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From Death Comes Life: Recovery and Revolution in the Wake of Epidemic Outbreaks of Mountain Pine Beetle

The loss of mature pine trees to mountain pine beetles in sensitive watersheds raised fears that influxes of nutrients and sediment might threaten key sources of drinking water. *(Photo by Karl Malcolm)*

To stand witness to a wave of mountain pine beetles sweeping across a favorite western landscape or to view the staggering aftermath is an exercise in humility. Like other forces of nature these eruptions remind us of the tendency for natural systems to operate beyond our control. Halting an outbreak of pine beetles with available management tools can sometimes seem as hopeless as stopping the tide with a bucket.

The transformation of forested pine slopes from verdant to gray is a change that soon follows infestation, and the consequences of an outbreak as large and intense as that observed in the past two decades are not yet fully understood. This lack of knowledge is easily defensible. The spatial extent and extreme rates of tree mortality characteristic of the current epidemic are simply unprecedented in recorded history.

In hopes of better understanding the repercussions of beetle infestation on the landscapes of western North America, researchers have been studying the phenomenon since its outset. Their findings are beginning to reveal the patterns of forest and watershed response in afflicted ecosystems post beetle-attack, and stand to guide management decisions in the dramatically altered forests pine beetles leave in their wake.

SUMMARY

Changing climatic conditions and an abundance of dense, mature pine forests have helped to spur an epidemic of mountain pine beetles larger than any in recorded history. Millions of forested acres have been heavily impacted and have experienced extreme rates of tree mortality. This has raised concerns among many people that the death, desiccation, and decomposition of the overstory could have dramatic and negative consequences for affected ecosystems. Compromised water quality, increased fire danger, and losses in timber production are among the primary concerns of what could lie ahead for beetle-stricken landscapes.

Researchers at the Rocky Mountain Research Station have been studying the current outbreak since its inception in hopes of shedding light on what the future might hold after the waves of mountain pine beetles recede. Through ongoing studies focused on the water, vegetation, fuels, and management practices employed in infested forests, they are beginning to piece together a picture of the long-term change that surging beetle numbers impart on the land. While much remains to be learned about the current outbreak of mountain pine beetles, researchers are already finding that beetles may impart a characteristic critically lacking in many pine forests today: structural complexity and species diversity.

SETTING THE STAGE FOR ERUPTION

The rising minimum temperatures seen across much of the Mountain West have helped pine beetles overwinter more successfully while prolonged drought has rendered some trees more susceptible to attack. The warming trend extends the period of beetle activity and spurs their expansion, among other species, to higher elevations where colder temperatures historically proved fatal. Dense, homogenous, mature forests of lodgepole pine are comprised of the large trees most favored by mountain pine beetles, predisposing them to infestation. Similar patterns of beetle expansion have been observed in non-pine forests as well, where specialized nemeses like the spruce beetle wreak havoc in stands of their preferred tree species. Not surprisingly, the expansion of beetles happens swiftly and with striking results when food supplies are contiguous and temperatures relatively mild. Aside from the tarnished visual appeal of attacked landscapes, equally dramatic ecological impacts might reasonably be expected.

Mature stands of lodgepole, ponderosa, and the higher-elevation limber pine have been among the most heavily hit. In the case of lodgepole, overstory mortality often exceeds ninety percent. The response of infested trees to attack by beetles is nearly instantaneous, sparked by adults and larvae chewing through phloem and transmitting blue stain fungi via the xylem. Unfortunately for infected trees, this fungi-induced clogging has serious consequences for trees' ability to transport life-sustaining water from roots to foliage. In as little as two weeks scientists detect declines in water transport through infested trees and in their foliar moisture; the trees continue to dry over the course of the year long before their needles start to fade. These changes are eventually manifested by a clear progression: green to yellow to red to brown, and ultimately gray as otherwise evergreen trees desiccate and ultimately lose their needles.

Aspen rebounds in the wake of outbreaks of mountain pine beetles, benefiting some species of wildlife and creating patches of forest that are less prone to wildfire. (Photo credit Scott Peckham)

Unless salvaged through opportunistic timber harvests, which are unfeasible in many areas, the gray skeletons that ultimately result from severe infestations remain, but the role of these [now-dead] trees in the ecosystem is dramatically altered. Transpiration and consumption of nutrients cease, leading to heightened concerns of heavy runoff which could cause soil erosion and nutrient release into streams in beetle-stricken landscapes. Ignitability of dying and dead trees also rises, giving cause for concerns related to wildfire danger. Other worries stem from reports of poor seedling recruitment following beetle outbreaks in northern climates, and the notion that forest recovery could be compromised at vast scales in the long term. With tens of millions of acres already affected, from western Canada to Mexico, the need for an improved understanding of what lies ahead for these forests is pressing.

UNDERSTANDING THE UNPRECEDENTED

Through a series of studies focused on soil, water, vegetation, and management actions taken in areas hard-hit by the current outbreak of mountain pine beetles, researchers at the USDA Forest Service Rocky Mountain Research Station worked to shed light on key areas of concern. "We know quite a bit about what happens in these ecosystems following disturbances like clearcutting and fire," says Research Biogeochemist Chuck Rhoades, a lead scientist on the project. "But beetle kill is very different. Change induced by beetles is less abrupt, and, unless beetle-killed trees are cut, they remain part of the overstory for years." Both of these traits have important implications for how a stand regenerates and how watersheds respond.

Rhoades and his colleagues, which include fellow U.S. Forest Service researchers

Rob Hubbard, Byron Collins, Kelly Elder, Mike Battaglia, and Paula Fornwalt, studied the outbreak in lodgepole pine-dominated forests of the southern Rockies, where mountain pine beetles have been especially pervasive. In northern Colorado and southern Wyoming alone, some four million acres of pine forest have been infested since 1996. Residents of the region are among the growing numbers who depend on lands impacted by beetles for their drinking water. Because other watershed-scale disturbances to the forest canopy, like clearcutting and fire, typically affect runoff, water quality, and the influx of nutrients into nearby streams, it was feared that the loss of overstory trees to beetles could pose similar threats.

In the absence of management, beetle-killed pines lose their needles gradually while surviving understory vegetation capitalizes on increased availability of water, sunlight, and nutrients. (Photo by Chuck Rhoades)

To understand the effects of pine beetle outbreaks on water quality, the RMRS researchers collaborated with USGS scientists to look at changes that occur in the soils directly beneath beetle-infested trees. They collected soil beneath trees that were categorized as green-phase, (healthy or freshly attacked), red-phase (1-3 years post-attack, retaining 50-100% needles), or gray-phase (4 or more years post-attack; no needles) based on the stage of their response to infestation. Through a series of laboratory tests, each soil sample was analyzed for water and nutrient content and values were compared among the varying levels of tree disease. Results showed that nutrients and moisture were less abundant beneath green-phase trees compared to more advanced stages of infestation. Rhoades attributes this finding to a combination of factors. "Part of the initial increase in nutrients and moisture under dead and dying trees is due to reduced uptake," he says. "But the sick and dead trees are also losing needles that fall to the ground and help retain soil moisture. And, as trees decay, they release nutrients back into the system."

To assess the effects of these changes on the waterways downslope, the researchers tracked nitrate export from beetle-infested watersheds throughout Colorado. One of their key sites was the Fraser Experimental Forest, where stream water nitrate concentrations were measured weekly for eight years, from 2003 through 2008. These years spanned the onset of beetle infestation through the time when beetles had accounted for 50 – 90% mortality of canopy trees. The researchers also collected stream water samples from reservoirs that hold drinking water for residents of the Front Range. Findings from both water chemistry studies helped allay concerns that water quality would suffer following outbreaks of mountain pine beetles. Even when 50 – 95% of the canopy had been killed by beetles at the Fraser Experimental Forest there was less than a 30% increase in stream water nitrate concentration compared to pre-infestation levels. When compared to the amount of nitrogen entering the watershed through atmospheric deposition, this increase is nearly negligible. Comparisons of nutrients in basins infested by mountain pine beetles told a similar story. "Variability in stream nutrients and carbon between the study areas differed more due to factors such as basin size, elevation, and forest cover," says Rhoades. "Conversely the extent of beetle mortality had little effect on water chemistry."

The explanation for the difference between beetle-kill and other large-scale disturbances lies with the abundant vegetation that remains after beetle attack. Though the majority of the overstory trees succumb to mountain pine beetles, the forest is far from dead. Unlike a clearcut or fire, pine beetles have virtually no direct effect on plants other than large, mature pines. As these infested trees die their diminutive competitors respond vibrantly. Healthy understory plants stand poised, like a carpet of dry sponges, ready to soak up the water, sun, and fertility liberated by the assault around them. Uptake by the surviving understory strongly dampens runoff and nutrient input into waterways downslope. Measurements of the trees overshadowed by beetle-killed canopies showed that their growth rates doubled within a few years of release from competition. "The canopies gradually open up as dead pines shed their needles and boles start to fall," explains Rhoades. "This, combined with the increased availability of moisture and nutrients in the soil, promotes accelerated stand recovery through advance regeneration and the recruitment of new seedlings."

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TO CUT OR NOT TO CUT?

The practical limitations imposed by the remote, rugged topography, coupled with increasing fuel prices and declining timber markets will ensure that the vast majority of beetle-killed stands will not be harvested or otherwise manipulated by people. Still, understanding how beetle-killed stands respond to cutting is important for managers who are weighing options for the areas they can reach. Cutting dead trees can benefit the public by eliminating hazards around roads, camping areas, and hiking trails, and by removing sources of wildfire fuel. Fire and timber considerations make salvage logging and clearcutting more socially acceptable following beetle outbreak, and public backing has helped support a dramatic increase in clearcutting in some beetle-affected areas. The Sulphur Ranger District of the Arapaho-Roosevelt National Forest in Colorado is such a spot, where beetle-kill was extensive and the decade of 2000-2009 saw the highest level of cutting in recent decades owing to salvage of beetle-killed lodgepole pine.

The team conducted studies of stands harvested after beetle infestation at the Sulphur Ranger District that yielded informative results for managers considering salvage harvests. Mechanical removal of dead overstory by clearcutting promoted strong regeneration by shade-intolerant species, including lodgepole pine. To put the regeneration response in context, the U.S. Forest Service requires a minimum of 370 trees per hectare on 70% of plots to certify that treated areas have regenerated successfully, but to ensure sufficient, well-formed seedlings reach maturity, managers in the region aim for ten times that number. Based on post-harvest counts, seedlings in harvested beetle-killed stands numbered 5,800 per hectare - more than adequate for meeting the mandate. The research team noted that the brittle crowns of dry, dead pines tended to shatter when felled, thereby dispersing cones and seeds over larger areas than their green counterparts. This observation could at least partially explain the dense regeneration in harvested beetle-killed sites.

Another important finding from the study of harvested stands, which initially were comprised almost entirely of lodgepole pine, was that the prevalence of aspen jumped following clearcutting. Wildlife including moose, elk, and deer are quick to capitalize on regenerating aspen, and research forester Mike Battaglia explains why the resurgence is also important to people living in areas affected by mountain pine beetles. "By promoting aspen we reduce the flammability of the stand and impair its ability to conduct fires," he says. "Aspens don't burn nearly as easily as dry, dead pines, and they create heterogeneity across the landscape."

In the Fraser Experimental Forest in Colorado, beetle infestation resulted in 50-90% mortality of canopy trees. Fortunately, for those communities that depend on drinking water from these forested landscapes, the beetle mortality had little effect on stream water chemistry. (Photo by Tony Cheng)

Management actions geared towards trees impact other members of the plant community as well. For example, the researchers noted some adverse effects of clearcutting on native understory plants. Paula Fornwalt, who specializes in studying those species, found that total understory plant cover declined in treated sites compared to those where no cutting took place. The difference was apparently driven by the negative responses of several key native species to mechanical harvest. “Species in the genus Vaccinium declined markedly in our clearcut sites,” she said. “That genus includes shrubs related to blueberries that are important to some wildlife. They generally suffer in response to disturbance and copious direct sunlight.” Activities associated with salvage cutting may have other impacts on the plant community as well. For example, road building and vehicle use can inadvertently introduce or spread non-native plant species. Fornwalt’s data show an increase in some common non-natives in treated sites, but the changes were not sufficient to warrant great concern.

Even in places like the Sulphur District, where aggressive salvage efforts are made, treatments are not expected to reach more than fifteen percent of the afflicted landscape. According to Rhoades, the disparity between acres killed and acres treatable gives managers incentive for especially careful evaluation of proposed actions. “Accepting that we will be unable to treat the majority of the stands where serious outbreaks have occurred should motivate us to do a phenomenal job with the stands we do treat,” says Rhoades. With so many acres candidate for cutting, this ultimately boils down to being selective with where limited resources are invested and executing treatments well in places that are selected for cutting. The inability to treat stands in areas where treatments are untenable or impossible also underscores the importance of understanding stand responses in the absence of treatment.

THE TRAJECTORY OF UNTREATED STANDS

The research team made direct comparisons between lodgepole pine stands that were harvested and those left intact after beetle attack in locations throughout northern Colorado. Their comparisons indicated that post-beetle tree regeneration also occurs in the absence of management measures, though the response is less potent. Densities of new seedlings in untreated sites were roughly one quarter as abundant as those in clearcut stands, with the difference owed to a combination of factors. Unlike treated stands, those left uncut are limited by a lack of exposed seedbed. Cutting the dead overstory also increases resources available to new seedlings compared to stands that remain untreated. While regeneration of new seedlings in the southern Rockies was considerably lower in untreated stands than in clearcuts, the untreated sites fared far better than stands elsewhere. In British Columbia for example, many pine forests contain a ubiquitous layer of moss that prevents most pine seeds from reaching soil. As a result, post-outbreak recovery of stands in these settings is less robust, and relies almost entirely on the stimulated growth of surviving trees that were present before infestation. The combination of new seedlings and accelerated advance regeneration should help the pine forests farther south in the continental U.S. respond and regenerate relatively quickly.

Aside from promoting mixed age structure and helping to maintain native understory communities, retention of the dead overstory favors a shift in tree species composition. Untreated beetle-killed sites differ from clearcut sites, where lodgepole and aspen surge, and from the nearly monotypic lodgepole composition that was present prior to infestation. “We see increased rates of growth for the smaller trees that survived the outbreak,” reports Rhoades. “But there is also recruitment of new seedlings beneath the dead canopy. Those include lodgepole pine, subalpine fir, and aspen, with subalpine fir as the most abundant species of new recruit.” Because subalpine fir seedlings grow poorly in full light, where lodgepole thrives, the shaded growing sites available beneath dead overstory trees likely drive this shift.

Forest growth simulations based on counts of seedling recruits at sites located throughout northern Colorado indicated that harvesting will perpetuate dominance of lodgepole pine with the stand structure returning to

Clearcutting beetle-killed lodgepole pine stands promotes rapid lodgepole regeneration, in part due to the brittle nature of the dry crowns and cones that shatter and disperse seeds when dead trees are felled. (Photo by Chuck Rhoades)

KEY FINDINGS

- Tree regeneration is abundant in both cut and uncut beetle-killed stands, and subalpine fir recruitment is higher in stands where dead pine trees are not harvested.
- Aspen increases following mountain pine beetle outbreak and will benefit some wildlife species and possibly slow the spread of future wildfires.
- Surviving understory trees respond vigorously as beetle-killed canopies open and more water and nutrients become available.
- Multiple independent studies have found that water quality changes in watersheds infested by mountain pine beetles are minor; the positive growth response of the remaining forest vegetation and increased demand for soil nutrients are the likely explanation.
- Bark beetle outbreaks promote diversity in the species composition, age, and structure of the forests they infest, which may benefit forest health through increased resilience following future disturbance.

pre-outbreak levels in about a century. In contrast, untreated stands are predicted to achieve pre-outbreak basal areas roughly twenty years sooner because they remain partially stocked after beetle outbreak. Untreated stands will also experience a shift from overstory dominance of lodgepole pine to subalpine fir. This change could have diverse ecological impacts. Battaglia explains how increased fir might affect fire behavior. "Unlike lodgepole pine, which self-prune and hold their crowns high above the ground, fir trees retain limbs and foliage near the ground as they grow," he says. "These low limbs can act as ladder fuels by drawing surface fires up into the forest canopy." Aside from favoring more fir, uncut, beetle-killed stands promote recruitment of aspen. And, while fir might raise the risk of crown fires, intermingling aspen may partially counteract that threat.

Intense, stand-replacing fires historically played a role in maintaining forest health at the landscape level. "We've always had beetles and fire in these landscapes," says Battaglia. "These disturbances may have acted in concert to promote diverse age structure and patchy, intermixed distributions of tree species. Having landscape-level heterogeneity in species and size classes can reduce the susceptibility of these forests to widespread beetle outbreaks because not all of the trees would be susceptible." With human development increasingly interspersed in forests prone to beetle attack, fires that may be ecologically warranted can also be catastrophic. "Stands that threaten people from a wildfire fuel standpoint should be prime candidates for treatment," Battaglia says.

WITH STRUCTURAL DIVERSITY COMES BIODIVERSITY

Although an increase in subalpine fir may elevate fire risk in forests recovering from beetle infestation, untreated beetle-killed stands may be of great benefit to non-human forest inhabitants. The prevalence of fir following beetle outbreaks could be a boon for wildlife species that rely on the complex vertical structure that is generally lacking in lodgepole pine-dominated stands. The same low fir limbs that can carry fire into the canopy provide food, thermal cover, and protection from predators for a host of wildlife including snowshoe hare, favorite prey for the Canada lynx. Species of conservation concern ranging from Mexican spotted owls to the Canada lynx could respond positively to the structural complexity induced by mountain pine beetles. By driving these shifts at a huge spatial scale, beetles might even be viewed as a biological mechanism for creating the habitats that now limit some of the species we care most about.

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The costs and benefits of beetle outbreaks are clearly a matter of perspective. For the understory plants translating sunlight to growth in a new canopy gap or the animals previously limited by deficient structure, the outcome is good fortune. To people who lost favorite trees, saw a treasured view transformed, or perceive a heightened risk of fire, beetles are a scourge. As infestations affect new areas and previously decimated stands progress in their recoveries, research continues and our education as scientists, land managers, and citizens proceeds. Sustained, long-term monitoring holds promise for new discoveries and improved understanding of life after beetle-kill. We move forward with the humbling knowledge that massive swaths of North American pines have been radically altered for decades to come and that the scale of impact is beyond our capacity for treatment. And yet the most informative and striking lesson thus far may be the response that occurs in our absence. Apparently without posing serious threats to water quality or long-term ecosystem viability, mountain pine beetles may increase the structural complexity and species diversity of high elevation forests. These characteristics could have substantial benefits in the near term and, perhaps more importantly, they are the keys to improved resilience in our future forests.

FURTHER READING

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MANAGEMENT IMPLICATIONS

- The vast majority of beetle-killed forests are inaccessible to harvesting operations primarily because of steep topography, lack of road access, and weak timber market economics; the untreated forests that recover are likely to support a mixture of conifer species and an increased amount of subalpine fir compared to harvested areas.
- The limited amount of post-bark beetle treatment and salvage harvests should be targeted at stands that pose the greatest risk as fuels for wildfire.
- Mountain pine beetle outbreaks may help create the structurally and compositionally diverse habitat types and favor expansion of wildlife species of conservation concern.

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