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.

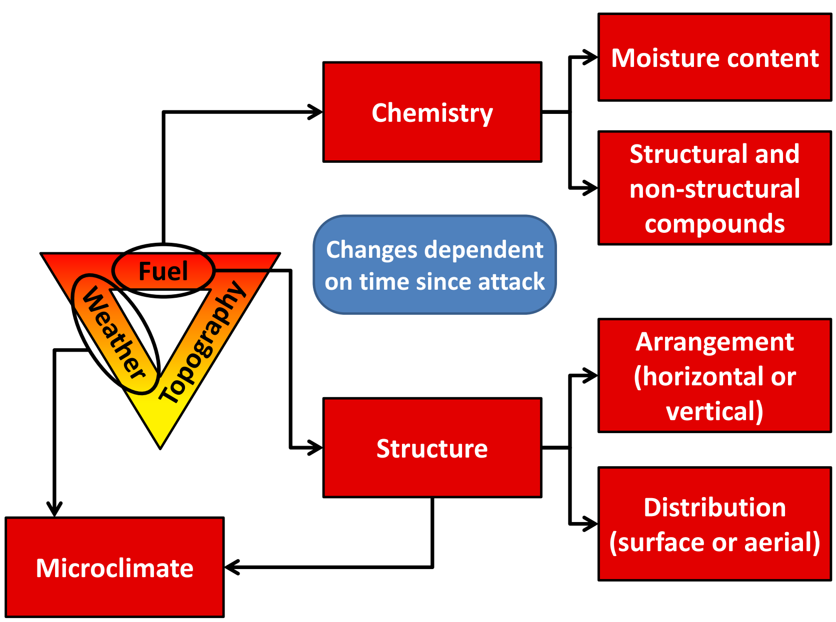

Figure 3.1. The MPB epidemic has altered fuel and microclimate conditions in forest stands. Fuel loads and microclimates will change over time due to management decisions and forest regrowth. These changes can result in unexpected fire behavior, with serious implications for fire operations (diagram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

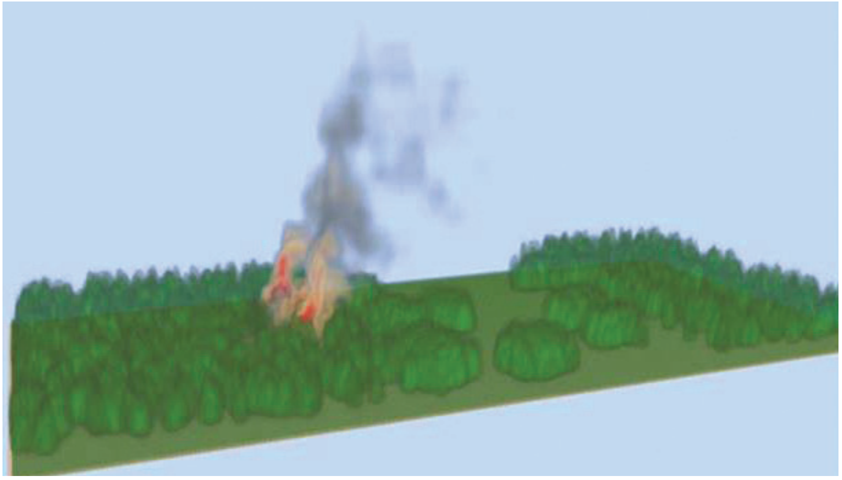

Figure 3.2. Physics-based fire models such as FIRETEC (pictured here) simulate fire spread in three dimensions and at much higher resolution than standard fire models. These detailed models are useful for exploring how disturbances, such as MPB outbreaks, affect fuel loads and fire behavior (figure by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

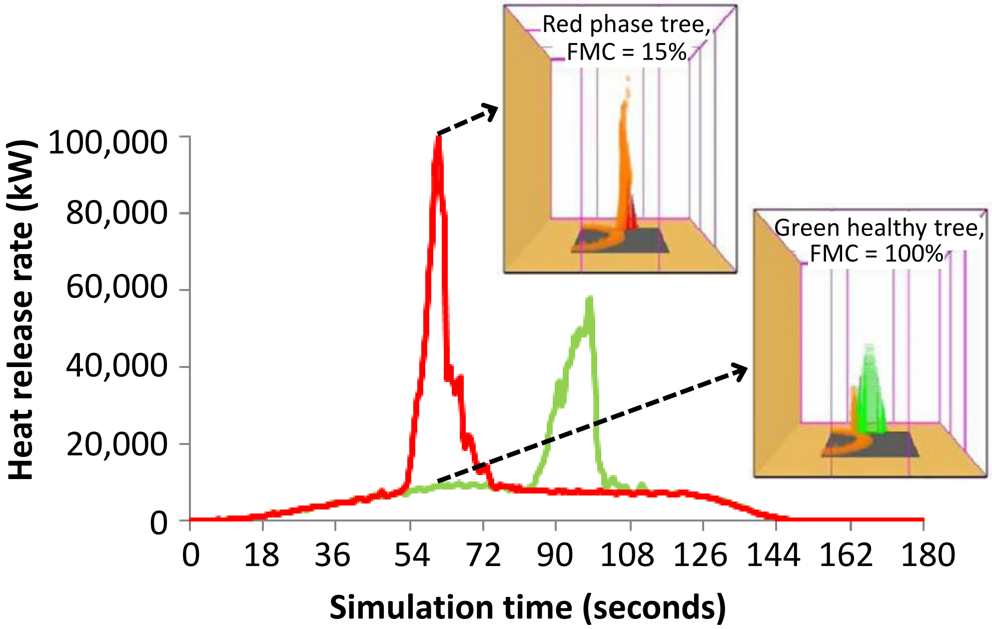

Figure 3.3. Comparison of heat released by consumption of a red-stage tree and a healthy, green tree as modeled with the Wildland-Urban Interface Fire Dynamics Simulator (WFDS). Both trees have identical fuel properties except that the red-stage tree has lower foliar moisture content (FMC). The maximum 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.

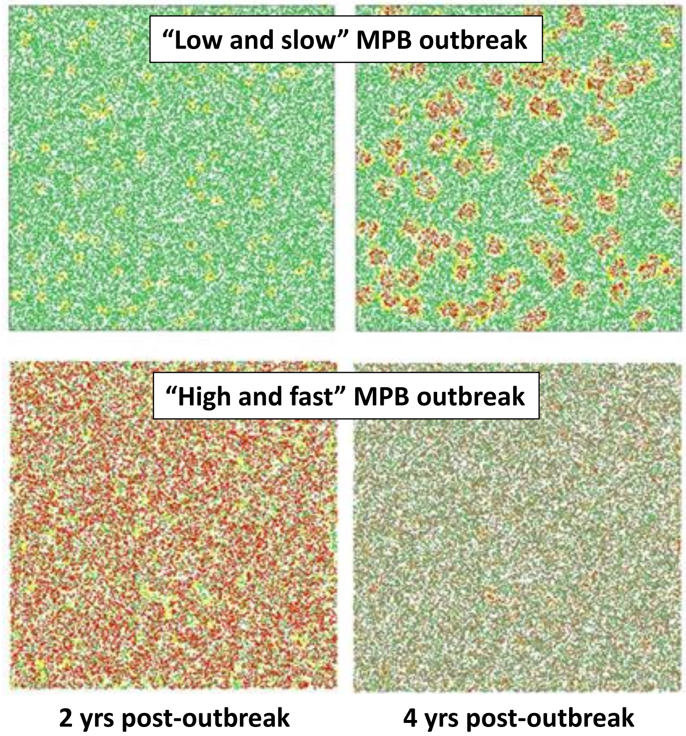

Figure 3.4. Forest Service researchers developed a simple model to examine how the rate and intensity of MPB outbreaks might change fuels and fire behavior over time. The "low and slow" scenario involved a slower rise in the proportion of red-stage trees, peaking below 20 percent of trees around year 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

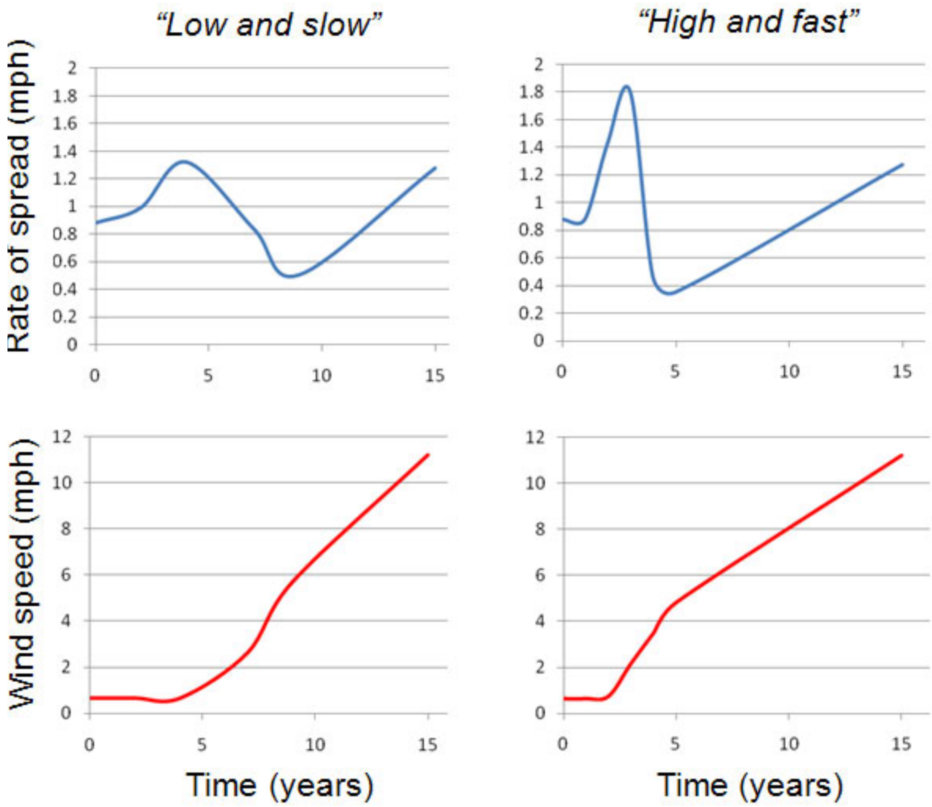

Figure 3.5. Potential effects of "low and slow" versus "high and fast" MPB outbreaks as modeled with the Wildland-Urban Interface Fire Dynamics Simulator (WFDS). Peak rates of spread are potentially greater for "high and fast" outbreaks due to the abundance of red-stage trees. As trees fall to the ground, 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	• 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?

Literature cited

Collins, B.J., C.C. Rhoades, M.A. Battaglia, and R.M. Hubbard. 2012. The effects of bark beetle outbreaks in forest development, fuel loads, and potential fire behavior in salvage logged and untreated lodgepole pine forests. Forest Ecology and Management 284:260-268.

Hicke, J.A., M.C. Johnson, J.L Hayes, and H.K. Priesler. 2012. Effects of bark beetle-caused tree mortality on wildfire. Forest Ecology and Management 271:81-90.

Hoffman, C., P. Morgan, W. Mell, R. Parsons, E.K. Strand, and S. Cook. 2012. Numerical simulation of crown fire hazard immediately after bark beetle-caused mortality in lodgepole pine forests. Forest Science 58(2):178-188.

Hoffman, C.M., C.H. Sieg, P. Morgan, W. Well, R. Linn, C. Stevens-Rumann, J. McMillin, R. Parsons, and H. Maffei. 2013. Progress in understanding bark beetle effects on fire behavior using physics-based models. Technical Brief CFRI-TB-1301. Colorado State University, Colorado Forest Restoration Institute, Fort Collins, CO. 10 pp. [online] URL: http://coloradoforestrestoration.org/wp-content/uploads/2014/01/2013_Hoffman-etal_PhysicsBasedModels.pdf.

Jenkins, M.J., J.B. Runyon, C.J. Fettig, W.G. Page, and B.J. Bentz. 2014. Interactions among the mountain pine beetle, fires, and fuels. Forest Science 60. [online] URL: http://dx.doi.org/10.5849/forsci.13-017.

Jolly, W.M., R.A. Parsons, A.M. Hadlow, G.M. Cohn, S.S. McAllister, J.B. Pop, R.M. Hubbard, and J.F. Negron. 2012a. Relationships between moisture, chemistry, and ignition of Pinus contorta needles during the early stages of mountain pine beetle attack. Forest Ecology and Management 269:52-59.

Jolly, W.M., R.A. Parsons, J.M. Varner, B.W. Butler, K.C. Ryan, and C.L. Gucker. 2012b. Do mountain pine beetle outbreaks change the probability of active crown fire in lodgepole pine forests? Ecology 93(4):941-946.

Linn, R.R., C.H. Sieg, C.M. Hoffman, J.L. Winterkamp, and J.D. McMillin. 2013. Modeling wind fields and fire propagation following bark beetle outbreaks in spatially-heterogeneous pinyon-juniper woodland fuel complexes. Agricultural and Forest Meteorology 173:139-153.

Page, W.G., M.E. Alexander, and M.J. Jenkins. 2013. Wildfire's resistance to control in mountain pine beetle-attacked lodgepole pine forests. Forestry Chronicle Volume 89(6):783-794.

Schoennagel, T., T.T., Veblen, J.F. Negron, and J.M. Smith. 2012. Effects of mountain pine beetle on fuels and expected fire behavior in lodgepole pine forests, Colorado, USA. PLoS One 7:e30002. [online] URL: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0030002.

Schroeder, D. and C. Mooney. 2012. Fire behavior in simulated mountain pine beetle-killed stands. Final Report. FPInnovations, Wildfire Operations Research, Hinton, Alberta. 17 pp. [online] URL http://wildfire.fpinnovations.ca/64/ArcherMPB_Final.pdf.

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

USDA Forest Service. 2011. Beetle fact sheet. U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Golden, CO. 2 pp. [online] URL: http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5337223.pdf.

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.