

WHEN THE WELL RUNS



Drought sets the stage for crowded forests to succumb to bark beetles. Chris Fettig has been studying tree mortality around the globe for decades, but he was unprepared for the large-scale event that hit California’s central and southern Sierra Nevada in the last several years.

Summary

A record die-off of ponderosa pines in the Sierra Nevada in 2016 led Chris Fettig, a research entomologist with the U.S. Forest Service’s Pacific Southwest Research Station, to investigate the cause and what precipitated the event. While bark beetles typically get the blame, Fettig suspected something more must have been at work for such devastation to occur.

Fettig knew bark beetles have long played a role in ecosystem dynamics and focusing on them alone would not lead to an effective approach to managing forests as a valuable resource. Drought and other factors can create a perfect storm that leave trees vulnerable to massive bark beetle outbreaks. Even without the bark beetle, the severe drought of the last several years may have damaged trees beyond their ability to recover.

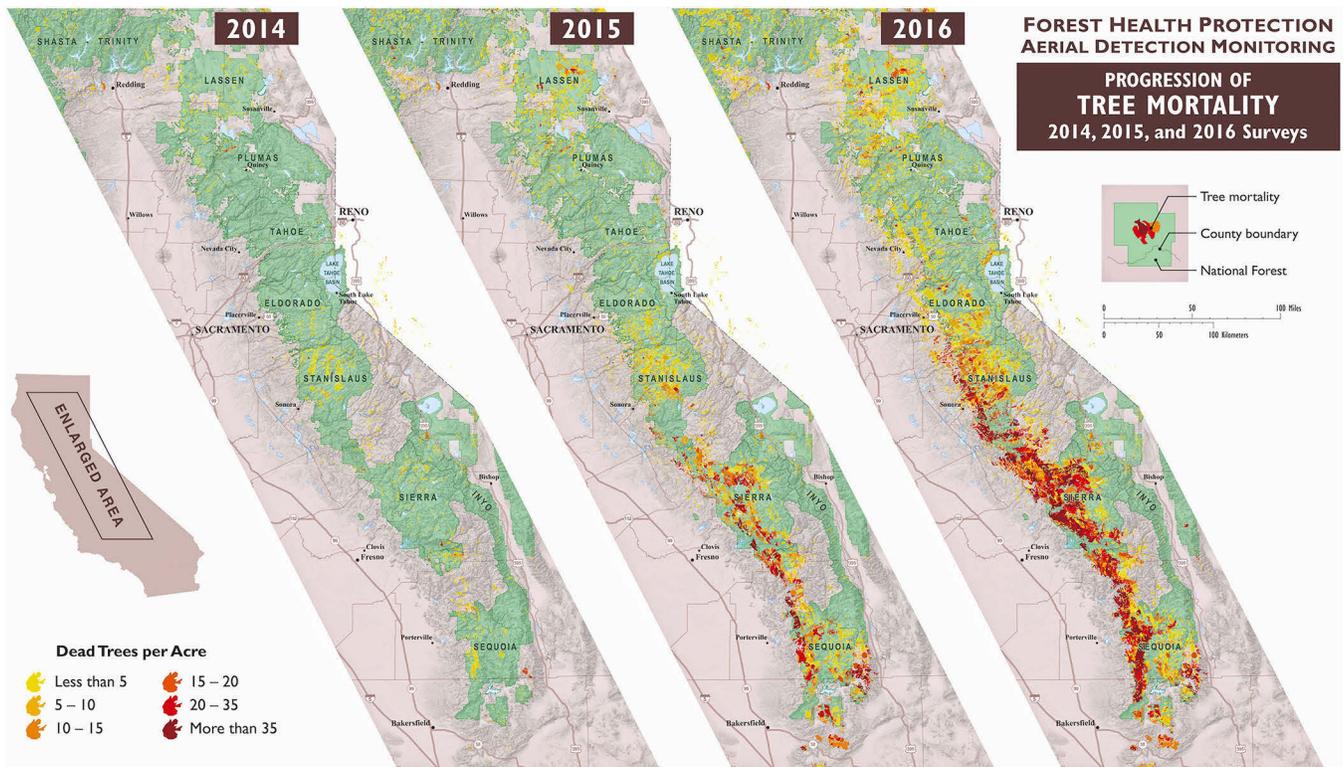
Future climate projections call for hotter, drier conditions that will continue to stress tree populations in the Sierra Nevada. However, land management practices can promote forests that are more resilient to both drought and bark beetles. Managing for appropriate stand density and species type can help forests adapt to changing conditions.

It is now well known that bark beetles and drought have been taking a heavy toll in the Sierra Nevada, killing an estimated 129 million trees since 2010. In 2016 alone, 62 million trees died, representing more than a 100 percent increase in tree mortality across the state compared to levels observed in 2015. Millions of additional trees are weakened and expected to die in the coming months and years.

“Quite simply, I was surprised by the magnitude,” said Fettig, a research entomologist with the U.S. Forest Service’s Pacific Southwest Research Station in Davis, California. “This is an event that we have not seen in recorded history for the species of bark beetle responsible for most of the tree mortality observed.”

“In addition to the size of the area impacted, what makes this event unique is how fast it has occurred, the size of the trees involved and the fact that large numbers of people live and recreate in these areas,” Fettig said.

Understanding the dynamics of why such a large die-off of trees occurred can help land managers cope with changing climatic conditions and ensure that economically, socially and ecologically valuable forests continue to thrive into the future.



A Crime of Opportunity

Of the 550 species of bark beetles in North America, only about 15 cause large amounts of tree mortality, and only eight of those are active in California. Fettig had a hunch about the culprit in this most recent die-off.

The western pine beetle is known to target ponderosa pines, the species of tree that has suffered the most. But for definitive proof, Fettig set to work in the field to examine trees and find out what exactly was responsible for causing the high levels of tree mortality observed.

An adult bark beetle bores into a tree where it lays its eggs. The larvae then hatch and the young beetles spend most of their lives in the tree before emerging as mature beetles ready to repeat the cycle. During its life cycle, each bark beetle species in California leaves

a distinctive fingerprint in the form of “gallery patterns” or etchings on the inner bark or phloem.

When Fettig peeled back the bark of dead and dying trees to examine their phloem, the fingerprints were unmistakable. The western pine beetles had launched a massive attack against ponderosa pines in the Sierra Nevada. But bark beetles have been a part of the natural ecosystem for millennia, so how did things spiral out of control so quickly?

Healthy trees emit sap (resin or pitch) into the holes that bark beetles create in the tree bark.

This sticky resin can control the attackers by drowning them. Therefore, for such a huge kill to occur, there had to be something else at work. Something that set the stage for the destruction. It looked suspiciously like a crime of opportunity.



Too Many ‘Straws’ In The Ground

To understand the relationship between drought and bark beetles, Fettig and his colleagues poured over hundreds of past research papers. Their findings were summarized in the article “Observed and Anticipated Impacts of Drought on Forest Insects and Diseases in the United States,” published in the May 2016 issue of *Forest Ecology and Management*.

Fettig knew that severe bark beetle outbreaks occur when trees are stressed. This can be caused by a number of factors, such as drought, warmer temperatures, air pollution, or overcrowded forests that create competition for resources.

When forest density is high, competition for water is amplified, and with too many “straws” trying to pull moisture from the ground, trees are unable to get the water they need to maintain their

vigor and repel beetles. Trees in less dense stands are generally healthier and better able to repel beetles and survive attacks.

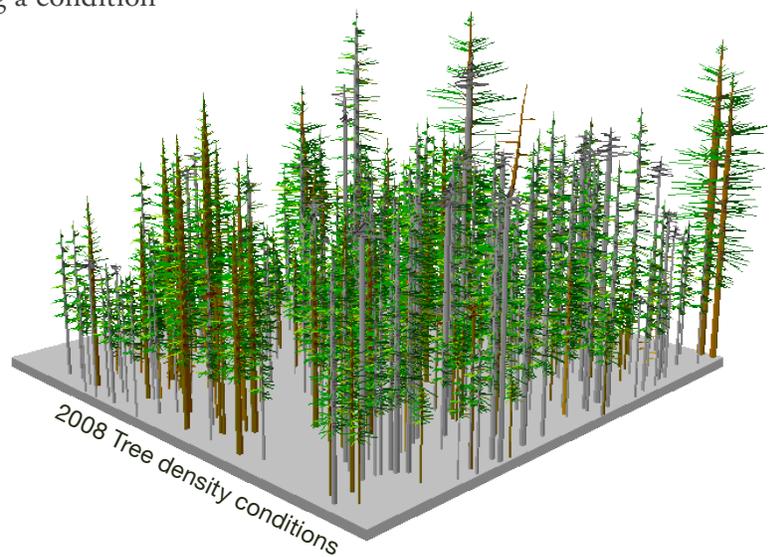
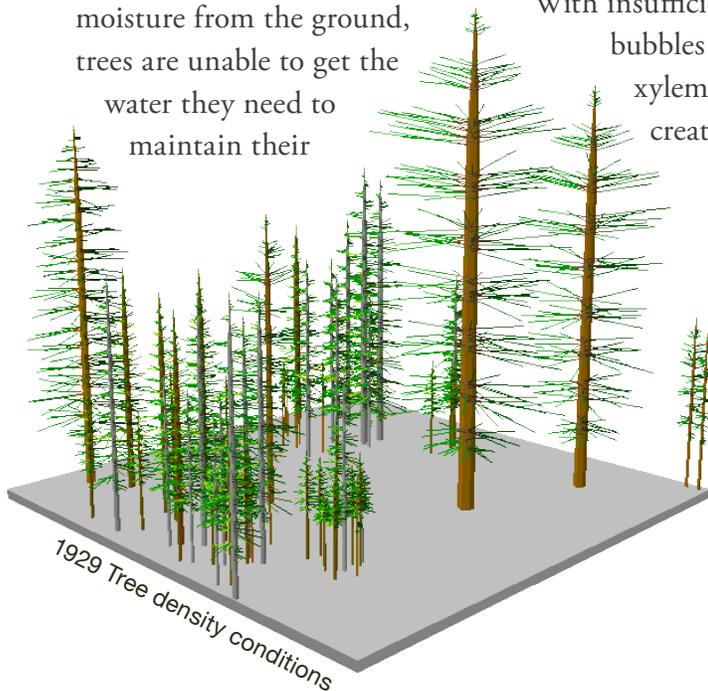
Thirsty Trees Are Vulnerable Trees

Research also repeatedly showed how drought conditions cause individual trees to react in a way that creates an opportunity for pests. Trees that aren’t getting enough water close their stomata, the tiny openings in leaves and needles through which plants breathe, to minimize loss of moisture. Closing the stomata also reduces the uptake of carbon dioxide, which in turn decreases photosynthesis, slowly starving the trees. This leaves them weak and less effective at defending themselves from bark beetles and other pests.

Intense drought also affects the ability to transport water, a tree’s lifeblood, throughout the plant. With insufficient precipitation, bubbles form in the xylem, or vascular tissue, creating a condition

known as cavitation. This can prevent the distribution of much needed water up the trunk and out to limbs, again, weakening the tree and its defenses. This condition also affects the ability to deploy terpene-rich resins that trees use to “pitch out” invaders.

After several years of severe drought, the winter of 2016-2017 yielded record precipitation in much of California. That might sound like good news, but it won’t necessarily give damaged trees relief. “Cavitation can permanently damage trees, meaning heavily cavitated trees may still die despite this winter’s precipitation,” Fettig said. However, Fettig expects to see a decline in most bark beetle numbers in the Sierra Nevada in 2018 and associated reductions in levels of tree mortality. The exception is in the most heavily impacted areas, where most of the susceptible hosts have already been killed. There, little or no change is expected to be observed.



Managing For Resilience

Fettig's research also focuses on increasing resilience to future droughts and bark beetle infestations through land management that better matches stand densities to water availability. In April 2007, he and his colleagues published "The Effectiveness of Vegetation Management Practices for Prevention and Control of Bark Beetle Infestations in Coniferous Forests of the Western and Southern United States." Their findings include the following:

- Bark beetles are a natural component of forest ecosystems. Eradication is neither possible nor desirable, and periodic outbreaks will occur as long as susceptible forests and favorable climatic conditions exist. Efforts to prevent undesirable levels of bark beetle-caused tree mortality must focus on changing stand susceptibility through reductions in tree competition, disrupting beetles' ability to find hosts and reducing the fecundity, fitness and survivorship of target bark beetle species.
- Efforts to prevent undesirable levels of bark beetle-caused tree mortality at the landscape level must account for the spatial distribution of both forest types and stand ages. In many areas, treatments should be implemented to increase heterogeneity.
- Management to reduce stand or landscape-level susceptibility to bark beetles must address factors related to tree density.

The large loss of trees in 2016 from bark beetles and drought highlights the indirect, but profound effects that climate can have on an ecosystem. And while foresters and land managers cannot control the amount of rain that will fall in the future, they can take steps that will help forests emerge with a better chance of survival while continuing to constitute a valuable resource for the region and the nation.

Key Findings

- Drought stresses trees in a number of ways, making them less able to resist pests like bark beetles.
- In times of drought, trees close the tiny openings, called stomata, in their leaves or needles to conserve moisture. But this reduces the trees' carbon dioxide uptake and their ability to photosynthesize, thereby reducing tree health and vigor.
- Cavitation of the internal vascular structures trees use to transport water throughout the plant can be permanently damaged by drought. Insufficient moisture also compromises the trees' ability to produce resin and "pitch out" bark beetles.

Land Management Implications

- Meteorological forecasts point to the southern Sierras transitioning to a climate that will be drier, making it increasingly important to manage forests for drought and resistance to pests.
- The most effective way to help trees resist bark beetles in times of drought is to manage stand densities prior to drought to reduce competition for vital resources. Less dense stands better reflect the historical state of forests.
- Actively managing forests through the use of mechanical thinning and prescribed burning can help reduce tree density and create a forest that is more resilient to bark beetle outbreaks.
- Land managers may have to rethink which species are appropriate for their area in light of changing climatic conditions. For example, ponderosa pines might not be a good fit for lower elevations in the future as conditions may become too hot and dry to sustain them.

Questions & Answers

Could we have averted or limited this large-scale tree mortality event?

Mechanisms contributing to bark beetle outbreaks are complex and include density-dependent and density-independent factors. However, two conditions must be met for an outbreak to occur: 1) There must be several years of weather conducive to beetle survival and population growth; and 2) there must be an abundance of susceptible host trees.

Most experts agree that the use of prescribed fire and mechanical thinning treatments to decrease competition among trees would have reduced the scale and severity of tree mortality observed in the central and southern Sierra Nevada. However, we must also acknowledge the unusual level of drought stress observed in these forests, which reduces both the effectiveness of these treatments, as well as the ability of trees to repel bark beetle attack.

Have bark beetles adapted to changes in the climate?

In recent decades, billions of conifers have been killed by bark beetles in forests ranging from Alaska to Mexico, and several outbreaks are regarded as the largest and most severe in recorded history. For each of these records, we see a trigger that can be linked to climate change, whether expressed directly through the bark beetle species (e.g., increases in temperature that increase the number of generations produced) or indirectly through the host (e.g., the drought's effect on ponderosa pine in the central and southern Sierra Nevada).

With the drought over, at least for this year, how long before trees are healthy enough to repel beetles?

For some bark beetles, we expect to see an immediate decline in their population. Others are capable of causing widespread tree mortality for several years after drought conditions have been alleviated. The western pine beetle, the species responsible for causing most of the tree mortality in the central and southern Sierra Nevada, fits somewhere in the middle. Given that the western pine beetle has multiple generations per year and initiates flight at the beginning of the growing season (i.e., before trees have time to respond to increases in growing space associated with tree mortality), we expect some elevated levels of tree mortality to continue in 2018, and then to begin to decline. However, in the most heavily impacted areas, most of the susceptible trees have already been killed, so we don't anticipate changes in those tree mortality levels.

Scientist Profile

Chris Fettig is a research entomologist with the Pacific Southwest Research Station. He studies the roles and impacts of insects in forest ecosystems, as well as how to mitigate their effects. He received his Ph.D. in forest entomology from the University of Georgia in Athens.



Bark beetle being expelled by a healthy tree

What's Next?

Following the recent die-off of ponderosa pines in the Sierra Nevada, Fettig and his colleagues at the Pacific Southwest Research Station have established research plots to determine which species of trees will emerge as new dominant or co-dominant species within the forest and what the tree species mix will look like. For example, as a thick layer of forest litter and dead pine needles carpet the ground, it could block ponderosa pine seeds from coming into contact with the soil and germinating. As some trees die and stands thin, the increase in sunlight reaching the forest floor also can affect what types of plants thrive or could result in the proliferation of weeds. So far, oaks and cedars seem to be the tree species least affected by this mortality event, but it remains to be seen what consequences that might have.

Fettig is currently studying test plots to determine the optimal combination of species and stand densities for optimum health in a hotter, drier environment. Related work by Pacific Southwest Research Station scientists is looking at how forest fuels are affected over time by dead and dying trees, and how this might contribute to fire risk and the danger of large-scale wildfires.▲



For Further Reading

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- Fettig, C.J. et al. 2007. *The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States*. *Forest Ecology and Management* Vol. 238, pp. 24–53.
- Fettig, C.J. et al. 2013. *Changing climates, changing forests: A Western North American perspective*. *Journal of Forestry*. Vol. 111, No. 3, pp. 214–228.
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- Kolb, T.E. et al. 2016. *Observed and anticipated impacts of drought on forest insects and diseases in the United States*. *Forests Ecology and Management*. 380: 321–334.

Web Resources

- <http://bit.ly/SierraEcoRestoration>



Learn more about the Pacific Southwest Research Station at <https://www.fs.fed.us/psw> or scan the QR code to the left with your smart device.

Credits

Dry soil texture (front cover) by hotblack at morguefile.com (0001379338996)