010). Managers can use simulated future conditions as tools for multi-decadal planning and conservation.

In addition, models can assess ecosystem responses at different spatial and process scales, such as landscape-scale shifts in species abundance, composition, or carbon balance and stand-level vegetation recovery resulting from dynamic climate-vegetation-disturbance interactions (Fig. 5.3). Forest Service researchers and managers are currently developing an integrated, dynamic model to predict changes in bird habitat suitability based on the likelihood of fire and MPB outbreaks. The model incorporates the role of temperature on the developmental phenology of the MPB, as well as the influence of climate on host tree defenses.

Understanding the assumptions and limitations of models, including appropriate spatial and temporal scales, is critical to management applications. Uncertainty

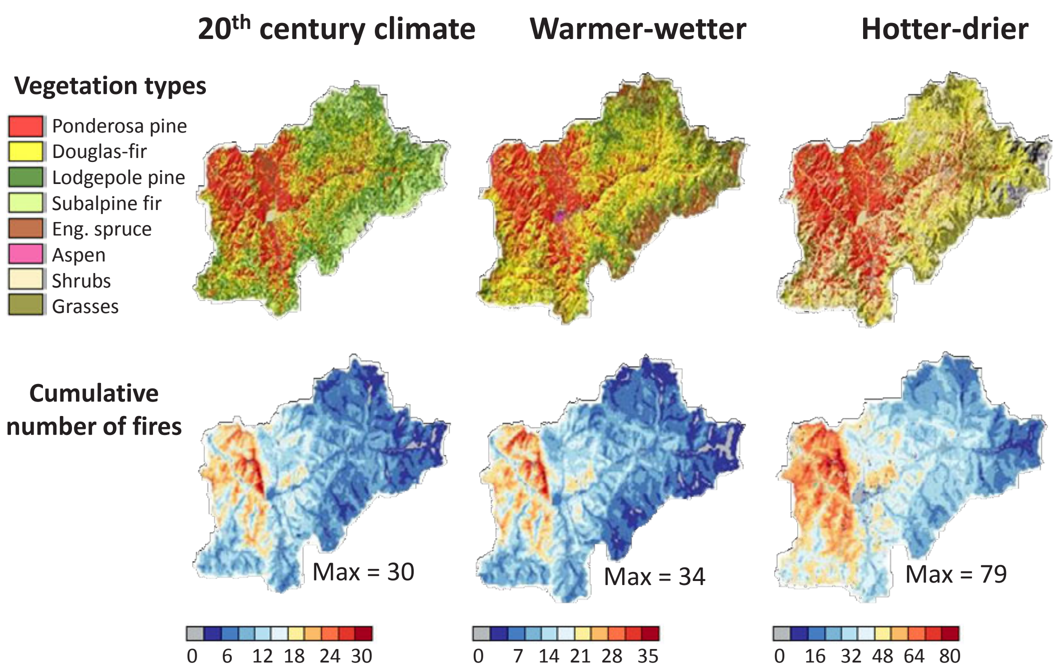

Figure 5.3. Climate-driven changes in vegetation types and fire regimes simulated using the FireBGCv2 model for the East Fork of the Bitterroot River, MT (Holsinger and others in review).

in model predictions can be especially high for short-term projections over large landscapes. In addition, the resolution of available data might be too coarse for predicting changes in habitat components important to wildlife species (*e.g.*, distribution of snags).

Habitat suitability indices can inform short-term management decisions, but mechanistic models that incorporate landscape dynamics are needed to support long-term planning. For example, models have been developed to simulate the effects of climate change scenarios on the distribution of 135 tree species and 150 bird species in the eastern United States (Iverson and others 2011). These models are helpful for projecting the locations of high-quality habitats under potential future conditions. However, they should only be applied at very coarse scales, much larger than the typical management project scale.

Management Implications

- Our understanding of wildlife responses to the MPB epidemic is much more limited than our understanding of post-epidemic vegetation responses and fire hazards responses. Managers and researchers need to identify information gaps and uncertainties.
- Scenario planning and simulation modeling are useful approaches to support decision-making in the face of future dynamic ecosystem conditions.
- Managers and researchers from different disciplines need to collaborate to develop models that incorporate multiple disturbance trajectories, different patterns of vegetation change, and alternative management treatments to estimate a range of possible future conditions (see Chapter 8).

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Meet the chapter presenters and authors

Barbara Bentz has served as a Research Entomologist with the Rocky Mountain Research Station in Logan, UT since 1991. Her research interests include the biology, ecology, and management of MPBs. Barbara's recent research has focused on modeling climate change influences on MPBs populations and the interactions between fire and MPBs. Barbara can be reached at bbentz@fs.fed.us; 435-755-3577.

Beth Hahn is the Branch Chief of Wilderness Science at the interagency Aldo Leopold Wilderness Research Institute, in Missoula, MT. Previously, she worked as the Regional Wildlife Ecologist for the Northern Region of the Forest Service stationed in Missoula, MT. In that capacity, she worked on a variety of multi-scale inventory and monitoring programs, habitat analyses, and plan revision and amendments. Reach Beth at bhahn@fs.fed.us; 406-542542-3244.

Bob Keane is a Research Ecologist with the Rocky Mountain Research Station at the Missoula Fire Sciences Lab. Bob's recent research includes 1) developing ecological computer simulation models for the exploring landscape, fire, and climate dynamics, and 2) investigating the ecology and restoration of whitebark pine. Reach Bob at rkeane@fs.fed.us; 406-329-4846.

Rachel Loehman is a Research Ecologist with the Rocky Mountain Research Station at the Missoula Fire Sciences Lab. Rachel's research includes spatial modeling of climate change effects on ecosystem processes, climate drivers of wildfire, and disturbance ecology. Reach Rachel at raloehman@fs.fed.us; 406-829-7386.

Vicki Saab is a Research Wildlife Biologist with the Rocky Mountain Research Station in Bozeman, MT. Her research interests include disturbance ecology and avian ecology, with an emphasis on cavity-nesting birds and other small landbirds. Her research focuses on avian distributions and demographics in relation to wildfires, MPB epidemics, and forest restoration activities. Vicki can be reached at vsaab@fs.fed.us; 406-994-5032.

Chapter 6—Beetles among us: Social and economic impacts of the MPB epidemic

Authors: Krista Gebert, Greg Jones, Patty Champ, Mike Czaja, Chuck Oliver, Paul E. Cruz, and Jessica Clement

Presenters: Krista Gebert, Greg Jones, Patty Champ, Mike Czaja, Chuck Oliver, Paul E. Cruz, and Jessica Clement

Introduction

Healthy forest ecosystems provide many goods and services that are vital to human well-being. When forest ecosystems are impacted by disturbances, such as the widespread mountain pine beetle (MPB) epidemic, the services provided by these ecosystems are also affected. Likewise, management in response to large-scale forest disturbances impacts both the natural and human environment. These management actions are costly in terms of the amount of taxpayer dollars required to carry them out and in terms of their opportunity costs, especially in areas lacking economically-viable uses of beetle-killed timber. In the budget-constrained environment of land management agencies, more money spent dealing with dead and dying trees often means less money spent on services like building trails, improving wildlife habitats, and ecological restoration.

To date, management responses to the MPB epidemic have focused on public safety, with hazardous tree removal around public campsites, roads, and infrastructure given high priority. However, the MPB epidemic has numerous social and economic impacts beyond human safety. For example, the MPB epidemic affects consumptive uses of the forest, such as timber and biomass production, as well as non-consumptive uses, such as tourism and recreation. The MPB epidemic can also impact other services that the forest provides to humans, such as water quality or quantity and soil stability. Property values can also be impacted by increased risk of wildfires and/or the loss of scenic beauty.

The widespread nature of the MPB epidemic—affecting large portions of Colorado, Idaho, Montana, and Wyoming—exacerbates social and economic costs since both more area and more people are affected. For example, the MPB attack might have decimated favorite nearby recreation sites as well as farther-flung recreation areas, leaving people without alternatives. The extent of the epidemic makes it impossible to mitigate all hazards everywhere. Land management agencies must use a triage approach to prioritize hazardous tree removal and fuel treatments.

The social and economic impacts of the MPB epidemic are many, but research on this topic is limited. Such research is necessary to understand the tradeoffs associated with management options and to help land managers allocate limited budgets to address public concerns. Additionally, insight into the benefits and costs provided by various management options can be communicated to stakeholders to enhance the public understanding and support of the unavoidable tradeoffs that must be made.

Research highlighted in this webinar focused on areas where research is available concerning the social and economic effects of the MPB epidemic. These efforts focused on (1) opportunities and challenges for utilizing beetle-killed trees for woody biomass, (2) impacts of pests on non-market values, and (3) public perceptions of forest management following the MPB epidemic. Land managers from Bitterroot National Forest in Montana and the Arapaho-Roosevelt National Forest in Colorado also provided thoughts and insights about socio-economic impacts of the MPB.

Research findings

Research finding #1: The availability of forest industry infrastructure greatly affects the cost of tree removal and, therefore, the amount of mitigation and hazard removal that can be accomplished.

Management Implications	• The feasibility of selling woody material to offset treatment costs depends on hauling distances, transportation costs, market prices, and prices of alternatives (*e.g.*, natural gas).

Forest-industry infrastructure is crucial for dealing with the MPB epidemic. States with robust forest-products infrastructure, such as Montana, can finance

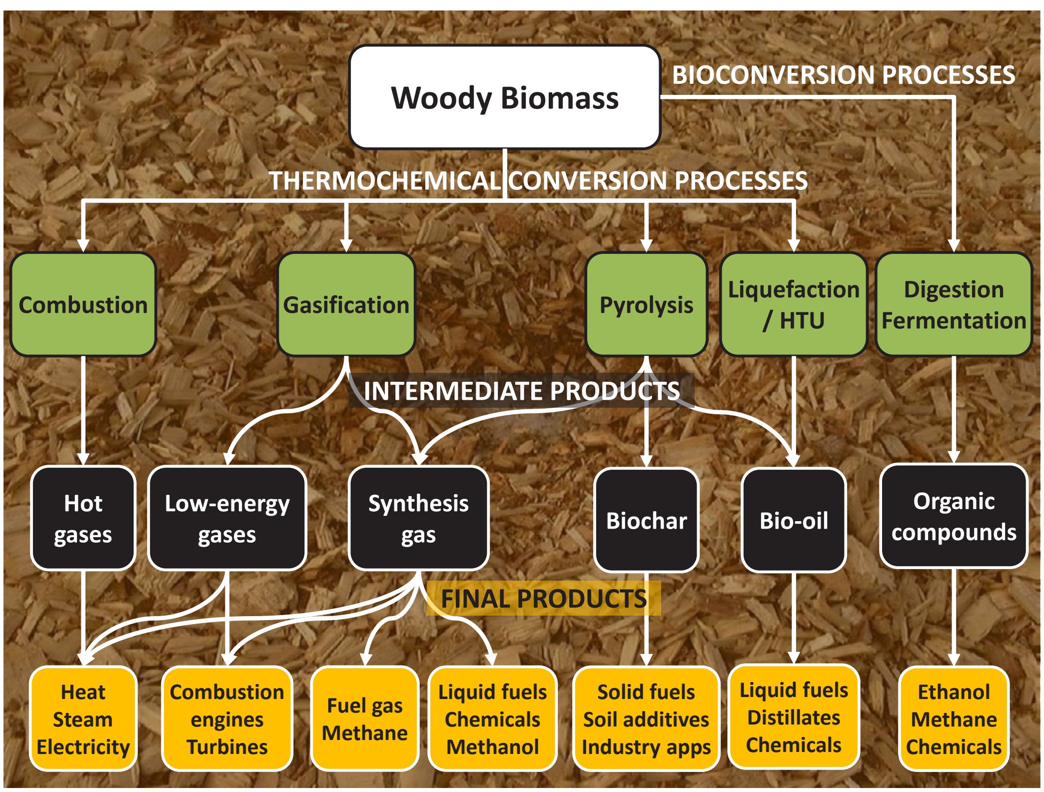

Figure 6.1. Several technological approaches are available for converting biomass into different forms of bioenergy (adapted from McKendry 2002).

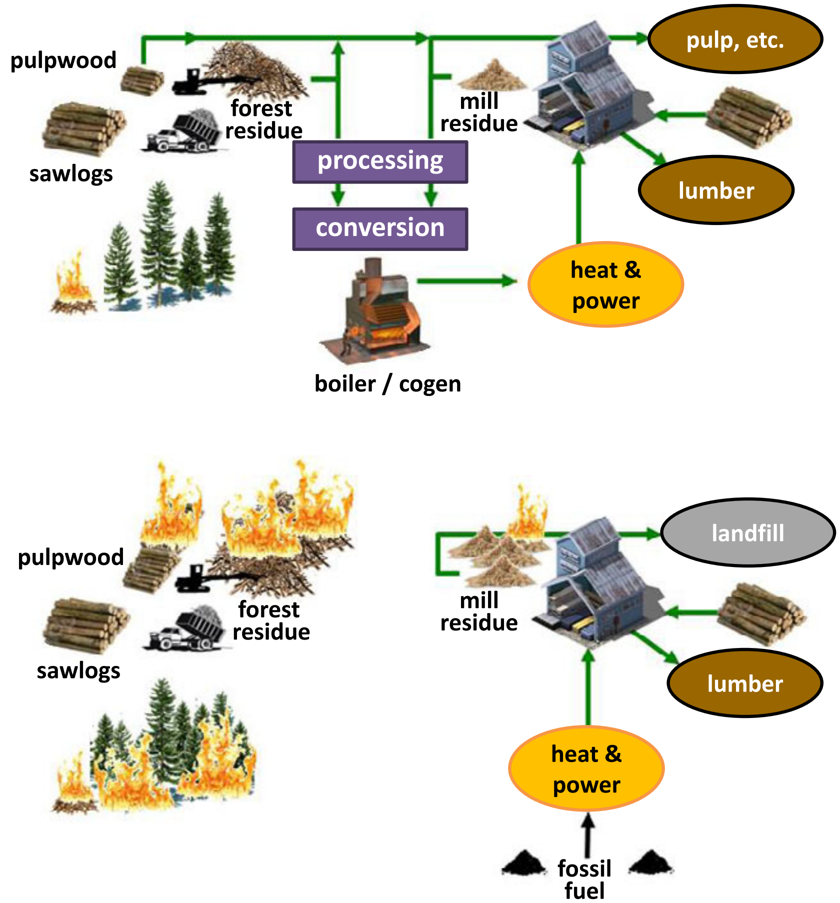

Figure 6.2. Fully integrated wood processing infrastructure (top) enhances the ability of industry to utilize timber and biomass removed from forests. In contrast, the absence of an integrated wood processing infrastructure (bottom) leaves management agencies with fewer or no options for offsetting treatment costs. Woody material is often left on-site or piled and burned (figure by Nate Anderson, USDA Forest Service).

at least some of their management costs by selling some or all of the material. Various technologies for converting biomass into energy are available (Fig. 6.1), but there are significant challenges involved. When a fully-integrated wood processing infrastructure exists, the ability to utilize the timber and biomass removed as a result of treatments is greatly enhanced. In places where such infrastructure is sparser, like in Colorado, the material is often piled and burned in the woods, offsetting none of the costs of treatment (Fig. 6.2).

Additional and new types of wood-processing infrastructure are needed in many areas of the country. However, there are significant challenges to developing the capacity of private industries to utilize woody biomass. Uncertainty in feed-stock availability over time can reduce the willingness of investors to develop new facilities or update old facilities. The removal and use of woody biomass is economically infeasible in many areas due to high transportation costs to haul timber or biomass from infested forests to far-away mills. Transportation costs increase with the distance that material must be hauled to the processing facility (Jones and others 2013).

The economic feasibility of selling the material also depends on the price that the material receives on the market. Market prices for material and the price of diesel fuel are volatile factors that make the economics of biomass removal uncertain over time (Fig. 6.3). Prices that people are willing to pay for woody material is highly influenced by the end use of the material (lumber, posts poles, fuel) and the price of alternatives. For example, the price of natural gas and other conventional

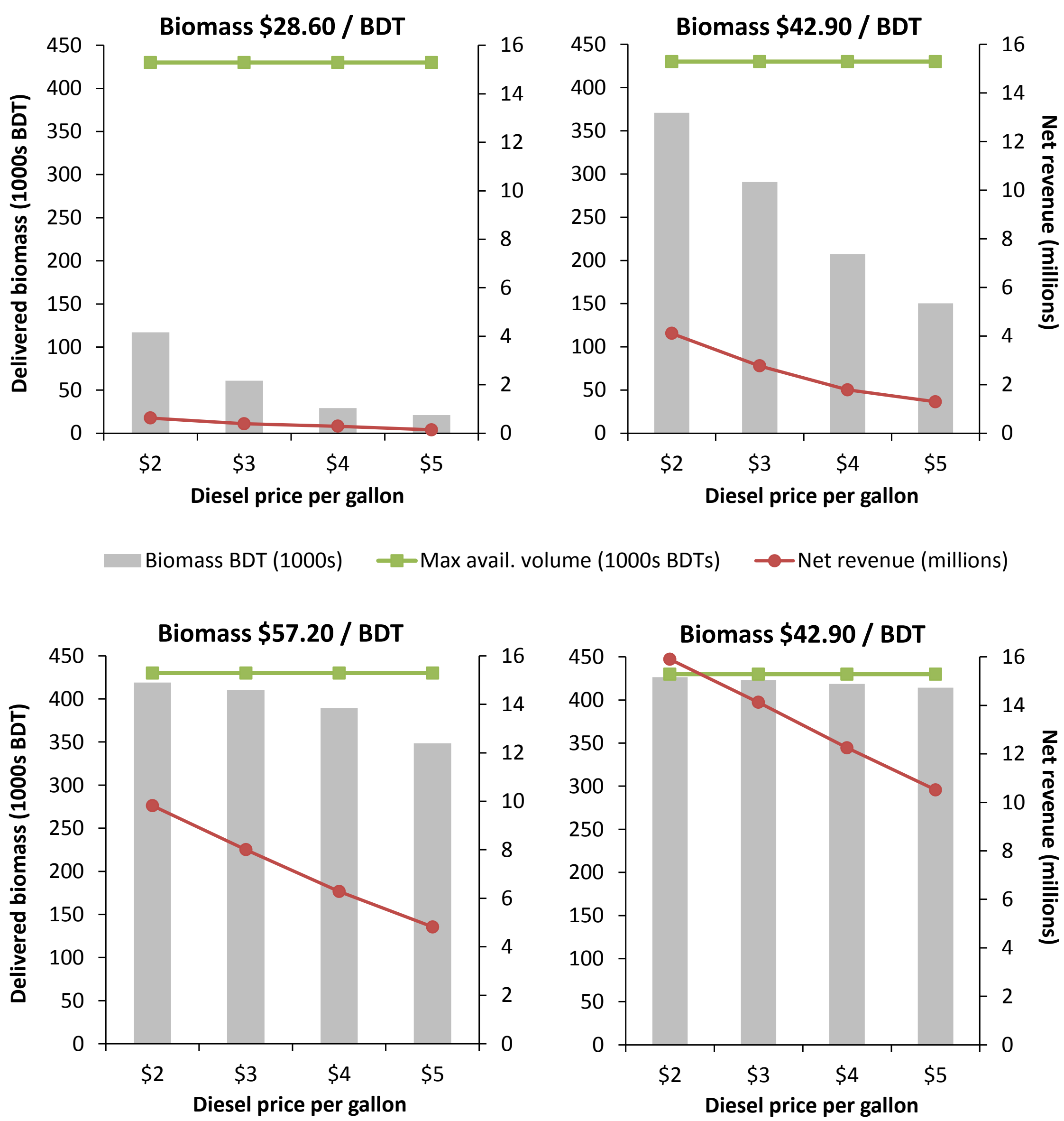

Figure 6.3. The amount of biomass (BDT = bone dry ton) that is economically feasible to deliver depends on biomass prices and diesel fuel costs (modified from Jones and others 2013).

fuel types will influence the purchase price for biomass: the lower the cost of natural gas, the lower the price purchasers are willing to pay for biomass.

Research finding #2: Forest biomass use can replace fossil fuels and reduce emissions relative to piling and burning.

Management Implications

- Piling and burning biomass emits large quantities of carbon dioxide and particulate matter without offsetting the use of fossil fuel.
- Where infrastructure is available, utilizing biomass for thermal energy can reduce greenhouse gas and particulate matter emissions and offset fossil fuel use.

Scientists at the Rocky Mountain Research Station compared emissions from (1) piling and burning forest residues onsite vs. burning natural gas for energy,

(2) piling and burning forest residues onsite vs. burning #2 distillate oil for energy, and (3) burning forests residues in a boiler for thermal energy (Jones and others 2010a,b). They found that burning forest residues (including trees killed by the MPB that can no longer be used as saw timber) in a boiler emitted levels of carbon dioxide similar to piling and burning woody material. However, total emissions are lower for burning biomass in a boiler for thermal heat because it replaces the need to burn fossil fuels (Fig. 6.4). In addition, burning biomass in a boiler emits far less particulate matter (Fig. 6.5) and methane than piling and burning biomass. Emissions were lower for biomass utilization even after accounting for transportation of the material by truck.

These results show that the utilization of biomass (including that produced from beetle-killed trees) can produce several benefits, including meeting energy needs and reducing greenhouse gas and particulate matter emissions. This may be particularly advantageous in areas where air quality standards restrict burning.

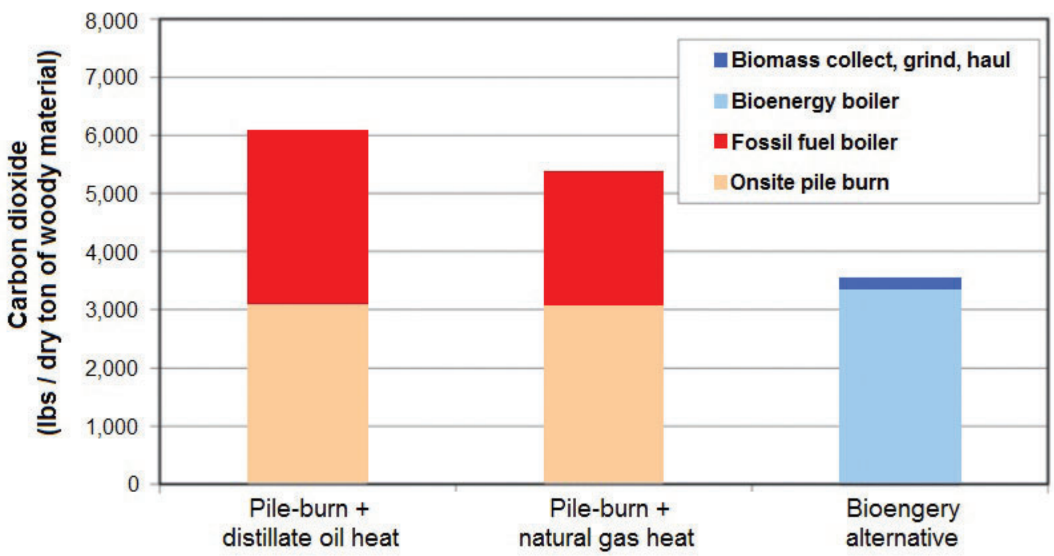

Figure 6.4. Burning biomass in a boiler or in piles emits similar levels of carbon dioxide (lbs CO2 / dry ton of woody material). However, total emissions are lower for burning biomass in a boiler for thermal heat because it replaces the need to burn fossil fuels (Jones and others 2010a,b).

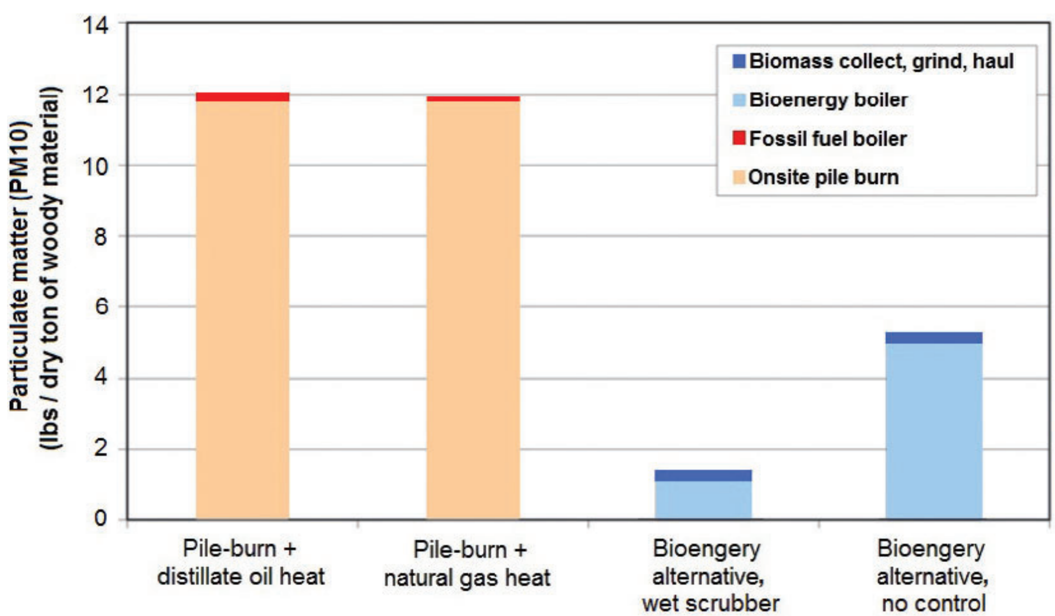

Figure 6.5. Burning biomass in a boiler emits far less particulate matter (lbs of PM10 [particulates <10 microns in diameter] / dry ton of woody material) than piling and burning biomass. This is true with or without wet scrubbers to remove particulates (Jones and others 2010a,b).

Research finding #3: The MPB epidemic has substantial impacts on both nonmarket and market values.

Economists evaluate the worth of market values based on prices set through supply and demand. Real estate, timber products, and forestry equipment are examples of market values. Non-market values are different from market values because they do not have price tags. Since there is no market for these values, it is harder to quantify their economic worth. Examples include scenic beauty, some recreation opportunities, and biodiversity. Very few researchers have evaluated the impact of the MPB on nonmarket values.

A review paper found 22 studies related to nonmarket valuation and forest insect pests, but only 8 of these studies measured the nonmarket values associated with MPB outbreaks (Rosenberger and others 2012). Seven of these studies were done in the Intermountain West and one was from the Northwest, and all but one were published from 1975 to 1991. The types of values estimated included effects on property values, recreation, and total economic value. All of these studies indicated there are substantial economic losses associated with MPB outbreaks.

Losses in recreation benefits were estimated to be approximately $2 million per year (in today's dollars) on the Targhee National Forest following a MPB outbreak (Michalson 1975). A study assessing the effect of beetle-killed trees on home prices in Colorado found that sale prices were decreased by $648 for every dead tree within 330 feet of a house. The average sale price was $276,000 and the average number of dead trees was four (Price and others 2010).

Impacts of MPB outbreaks on nonmarket values are an important social and economic issue. More research is needed to provide adequate information about the tradeoffs associated with management of MPB epidemics. Available research clearly demonstrates that the benefits forests provide to people are diminished by MPB outbreaks. These losses are not adequately captured by analyses of traditional economic markets.

Research finding #4: Citizens in northern Colorado and southern Wyoming generally favor the use of beetle-killed trees for wood products, but many are skeptical that forest managers are doing enough in response to the MPB epidemic.

Management Implications

- Public support for hazardous tree removal is high (in the region studied).
- Communicating management challenges and feasibility issues to the public is important for developing mutual respect.
- Closing roads and posting signs will not discourage some citizens from recreating in areas with hazardous trees. Some people are willing to accept a greater degree of risk.

Researchers at Colorado State University and their collaborators surveyed households in northern Colorado and southern Wyoming from 2011-2012 about their perceptions of the MPB epidemic (Czaja and others 2012). About 740 individuals responded to the survey, representing a broad cross section of citizens in the region.

The majority of respondents (92 percent) agreed that land managers should use trees killed by the MPB for wood products and biomass. About three-fourths of respondents disagreed that beetle-killed trees should be left in the forest. A majority of respondents (96 percent) agreed that people who recreate in forests should accept some of the risk associated with falling trees, but about three-fourths of respondents agreed that some activities should be restricted or made inaccessible.

Several questions addressed the trust that respondents had in actions taken by land management agencies. Only 59 percent of respondents agreed that forest managers are doing everything they should in response to the MPB epidemic. In contrast, greater trust was put in the knowledge and skills of managers about prescribed burns and wildfires. A majority of respondents (82 percent) agreed that forest managers know how to effectively conduct prescribed fires, and 87 percent agreed that forest managers know how to respond to naturally-caused wildfires. A lower number of respondents (61 percent) agreed that forest mangers know how to effectively manage smoke resulting from prescribed fires. An important caveat is that these responses were collected prior to a fatal and destructive prescribed burn that escaped control lines in northern Colorado. This study indicates that the citizens are not convinced that managers have a well-defined strategic plan for responding to the epidemic. Greater dialogue between managers and the public might increase agency awareness of ecological, social, and economic implications of post-epidemic management options while also increasing stakeholder support for agency decisions.

Manager perspectives

The public is concerned about the impact of the MPB on recreational opportunities and aesthetics.

Management Implications

- Managers should be proactive when facing increased risk of disturbance events. Reducing hazards associated with MPB outbreaks or wildfire can maintain aesthetic beauty and protect infrastructure better than post-disturbance mitigation projects.
- Communication among managers can improve decision making by sharing lessons learned from previous disturbances.
- Managers and the public should discuss inevitable tradeoffs posed by the epidemic and develop a triage strategy for hazardous tree removal. This might increase public trust that land management agencies are adequately responding to the MPB epidemic.

The personnel from the Bitterroot National Forest and Arapaho-Roosevelt National Forest shared their thoughts on the social and economic impacts of the MPB epidemic, which are summarized here.

Forest Service units within the footprint of the MPB epidemic have to balance concerns for human safety with the demands for beautiful and accessible recreation facilities. Experiences with the epidemic on the Helena National Forest prepared managers of the Bitterroot National Forest for what was coming, allowing them to be proactive rather than reactive. As such, the managers of the Bitterroot National Forest were able to remove hazardous trees and promote scenic beauty at a popular campground before the MPB epidemic. Residual trees at the campground survived the MPB outbreak, and as a result there was little concern about the safety of campers after the outbreak (Fig. 6.6).

However, a proactive approach is not always possible or wise. For example, managers on the Arapaho-Roosevelt National Forest thinned trees around popular campgrounds, but they had to return several times as more trees succumbed to MPB infestations. Re-entry carries additional costs to land management agencies. Continual thinning of trees can lead to a lack of privacy and shade in campgrounds (Fig. 6.7), causing some people to go elsewhere or participate in different types of recreational activities.

The public is often quite familiar with wildfire and prescribed fire and generally trusts that the agency knows how to handle these activities (Czaja and others 2012). They have less trust regarding agency response to the MPB epidemic, making communication and education particularly important. Managers, stakeholders, and the public should frequently communicate about the future of post-epidemic forests. There needs to be better public involvement in discussions about likely impacts of management decisions, priority setting, and inevitable tradeoffs posed by the MPB epidemic. Clearly articulated goals can guide post-epidemic salvage operations and balance the ecological, social, and economic tradeoffs of management decisions.

Remaining Questions & Knowledge Gaps

- As the need for hazardous tree removal declines, is there an adequate supply of federal timber to support new and existing forest products infrastructure? Are unrealistic expectations being created about the feasibility of wood products industries?
- What opportunity costs are associated with management responses to the MPB epidemic (*e.g.*, using money from other programs and/or reduced capacity to undertake other management activities)? What effect will this have on future forests and the benefits they provide to people?
- To what degree are concerns about safety and/or diminishing aesthetic values changing forest visitation and use patterns? What effects will this have on forest recreation programs, budgets, etc.?
- What will campgrounds impacted by the MPB epidemic look like 5 years from now? 10 years from now? Is there a need for artificial structures to provide shade and screening?

Figure 6.6. Managers on the Bitterroot National Forest removed hazardous fuels and were able to protect residual trees and aesthetic beauty at a favorite campground during the MPB epidemic. The same picnic table is highlighted in both images (photos by Erica Strayer, USDA Forest Service).

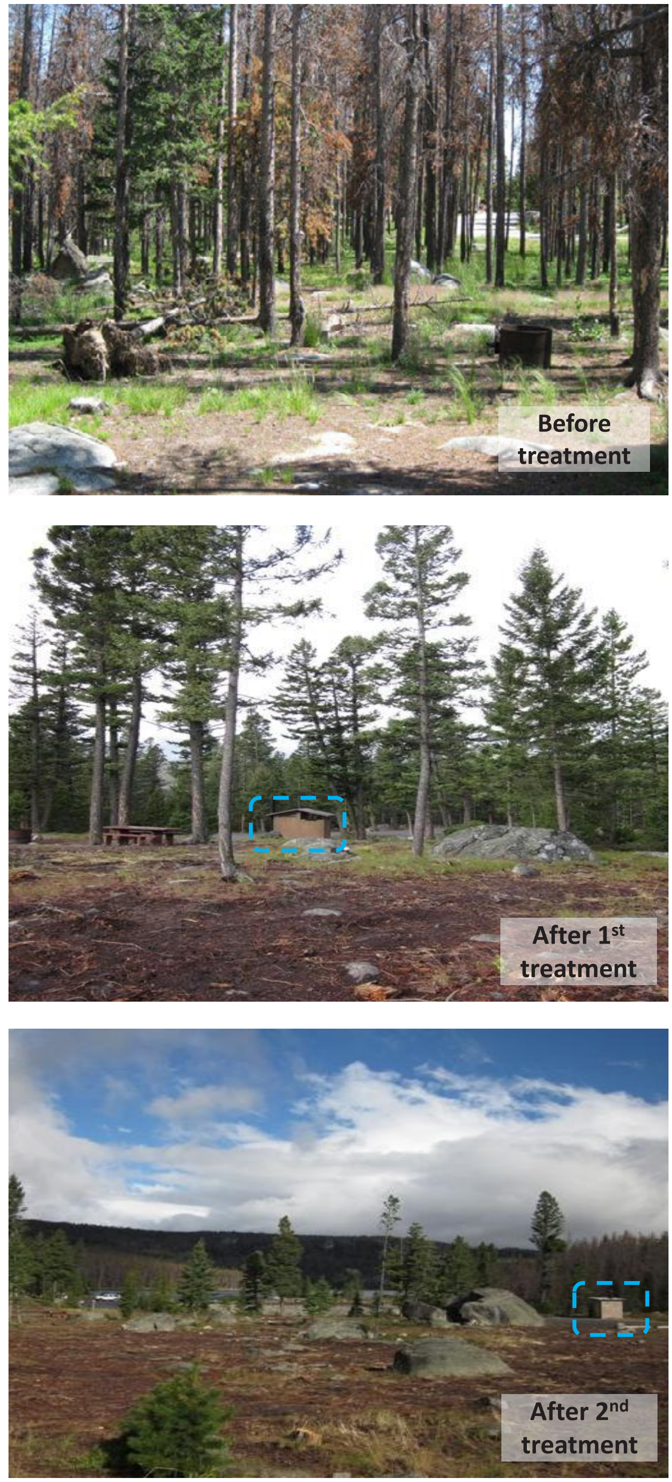

Figure 6.7. Managers on the Arapaho-Roosevelt National Forest removed hazardous trees several times during the MPB epidemic, compromising privacy, shade, and aesthetic beauty at a popular campground. The same facility is highlighted in the two post-treatment images (photo by Erica Strayer, USDA Forest Service).

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Meet the chapter presenters and authors

Patty Champ is an economist with the Rocky Mountain Research Station in Fort Collins, CO. She has been with the station for 18 years. Her broad interest is in understanding public preferences related to land management issues. She is an expert on nonmarket valuation methods, and she conducts research on wildfire risk and homeowners in the wildland urban interface. Reach Patty at pchamp@fs.fed.us; 970-295-5967.

Jessica Clement has conducted human dimensions in natural resources research in Colorado, Wyoming, and Montana for about twenty years. She currently leads the Collaborative Leadership Program for the Ruckelshaus Institute at the University of Wyoming. She is trained in ecology and social science, with a research focus on collaborative natural resource decision-making processes. Reach Jessica at jessica.clement@uwyo.edu; 719-641-6680.

Paul E. Cruz is the Forest Recreation Program Manager for the Arapaho and Roosevelt National Forests and Pawnee National Grassland. Other positions he has held with the agency include Forest Travel Rule Implementation Team Leader, Acting Recreation Fee and Business Systems Program Manager, Acting District Ranger, and District Recreation Staff Officer. Prior to his 1990 transfer to the Forest Service, Paul was a Soil Conservationist with the USDA Soil Conservation Service. Paul can be reached at pecruz@fs.fed.us; 970-295-6614.

Mike Czaja is a retired lieutenant colonel in the US Army and doctoral candidate at Colorado State University. He is interested in wildland fire-related social science research. In addition to being a volunteer wildland fire fighter and public information officer trainee with the Larimer County Sheriff's Office, he is a fire-prevention volunteer with the Canyon Lakes Ranger District of the Arapaho-Roosevelt National Forest. Mike can be reached at michael.czaja@colostate.edu; 970-491-1494.

Krista Gebert is the Regional Economist for the Northern Region of the Forest Service. She accepted the position as Regional Economist in July of 2010, after nearly 15 years as a researcher with the Rocky Mountain Research Station in Missoula. Krista has authored or co-authored more than 30 topics on topics including timber sale economics; rural development; economic dependency on forest-related industries; and the economics of wildland fire management. Reach Krista at kgebert@fs.fed.us; 406-329-3696.

Greg Jones is a retired Research Forester with the Human Dimensions Science Program, Rocky Mountain Research Station in Missoula, MT. Greg earned his Ph.D. is in Forest Economics from Iowa State University. His research included forest fuel treatment economics, biomass supply from forest treatments, and utilization of forest treatment residues. Greg can be reached at jgjones@fs.fed.us; 406-329-3396.

Chuck Oliver has been with the Forest Service for over 20 years. He is currently the District Ranger on the Darby Ranger District of the Bitterroot National Forest in Montana. He started his Forest Service career as a range conservationist for the Butte Ranger District of the Deerlodge National Forest, and he was previously the District Ranger on the Parks Ranger District of the Medicine Bow/Routt National Forest. Reach Chuck at coliver01@fs.fed.us; 406-821-3913.

Chapter 7—Small bugs with big impacts: Ecosystem and watershed-level responses to the MPB epidemic

Authors: Rob Hubbard, Kelly Elder, Chuck Rhoades, Polly Hays, and Bruce Sims

Presenters: Rob Hubbard, Kelly Elder, Chuck Rhoades, Polly Hays, and Bruce Sims

Introduction

Mountain pine beetle (MPB) outbreaks have the potential for prolonged impacts on the delivery of clean water from infested subalpine watersheds throughout the West. Sixty-five percent of the West's water supply originates on forested land (Brown and others 2008), much of which has been affected by an unprecedented MPB epidemic over the past decade. Some lodgepole pine stands in Colorado have lost more than 70 percent of their basal area following the MPB epidemic (Collins and others 2012). The death of pine trees leads to increased availability of light, water, and nutrients for residual overstory trees and understory vegetation; it can also result in increased water and nutrient runoff.

The MPB epidemic may have a large influence on the energy and water balance of subalpine ecosystems. Water balance in the subalpine zone is modeled as the volume of water stored along with a series of water inputs and outputs from the system. The storage component includes ground water, soil moisture and snow pack. Inputs consist of precipitation in the form of rain and snow, and outputs include sublimation from the snowpack surface and from snow intercepted by tree canopies, evaporation from snow-covered and snow-free surfaces, and transpiration from trees and other vegetation during the growing season. Intercepted snow sublimates at a faster rate than snow on the ground due to its greater surface area and exposure to incoming solar radiation and heat transfer from the air. Water that is not lost to sublimation, evaporation, or transpiration is available for stream flow (Fig. 7.1).

Energy and water balances change throughout the year in subalpine forests. During winter, the net energy balance is negative, allowing snow to accumulate through the cold season. The energy balance becomes positive during spring, and this excess energy is used to warm and subsequently melt snowpack. The soil moisture deficit from the previous growing season is replenished as snowmelt moves into the soil. Ground water levels rise, and eventually stream flow increases relative to base flow levels during the winter. Trees also begin to transpire as temperatures warm, transferring soil moisture to the atmosphere.

Landscape-scale MPB epidemics have the potential to cause large changes in water balance in these subalpine watersheds. Snow is the dominant precipitation input in the subalpine zone where the MPB is most active, and snowmelt accounts for the vast majority of water available for runoff, agricultural, and municipal uses. After logging operations, decreased snow interception by tree

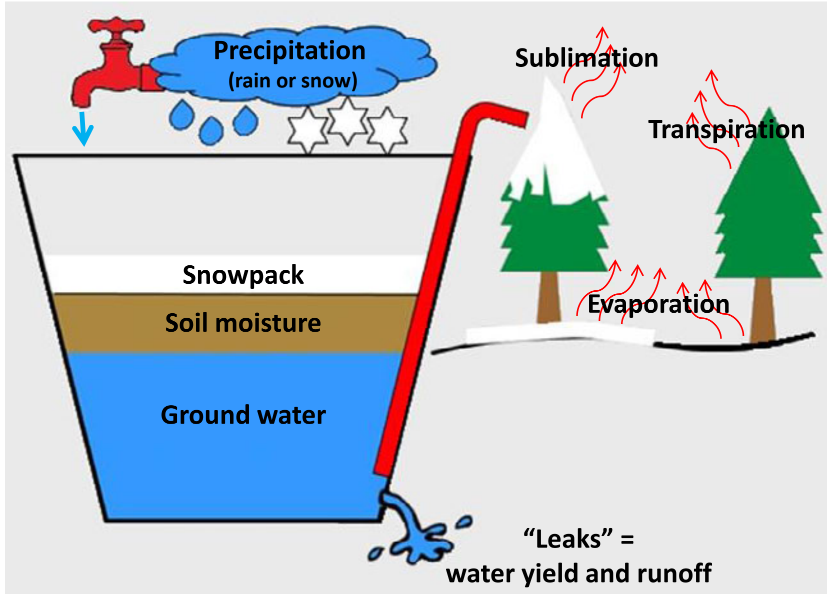

Figure 7.1. The water balance of an ecosystem is conceptualized as faucets, buckets, straws, and leaks. The faucet represents inputs of water from precipitation; the buckets represent pools of water in the ecosystem (i.e., snowpack, soil moisture, and ground water). Water moves out of the system through sublimation, evaporation, and transpiration (represented as a straw), and it leaves the system as water yield and runoff (represented as a leak in the bucket) (figure by Kelly Elder, USDA Forest Service).

canopies leads to increased snowpack accumulation (Woods and others 2004; Troendle and King 1985).

Similarly, the magnitude and timing of post-beetle snowmelt will be affected by the changes in the tree canopy, even though the forest overstory will deteriorate more slowly following a beetle attack than following tree harvesting. The net effect of the changing snowpack accumulation and water and nutrient use in beetle-killed forests varies depending on environmental conditions, tree species composition, the density of the forest understory, and management decisions. At the same time, these impacts are occurring against the backdrop of climate change, which is already impacting seasonal stream flows. Rood and others (2008) compared hydrographs from the early 1900s and early 2000s, and they found that many rivers across the West are experiencing higher winter flows, earlier spring run-off and peak flows, and reduced flows in the summer and early autumn. We have yet to see how these alterations might interact with watershed-scale impacts of the MPB epidemic.

In this webinar, we presented research on MPB-induced changes in energy and water balances, tree physiology, and nutrient cycling. These processes influence stream flow and nutrient and sediment export from affected watersheds.

Research findings

Research finding #1: Blue stain fungi associated with the beetles are primarily responsible for tree deaths during MPB outbreaks.

MPBs disrupt two basic life-sustaining processes in trees they infest. Adult beetles consume phloem tissue when building egg galleries and developing larvae consume phloem for food until maturity. Phloem feeding by adult and larval beetles contributes to some amount of phloem girdling, disrupting the transport of carbohydrates from the canopy to other tissues within the tree.

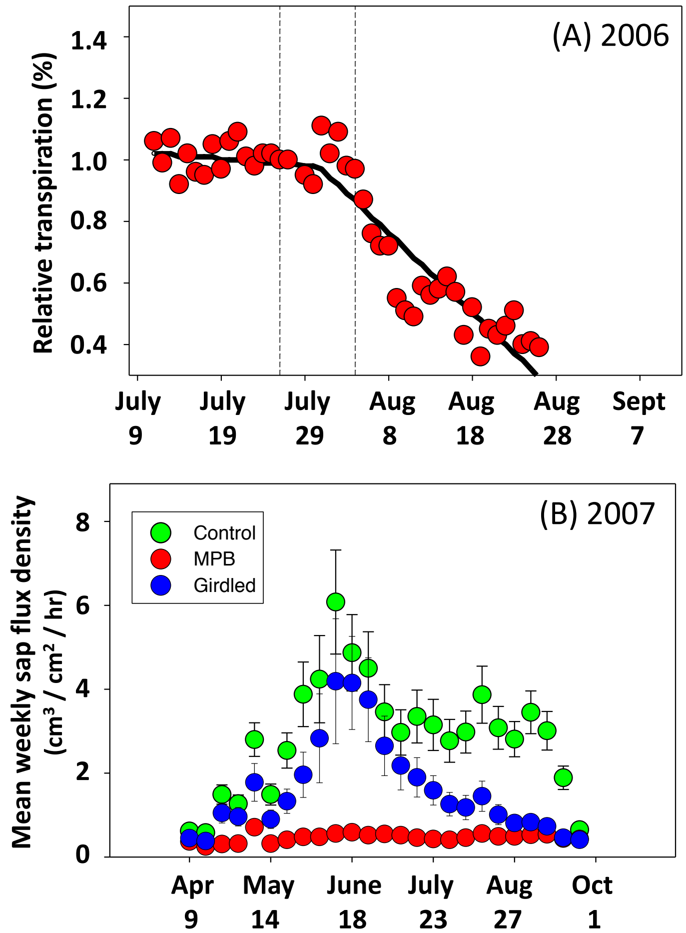

Figure 7.2. Relative rates of transpiration for beetle-attacked trees compared to control trees before and following MPB infestation (A), and mean sap flux density in the growing season following MPB infestation for beetle-attacked, girdled, and control trees (B). Error bars represent the variation between trees (figure modified from Hubbard and others 2013).

MPBs also carry a diversity of pathogenic spores from several genera of fungi (Yamaoka and others 1995; Kim and others 2008). Fungal spores carried into trees by MPBs germinate and spread fungal hyphae into tree tissue responsible for conducting water (*i.e.,* xylem in the sapwood). These fungi essentially block water transport from the soil to the canopy (Ballard and others 1984).

Studies at the Fraser Experimental Forest suggest that fungal infection of the xylem tissue is the primary cause of tree mortality. Fungal infections cause a rapid decrease in tree transpiration following a successful MPB attack. Tree water use can slow measurably ten days following a MPB attack, decline to 50 percent by the end of the summer, and essentially reach zero by the beginning of the next growing season (Fig. 7.2). Mechanically girdling trees without fungal infection resulted in slower transpiration rates during the first growing season, but transpiration rates of these trees were similar to control trees during the following summer. This experiment demonstrates that fungal infections, not phloem consumption by beetles, are primarily responsible for tree deaths during MPB outbreaks (Hubbard and others 2013).

Research finding #2: Tree mortality caused by the MPB epidemic substantially alters energy and water balances in subalpine forests.

Forest cover is a critical driver of water balance in subalpine environments. MPB outbreaks cause changes to water and energy balance as trees transition from live canopies to dead foliage (*i.e.,* red stage), and finally to losing all of their needles (*i.e.,* gray stage).

Management Implications

- Soil water availability and stream flow can increase during the red stage as transpiration of dead and dying trees declines.
- Greater increases in soil water availability and stream flow are possible during the gray stage as less snow is intercepted by needle-less tree canopies.
- Removal of hazard trees can decrease canopy interception, thereby enhancing snowpack accumulation in forests impacted by the MPB. However, removing large groups of trees can decrease snow accumulation due to wind scour.

Transpiration declines between the green and red stages. The introduction of blue stain fungi by MPBs causes pine needles to discolor and turn red as transpiration declines. Transpiration ceases altogether by the beginning of the first post-infection growing season (Hubbard and others 2013). Water previously removed by transpiration is then available for soil recharge, residual vegetation transpiration and/or stream flow.

Changes in watershed-level transpiration rates depend on the amount of MPB-induced tree mortality (which in turn depends on the original species composition and management history). Total basal area was reduced by 25 percent in managed mixed-species subalpine watersheds at Fraser Experimental Forest, whereas basal area losses averaged 40 percent in unmanaged stands (Fig. 7.3). These changes in basal area resulted in proportional changes in overstory transpiration rates. Transpiration in two managed watersheds was reduced by 20 and 29 percent, but transpiration in two unmanaged watersheds was reduced by 41 and 45 percent (Rob Hubbard, USDA Forest Service, *unpublished data*).

Interception does not change significantly between the green and red stages. Dead needles may intercept as much snow as living needles. However, interception begins to decline as trees transition into the gray stage, shedding their

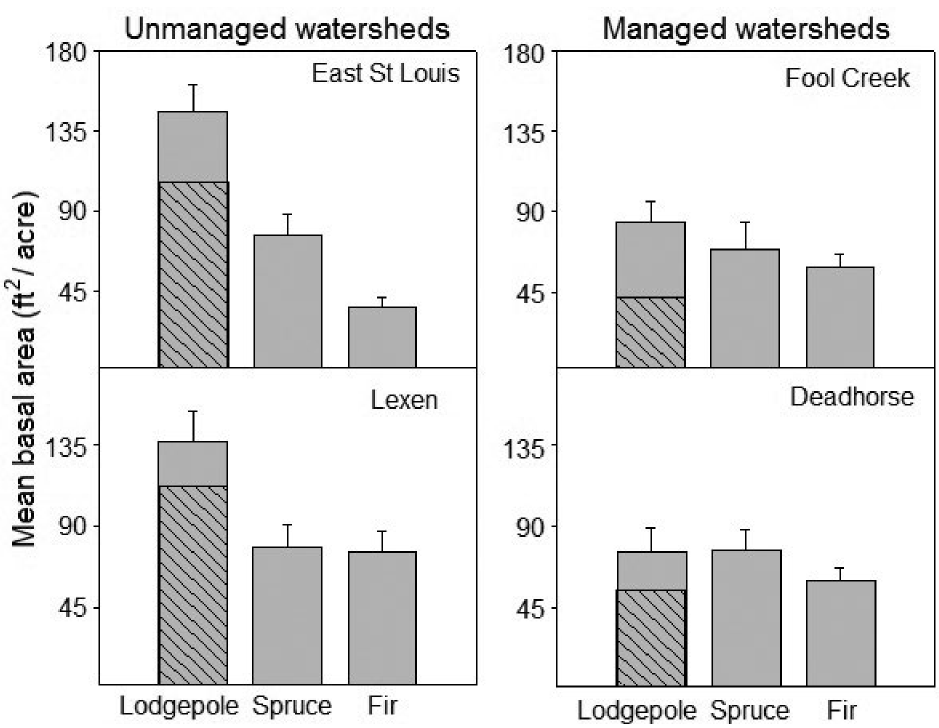

Figure 7.3. MPB-induced mortality of lodgepole pine trees (hatched bars) in unmanaged and managed watersheds at the Fraser Experimental Forest. Error bars represent the variation between subplots plots in each watershed (Chuck Rhoades, Rob Hubbard, and Kelly Elder, USDA Forest Service, unpublished data).

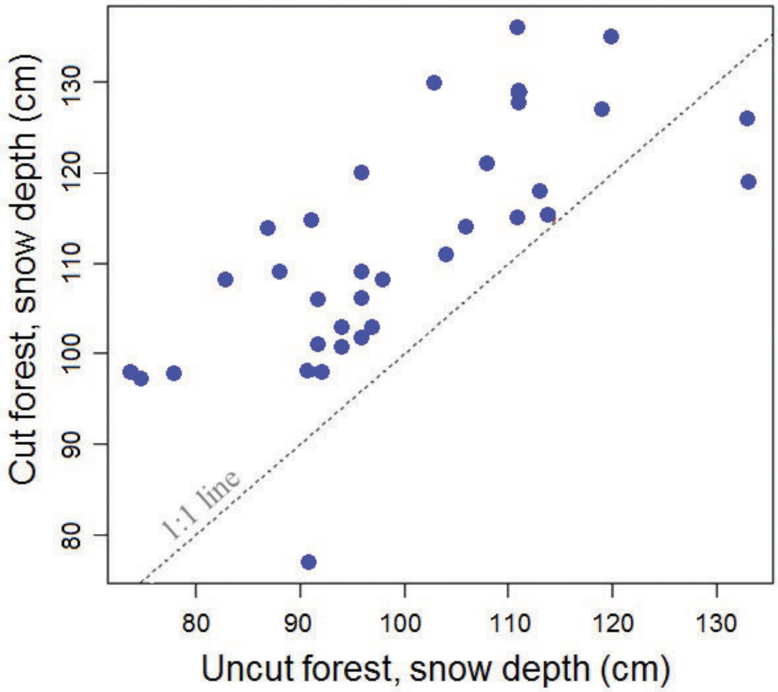

Figure 7.4. Snow depth for transects located in uncut versus harvested MPB-affected lodgepole stands. Study plots were located on the Fraser Experimental Forest, Colorado State Forest, Routt National Forest, and Medicine Bow National Forest in Colorado. The mean differences in snow depth are similar to differences observed in clear cuts versus unharvested areas impacted by the MPB (Kelly Elder, USDA Forest Service, unpublished data).

needles over a period of 1 to 5 years. Once all needles have been shed from the tree, interception is significantly lower, but it will not be zero until a tree topples to the ground anywhere from 1 to 15 years following MPB attack (Mitchell and Preisler 1998).

Less interception by tree canopies can translate into greater snowpack accumulation (Woods and others 2004). Preliminary results from the Fraser Experimental Forest suggest that snow and rain throughfall increase when a larger portion of the overstory is killed by the MPB. Snow accumulation (*i.e.,* depth, density, and water equivalent) are significantly higher in gray-stage forests that experience harvesting relative to uncut stands (Fig. 7.4). However, several harvested stands had lower snow depths. This is potentially from high wind scour due to plot location and/or the large size of the harvest units. Differences in silvicultural treatments could have also affected snowpack accumulation, with greater accumulation resulting from even thinning versus group-retention thinning (Woods and others 2004).

Research finding #3: Changes in the water balance of subalpine forests are likely different after tree harvesting than after mortality from the MPB epidemic.

Researchers and water managers have experimented with tree removal to increase stream flow for more than a hundred years. For example, researchers removed 50 percent of the forested basal area from the Fool Creek watershed in the Fraser Experimental Forest and observed a 40 percent increase in stream flow relative to an untreated watershed (Troendle and King, 1985). Over a 50-year period following basal area reduction, the average increase in stream flow was 29 percent (Kelly Elder and Laurie Porth, USDA Forest Service, *unpublished data*).

Management Implications

- Increases in water yields following the MPB epidemic are less substantial than increases resulting from clear-cutting operations. This is due to a more gradual decline in transpiration and interception rates and the greater abundance of live, residual vegetation in MPB affected forests.
- Advance regeneration and newly established vegetation utilize much of the soil water made available after the death of overstory trees, dampening increases in stream flow after the MPB epidemic.
- Retaining slash in post-epidemic forests (*e.g.,* lop and scatter) can increase snow accumulation by reducing wind scour. This potentially leads to greater water yields during the spring melt.

Changes in peak flow and overall runoff in the Fool Creek watershed were driven by reduced losses from interception and transpiration, as well as increased snow deposition into harvested strips. A recent analysis of yearly stream flows from Fool Creek estimates that hydrologic recovery would have occurred approximately 60 years following harvest had no further disturbance altered the system (Kelly Elder and Laurie Porth, USDA Forest Service, *unpublished data*).

It is not known if these studies are appropriate analogs for the impact of tree mortality from the MPB and subsequent tree harvesting. Studies that have examined impacts of MPB outbreaks on stream flow are relatively rare. Stream flows from infested watersheds will likely have a very different response over time due to differences in the energy and water balance of harvested versus beetle-killed forests.

Increases in stream flow are often lower following beetle-induced tree mortality than after tree harvesting. Between 1939 and 1946 a large spruce beetle outbreak killed approximately 20 percent of the basal area within the White River watershed in northwestern Colorado. During the 25-year period after the spruce beetle infestation, the average increase in water yield was 15 percent, and the largest increase occurred 15 years after the outbreak (Love 1955; Bethlahmy 1974). During the current MPB epidemic, stream flow was not different between a watershed infested by the MPB in 2003 and one not infested until 2008 (Fig. 7.5). These watersheds were decent analogs of each other, with a strong correlation in streamflow patterns prior to the MPB epidemic (Kelly Elder and Laurie Porth, USDA Forest Service, *unpublished data*).

Paired watershed studies are of little use in detecting long-term changes in stream flow induced by the MPB epidemic. This is because most basins with lodgepole pine across the Rocky Mountain West have been significantly impacted by MPBs. Instead, researchers are detecting changes in downstream flows by comparing annual precipitation patterns and discharge from beetle-impacted basins.

Why might the magnitude of water yield increase be lower following beetle-inducted tree mortality than after tree harvesting? Different rates of tree removal and different amounts of remaining live vegetation are primary factors explaining this pattern.

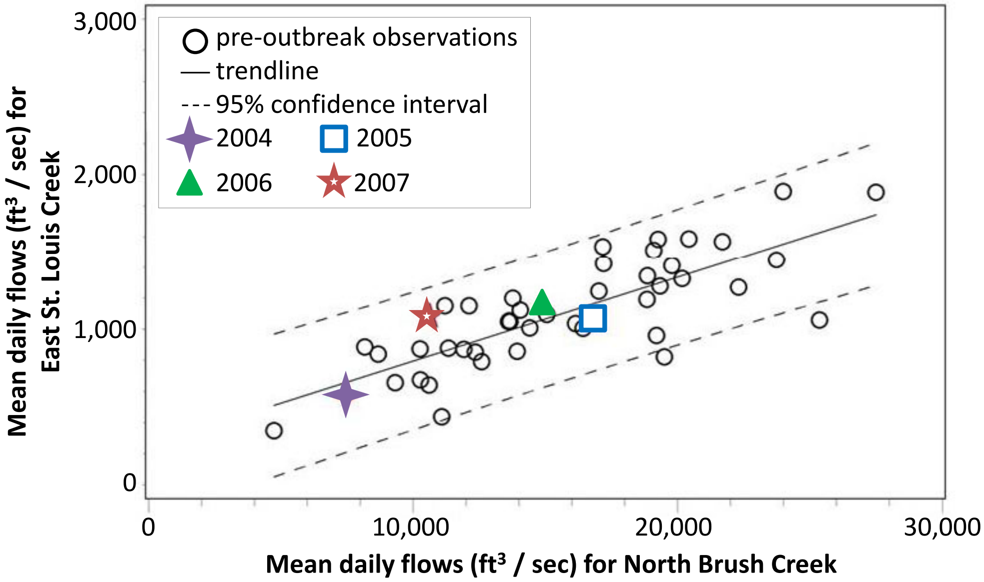

Figure 7.5. Mean daily flows from unaffected North Brush Creek watershed in southern Wyoming versus MPB-affected East St. Louis basin on the Fraser Experimental Forest, Colorado. Black circles represent pre-beetle altered flows and other icons represent post-beetle impacted flows. The solid regression line show the pre-beetle fit between the basin flows (data prior to 2003) and the dashed line show the 95 percent confidence interval. This data suggests that as of 2007, flows were still behaving as expected from an unaltered hydrologic regime (Kelly Elder and Laurie Porth, USDA Forest Service, unpublished data).

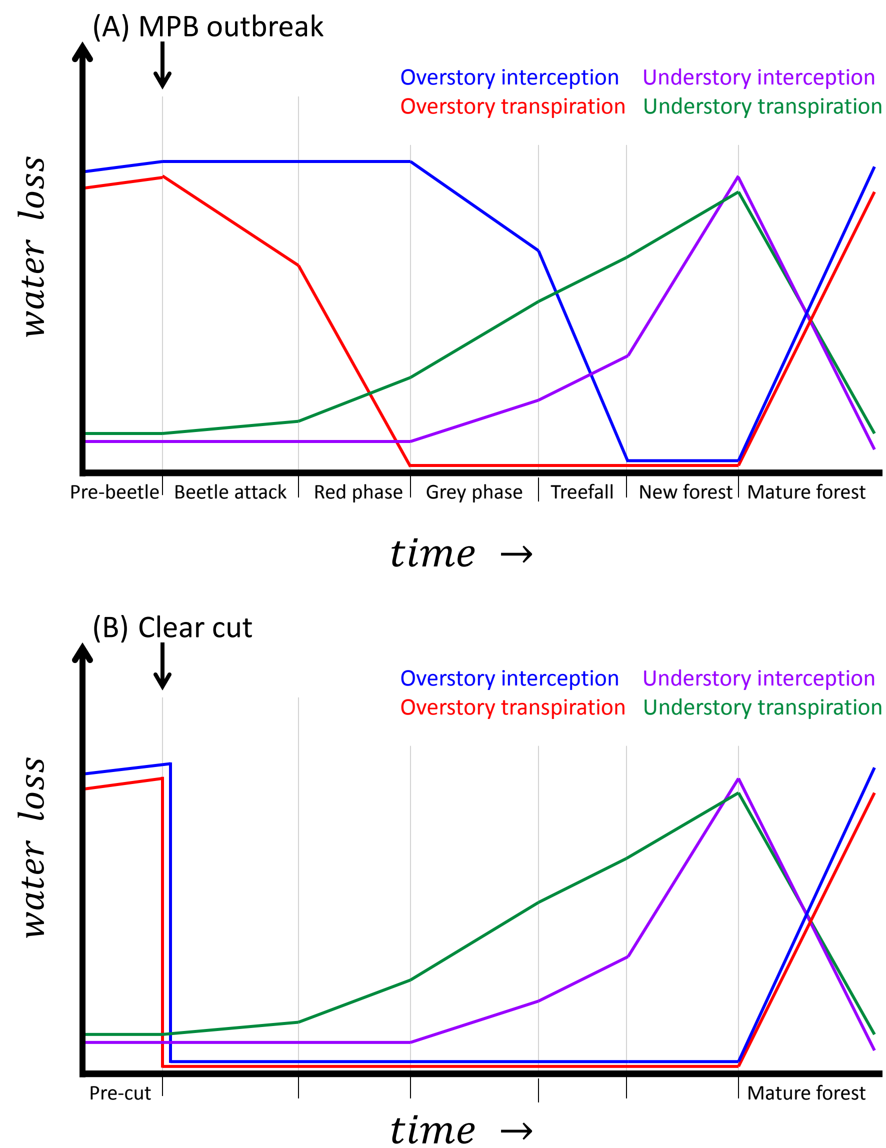

Figure 7.6. Changes in water loss in MPB-impacted mature forests (A) versus clear cut mature forests (B) (figure by Kelly Elder, USDA Forest Service).

Hydrologic recovery is generally slower following harvesting, resulting in a greater and more prolonged increase in stream flow (Fig. 7.6). Harvesting results in immediate removal of trees, resulting in immediate reductions in water losses from overstory interception and transpiration. In contrast, trees killed by MPBs shed their canopies slowly and remain part of the ecosystem for many decades, resulting in slower declines in interception and transpiration.

The amount of remaining live, vegetation also differs between a harvested and beetle-impacted watershed. MPBs only attack mature lodgepole pine trees in subalpine forests, leaving other overstory species and understory vegetation unaffected. This residual vegetation can quickly respond to increased water availability, reducing the amount of water contributing to stream flow. In contrast, harvest operations can remove all of the overstory trees and leave behind a much smaller amount of residual vegetation., However, harvesting can also increase surface roughness and lead to greater snow accumulation, especially when slash is left on-site.

Research finding #4: The MPB epidemic has had little effect on nitrogen losses from impacted watersheds.

Management Implications

- The MPB epidemic has marginally increased stream nitrate concentrations, but the changes do not pose threats to water quality.
- Protecting tree regeneration and enhancing establishment of new vegetation can help mitigate nitrogen losses from forest soils to streams.

Wildfire and logging often result in elevated nitrogen in stream water caused by changes in nutrient demand and nutrient cycling. The biogeochemical consequences of insect outbreaks are more uncertain. Overstory mortality resulting from MPB outbreaks results in lower stand-level demands for nutrients and waters. Several studies have similarly shown that soil resources increase under dead and dying trees. Clow and others (2011) observed greater soil moisture and nitrogen availability under recently-attacked and gray-stage trees in Grand County, CO (Fig. 7.7). This increase was potentially due to lower plant uptake, slower soil nitrogen turnover, and increased litter inputs.

Greater instantaneous soil nitrogen is apparent under beetle-killed trees, but there is little evidence that much of this nitrogen enters stream water. At Fraser Experimental Forest, nitrogen export in stream water following the MPB epidemic was less than 10 percent of observed seasonal variation (Fig. 7.8), and concentrations are well below EPA thresholds for water quality (120 parts per billion [ppb] for total nitrogen and 14 ppb for nitrate). Other studies across Colorado show similarly low nitrogen export from watersheds affected by the MPB epidemic (Rhoades and others 2013).

Why are stream nitrogen responses to the MPB epidemic so small? One reason might be increased nitrogen uptake by residual, live vegetation: at Fraser Experimental Forest, average foliage nitrogen content has increased from 0.8 to 1.3 percent in live pine trees located near beetle-killed trees (Hubbard and

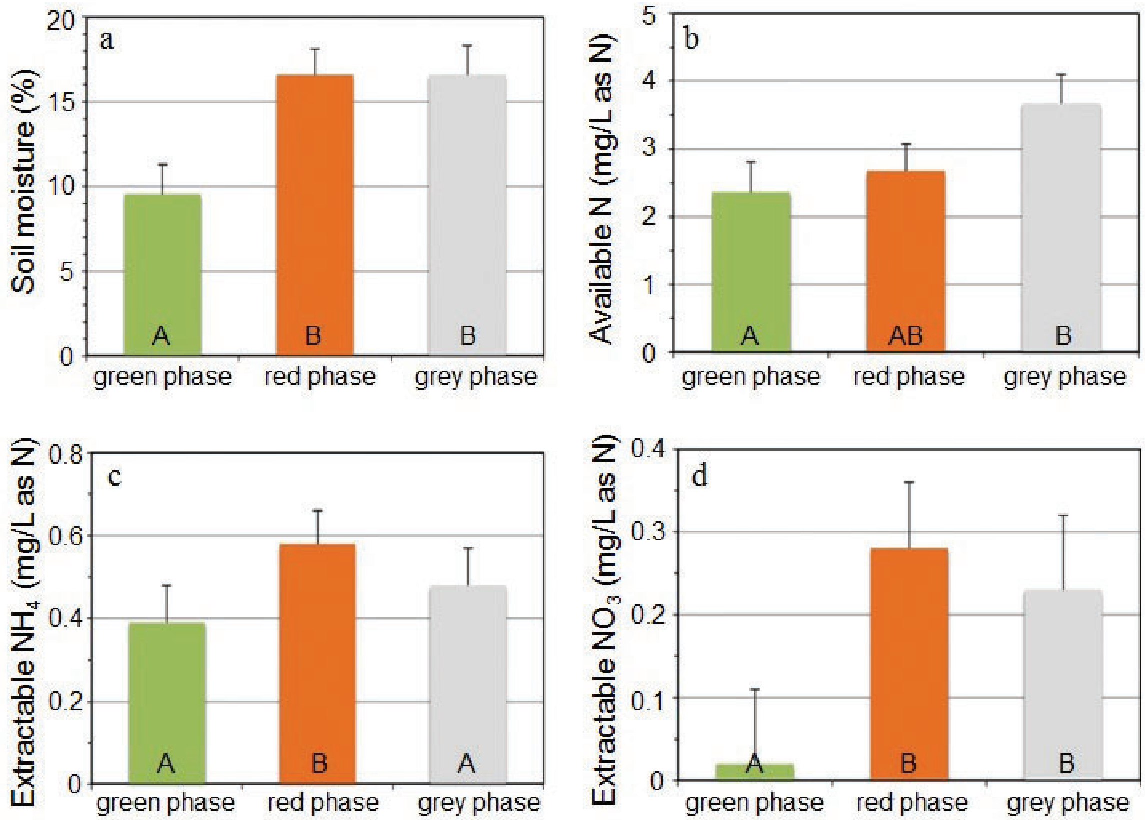

Figure 7.7. Means and standard deviations of soil (a) moisture, (b) available nitrogen, (c) extractable ammonium (NH4+), and (d) extractable nitrate (NO3-) in soils collected under live, red-stage, and gray-stage trees. Different letters indicate that the distributions were significantly different at $p < 0.1$ (figure from Clow and others 2011).

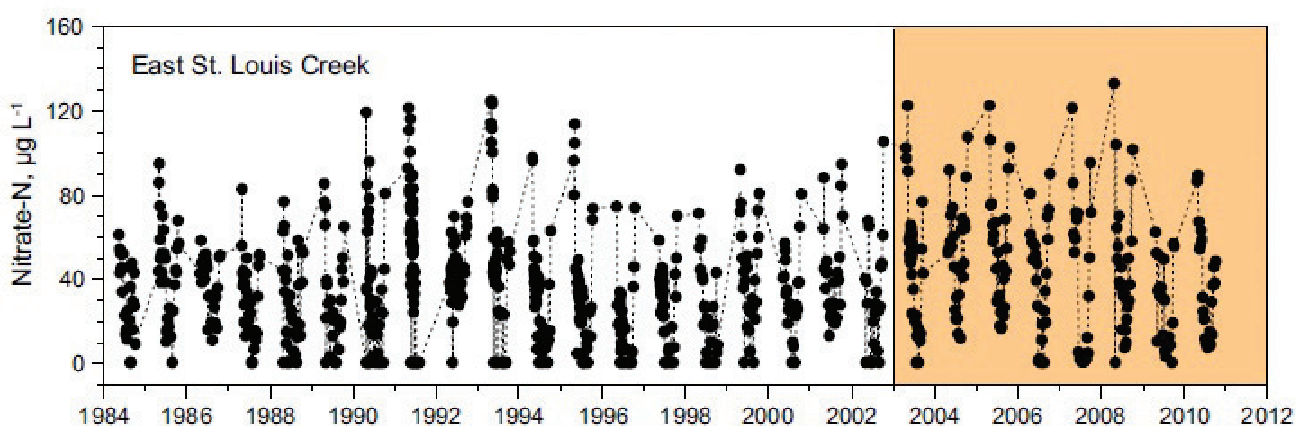

Figure 7.8. Nitrate (NO_3^-) concentrations in East St. Louis Creek on the Fraser Experimental Forest, CO, before extensive MPB kill of trees and during years of beetle kill (shaded area). Annual variation in nitrate concentrations dwarfs potential impacts of the MPB epidemic on water quality (figure from Rhodes and others 2013).

others 2013). More than 25 percent of trees sampled from four watersheds at Fraser showed increased growth in response to beetle-induced mortality of nearby trees. Likewise, seedlings are colonizing beetle-impacted areas across northern Colorado, and advance regeneration trees are growing faster than previous years in response to increased resource availability (Collins and others 2011).

Remaining Questions & Knowledge Gaps	
Remaining Questions & Knowledge Gaps	• How will the magnitude and timing of changes in water quality and quantity vary over time as forests recover from the MPB epidemic? Are these responses similar or different for watersheds in other parts of the beetle-killed landscape? • To what degree does beetle-induced tree mortality change snow accumulation and retention over time? • How will water and nutrient uptake by residual live vegetation change as forests recover from the MPB epidemic? • What impact will future disturbances (*e.g.,* forests insects and diseases, wildfires, and management activities) have on watershed processes in areas impacted by the current MPB epidemic? • What are the implications of salvage harvesting in riparian areas for wildlife habitat, soil water holding capacity, stream temperatures, etc.?

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Meet the chapter presenters and authors

Kelly Elder has worked as a Research Hydrologist with the Rocky Mountain Research Station since 2000. He received his Ph.D. in physical geography and hydrology from the University of California, Santa Barbara. Kelly's research examines consequences of MPB outbreaks and management on watershed processes, with a particular focus on water balance of subalpine forest systems. He can be reached at kelder@fs.fed.us; 970-498-1233.

Polly Hays is the Water Program Manager for the Rocky Mountain Region of the Forest Service, a position she has held since 2000. She has regional-level responsibilities for watershed management and restoration, water quality, and water rights. Polly earned her M.S. in Geosciences from the University of Arizona. Reach Polly at pehays@fs.fed.us; 303-275-5096.

Rob Hubbard has worked as a Research Ecologist with the Rocky Mountain Research Station since 2005. He worked as a Research Ecologist for the Coweeta Hydrologic Lab in North Carolina after graduating with his Ph.D. in Forest Ecology from Colorado State University. Rob's research explores how forests respond to disturbances and the role that plants play in regulating hydrologic processes. Reach Rob at rhubbard@fs.fed.us; 970-498-1260.

Chuck Rhoades is a watershed biogeochemist and has been with the Rocky Mountain Research Station since 2003. He earned his Ph.D. in forest biogeochemistry and soil ecology from the University of Georgia in 1998. Chuck's research interests focus on forest biogeochemical processes that regulate the delivery of clean water and sustain productive soils and forests. He can be reached at crhoades@fs.fed.us; 970-498-1250.

Bruce Sims is the Regional Hydrologist for the Northern Region of the Forest Service, a position he has held since 2000. Bruce has done research on the effects of prescribed fire on water quality, and he co-authored a general technical report looking at the effectiveness of post-fire hillslope treatments. He received his M.Ed. in Geography and M.S. in Watershed Management from the University of Arizona. Bruce can be reached at bsims@fs.fed.us; 406-329-3447.

Chapter 8—Moving forward: Responding to and mitigating effects of the MPB epidemic

Authors: Claudia Regan, Barry Bollenbacher, Rob Gump, and Mike Hillis

Presenters: Claudia Regan, Barry Bollenbacher, Rob Gump, and Mike Hillis

Introduction

The final webinar in the Future Forest Webinar Series provided an example of how managers utilized available science to address questions about post-epidemic forest conditions. Assessments of current conditions and projected trends, and how these compare with historical patterns, provide important information for land management planning. Large-scale disturbance events, such as the MPB epidemic, can change future vegetation conditions, disturbances and disturbance interactions, and habitat for wildlife species. This case study from the Beaverhead-Deerlodge National Forest illustrates the value of rapid assessments for conservation planning, and it provides a template for future science-management collaboration.

Lessons learned

Lesson learned #1: The involvement of diverse resource specialists can improve the focus and outcomes of rapid assessments and create opportunities for science-management partnerships.

The Beaverhead-Deerlodge National Forest experienced substantial tree mortality from the MPB epidemic, with approximately 50 percent of the forested area infested by 2009. At the same time, this forest is experiencing an outbreak of western spruce budworm. This widespread tree mortality created a management need for information on potential impacts of the MPB and alternative management responses.

A diverse team of experts convened to address these goals and information needs. Resource managers and specialists with the Beaverhead-Deerlodge National Forest contracted employees with TEAMS (Talent, Expertise, Agility, Mobility, and Simplicity) Enterprise to recommend silvicultural prescriptions and identify treatment areas. Managers and specialists with the Beaverhead-Deerlodge National Forest and Northern Region then formed an assessment team with the Ecosystem Research Group (ERG)[7] to build on these recommendations.

The rapid assessment was comprehensive, but also focused, due to the unique perspectives of different resource specialists regarding important ecosystem components. The team developed the following goals for the assessment:

[7] *ERG is a government contractor specializing in natural resource inventory and assessment.*

1. Evaluate long-term trajectories of vegetation conditions across the National Forest and broader landscape, with a focus on distributions of forest size classes, crown closure, and cover types.
2. Determine the scale and intensity of treatment impacts on wildlife habitats and species viability, especially for the northern goshawk, flammulated owl, black-backed woodpecker, fisher, elk, pileated woodpecker, Canada lynx, wolverine, and grizzly bear.
3. Assess the potential severity of future disturbances (especially wildfire) across the landscape.
4. Identify projects that might move the forested landscape towards desired future conditions as defined by the Forest Plan.

Due to the Forest's urgent need for information about the MPB epidemic, interactions with non-governmental organizations were limited. Future assessments could greatly benefit from greater involvement with diverse stakeholders groups (*e.g.*, The Nature Conservancy, The Wilderness Society, The Defenders of Wildlife, The Wildlife Society, and commodity interest groups) to effectively incorporate their perspectives and encourage collaborative learning among all parties.

Lesson learned #2: Simulation models are useful tools for comparing impacts of treatment options and exploring future scenarios, especially when models are tailored to local conditions.

Simulation models help resource managers explore future conditions under different management and no-management scenarios. The assessment team for the Beaverhead-Deerlodge National Forest used SIMPPLLE (SIMulating Patterns and Processes at Landscape scaLEs) for this purpose. SIMPPLE is a landscape simulation model that produces spatially-explicit projections of how forest stands and forested landscapes might change over time (Chew and others 2012). The model accounts for variability in topography, wind direction, fuels, and conditions in adjacent stands, as well as projected future climate and disturbances. The project only took a couple of months to complete because the SIMPPLE model was already parameterized for the Northern Region as part of the Forest Plan Revision process.

The model employs "logic pathways" describing trajectories of vegetation change. The assessment team tailored these logic pathways to local conditions using the Northern Region's vegetation map (VMAP), regional LANDFIRE data, and aerial detection surveys of MPB activity. These datasets were compared to more accurate information from Forest Inventory and Analysis (FIA) plots where possible (Ecosystem Research Group 2010). In addition, fire and fuel staff with the National Forest worked with fire modeling specialists to improve the accuracy of LANDFIRE data for the area (Fig. 8.1).

The team used SIMPPLE to assess the quantity and spatial arrangement of wildlife habitat through the use of "queries." Queries function as habitat models, providing descriptions of important habitat characteristics for different species. The validity of model output depends on accurate identification of habitat

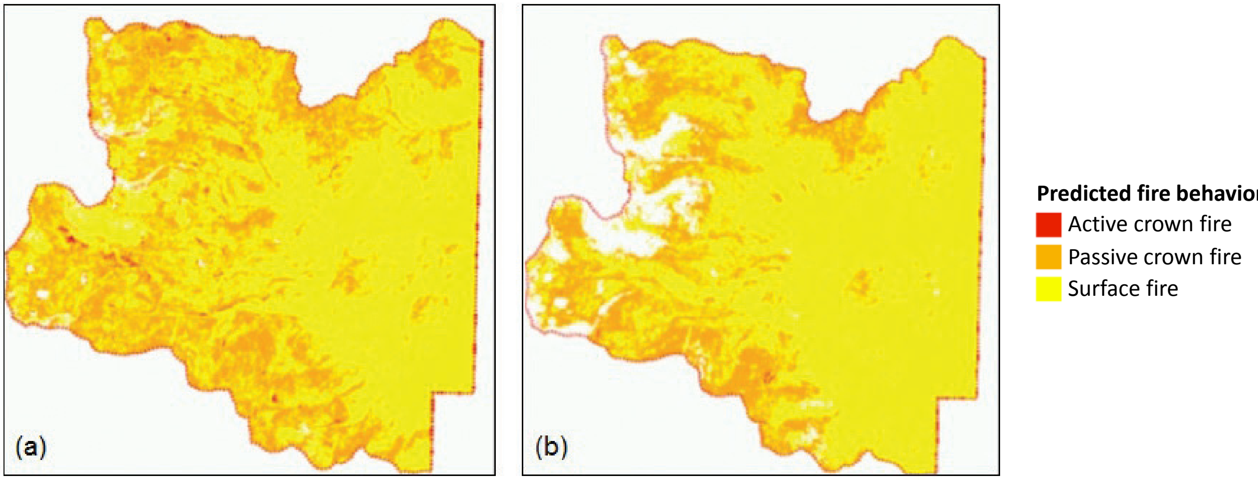

Figure 8.1. Managers and researchers used local data and expertise to refine LANDFIRE data for the Beaverhead-Deerlodge rapid assessment. FlamMap predictions of fire spread and behavior across a 60,000 acre treatment unit were substantially different when the team used the refined dataset (a) instead of the raw LANDFIRE data (b).

characteristics most constraining to specific wildlife species. Therefore, the assessment team created queries for each species based on an extensive literature review and communication with Forest Service wildlife biologists. For example, the assessment team focused on stands with large trees (dbh ≥ 10 inches) and dense understories when assessing suitable nesting habitat for northern goshawks.

The rapid assessment and simulation modeling provided important insight to resource managers and specialists with the Beaverhead-Deerlodge National Forest and the Northern Region. The results have already informed decision making and changed plans for project implementation. Forest managers were especially grateful to the assessment team for detailed information on cumulative effects to wildlife habitat. Species viability is evaluated at the forest-level per Forest Planning Regulations, so the finer-resolution information from this assessment is essential for planning at the project level. Managers with the National Forest have already incorporated the assessment findings into NEPA analyses and used them for forest-wide consultation with the U.S. Fish & Wildlife Service on delineation management of grizzly bear habitat.

Lesson learned #3: Assessments should consider the effects of natural disturbances and management actions at different spatial scales and over different timeframes.

Model output from SIMMPLE was used to compare the potential impacts of management strategies at different spatial scales, information that is important for conservation biological diversity (Haufler 1999). The rapid assessment was conducted for three spatial scales: the landscape in and around the Beaverhead-Deerlodge National Forest (8.3 million acres), the forested portion of the Beaverhead-Deerlodge National Forest (2.6 million acres), and twelve smaller landscapes within the National Forests (20 to 573 thousand acres) (Fig. 8.2).

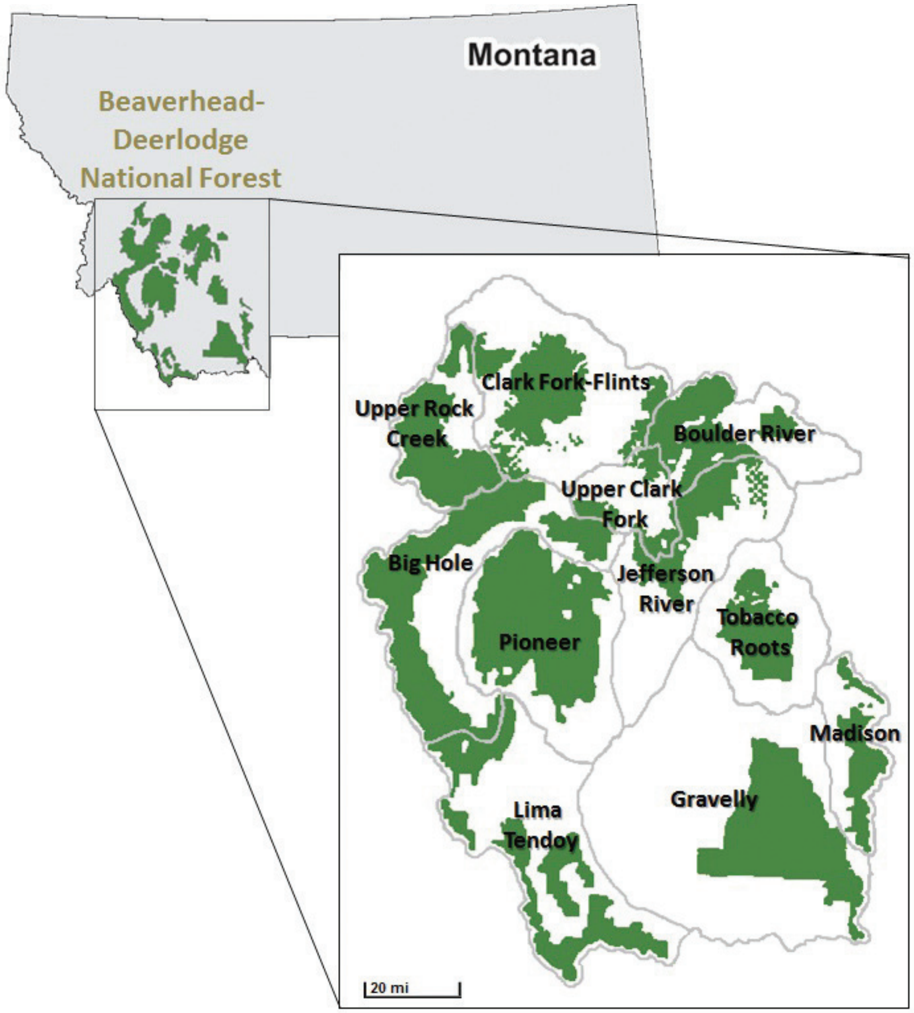

Figure 8.2. Map of 11 landscape areas for the Beaverhead-Deerlodge National Forest's rapid assessment (National Forest System land in green).

Results from simulation modeling for the Beaverhead-Deerlodge National Forest demonstrate that the effects of natural disturbances and silvicultural treatments varied with scale (Ecosystem Research Group 2010):

- Treatments substantially altered vegetation characteristics, such as forest structural stage and canopy cover, within treated stands. However, the percentage of the landscape occupied by different cover types was similar among treatments and no-treatment scenarios at the end of the simulation period (Fig. 8.3).
- Simulated treatments affected fire occurrence at both the treatment and landscape scale. Some simulated treatments resulted in 50 percent fewer acres burned compared to the no-treatment scenario, and all treatments combined resulted in 8 percent fewer acres burned across the landscape.
- The availability of wildlife habitat across the entire landscape remained relatively unchanged during the 50-year simulation period, regardless of the treatment or no-treatment scenario. Exact locations of potential habitat for the nine focal species varied among treatment scenarios, resulting in observable differences within individual treatment units (Fig. 8.4).

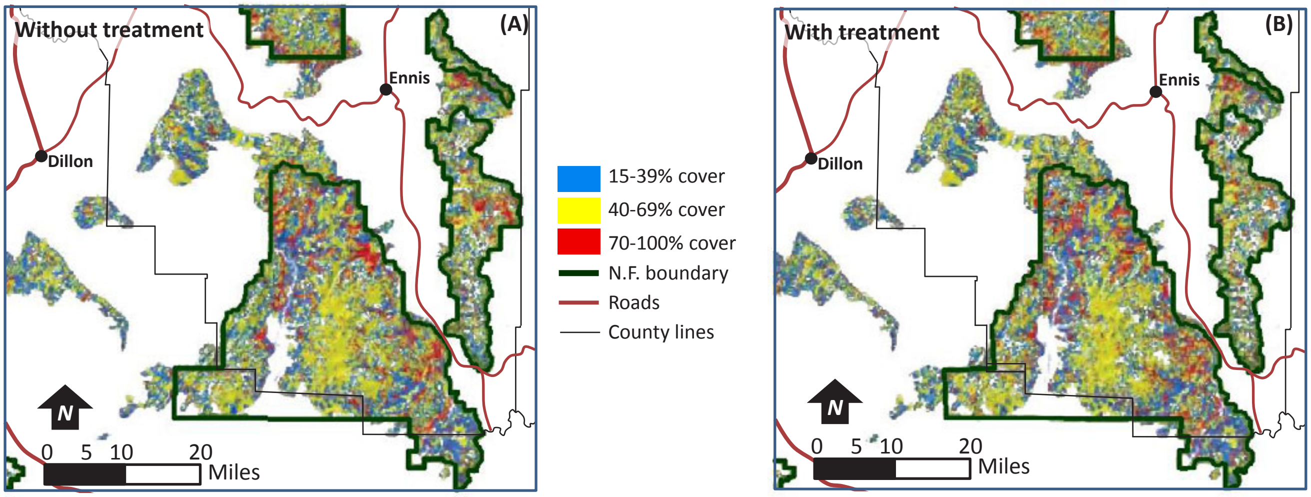

Figure 8.3. Modeled canopy cover for the year 2060 on the Gravelly and Madison landscape areas of the Beaverhead-Deerlodge National Forest. No treatment (A) and treatment (B) scenarios resulted in fairly similar predictions of canopy cover at the spatial scale of landscape areas (adapted from Ecosystem Research Group 2010).

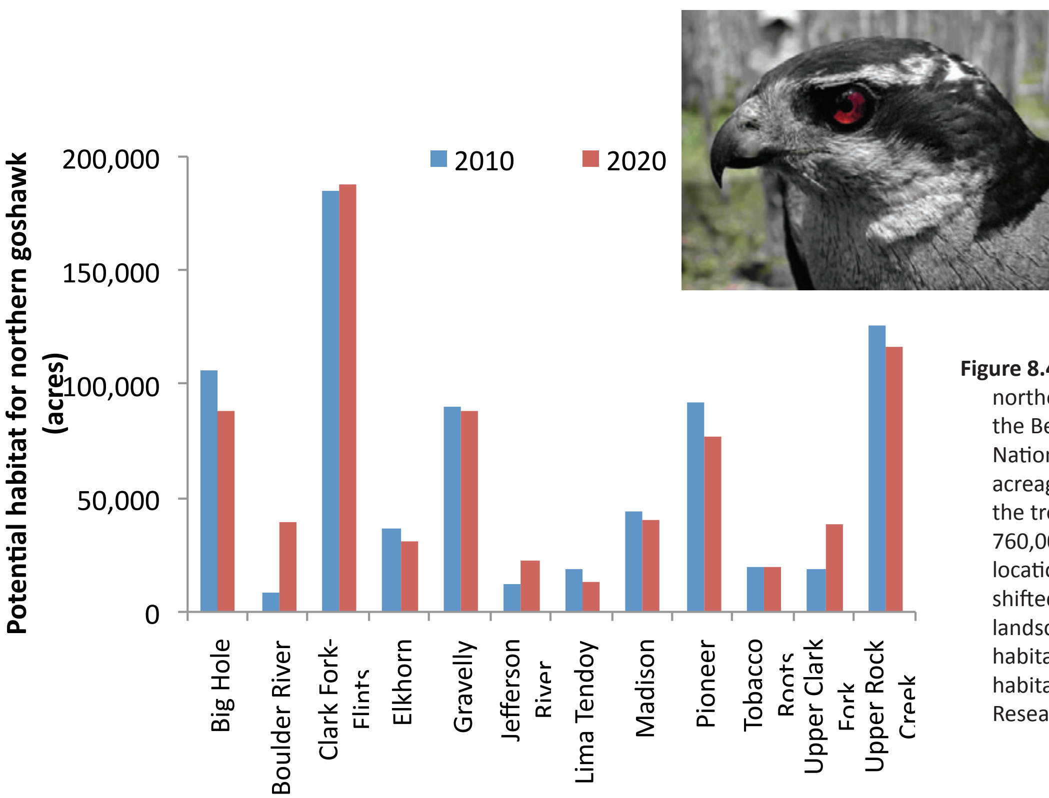

Figure 8.4. Potential habitat for northern goshawk in and around the Beaverhead-Deerlodge National Forest covered similar acreage in 2010 and 2020 under the treatment scenario (about 760,000 acres). However, the location of potential habitat shifted over time, with some landscape units gaining potential habitat and others losing potential habitat (adapted from Ecosystem Research Group 2010).

The assessment team was initially surprised by the minor impact that treatment scenarios had on vegetation, disturbances, and wildlife habitat. Upon further consideration, they realized that the limited extent of proposed treatments likely resulted in these predicted outcomes. Simulated treatments only covered 350,000 acres (13 percent) of the forested portion of the Beaverhead-Deerlodge National Forest. Budgetary constraints, feasibility considerations, and other management objectives limit the acres that can reasonably be treated.

Lesson learned #4: Managers and researchers need to consider model assumptions and limitations when interpreting results.[8]

The rapid assessment for the Beaverhead-Deerlodge National Forest highlights the utility of simulation modeling for assessing potential futures of disturbance-prone forests. This case study also points to the value of multi-scaled assessments for informing resource management planning and management actions. Another key aspect of the Beaverhead-Deerlodge National Forest assessment is the team's explicit consideration of model assumptions and limitations.

Complexity in ecosystem processes and disturbance interactions, as well as uncertain future conditions, render it impossible to predict treatment effects and future vegetation patterns with certainty. This reality was discussed and acknowledged by the assessment team for the Beaverhead-Deerlodge National Forest. Assumptions for the rapid assessment and SIMPPLLE model are clearly listed in the final report from the Ecosystem Research Group. The report also describes the level of certainty for projections of potential habitat by wildlife species. High certainty is attributed to projections for northern goshawk habitat due to an abundance of local data on nest locations. In contrast, projections for flammulated owl habitat are less certain. The National Forest had less data on nest locations for the owl, and the remotely-sensed vegetation data had low reliability for detecting key habitat features, such as low density Douglas-fir stands.

The assessment team regarded SIMPPLLE output as a "best guess" based upon current research on disturbance impacts, stand development, and characteristics of wildlife habitat. They decided that the rapid assessment would provide the most supportable results and applications for planning and project implementation if interpreted comparatively (*e.g.*, Scenario X results in more acres of aspen cover type than Scenario Y) rather than predictively (*e.g.*, Scenario X results in Z acres of aspen cover type).

[8] *This lesson learned reinforces material presented in Research Finding 3 of Chapter 5.*

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Meet the chapter presenters and authors

Barry Bollenbacher recently celebrated his 40th year with the Forest Service! He has served in his current position as Regional Silviculturist for the Northern Region since 1992. Barry works closely with researchers from the Rocky Mountain Research Station and other organizations to help incorporate science into silviculture prescriptions, forest plans, and regional training programs. Barry graduated from Michigan State University in 1975 with a bachelor's degree in Forestry. Barry can be reached at bbollenbacher@fs.fed.us; 406-329-3297.

Rob Gump is the Forest Silviculturist and Ecologist for the Beaverhead-Deerlodge National Forest. Rob has held this position since 2008, as well as previously from 1990 to 1996. He also spent 27 years with the Forest Service in the Northern and Pacific Northwest Regions. Rob is certified silviculturist, and he has been active with the fire and fuels management community for almost 30 years. Reach Rob at rgump@fs.fed.us; 406-683-3965.

Mike Hillis worked as a wildlife biologist for the Forest Service for 34 years, primarily in the Northern and Pacific Northwest Regions. He retired in 2003 and has since worked as the Senior Wildlife Biologist for the Ecosystem Research Group out of Missoula, MT. Mike specializes in long-term, broad-scale modeling for species potentially at risk in the northern and central Rockies. He graduated from Oregon State University in 1970 with a Bachelor's degree in Wildlife Biology. Mike can be reached at mhillis@ecosystemrg.com; 406-721-9240.

Claudia Regan is the Regional Ecologist with the Rocky Mountain Region of the Forest Service. She has worked with the agency as a full-time employee for 18 years and in temporary or seasonal capacities for 6 years. Regional Ecologists serve as applied scientists who bridge scientific research with resource management issues and work toward information synthesis, delivery, and application. Claudia has Bachelor's and Master's degrees in Forest Science from Southern Illinois University and a Ph.D. in Ecology from Colorado State University. Reach Claudia at cregan@fs.fed.us; 303-275-5004.

Appendix A. Scientific names of insect, plant, animal, and fungi species.

Common name	Scientific name
Insect species	
Western spruce budworm	*Choristoneura occidentalis*
Lodgepole needle miner	*Coleotechnites milleri Busck*
Mountain pine beetle	*Dendroctonus ponderosae*
Tree species	
Subalpine fir	*Abies lasiocarpa*
Engelmann spruce	*Picea engelmannii*
Whitebark pine	*Pinus albicaulis*
Bristlecone pines	*P. aristata and P. longaeva*
Foxtail pine	*P. balfouriana*
Pinyon pines	*P. edulis and P. monophylla*
Limber pine	*P. flexilis*
Ponderosa pine	*P. ponderosa*
Scotch pine	*P. sylvestris*
Lodgepole pine	*P. contorta*
Quaking aspen	*Populus tremuloides*
Animal species	
Northern goshawk	*Accipiter gentilis*
Elk	*Cervus canadensis*
Pileated woodpecker	*Dryocopus pileatus*
Wolverine	*Gulo gulo*
Canada lynx	*Lynx canadensis*
Fisher	*Martes pennant*
Flammulated owl	*Otus flammeolus*
Lazuli bunting	*Passerina amoena*
Black-headed grosbeak	*Pheucticus melanocephalus*
White-headed woodpecker	*Picoides albolarvatus*
Black-backed woodpecker	*Picoides arcticus*
American three-toed woodpecker	*Picoides dorsalis*
Downy woodpecker	*Picoides pubescens*
Hairy woodpecker	*Picoides villosus*
Chickadees	*Poecile spp.*
Golden-crowned kinglet	*Regulus satrapa*
Bull trout	*Salvelinus confluentus*
Mountain bluebird	*Sialia currucoides*
Pine squirrel	*Tamiasciurus hudsonicus*
Grizzly bear	*Ursus arctos horribilis*
Fungi species	
Blue-stain fungus	*Grosimannia clavigera*

Rocky Mountain Research Station

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide. For more information, please visit the RMRS web site at: www.fs.fed.us/rmrs.

Station Headquarters

Rocky Mountain Research Station
240 W Prospect Road
Fort Collins, CO 80526
(970) 498-1100

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