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Burning and Beetles: Why Does Fire Spark Bark Beetle Attack?

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Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

Prescribed burn operations at Crater Lake National Park as part of this study. Crater Lake National Park staff and others from the National Park Service units in the region assisted with the burns. Credit: Jen Hooke.

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Why Does Fire Spark Bark Beetle Attack?

Summary

Prescribed burning is now a routine technique used in forests. In some cases, these forests have not experienced fire for decades. Sometimes, prescribed fire can lead to unexpected consequences. In Crater Lake National Park, prescribed burning to restore the mixed conifer forest there began in the late 1970s with unexpected consequences. Eventually researchers, including Jim Agee, determined that bark beetles were inflicting tree damage, and death. Agee's doctoral student, Dan Perrakis, focused his entire dissertation on trying to understand much more about the connections between fire, trees, and bark beetles. With Agee, he did a host of interdisciplinary experiments. He found that at Crater Lake resin flow does not protect trees from beetles. It may be that beetles use resin volatiles released by fire-exposed trees, to home in on weakened trees. Says Perrakis, "The major take home point with this is that the beetles and trees are engaged in an evolutionary arms race," Perrakis says. "But at Crater Lake, for now, the beetles are winning." With this, there may be emerging guidance on how managers and planners can better protect forests from the ravages of bark beetles.

Key Findings

- Tree mortality due to bark beetle attacks increases significantly after prescribed fire at Crater Lake National Park.
- Low vigor trees are more likely to die. But high vigor trees can also be prone.
- Trees of any vigor class increase resin flow, post-fire.
- Increased resin does not protect trees from death due to beetle attack.
- It is unclear whether resin chemistry changes as a result of fire. Beetles may home in on resin volatiles post-fire, to find and attack trees.

Introduction

Forests across the western United States are the focus of management efforts to restore fire-adapted ecosystems. However, bringing fire back is not always straightforward, and in some cases complex and unexpected cascades of consequences effect these forest ecosystems.

Crater Lake National Park is such a forest. It is home to grand old stands of ponderosa pine and white fir—the epitome of a classic dry Western forest. These forests—like many across the west—lacked fire for much of the 20th century. Fire restoration efforts began in the park in the 1970s.

But it quickly became clear that fire restoration at Crater Lake opened the proverbial can of worms—or in this case, a can of bark beetles. It turned out that the fire-adapted forests of Crater Lake had been weakened by the lengthy absence of fire. One consequence of this was that when fire was restored, many trees began to succumb to unexpected beetle attacks—clearly an outcome counter to restoration goals.

Jim Agee was once of the first researchers to note the evidence for this forest-wide malaise when he saw increased susceptibility of older pine trees to bark beetle attack. The details of this consequence of fire's absence are described elsewhere—including in a previous Joint Fire Science Program (JFSP) Brief like this one titled, *Restoring Mixed Conifer Ecosystems to Pre-Fire Suppression Conditions in Crater Lake National Park* (see Further Information section).

Fall burns at Crater Lake achieved fire behavior objectives, with flame lengths primarily between 30 centimeters to 1 meter and good coverage across experimental units. Credit: Dan Perrakis.

Meanwhile, Agee and his doctoral student, Dan Perrakis, knew that Crater Lake is one of thousands of similar stands across the western U.S., and as such, anticipated that beetle attack may well become an overarching concern throughout areas where fire is being reintroduced to forests.

According to Perrakis, "The trees were getting nailed by beetles after fire. We know prescribed fire is an excellent tool, so we wanted to know how to deal with the beetles given the clear need for restoring fire to these systems. We don't want to kill what we are trying to preserve." Up to 30 percent of pine trees at Crater Lake were killed by beetles, post-fire.

Knowing all this, Perrakis grew intent on learning the mechanisms underlying tree susceptibility to beetle attack. He goes on, "This whole thing is incredibly interdisciplinary. To fully understand what is happening after prescribed fire, we need to use entomology, fire ecology, physiology, biochemistry, and more. We need to look at multiple scales, and we need to use the impressive body of research already out there."

This is precisely the drive and questions that lead to Perrakis' dissertation project, funded in part by a JFSP grant. The results of this work will lend managers and planners around the country a deeper, more comprehensive understanding of why forests—shut off from fire for decades—may be weakened and more susceptible to bark beetle attacks. And what, if anything, they can do about it.

Seek mechanism, understanding

Perrakis and Agee had tracked ponderosa pine tree mortality since their prescribed fires back in 2002. Their long monitoring program showed that some trees died quickly, within the first year and that mortality continued in subsequent years. "Some of the trees were killed by the fire, but across the board, we could see that beetles were killing trees post-fire," says Perrakis. "What we weren't sure about was what the mechanisms were for tree death. That was our big focus."

"We knew that trees might have resin defenses against beetle attack, so we wanted to learn much more about that. We also wondered whether beetles are attracted to burned trees, and whether fire effects beetles directly. We didn't have much evidence for beetles being attracted to stressed trees, but other researchers had seen this," says Perrakis. "So, with these questions in mind, we wanted to look at a variety of possible mechanisms with as much interdisciplinary work as needed to be effective."

To that end, Perrakis lists the main questions he and Agee wanted to address:

- What is the relationship between fire and resin?
- How do trees make resin?
- What is the interaction between beetles and resin?
- How can we measure resin accurately? and
- Can we describe the physiology of how trees make resin?

The overarching theme of the research was to further describe how resin in these old ponderosa pine trees truly relates to bark beetle susceptibility. And, as such, how does fire shift that relationship. If trees produce resin in response to fire, should they then be less susceptible to beetle attack, as some have suggested with the idea of so-called resin defense? Resin defense, is the notion that trees increase resin production to protect themselves chemically against beetle attack. So why, if trees produce resin "defenses" in response to fire, would their level of beetle-induced mortality increase?

Ponderosa pines rely on their resin defenses for protection from insects and pathogens. Measuring the effectiveness of the resin defenses can be done using several methods, including creating a bark wound and collecting the emerging resin. Credit: Dan Perrakis.

This is one reason the initial mortality data at Crater Lake, post-fire, was surprising. The mortality data did not support the idea that trees were defending themselves against beetle attack. So what exactly, was going on?

A suite of six experiments

The team initiated a series of six separate experiments, all comprehensive enough it would seem, to be studies in their own right. Together, the experiments begin to unravel the mysteries of weakened forests and trees that are susceptible to beetle attack. The work lasted for more than four years—Perrakis and Agee monitored the trees from 2002 (after the prescribed burn) through to 2006. To share briefly the flavor of what they did, a thumbnail of each of the six experiments follow (drawn, in part, from their final JFSP report on this work):

1. For four years, the team evaluated the vigor and survivorship of 1,725 old ponderosa pine trees that had been prescribed burned in spring and fall fires of 2002 at Crater Lake National Park. They examined how the fire effected the trees, including effects on foliage, bole scorch, and roots. They visually classified trees for vigor (classed as A thru D; with A being high vigor, D being lowest vigor) as well as using increment cores to further assess vigor—high vigor trees are known to have fewer annual rings per centimeter.

2. Meanwhile, they evaluated the resin flow of 90 of the trees tracked in Experiment 1 across each vigor class for a period of five years. They measured resin one time per year in a subsample of each vigor class. For details on how they measured resin see the JFSP Brief cited below in Further Information, that highlights their earlier work.

3. To understand whether fire itself is really at play in initiating resin flow (e.g., resin defense), the team created fire and "fire surrogate" treatments to partition the effects of fire itself on resin flow. They did this work at Sun Pass State Forest, OR. To do this they simulated the effects of fire on some trees, including pruning to simulate crown damage and root trenching to simulate root damage, while they compared resin flow of these "surrogate" trees to ones that had actually burned.

4. Likewise, they did a similar experiment (also at Sun Pass State Forest) to further understand the effects of fire on resin flow, by heating tree boles by using charcoal fires around the base of trees, then measuring resin flow and comparing to control trees. Perrakis says wryly, "We barbecued the trees."

"We barbecued the trees."

5. The team also examined actual resin chemistry since it is known as a significant factor in making trees susceptible to beetle attack. They evaluated monoterpene chemistry of 46 trees at two locations: Okanogan-Wenatchee National Forest, WA and Sun Pass State Forest, OR.

6. And lastly, they compared their uniquely developed resin sampling methods to a more commonly used arch punch technique. The arch punch technique, though effective for measuring resin flow, tends to expose the tree to further beetle attack due to slow healing of the wound in the bark and phloem. The technique that Agee and Perrakis developed makes much smaller holes that heal faster, and that can be plugged with dowels—reducing the level of resin drip from the wound.

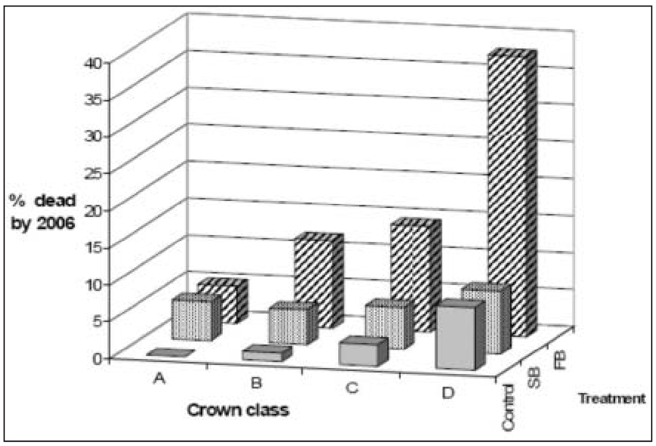
Fire weakens trees; increases resin flows

"With the first two experiments, we found clear evidence for beetle-induced mortality," says Perrakis. Specifically, the team noted 24 tree deaths resulting directly from the fire, or post-fire wind throw. Yet these accounted for only a small amount of the tree mortality over the course of the study. A total of 139 pines died during those four years—about 8 percent of the entire study population. "And most of those deaths were beetle-related," adds Perrakis.

The team also found, not surprisingly, that the least vigorous trees were most susceptible to mortality, and that mortality was highest in the first year after the burn. Control trees—trees in unburned plots—had very low mortality compared to the burned population; just 2.3 percent. So, clearly, prescribed fire makes certain old ponderosa pine trees much more susceptible to beetle-induced mortality. The spring burned trees had less mortality (6.1 percent) than the fall burned trees (16.4 percent), but this was likely a result of higher intensity fall fires.

Dead ponderosa pines - secondary mortality					
Treatment:	Control	SB	FB	Total dead	Total in study
Crown Class:					
A	0	1	5	6	182
B	3	11	31	45	756
C	7	15	23	45	664
D	3	5	11	19	123
Total dead	13	32	70	115	
Total in study	600	575	550		1725

Mortality of large ponderosa pines by treatment and Keen's (an established method to measure crown vigor) crown vigor class, 2003-2006, excluding direct mortality from fire and windthrow. SB: spring burn treatment; FB: fall burn treatment.



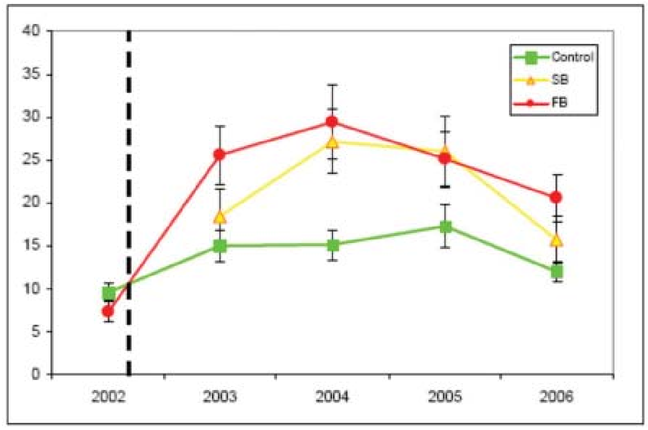
Post-treatment mortality of large ponderosa pines between spring 2003 and fall 2006, separated by Keen's class (A through D refer to crown vigor classes) and burn treatment type (Control: unburned; SB: spring burn treatment; FB: fall burn treatment).

So, did fire effect resin levels in burned trees? If so, did resin somehow help protect the tree from the ravages of beetles? "What we saw was that there was more resin in the vigorous trees, and less in trees of lower vigor," says Perrakis. "But we also saw increased resin in the treatments with the most dead trees—specifically the fall burns, so resin is not protecting the trees from death due to beetles." All the burned trees had higher resin levels than controls. He adds, "We really think that resin defense, in this case, is a flawed concept at least in the case of fire injury. Here we see that it just doesn't work to protect the tree."

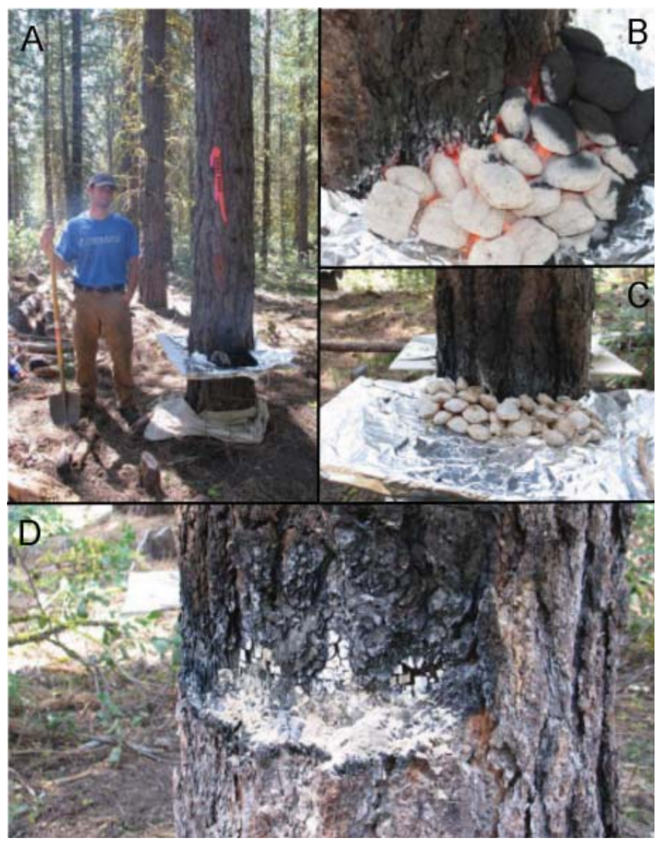
"We were particularly curious about the fire surrogate experiment," says Perrakis. Essentially, the question is this: If the trees sustained fire-like injury (surrogates) but not fire, would there still be increased resin production? Does the tree need fire in order to produce resin?

"And it turned out, that the only way to induce rapid resin increases in trees was with fire," he says. "Surrogate trees never showed increased resin in the duration of our experiments. So we could see, at least with this experiment, that fire or perhaps physical injury was required for increases in resin. But we still didn't know exactly what about the fire did this. We wanted to find that actual mechanism."

"So then we barbecued the trees," he says with a chuckle. "We used the charcoal briquettes and scorched the trees boles. And yes, we saw a response. Trees whose boles were scorched produced more resin."



Untransformed resin flow means and standard errors (of unit means) by year and treatment group; n = 4 trees per unit.



Bole charring treatment photos. Clockwise: A-Platforms and charcoal briquettes assembled and ignited; B-Close-up of burning briquettes; C-Position of briquettes around bole after combustion; D-Close-up of the burn scar on one side of a treated tree.

Smoky defense?

"So what does that mean?" he asks. "What we came to see is that so-called 'resin defenses'—at least in case of old ponderosa pines at Crater Lake—are not all they are cracked up to be. Increased resin is not protecting trees from bark beetle attacks, or subsequent mortality."

This is a surprise, given that literature exists suggesting the opposite is true—that resin defenses can and do protect some trees from some beetles, according to Perrakis. Yet, in this case, he wonders if the beetles are actually being attracted to the pine trees by way of resin chemical cues.

If that were true, the researchers may be able to detect chemical changes in the resin, after fire. This was what they attempted with experiment #5. Perrakis explains, "There are two components to the resin. Monoterpenes are the volatile solvent part of the resin, and the resin acids are the solidified gobs. Unfortunately, we don't have any solid evidence for chemical changes in the resin composition following fire. Mostly this is due to logistical issues with the fire that made data collecting difficult. There may be slightly elevated amounts of the monoterpenes after fire, but further data are needed to confirm this."

"Our results on this are fairly exploratory at this point," says Perrakis. "Still, we know that more trees were killed in the intensely burned fall burns. This suggests that the beetles are taking advantage of the increased resin production. So we know that the beetles are very tolerant of the trees' fairly nasty resins. And there is even some indication that the beetles actually use these chemicals to create their own pheromones and attract other beetles. The major take home point with this is that the beetles and trees are engaged in an evolutionary arms race," Perrakis says. "But at Crater Lake, for now, the beetles are winning."

As for the future? "Our evidence suggests that beetles detect the resin volatiles and that they home in on those," says Perrakis. "This is the mechanism of interest, and should be a fruitful area for future work. It also gives managers specific guidance when it comes to restoration and protecting these trees from beetles. We now suspect beetles are attracted to increased resin, so increases in resin can harm trees. Managers can minimize resin, perhaps by working for less intense prescribed fire; one way to do this would be to remove understory fuel before a burn and burn it away from the trees. Also, timing prescribed fires seasonally for less intense fires, like wetter spring fires."

"We now suspect beetles are attracted to increased resin, so increases in resin can harm trees."

One final note about their suite of experiments; the team's resin sampling method works. They had double checked and compared their unique sampling method to a more commonly used approach. They found that their approach produced comparable results with much less damage to the tree, so that repeat measurements on the same tree were possible without risking additional beetle attack.

Management Implications

- At Crater Lake, and likely elsewhere, increased resin flow does not protect trees from bark beetle attack. Managers can take steps to reduce beetle-induced mortality by focusing on reducing the intensity of prescribed fires (intense fires trigger higher resin responses).
- Although it is not proven, reducing intensity of fires may lower bark beetle mortality. Some ways to do this are to remove fuel and burn it elsewhere, to burn in seasons where fire will be less intense, and to take special precautions with trees of special interest to keep them from being stressed by fire.
- Managers can use resin sampling methods to test for increased resin flow, and take steps to protect trees from beetles by tracking resin in combination with management and prescribed fire plans.
- At Crater Lake, researchers are observing the evolutionary arms race between bark beetles and ponderosa pine trees. Right now, trees appear to be losing since beetles are attracted to fire-exposed and weakened trees by way of increased resin flow.

For now, the abundant research and emerging data from Agee and Perrakis' work at Crater Lake will help managers and planners around the country, as they continue to restore fire to trees evidently more prone to bark beetle attack. Their final report is extensive and insightful. Please review that report if this information is of further interest.

Example of measuring resin flow using two different methods on one tree at Leavenworth, WA. The scoop method is on the left, and the exposed xylem of the arch-punch scar is visible on the right. For additional details see the team's final report.

Further Information: Publications and Web Resources

Agee, J.K., and D.D.B. Perrakis. 2008. Why Burning Brings Beetles: Fire-Bark Beetle Interactions. Final Report for the Joint Fire Science Program for Project 05-2-1-92. Online at: http://www.firescience.gov/projects/05-2-1-92/project/05-2-1-92_05-2-1-92_final_report.pdf

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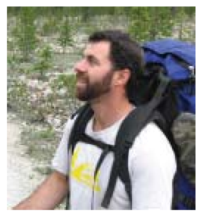
Scientist Profiles



Dan Perrakis recently completed his Ph.D. in forest ecology at the University of Washington studying the fire and bark beetle interactions described in this article. Since 2006, he has been working as a fire ecologist with Parks Canada out of Calgary, Alberta, focusing his project efforts mostly on fire monitoring and remote sensing.

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Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

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