United States Department of Agriculture
Forest Service

PNW Pacific Northwest Research Station

Science FINDINGS

issue one hundred seventy / february 2015

INSIDE

"Science affects the way we think together."
Lewis Thomas

Hidden In Plain Sight: Synthetic Pheromone Misleads Beetles, Protects Trees

Rob Progar

*Mountain pine beetles (*Dendroctonus ponderosae*) overwhelm a tree's defenses through a coordinated mass attack. The tree emits pitch in an effort to expel the bark-boring insect.*

IN SUMMARY

*In the last decade, pine forests throughout much of the western United States have been ravaged by the mountain pine beetle (*Dendroctonus ponderosae*). This bark beetle is native to the United States and has been responsible for massive tree kills in the past. The current outbreak, however, has been notably severe and wide ranging and the effects have been more dramatic and longer lasting.*

Scientists have documented infestations in areas never before recorded. The insect has expanded its host selection from its more-preferred species of pine—ponderosa, lodgepole, limber, whitebark, and sugar—to afflict species relatively untouched in previous outbreaks, such as Engelmann spruce and jack pine.

Rob Progar, an entomologist with the U.S. Forest Service's Pacific Northwest Research Station, recently completed a research project in a series of bark beetle studies that evaluates how well a synthetic version of the pheromone verbenone protects trees during a mountain pine beetle infestation. Verbenone is a chemical byproduct released by bark beetles, and it is present in high concentrations while beetles infest a particular tree. Scientists hypothesize that the insects interpret the pheromone as a sign that a host tree already has been colonized, and the beetles, therefore, should seek a different host tree.

Within some lodgepole pine forests, verbenone protected 54 percent of trees with diameters of 13 inches or more.

"If one could conclude as to the nature of the Creator from a study of his creation, it would appear that God has a special fondness for stars and beetles."
—J.B.S. Haldane, British evolutionary biologist (1892–1964).

The mountain pine beetle *(Dendroctonus ponderosae)* is native to the United States. The history of U.S. forests is peppered with periodic outbreaks when mild winters, along with an abundance of older, larger diameter trees, create conditions in which the beetles thrive at the trees' peril. As suitable habitat dwindles or other factors disrupt the pine beetles' life cycle, the insect fades away into relative obscurity until the next major outbreak.

Since the early 2000s, mountain pine beetles have worked their way through about 22 million acres of forest land in the western United States, leaving stands of dead trees in their wake. Scientists like Rob Progar have been working with forest health specialists, such as Steve Munson, to learn how the beetles inflict

their damage, and more importantly, how to stop it.

Progar, a research entomologist with the U.S. Forest Service's Pacific Northwest Research Station, has conducted four successive studies over the past 14 years to better understand how pine beetles select and attack their hosts. He also is testing ways to ward off infestations. In his most recent study, Progar worked closely with Munson, an entomologist with the U.S. Forest Service's Forest Health Protection division.

Munson and his Forest Health Protection colleagues stay abreast of the latest research to assist resource managers who seek assistance mitigating the loss of trees to mountain pine beetle infestations. Forest Health Protection personnel also serve a vital role in reporting back to researchers the efficacy of new treatments, or in making suggestions for new avenues of study.

"The management practices they want to implement, we first validate," says Progar. The epidemic proportions of the mountain pine beetle outbreak created numerous avenues for research. "Scientists had an insect population they could work with," says Munson. "As a result, it provided opportunities to develop new techniques and strategies on how to treat it."

It's not just the vast acreage that has made this most recent outbreak so problematic. Pine beetles are attacking tree species not typically known to host the insects.

"No one had ever recorded a mountain pine beetle outbreak of this magnitude in North America," Munson says.

While land managers have been waiting for this latest outbreak to end, researchers seized the moment to study the insect and the dynamics of an outbreak during this relatively short window of opportunity.

"Beetle behavior changes during the course of an outbreak," Progar says. "By studying infestations from a longer term perspective, we're able to better understand and recommend what treatments to use and when."

Progar synthesized his findings, along with research gathered by others during this outbreak and previous ones in "Applied Chemical Ecology of the Mountain Pine Beetle," published in the June 2014 issue of *Forest Science.*

KEY FINDINGS

- The success of verbenone treatments varies by tree size and forest densities, beetle population, and the time elapsed since the semiochemical was applied.
- Verbenone treatments are more effective at the beginning or end of an infestation when beetle populations are low to moderate.
- Even in areas where mountain pine beetle populations rapidly increase, verbenone-treated areas still had less tree mortality than untreated areas.

ANATOMY OF AN OUTBREAK

A single mountain pine beetle poses little threat to a tree. It's a mass attack by hundreds–sometimes thousands–of beetles on a single host that overwhelm the tree's defenses. The tree then serves as an incubator for thousands of larvae that will hatch, and en masse, overtake neighboring trees, repeating the cycle until all suitable hosts are exhausted. It can take 3 to 5 years for a population to move through a stand.

Steven Katovich, U.S. Forest Service/Bugwood.org

The many pitch tubes evident on this trunk indicate the tree has been colonized by mountain pine beetle. Periodic beetle outbreaks occur when suitable host trees reach a certain age and size, and beetle populations are bolstered by favorable, milder climate conditions.

Purpose of PNW Science Findings

To provide scientific information to people who make and influence decisions about managing land.

PNW Science Findings is published monthly by:

Pacific Northwest Research Station
USDA Forest Service
P.O. Box 3890
Portland, Oregon 97208

Send new subscriptions and change of address information to:

pnw_pnwpubs@fs.fed.us

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Science Findings is online at: http://www.fs.fed.us/pnw/publications/scifi.shtml

To receive this publication electronically, change your delivery preference here:

http://www.fs.fed.us/pnw/publications/subscription.shmtl

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Much research has been done to understand how pine beetles select a host, and once selected, how other beetles learn of it to stage the mass attack. The predominant theory is that pioneering females use a combination of random landings and visual cues to select a tree suitable for them to lay their eggs. Large-diameter trees, presumably, can accommodate multiple broods during the infestation. Compared to smaller trees, larger trees also have more phloem, a food source for the larvae.

Some studies have also shown that beetles are able to detect trees with thicker phloem, as well as injured trees, leading scientists to suspect that beetles can sense other chemical indicators emitted by trees when selecting a suitable host.

Mountain pine beetles prefer ponderosa (*Pinus ponderosa)*, lodgepole *(P. contorta)*, limber *(P. flexilis)*, whitebark (*P. albicaulis)*, and sugar pines *(P. lambertiana)*. In this most recent outbreak, however, beetles have infested less common hosts, such as Engelmann spruce *(Picea engelmannii)* and jack pine *(Pinus banksiana)*.

Progar discovered that in lodgepole pines, trees with a diameter of 13 inches or greater were preferred hosts, although any stand of trees with an average diameter of 8 inches could support an outbreak.

Once a suitable host is selected, the beetle broadcasts the information to initiate the mass attack. As early as 1931, scientists hypothesized that pine beetle aggregation resulted from some form of chemical-mediated attraction. Known as semiochemicals, these substances are used for communication, either between individuals of the same species or among different species. Pheromones are a type of semiochemical that trigger a social response among members of the same species. In 1967, the first aggregation pheromone, *trans*-verbenol, was identified for the pine beetle genus *Dendroctonus*.

The pheromone *trans*-verbenol is released in the female pine beetles' excrement, which when combined with host-specific chemical compounds, attracts both male and female pine beetles. As the beetles congregate and additional pheromones are released, more beetles are drawn to the host. During the latter stages of colonization, however, a different process begins.

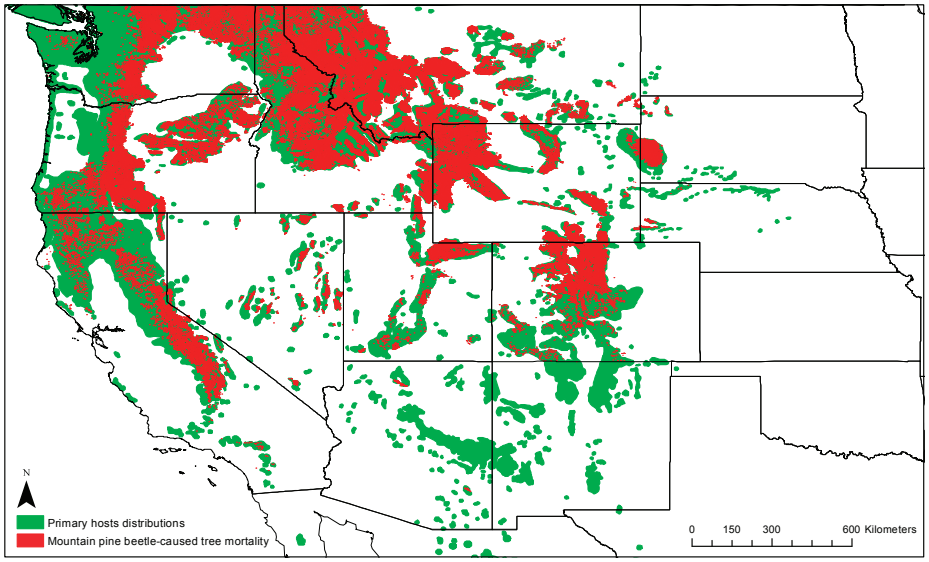
Microbes within the beetles' intestines and larval galleries begin converting the *trans*-verbenol and other byproduct compounds into verbenone. When a host tree is near capacity, the resulting high levels of verbenone provide a signal to incoming beetles that a different host should be selected. This limits the number of infesting beetles to a density that increases the likelihood of brood survival.

NO ROOM AT THE INN

Pheromones can either attract or repel. Some researchers explored the use of the attracting pheromones to draw in and then trap beetles. Progar, however, was more interested in the use of verbenol as an inhibitor of colonization. A synthetic version of verbenone had been tested for efficacy in protecting trees from beetle infestation, but the results were inconclusive. Progar wondered if the results were more influenced by beetle outbreak behavior as opposed to the effectiveness of verbenone.

"When reviewing the results of earlier work, researchers would change locations each year. They'd establish a study in a location for one year, and then the next year, they'd recreate the same study in a new location," Progar says. "They'd set up the same study again, but in later trials, the performance of verbenone would seem to become inconsistent. The problem was that by changing locations each year, the researchers were unable to note differences in the changing beetle population and the availability of preferred-sized host trees. The results were inconsistent, perhaps not because the verbenone was ineffective, but maybe because the beetles were behaving differently at different population levels."

In one study Progar attached verbenone pouches to trees within a stand of lodgepole pines before an outbreak occurred. He found that more than 54 percent of the larger trees (diameters of 13 inches or more) survived. In a subsequent study, however, where verbenone was applied to an area where more than 20 percent of available trees had already been killed the previous year, the pouches failed to provide adequate protection.



The range of mountain pine beetle outbreaks has greatly expanded since the last measured outbreak in 1982. The map shows outbreaks observed from 2001–2011 (red), along with the range of preferred host tree species (green).

"We believe we're seeing a shift in how beetles select hosts during the height of an outbreak," Progar says. "As the number of choice trees decline, beetles begin selecting smaller diameter trees or they'll still attack larger, verbenone-treated trees because they're disregarding the chemical signal, or possibly even becoming habituated to it."

Each point of failure, however, provides another opportunity for scientists to adjust the formula or delivery method to make verbenone more effective. The initial delivery method for verbenone was in 0.5-gram bubble caps attached to individual trees. The bubble caps eventually gave way to 5-gram pouches, which were later found to be more effective at 7 grams. Although the 7-gram pouches are still the prevailing delivery method for individual tree protection, it's not the most effective or efficient means of protecting a larger stand of trees. It is labor intensive, requiring pouches to be evenly distributed throughout the protected stand, and the pouch is only potent for a year.

Verbenone later was reformulated into biodegradable flakes and beads that, after Environmental Protection Agency registration and approval for public safety, could be dispersed aerially and be applied to larger or more remote areas. The effective application of 15 grams per tree is difficult to control through aerial application, but in test cases

where that threshold was met, the flakes were found to have a better success rate than the pouches at warding off beetle attacks.

Verbenone results vary by forest type and tree densities. This means that beetles likely use additional cues when selecting a host tree. If the presence of verbenone is inconsistent with other environmental cues or in the wrong ratio to aggregation signals, its effectiveness could be compromised. Erratic temperatures may also cause pouches or flakes to release too much verbenone too soon, thereby diminishing their long-term efficacy.

These initial failures and inconsistent results have caused some resource managers and forest health professionals to write off the use of verbenone, Munson explains.

"Some refused to use it because they felt it was ineffective," Munson says. "When the outbreak was at its peak, the results were not acceptable, particularly on ponderosa pine-affected landscapes, so they stopped using it altogether."

MOVING FORWARD

To date, the most effective defense against mountain pine beetle infestation is the use of insecticides. They provide better protection and tree survival rates, and their effects last longer than other available treatment methods. They also are more expensive.

"Ultimately, we would prefer to move away from insecticide applications and use pheromone repellents exclusively because of cost and to avoid potential effects to unintended species," Munson says.

Some settings prohibit the use of insecticides, such as along streams, rivers, and other riparian areas. Campgrounds, trailheads, or other high-traffic recreation areas are other areas where insecticide use is not ideal and semiochemical treatments, such as verbenone, are an option.

The latest evolution in verbenone is a paste-like substance called SPLAT® Verb (Specialized Pheromone and Lure Application Technology). Dispensed using a caulking gun and applied directly to the tree, SPLAT® Verb appears to provide a greater perimeter of protection than conventional verbenone delivery methods. Plus, the paste is biodegradable, so no clean up or post-treatment retrieval is necessary.

"I think the SPLAT® technology shows great promise," Progar says.

Chris Fettig, a research entomologist with the U.S. Forest Service's Pacific Southwest Research Station, led the product's development, and Progar has conducted studies on the product's efficacy. After years of testing, SPLAT® Verb was made commercially available in 2014.

"Now we're in the process of fine-tuning the application doses," Fettig says. Released in "dollops" onto trees, Fettig and his colleagues are trying to determine the least amount of SPLAT® Verb needed to provide sufficient protection.

Currently dispensed in about 2-inch-wide dollops, SPLAT® Verb provided 100-percent protection of lodgepole pines in a Wyoming study, whereas 93-percent tree morality was observed in the control. Fettig, Progar and Munson also are working on a variation of SPLAT® Verb designed to protect ponderosa pines from a relative of the mountain pine beetle: the western pine beetle *(Dendroctonus brevicomis).*

Until the science of semiochemical inhibitors is perfected, researchers and land managers

Rob Progar

Pouches of verbenone can protect trees from pine beetles if applied before the height of an infestation.

Chris Fettig

A dollop of SPLAT infused with verbenone (SPLAT® Verb) can be applied directly to a tree using a caulking gun. The dollop eventually biodegrades, eliminating the need for crews to return to the site to retrieve pouches.

are employing a combination of treatment methods to stave off the pine beetles. In a strategy typically referred to as integrated pest management, land managers use insecticides and silvicultural treatments such as tree removal and stand thinning, along with semiochemical treatments such as verbenone, to reduce a beetle population and protect trees.

High-value trees, for example, might receive an individualized application of insecticide or verbenone. A stand of trees might be thinned to a density more favorable for verbenone effectiveness. And any colonized trees might be removed and destroyed to prevent the beetle population from reaching a critical mass.

As this most recent outbreak rolls into its second decade, the beetle population has begun to decline. But some research suggests that future outbreaks will occur with greater frequency and intensity because of changing climate patterns, Progar says.

"Not only will a warmer climate reduce the number of beetles killed by severe cold, but it could also stress more host trees during drought conditions, and extend infestations to higher elevations with greater frequency, making more trees in a greater geographical range susceptible to attack," he says.

LAND MANAGEMENT IMPLICATIONS

- Verbenone isn't as effective as insecticides, but could be a viable alternative in areas where insecticide use may be limited, such as in campgrounds, along riparian areas, or near private homes.
- Verbenone appears less effective in forests with high tree densities. A management strategy that employs tree thinning could improve verbenone's efficacy.
- Verbenone appears most effective when mountain pine beetle populations are at low to moderate levels. However, even at high beetle populations where large proportions of the available hosts are infested in just a few years, significantly fewer hosts are killed by the beetles in treated areas.

Even as this outbreak winds down, research continues, driven by the fact that at some point, perhaps sooner than later, bark beetle populations will resurge. When the next outbreak does occur, the science will be that much more advanced, providing land managers with further options for mitigating the outbreak before it becomes an epidemic.

"During the course of our research, we've come across acres of pine forests decimated by pine beetles, but then, right in the middle of it all, will be a massive tree that, for whatever reason, was left untouched," Fettig says. "We hope that by time the next outbreak begins, we'll know why."

"Providence has hidden a charm in difficult undertakings which is appreciated only by those who dare to grapple with them."

—Anne Sophie Swetchine, Russian mystic (1782–1857)

U.S. Forest Service, Northern Region

Synthetic pheromones such as verbenone may be particularly useful around campgrounds or sensitive riparian areas where managers want to limit insecticide applications. Above, mountain pine beetle damage at a campground in the Helena National Forest, Montana.

FOR FURTHER READING

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ROBERT PROGAR is a research entomologist with the Pacific Northwest Research Station. His current projects include (1) developing reliable semiochemical or ecological methods for predicting, detecting, monitoring or mitigating unwanted disturbances by insects to support existing management strategies or help create new strategies that can insure productive and sustainable forest ecosystems, (2) evaluating the relationship between fire-caused injury and tree survival, and methods to increase tree survival following controlled burning, (3) using biological control to mitigate the impacts of invasive plants and insects, and (4) modeling response of arthropod species and feeding guilds to climate patterns.

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