Joint Fire Science Program
Fire Science Brief
RESEARCH SUPPORTING SOUND DECISIONS

The handiwork of the mountain pine beetle. Credit: Nancy Bockino.

Evaluating Bark Beetle and Wildfire Dynamics in the Greater Yellowstone Ecosystem

Summary

In the western United States, bark beetle outbreaks are at a record high—and of grave concern to forest managers and other stakeholders. There is a common belief that the high amounts of dead fuels produced by bark beetle infestations increase the chance of active crown fires. However, little is known about how bark beetle outbreaks and wildfire interact, and how that interaction influences the overall ecosystem structure and potential fire behavior. To better understand bark beetle/wildfire dynamics, a study was conducted in beetle-infested areas of the Greater Yellowstone Ecosystem (GYE) in northwestern Wyoming and adjacent portions of Montana and Idaho. Key questions that were addressed include: (1) What are the current patterns of beetle outbreaks in the GYE at both broad and fine scales? (2) How do beetle outbreaks influence wildfire probability and severity? and (3) How does the pattern of fire-damaged trees affect the pattern and severity of beetle outbreaks? By using a combination of extensive field data collection, remote sensing, and computer modeling techniques, researchers were able to shed light on these questions as well as provide forest managers with the critical information needed to make science-based decisions regarding the current and future management of this complex, post-disturbance landscape.

Key Findings

- Field data revealed that variables describing forest habitat and beetle pressure (that is, the proximity and abundance of local infestations in the early stages of the outbreak) in the surrounding landscape were better than plot-level measurements at explaining spatial patterns of beetle-caused tree mortality in susceptible stands of lodgepole pine, Engelmann spruce, and Douglas-fir. However, these variables were marginal predictors of whitebark pine mortality.
- Remote sensing analyses indicated that approximately 27 percent of the area in mature conifer forest in the Greater Yellowstone Ecosystem (GYE) showed moderate- to high-severity beetle damage (>20 percent basal area beetle-killed) in 2007 and that 45 percent of that area was not affected by beetles.
- Where both tree species were found together, mountain pine beetle tended to prefer whitebark pine over lodgepole pine, especially if white pine blister rust was present in whitebark pine.
- Rather than increase the likelihood of active crown fires in the short term (1–5 years post-outbreak), modeling results indicated that beetle outbreaks may actually reduce the probability of active crown fire under moderate fire weather conditions. At the extremes of fire weather conditions, either wet or extremely dry, beetle-caused tree mortality has essentially no impact on fire behavior.
- Mountain pine beetle was more likely to colonize lodgepole pine trees that had been injured by fire than those that were not, but the total and relative gallery area declined with increasing fire injury. Results suggested that brood success of mountain pine beetle is reduced in fire-injured trees.

Background and study objectives

The mountain pine beetle (MPB) (*Dendroctonus ponderosae*) may be as small as a grain of rice, but it's having a big impact on the forests of the western United States. Recent infestations have reached an all-time high, leaving behind acres of dead and dying trees and a growing unease among forest managers.

The MPB, a species of bark beetle, lives for less than a year and typically targets lodgepole pine (*Pinus contorta* var. *latifola*), ponderosa pine (*Pinus ponderosa*), and whitebark pine (*Pinus albicaulis*) tree species. The adult female beetles attack new trees by boring through the bark to the phloem layer, where they deposit their eggs. Once hatched, the larvae feed on the tissue of the host tree, girdling the tree in the process. The beetles also carry a fungus that hinders the tree's ability to draw nutrients and water. In response to the attack, the trees exude large amounts of resin to 'pitch out' the beetles.

The mountain pine beetle is commonly known as one of the most destructive forest pests in western North America. Credit: British Columbia's Ministry of Forests & Range.

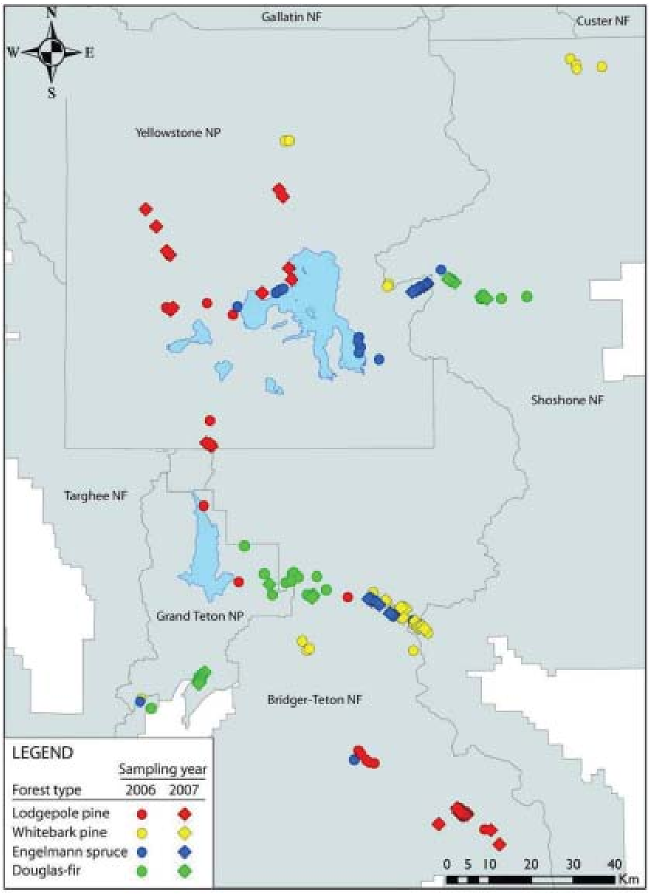
MPB is a native insect that has co-existed with lodgepole pine for thousands of years. Most of the time it is present in small numbers and kills only weak or injured trees, but every few decades MPB numbers increase dramatically to produce an outbreak. During an outbreak, the beetles can overwhelm the defenses of even healthy trees, and tree mortality can be extensive. Outbreaks typically are terminated by an episode of bitter cold weather, e.g., a week or more of temperatures below –20 degrees F. Such episodes of bitter cold have not been occurring over the past 10–20 years, and this climatic change is largely responsible for the very extensive and severe bark beetle outbreaks being seen across western North America.

Although few landscape-scale studies have been conducted on the interaction between beetle outbreaks and fire, it is commonly believed that these outbreaks can boost dead fuel loads, therefore boosting the likelihood of high-severity fire. This is especially relevant for lodgepole pine forests, which are among the most dynamic crown-fire dominated ecosystems in North America. Forest managers are also concerned about the unknown ecological and economic effects of these changing disturbance regimes.

To help understand the dynamics between bark beetles and fire, researchers conducted a study in the Greater Yellowstone Ecosystem (GYE) of northwestern Wyoming. The GYE is characterized by extensive subalpine forests and is dominated by lodgepole pine, but includes whitebark pine, subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and Douglas-fir (*Pseudotsuga menziesii*). Historically, fire has been a routine element of this landscape, with stand-replacing fires occurring at 100–300 year intervals throughout the last 10,000 years. Native phloem-eating insects have also been a common element of this ecosystem, with records of insect outbreaks dating back to 1909. The combination of recent fires—since 1988—and the current insect infestation—since about 2003—provided a window of opportunity to explore the relationship between these two factors and to characterize the patterns of beetle activity in the GYE.

Specifically, researchers addressed the following three key questions:

1. What are the current patterns of beetle outbreaks in the GYE at both broad and fine scales?
2. How do beetle outbreaks influence wildfire probability and severity?
3. How does the pattern of fire-damaged trees affect the pattern and severity of beetle outbreaks?

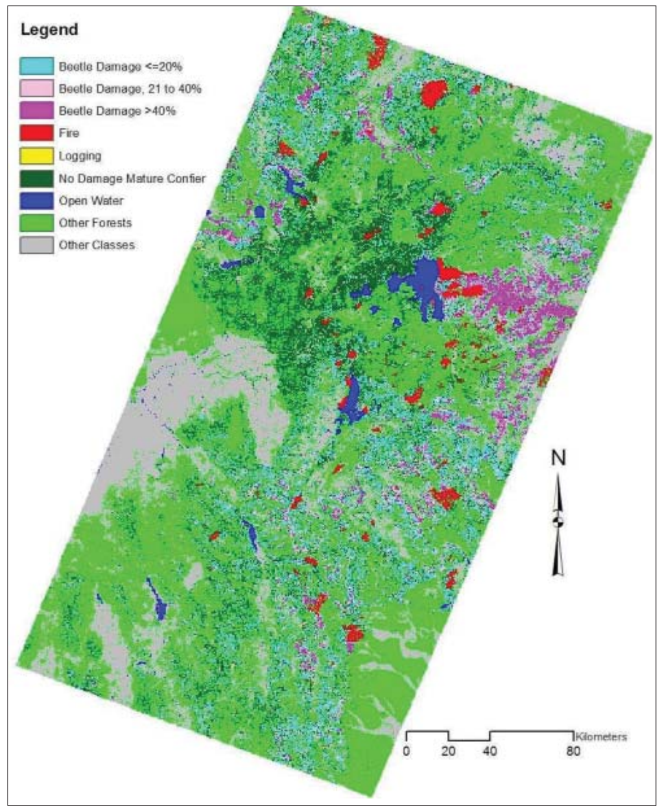


Study sites were sampled in 2006 and 2007 in the Yellowstone and Grand Teton National Parks, the Shoshone National Forest, and the Bridger-Teton National Forest.

Beetle outbreak patterns

Five years prior to the study, three species of bark beetles were at high outbreak levels in the GYE, including the MPB, which targets both the lodgepole and whitebark pine, the spruce beetle (*Dendroctonus rufipennis*), which targets Engelmann spruce, and the Douglas-fir beetle (*Dendroctonus pseudotsugae*), which targets Douglas-fir. To help determine the factors that explain the broad-scale patterns of mortality caused by the three beetle species, researchers conducted plot-based field studies in 135 susceptible stands to gather data on current and pre-outbreak forest attributes, current and early-outbreak beetle presence, site conditions, and stand and soil characteristics. Remotely sensed data were also used to complement the plot-based studies and to map the magnitude, spatial distribution, and temporal trend of the concurrent beetle outbreaks across the landscape.

Broad-scale study results revealed that bark beetle damage severity, which was based on relative basal area beetle-killed, ranged from 0 to 79 percent in lodgepole pine, 0 to 90 percent in whitebark pine, 0 to 98 percent in Engelmann spruce, and 0 to 89 percent in Douglas-fir. For lodgepole pine, beetle-caused mortality was related to the size and abundance of the host tree species at the plot scale, and, at the landscape scale, to the distance to the initial pockets of infestation at the early stage of the outbreak. Stands that had a greater proportion of larger stems and that were closer to early local infestations were more likely to experience high mortality. In whitebark pine, beetle-caused tree mortality was best predicted by the abundance of host tree basal area before the outbreak, and in Engelmann spruce, beetle damage was proportional to the amount of local infestations in the early stages of the outbreak within 500 meters of the plots. In Douglas-fir stands, beetle damage was proportional to the amount of conifer forest cover within 500 meters of the plots, and to the amount of local infestations in the early stages of the outbreak within 2 kilometers of the plots.



Maps derived from remote sensing show that disturbance severity was spatially heterogeneous, with widely distributed patches of high-severity beetle kill (represented in bright pink).

Through remote sensing, researchers were able to create maps that represented the spatial distribution of the bark beetle activity and tree mortality in the study area. These maps revealed that roughly 55 percent of the mature conifer forest in the GYE exhibited tree mortality associated with bark beetles: 10 percent of the area was in high-severity beetle kill (>40 percent basal area killed), 17 percent in moderate-severity beetle damage (20 to 40 percent basal area killed), and about 27 percent in low-severity beetle kill (<20 percent basal area killed). This substantial variation in severity of the beetle infestation created a spatially heterogeneous, fine-grained mosaic, with patches of high-severity beetle kill distributed widely across the landscape. The total area with moderate or high severity damage, while still considerable (27 percent of conifer forest cover), is nevertheless lower than popular perception. In addition, the remote sensing technology had the capability to not only determine if beetle attack was present, but also to map the severity of the infestation.

To delve even deeper into understanding the factors that might be contributing to bark beetle outbreaks, researchers assessed the fine-scale variations in stand characteristics at four study locations. The characteristics assessed included proximity of whitebark pine to MPB in mixed stands that are dominated by lodgepole pine and the influence of non-native white pine blister rust (WPBR [*Cronartium ribicola*]) on whitebark pine trees.

Trees that are symptomatic for white pine blister rust (shown here) may be weaker and therefore less resistant to beetle infestation. Credit: Susan Hagle, U.S. Forest Service.

Study results revealed that MPB overwhelmingly chose whitebark pine over lodgepole pine as the host tree species when both species occurred together. Preferential host selection by MPB was further enhanced in whitebark pine trees that were symptomatic for high levels of WPBR. However, even in the absence of blister rust, and in mixed pine stands, MPB still favored whitebark pine over lodgepole pine.

Beetle outbreaks and wildfire

The researchers determined the influence of beetle outbreaks on the probability and severity of wildfires in lodgepole pine forests by sampling in 25 lodgepole pine-dominated sites that represented a time-since-beetle outbreak chronosequence. They located five replicate stands in each of the following categories: undisturbed, red-needle stage (dead needles still on trees: 1–2 years post-outbreak), gray-needle stage (needles have fallen to the ground: 3–5 years post-outbreak), 25-year-old attacks, and 35-year-old attacks. In these sites, researchers measured dead surface fuels, live understory fuels, and canopy fuels (live and dead needles and twigs). These data were supplemented by 10 other sites that had been sampled in 1981 but where only surface fuels were measured. The fuel data measured in the field were then used to simulate potential fire behavior under different scenarios of fuel moisture content.

One common notion is that beetle outbreaks create large amounts of fuel and the potential for more severe wildfires, but findings from this study indicated otherwise. In the first 1–5 years following bark beetle outbreak, dead surface fuels (1-hour to 1,000-hour timelag fuels) and canopy base height in red and gray-stage beetle-killed stands were the same as in undisturbed stands. However, canopy fuel moisture, canopy fuel load, and canopy bulk density in red- and gray-stage stands were much lower than in undisturbed stands. In stands that had been attacked longer ago (25–35 years), canopy fuel load and canopy bulk density were still low, and canopy base height was much lower than in undisturbed stands because of the rapid growth of understory saplings that created ladder fuels. During the 2- to 35-year post-outbreak period covered by the study, the 1,000-hour fuels (primarily large beetle-killed trees) doubled, the 1-hour fuels decreased, and the 10-hour and 100-hour fuels did not change.

Simulation results suggested that under low wind speed conditions and when fuels were not very dry, most stands were predicted to have surface fires, whereas at very high wind speeds and when fuels were extremely dry, stands of all stages eventually achieved crowning. However, under intermediate fire weather conditions, probability of active crown fire was lower in the red and gray-stage stands compared to the undisturbed stands, probably because of the 50 percent reduction in canopy fuels. In addition, modeling results revealed that because understory sapling growth greatly reduced canopy base height in the 25- and 35-year post-outbreak stands, there was a greater potential for torching in these stands; however, crowning was unlikely, and thus only passive crown fires were predicted.

Were these findings surprising? Yes, according to the principal investigators, who stated, “While we hypothesized that the likelihood of severe crown fires may not increase following the bark beetle epidemic, it was somewhat surprising that the probability of active crown fires may actually be reduced by these events. Also, most maps that represent beetle-killed trees tend to homogenize the landscape and imply that most or all of the trees within an ‘affected’ polygon are dead. Our maps created using innovative remote sensing techniques revealed that areas of very high mortality are much less extensive and more widely scattered than previously thought, which could have a profound impact on future forest structure and function.”

Fire-injury and bark beetle infestation

To identify how and if the pattern of fire-damaged trees affect the pattern and severity of MPB outbreaks, researchers studied trees within eight burns of lodgepole pine forests in the GYE, all of which occurred between 2006 and 2008. Each tree was assessed for the level of fire injury (low, moderate, or high), the presence of bark beetle species, and for the presence of pathogens such as Comandra blister rust (*Cronartium comandrae* Pk) and Dwarf mistletoe (*Arceuthobium* species).

Researchers discovered that MPB were more likely to colonize fire-injured lodgepole pine trees, first targeting trees with moderate fire damage, then trees with low fire damage, and finally trees with high fire damage. However, brood success of bark beetles was substantially reduced in severely fire-injured lodgepole pine trees. Therefore, fire-injured trees are unlikely to trigger an outbreak of MPB, unless additional factors such as drought or warm temperatures come into play.

Managing the post-disturbance landscape

For some tree species, such as whitebark pine, it appears that climate warming may be a factor in increased bark beetle infestations. In the past, whitebark pine forests in the GYE were not severely affected by MPB outbreaks due to colder temperatures, which limited the survival and reproduction of the beetles at the higher elevations where whitebark pine is found. Now with warmer temperatures, a natural susceptibility to blister rust, and elevated mortality in the current outbreak, the whitebark pine community is at greater risk of extreme tree mortality or even local extirpation compared to other conifers. Unfortunately for managers, there may be relatively little that can be done immediately to mitigate losses of whitebark pine forests in the GYE. However, some whitebark pine trees appear to be resistant to WPBR, and cones and seeds of these trees are being collected and stored for possible future plantings.

On a positive note, younger or suppressed lodgepole pines, Engelmann spruce, subalpine fir, and other tree species may actually benefit from the recent beetle outbreaks. Since bark beetles primarily attack larger mature trees, the younger or smaller surviving trees will grow rapidly in response to increased light, soil moisture, and nutrient availability. Wildlife species are also likely to benefit from the increase in herbaceous and understory vegetation.

Based on research results, it appears that prioritization of fuel management activities in beetle-killed stands for the sole purpose of reducing fire hazard may not be warranted in the study area. Fuel treatments may be important to protect buildings or other infrastructure from fire. However, the results indicate that green lodgepole pine forests can burn as readily as beetle-killed forests; therefore fuel reduction may be equally important in green, red, and gray stands—wherever vulnerable resources are at risk of fire damage. Similarly, typical salvage operations and local mitigation actions may be performed, such as fuel reduction near homes and removal of dead trees near power lines and roads. However, our findings do not support the idea that landscape-scale fuel treatments are necessary to mitigate fire risk in the wake of bark beetle outbreaks. In addition, this research does not demonstrate a need for intensive salvage of surviving but injured trees after fire in order to prevent a post-fire bark beetle outbreak.

What is comforting for managers, however, is that the lodgepole pine forests of the Greater Yellowstone Ecosystem have not been "destroyed." Study data indicated that restocking has and will continue to occur naturally in almost every beetle-affected stand. Severely-thinned forest canopies will fill in again mainly through the growth of pre-existing advance regeneration, and, while stand-level productivity may decline at first, surviving plants will grow rapidly. For the next several decades, many lodgepole pine forests in the GYE will be composed of smaller, younger trees, but overall, lodgepole pine forests will continue to be a dominant component of this landscape.

Management Implications

- The presence or absence of MPB attack may not be a useful criterion to determine where and when fuel treatments should be carried out because undisturbed green stands are as likely to burn as beetle-killed stands.
- Salvage operations and local mitigation efforts may be conducted to remove hazard trees near roads, power lines, and other vulnerable structures, or to obtain marketable timber. However, the rationale of mitigating a perceived increased likelihood of active crown fire in MPB-killed lodgepole pine using salvage harvesting is not supported by this research.
- The need to conduct postfire salvage of surviving but injured trees, as a method for preventing a future bark beetle outbreak, is not supported by this research.
- The lodgepole pine forests in the GYE have not been "destroyed" and are expected to regenerate naturally. Whitebark pine forests appear to be much more vulnerable to severe ecological degradation due to the triple threat of bark beetles, blister rust, and climate change.

Further Information: Publications and Web Resources

NASA press release and video about this project: http://www.nasa.gov/topics/earth/features/beetles-fire.html

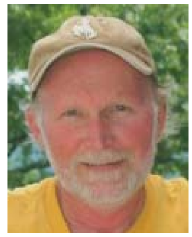
The Tinker Lab Website: http://www.uwyo.edu/tinkerlab/default.htm

The Turner Lab Website: http://landscape.zoology.wisc.edu/

Whitebark Pine Research: http://www.uwyo.edu/tinkerlab/Whitebark%20Research.htm

Yellowstone National Park, The National Park Service's Web site: http://www.nps.gov/yell/planyourvisit/yellsciweb.htm

Scientist Profiles



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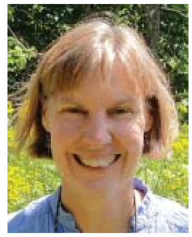

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