Final Report: Forecasting Impacts of Mountain Pine Beetle on Lodgepole Pine Forests

CSU PI: Monique E. Rocca

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A. Project overview and accomplishments

We investigated how subalpine forest structure and composition are likely to respond to combinations of climate-induced stresses brought by insect epidemics, changing fire regimes, and their interactions. Lodgepole pine forests have experienced a severe, drought-induced outbreak of the mountain pine beetle in recent years, raising concerns amongst land managers and the public about the wildfire hazard posed by insect-killed trees and what will grow where vast lodgepole pine stands once stood. It is widely believed that insect outbreaks set the stage for catastrophic wildfires because they create great quantities of dead fuels. There is considerable uncertainty regarding how the current mountain pine beetle outbreak will impact future fire behavior in beetle-killed stands. However, it is thought that the risk of a crown fire may be greater in stands composed primarily of standing dead trees with red needles than in stands of green trees.

We accomplished the following objectives:

1) We characterized landscape patterns of lodgepole pine mortality, serotiny, and the diversity of forest/woodland stand structures following the mountain pine beetle outbreak in Rocky Mountain National Park. We focused on the factors affecting the survival and the regeneration of tree species.
2) We tested interactions between insect-induced tree mortality and wildfire behavior. We utilized prescribed fire in beetle-impacted stands to investigate the flammability of lodgepole pine crowns.
3) Utilizing forest simulation models, we predicted forest developmental trajectories 100 years into the future.

B. Key Findings

1. Mortality Patterns

Across the landscape, mean mortality, or the proportion of trees killed, reached 47%; however, 71% of basal area was killed. Surviving stand structure experienced large decreases in diameter (17 to 11 cm), basal area (29 to 8.5 m2 ha-1), and density (1393 to 915 trees ha-1). Environmental factors (elevation and moisture) and tree size greatly influenced mortality rates early in the outbreak. Later stages of the outbreak showed stronger relationships with stand structure factors (tree size, basal area, proportion of non-host trees, density and stand age). Forest heterogeneity increased within forest stands, while heterogeneity among stands on the landscape declined over time.

Management implications: The current mountain pine beetle outbreak has caused extensive changes to the subalpine forest landscape, but high densities of surviving trees and increased stand-scale heterogeneity will allow forest recovery and increased resistance in the face of future outbreaks.

2. **Stand structure and composition**
Our results indicate that surviving trees, including both canopy trees and saplings, are plentiful in most of the post-outbreak forests. Post-outbreak stand structure and composition varied depending on pre-outbreak stand structure and composition. Subalpine fir, Engelmann spruce, and aspen have modestly higher relative abundances after the outbreak. Currently, lodgepole pine remains the dominant species on approximately 85 percent of the landscape.

Management implications: Mountain pine beetle has not destroyed the forest, as there are many surviving trees, including lodgepole pines that are too small to be susceptible and trees of non-host species, in the areas impacted by the outbreak. Active restoration efforts such as tree planting are not necessary in this landscape, as most stands are "fully stocked" according to US Forest Service criteria. Whether this finding holds in other areas where lodgepole pine forests have been impacted by mountain pine beetle is the subject of ongoing research.

3. **Serotiny patterns and viability of serotinous cones**
We detected a slight decrease in serotiny with increasing elevation. Other factors influencing serotiny are still being analyzed. There was no significant difference between germination success rates of seeds from living trees vs. the seeds from mountain pine beetle-killed trees that had been dead for ~5 years.

Management implications: Lodgepole pine seeds in serotinous cones are likely to remain viable for at least a few years following tree mortality. Therefore, forest regeneration likely will not be limited by seed viability in stands with serotinous cone bearing trees. Whether seeds are eventually released from unburned serotinous cones on dead trees, and the rate at which lodgepole pine seedlings can establish in the absence of fire, remains unknown and is the subject of ongoing studies.

4. **Flammability of beetle-killed trees**
We demonstrated that the increased crown fire risk following tree mortality is relatively short-lived. Working with NPS fire management staff, we used a propane torch to ignite the bases of individual lodgepole pine trees in April, 2009. We tested flammability across a spectrum of crown conditions from unattacked green trees, to trees with full crowns of red needles, to trees that had been attacked several years ago and had lost most or all of their needles. We found an increase in crown flammability in red-crowned trees relative to unattacked trees. As red needles begin to fall from the tree, crown flammability decreases.

Table: Percentages of trees ignited at the base that carried fire.

Lodgepole Crown	N	% carried fire
alive, not attacked	5	0%
attacked, still green	3	0%
mixed red and green needles	1	100%
80-100% needles remaining	3	100%
60-79% needles remaining	2	50%
40-59% needles remaining	3	0%

Management implications: The increase in fire risk immediately following the beetle outbreak is a reality. However, it may be short-lived because the forest canopy loses its flammability once the trees lose their needles. Park managers had hoped that by burning red needles off trees with a propane torch, canopy fuel breaks could be prepared near the park boundary to

protect surrounding lands from spreading crownfire leaving the park. However, the rarity of appropriate burn windows, coupled with the short duration of red, flammable trees, make this approach infeasible.

5. Landscapes of the future

We projected future forest conditions over a 100 year time period using an established forest growth model, the Forest Vegetation Simulator (FVS). Basal area and quadratic mean diameter declined substantially following the outbreak, yet these forest attributes recover within 40-100 years in most areas. Pure lodgepole pine forests with low post-outbreak survivorship were the exception to this rule and could be slower to recover, depending on the abundance of future tree seedling establishment. Simulation results indicate that the release of surviving trees, rather than the establishment of new seedlings will be the most important mechanism for forest renewal. Lodgepole pine will remain the dominant species on approximately 40% of the landscape, but spruce-fir and aspen become dominant in the remaining areas.

Management implications: At least in the absence of future disturbances (beetle outbreaks, fires) or sudden climate changes, the landscape will remain forested, and non-lodgepole species will increase in areas where they are already present in the understory. Some areas of pure lodgepole pine (approx 20% of the landscape) may not recover quickly unless future seedling establishment is rapid. In these areas, future fires (prescribed or lightning-ignited) might increase seed release from serotinous cones to promote lodgepole regeneration, however this requires further study.

C. Outputs

Results from this study have been disseminated to both public and professional audiences through a variety of venues. We educated members of the public on the consequences of the pine beetle outbreak at the Gilpin County Fire Symposium (March 2009) and the RMNP's Science Behind the Scenery Program (July 2009), and RMNP's Lyceum lecture series (April 2011). We educated ROMO staff and members of the public and on the consequences of the pine beetle outbreak through five presentations (three oral, two posters) at the Rocky Mountain National Park Biennial Research Conference (March 2010 in Estes Park, CO) and at the RMNP Science Day (Feb 2009).

Scientists and land managers learned about our results through presentations at the Association for Fire Ecology's International Fire Ecology and Management Congress (Dec 2009), and the US Chapter of the International Association for Landscape Ecology's Twenty-fifth Anniversary Symposium (April 2010). We organized and hosted the first Mountain Pine Beetle Science Symposium, held on the CSU campus, Dec 11, 2009. We co-authored a report for the Colorado Forest Restoration Institute entitled "Some Ecological Considerations Regarding the Future Range of Variability of Lodgepole Pine Ecosystems in Colorado and Wyoming". We also co-authored a poster with ROMO fire management on the impacts of mountain pine beetle on wildland fire behavior at the National Park Service Fire and Aviation Management Conference (Feb, 2010 in San Antonio, TX). Our results have been incorporated into RMNP's campfire programs and the National Park Service's Parks in Peril report.

We have conducted numerous interviews with local media outlets including two Denver television news stations and the Fort Collins Coloradoan, and our research has been featured in several local public radio news segments. We were featured in an article in CSU's alumni magazine.

Three graduate students and at least four field assistants gained experience and training in ecological research conjunction with this study. Three M.S. theses have been published and posted on the CSU library website.

Two scholarly articles have been published, and three more are in review or in revision.

Citations (*copy submitted with this final report):

Publications and Reports

Diskin, M., J.S. Sibold, and M.E. Rocca. After the 2000's mountain pine beetle epidemic: projected future forest conditions in lodgepole pine forests of Rocky Mountain National Park, CO, USA. *In preparation* for Forest Ecology and Management.

Nelson, K.N. and M.E. Rocca. Aspen sucker density and growth following mountain pine beetle outbreak. *In revision* for Canadian Journal of Forest Research.

*Diskin, M., M.E. Rocca, K. Nelson, C. Aoki, and W.H. Romme. 2011. Forest regeneration trajectories in mountain pine beetle-disturbed forests of Rocky Mountain National Park. Canadian Journal of Forest Research 41: 782–792.

*Aoki, C.F., W. H. Romme, and M.E. Rocca. 2011. Lodgepole pine seed viability following tree death from mountain pine beetle attack in Colorado, USA. American Midland Naturalist 165(2):446-451.

Brown, P., M. Rocca, J. Clement, G. Hayward, C. Rhoades, B. Collins, and R. Skorkowsky. 2010. Some Ecological Considerations Regarding the Future Range of Variability of Lodgepole Pine Ecosystems in Colorado and Wyoming. Colorado Forest Restoration Institute Pre-conference Report for Beyond the Bugs: The Future Range of Variability of Communities and Forest Landscapes, April 2010. [http://warnercnr.colostate.edu/images/docs/cfri/SomeEcologicalConsiderations_FRV_CFRI_2010April.pdf]

*Rocca, M. E. and W. H. Romme. 2009. Beetle-infested forests are not "destroyed". Frontiers in Ecology and the Environment 7:71-72.

Theses

Aoki, C. 2010. Fire history and serotiny in the Rocky Mountains of Colorado. M.S. Thesis. Colorado State University, Fort Collins, CO.

*Diskin, M. 2010. Forest regeneration trajectories in mountain pine beetle-disturbed forests of Rocky Mountain National Park. M.S. Thesis. Colorado State University, Fort Collins, CO.

*Nelson, K. 2009. The effect of mountain pine beetle caused mortality on subalpine forest stand and landscape structure in Rocky Mountain National Park, CO. M.S. Thesis. Colorado State University, Fort Collins, CO.

Presentations

April 2010. Rocca, M.E, M. Diskin, C. Aoki, K. Nelson, and W.H. Romme. Forest Regeneration Trajectories in Mountain Pine Beetle-Disturbed Forests of Rocky Mountain National Park. 2010 US-IALE Twenty-fifth Anniversary Symposium, Athens, GA.

April 2010. Nelson, K., Rocca, M.E., C. Aoki, M. Diskin, and W.H. Romme. Mountain Pine Beetle-Related Lodgepole Pine Mortality: Multi-Scale Causes and Effects in Rocky Mountain National Park, CO. 2010 US-IALE Twenty-fifth Anniversary Symposium, Athens, GA.

March 2010. Nelson, K. and Rocca, M.E. Aspen Sucker Density and Growth Following Mountain Pine Beetle Outbreak. Rocky Mountain National Park Biennial Research Conference, Estes Park, CO.

March 2010. Diskin, M., Rocca, M.E, C. Aoki, K. Nelson, and W.H. Romme. Forest Regeneration Trajectories in Mountain Pine Beetle-Disturbed Forests of Rocky Mountain National Park. Rocky Mountain National Park Biennial Research Conference, Estes Park, CO.

March 2010. Aoki, C., W.H. Romme, Rocca, M.E, Sibold, J.S., M. Diskin, and K. Nelson. Serotiny in Lodgepole Pine of Rocky Mountain National Park. Rocky Mountain National Park Biennial Research Conference, Estes Park, CO.

March 2010. Williamson, N, M. Lewelling, M.E. Rocca, W.H. Romme, C. Aoki, M. Diskin, and K. Nelson. Impacts of Mountain Pine Beetle on Lodgepole Pine Fire Behavior in Rocky Mountain National Park, Colorado. Rocky Mountain National Park Biennial Research Conference, Estes Park, CO.

March 2010. Nelson, K., Rocca, M.E., C. Aoki, M. Diskin, and W.H. Romme. Mountain pine beetle-related lodgepole pine mortality: multi-scale causes and effects in Rocky Mountain National Park, CO. Rocky Mountain National Park Biennial Research Conference, Estes Park, CO.

February 2010. Williamson, N, M. Lewelling, M.E. Rocca, W.H. Romme, C. Aoki, M. Diskin, and K. Nelson. Impacts of Mountain Pine Beetle on Lodgepole Pine Fire Behavior in Rocky Mountain National Park, Colorado. National Park Service Fire and Aviation Management Conference, San Antonio, TX.

Rocca, M. E., C. Aoki, M. Diskin, K.Nelson, M. Lewelling, N. Williamson, and W.H. Romme. Forest dynamics and fire behavior following mountain pine beetle mortality in Rocky Mountain National Park. Presented at the 4th International Wildland Fire Ecology and Fire Management Congress, Savannah, GA, December 2009.

December 2009. Rocca, M.E, C. Aoki, M. Diskin, K. Nelson, M. Lewelling, N. Williamson, and W.H. Romme. Forest dynamics and fire behavior following mountain pine beetle mortality in Rocky Mountain National Park. 4th International Fire Ecology and Management Congress: Fire as a Global Process, Savannah, GA.

December 2009. Diskin, M., Rocca, M.E, W.H. Romme, C. Aoki, and K. Nelson. Successional trajectories of mountain pine beetle-disturbed lodgepole pine forests depend on initial forest conditions. Mountain Pine Beetle Science Symposium, Colorado State University, CO.

December 2009. Nelson, K., Rocca, M.E., C. Aoki, M. Diskin, and W.H. Romme. Lodgepole pine mortality patterns through early, middle, and late stages of a mountain pine beetle eruption in Rocky Mountain National Park, CO. Mountain Pine Beetle Science Symposium, Colorado State University, CO.

September 2008. Diskin, M., Rocca, M.E, and W.H. Romme. The Effects of Mountain Pine Beetle Disturbances on Understory Vegetation Patterns in Lodgepole Pine Forests of Rocky Mountain National Park. The Yellowstone Fires: ’88 and Beyond, Jackson, WY.

September 2008. Nelson, K., Rocca, M.E, and W.H. Romme. Mountain Pine Beetle Mortality and Scale: Patterns in Rocky Mountain National Park. The Yellowstone Fires: ’88 and Beyond, Jackson, WY.

D. *Future work*

This work is ongoing. We plan to take advantage of any opportunities to further investigate the relationship between beetle mortality and fire behavior. The same factors that limit the utility of a propane torch for burning away canopy fuels (see B.4. above) limited our sample size for testing fire behavior in dead trees. However, if there are future prescribed fires or wildfires that occur in beetle-impacted parts of the park, we will develop studies to build on our first fire behavior experiment.

We will also use any future fires in the park to study how fire after the beetle outbreak will influence future forest development, for example, by killing seedlings and small trees and by releasing seeds from serotinous cones. Such a study would help determine whether managers should consider prescribed fire through beetle-affected stands in order to promote lodgepole pine seedling establishment, or whether lodgepole pine will regenerate in the absence of fire.

Besides studying future fires, we also will continue to monitor growth release of surviving trees and seedling establishment to improve our projections of the future forest. We also would like to develop more sophisticated, landscape-scale models to test the combined effects of a changing climate, altered fire regimes, and beetle outbreaks on the future forest. Our results would be applicable to a wider geographic region if we were to expand the geographic extent of our study to include the east side of Rocky Mountain National Park and surrounding areas.

We are seeking additional funding sources to pursue these topics.