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BATTLING A GIANT KILLER

The iconic eastern hemlock is under siege from a tiny invasive insect

By **Gabriel Popkin** *in Highlands, North Carolina; photography by* **Katherine Taylor**

On a frigid morning this past March, arborist Will Blozan snuck behind a small church here and headed down into a gorge thick with rhododendron. He crashed through the shrubs until he spotted the gorge's treasure: the world's largest known living eastern hemlock tree, known as the Cheoah.

In 2006, Blozan had climbed the nearly 50-meter-tall giant and calculated that it contained 44.29 cubic meters of wood—then a record. Blozan would later discover two even larger hemlocks in the nearby Great Smoky Mountains National Park. Both of those champions, however, are now dead.

So are millions of other hemlocks across eastern North America. They've been reduced to leafless gray skeletons by the hemlock woolly adelgid (*Adelges tsugae*), a tiny sap-sucking insect about the size of a pinhead. Originally from Japan, the adelgid has spread from Georgia to Maine in recent decades, entering new hemlock stands every year. Left unchecked, it kills nearly every tree it attacks. Paradoxically, large, seemingly vigorous trees like the Cheoah often go fastest.

For years, forest managers have been in a fierce fight against the adelgid, and the battle has recently expanded to new fronts. The Cheoah and hundreds of thousands of other hemlocks are still alive because they have been treated with insecticides. But that's an expensive and labor-intensive tactic, so scientists are trying out more sustainable strategies. They're rearing and releasing predatory insects that eat the adelgid, and even looking for rare hemlock genes that might help them breed resistant trees. Eastern hemlocks, warns forester Jesse Webster of the Great Smoky Mountains park, "are in intensive care." Like the family of a gravely ill patient, ecologists are also preparing for the possibility that these efforts will fail, and the eastern forest will lose one of its defining species.

Near death, a barren hemlock in the Harvard Forest in Massachusetts displays the telltale effects of an attack by hemlock woolly adelgids.

TSUGA CANADENSIS is one of eastern North America's largest native conifers. It has been called the "redwood of the east" and the "queen of the conifers." A healthy tree resembles an evergreen waterfall; overlapping layers of short, downy needles cascade from the crown almost to the ground.

Biologists believe the species diverged from its Asian cousins some 23 million to 40 million years ago. When Europeans arrived nearly 500 years ago, hemlocks dominated valleys in the 3000-kilometer Appalachian corridor and grew as far north as present-day Canada and as far west as Minnesota. Loggers once targeted the tree, but typically not for its wood, which is brittle. Instead, they prized its coffee-colored bark, which is rich in the tannins traditionally used to tan leather.

Distinctive tufts help protect adult hemlock woolly adelgids. The insects stay put once they start feeding on hemlock needles.

Hemlocks nurture an ecosystem that has evolved nowhere else. Their defining characteristic is deep shade; unlike many pines, hemlocks keep needles on their lower branches, creating a thick canopy that blocks up to 99% of sunlight. Few plants grow in the gloom, but a hemlock seedling can bide its time for decades or more, waiting for a sunlit opening. Hundreds of species of insects, mites, and spiders appear to live primarily or exclusively in hemlock forests, and some aquatic invertebrates eat the hemlock needles that fall into mountain streams. Many migratory birds seek out the trees.

The oldest known specimen was 555 years old when dendrochronologist Edward Cook measured it in 1991; just four other eastern tree species are known to live longer. "There's no tree, certainly in the east, that has anything like that kind of complete control" over its environment, says David Foster, an ecologist and director of the Harvard Forest in Petersham, Massachusetts.

THE HEMLOCK'S MIGHTY GRIP is now being loosened by the diminutive *A. tsugae*. Hemlock woolly adelgids "are bizarre little things," says entomologist Lynne Rieske-Kinney of the University of Kentucky in Lexington. An adult is about a millimeter long, with a threadlike proboscis that can be three times as long as its body. They can easily catch a ride to new trees on the wind or on birds and mammals. Once an adelgid pierces the base of a hemlock needle and starts sucking out starch, starving the tree, it stays put and envelops itself in a distinctive white fluff—hence the "woolly"—to protect itself and its eggs. The adelgid reproduces asexually in North America, rapidly spawning genetically identical offspring. All you need to get an outbreak, Rieske-Kinney explains, is "a susceptible host and one insect."

Nobody knows for sure how the Asian species got to North America, but all evidence points to ornamental hemlocks that were imported from Japan. The invader was first documented near Richmond in 1951. It went essentially unnoticed until 1986,

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when Mark McClure, then a scientist with the Connecticut Agricultural Experiment Station in New Haven, warned that it was killing trees in his state. Two years later, researchers found adelgids in Virginia's Shenandoah National Park, and by 1994 most of the park's hallmark hemlocks were dead or dying. "That was a big wake-up call," says entomologist Rusty Rhea of the U.S. Forest Service's Southern Research Station in Asheville, North Carolina.

Alarmed, federal biologists moved to stop the invasion. But there was one problem, recalls recently retired Forest Service entomologist Brad Onken: They knew nothing about the adelgid. "We had to really start from scratch."

AS THE TREES KEPT DYING, researchers scrambled to locate and inventory important stands. Blozan and his colleagues, for instance, used aerial photos and ground surveys to locate 75 hemlocks that were taller than the previously known record of 48.8 meters. All stood within a 100-kilometer-wide area that includes parts of North Carolina, Tennessee, Georgia, and South Carolina; most were within the Great Smoky Mountains park. Blozan and colleagues measured the trees and found that, contrary to theory, hemlocks reached their largest sizes at the southern edge of their range, not the geographical center.

Unfortunately, the large southern trees also proved among the most vulnerable to the adelgid, because the region's relatively mild winters didn't keep the insect in check. To fight infestations, some researchers tried soaps and oil-based insecticides, with only modest success. One problem is that the adelgid attacks hemlock needles from below, where aerial spraying doesn't reach. In 2003, however, the chemical company Bayer gained the necessary approvals to sell neonicotinoid insecticides—primarily used in agriculture—for use in forests. Unlike soaps and oils, neonicotinoids are systemic; trees pull the chemicals into their tissues and can become toxic to insects for 5 years or more. The compounds gave forest managers a powerful new weapon, but they came too late for the 75 "superlative" hemlocks, Blozan says. The insects, aided by a major drought, weakened them beyond saving.

Other trees have been luckier. On a rainy spring morning earlier this year, Great Smoky's Webster bounded up a streamside trail in the Low Gap conservation area near Cosby, Tennessee, to show off the results of an aggressive chemical campaign against the adelgid. Massive hemlocks towered overhead. Most had lower branches killed by the insects, but the upper branches were lush, thanks to workers who have injected insecticides into—or drenched the soil around—more than 200,000 trees since 2002.

The effort has saved some of eastern North America's last remaining old-growth temperate rainforest, Webster says. But the chemicals have downsides. They can harm invertebrates, so their use is limited, especially near streams. (Neonicotinoids have been implicated in harming bee populations, but bees do not pollinate hemlocks and so are unlikely to be affected.) They also aren't cheap; costs are declining, but treating a single 30-centimeter-diameter tree requires $1.20 worth of chemicals plus labor, and projects often involve thousands of trees. And, in the end, insecticides do not permanently eliminate adelgids; they only reduce the numbers. "Chemical treatments are just a Band-Aid," Rhea says.

The hemlock woolly adelgid's spread prompted ecologist David Orwig of the Harvard Forest in Massachusetts to launch an unusual study of forest death.

THE LONG-TERM CURE, Webster believes, is down the road at a facility called an insectary. Here, personnel from the park, the Forest Service, and the University of Tennessee, Knoxville, are cultivating four species of adelgid-eating beetles—part of a larger effort to develop biocontrol methods.

Hammering some wet hemlock branches with a stick, Webster manages to collect one of the attack insects—a torpid 3-millimeter-long black *Laricobius nigrinus* beetle—on a white canvas "beat sheet." Thousands of its cousins, whose ancestors lived in the Pacific Northwest, have been released at 120 sites in the park, and at hundreds of other places in the 20 states now infested with the adelgid. The goal is to establish permanent populations of beetles that do nothing but hunt adelgids.

It took decades to get this far. The adelgids exploded in eastern North America partly because few native insects eat them. So scientists looked abroad for predators, in the adelgid's home range. The first promising candidate was a tiny ladybird beetle that McClure and a Japanese scientist found in 1992, munching adelgids on a local hemlock species. After testing to ensure that the beetle wouldn't harm North American ecosystems, forest managers began releasing it by the millions in the United States. "There was a lot of optimism," recalls Scott Salom, an entomologist at the Virginia Polytechnic Institute and State University in Blacksburg, who has led much of the biocontrol research. But hope faded as the introduced insects disappeared without making a dent in adelgid numbers.

Other candidates show greater promise. A few biocontrol insects, including the beetle Webster found at the insectary, have established stable, but small, wild populations. But rearing the insects has been challenging. Salom's technicians spend days trying to coax finicky beetles to reproduce in rooms cooled to 18°C or below. Recent cold winters have complicated matters by killing the adelgids that, ironically, researchers now need to feed their beetles. That's one reason scientists are exploring other biocontrol options, including a silver fly native to the Pacific Northwest and a fungus that may kill adelgids. A discouraging precedent tempers hopes. In the 1900s, scientists introduced more than 30 different insects to the eastern United States and Canada to try to control the balsam woolly adelgid (*Adelges piceae*), a related insect that devastates native fir trees. Each introduction failed, and the balsam adelgid is still a serious pest. "There are dozens of reasons why biocontrol programs don't work quite as planned," Rieske-Kinney says. "Biological control is not for the faint of heart."

A FEW SCIENTISTS think the hemlock's future rests not with finicky beetles, but with special genes. As early as

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the mid-2000s, scientists noticed that a few hemlocks appeared to resist adelgid infestations longer than their neighbors. Now, the hunt is on for genes that might be responsible. Ecologists Richard Casagrande and Evan Preisser of the University of Rhode Island, Kingston, have collected cuttings from what some call "putatively resistant" hemlocks found at isolated sites in New Jersey, Connecticut, and elsewhere, and they are now growing seedlings in Rhode Island and North Carolina. Some do seem to be less susceptible to the adelgid, Preisser says. That may be because the trees contain unusually high levels of terpenes, chemicals that can provide resistance to insects, says ecologist Joseph Elkinton of the University of Massachusetts, Amherst.

Others are skeptical about the effort. "In my estimation, there's not much hope that we're going to find genetic resistance to this insect," the Forest Service's Rhea says. He and others note that the hemlock has relatively little genetic variation through its range, making resistant outliers unlikely.

The Forest Service is trying another approach: figuring out how to protect hemlocks from other stresses, so they are more likely to resist the beetle. Biologists from the service and North Carolina State University (NC State) in Raleigh are studying how well hemlocks grow under different conditions, including sunlit or shaded, and with and without deer fences, weeding, and fertilizers. They are also evaluating combinations of chemical and beetle treatments. As Bud Mayfield, a U.S. Forest Service entomologist at the Southern Research Station in Asheville, explains, "maybe one thing won't let you grow hemlocks, but four things will."

The service is also preparing for the worst-case scenario: the extinction of eastern hemlock in the wild. It is funding Camcore, a tree breeding and conservation group housed at NC State, to collect seeds and genetic material from eastern hemlocks and the related, but rarer, Carolina hemlock. The group has planted trees in places likely to remain adelgid-free, including Chile and Brazil, in case they are needed to help seed reintroductions. "If everything else fails," says NC State biologist Robert Jetton, "we're the hemlock insurance policy."

ONE GROUP OF ECOLOGISTS reacted to the adelgid not by trying to save the hemlock, but by trying to learn from its death. In 1995, when ecologist David Orwig started his first research position at the Harvard Forest, the adelgid was working its way north toward the 1500-hectare research preserve, which holds extensive hemlock stands. Rather than invest in insecticides or beetles, Orwig and his colleagues decided to take the rare opportunity to study what happens when an ecologically important tree disappears. "At this site, I think you could learn more, unfortunately, by watching the demise of hemlocks than by trying to save them," Orwig says.

The adelgid's arrival also represented an experimental ecologist's dream, says Foster, Orwig's colleague. It's "the gentlest way that you can alter the abundance of something," he says. "You're not directly disturbing anything else; you're just selectively affecting the one species."

Because Harvard Forest is part of the National Science Foundation's Long Term Ecological Research Network, the researchers were already collecting preinfestation baseline data. The floor of Prospect Hill, the forest's main hemlock study site, sprouts a garden of instrumentation, including moisture sensors and baskets for capturing leaf litter. Metal bands called dendrometers record the growth of almost a thousand trees. A 34-meter tower rises above the canopy to measure gases emanating from the forest. As a result, Prospect Hill now hosts one of the world's most comprehensive studies of forest death.

During a recent visit to the site, Orwig noted that some trees have survived longer than expected. But from the tower, he pointed out the yellowish needles that are the hallmark of a dying hemlock. "This should be a sea of bright green right now," he lamented. "This is just kind of sick."

The Harvard researchers haven't just watched their hemlocks decline in real time; they've also accelerated the process. In 2003, they girdled or felled some healthy trees, then watched what happened. As the trees decayed, wood and nutrients entered streams and the trunks began releasing carbon. In newly sunlit clearings, black birch, white pine, and other saplings shot up.

In a 2014 book that summarizes their findings, Orwig and his colleagues predict that dying hemlock forests will store less carbon for a decade or two, but that fast-growing young trees will eventually reverse the trend and soak up carbon even faster than the absent hemlocks. Stream flows might decline, because deciduous trees use more water. But local forest biodiversity is likely to increase, because deciduous forests typically support more species. At a broader scale, however, the researchers believe the New England landscape will become more homogeneous as hardwoods replace hemlocks. In short, they say, the forest will live on, changed but still functional.

THANKS TO REPEATED chemical treatments, the Cheoah hemlock is still standing. But Blozan says that in big trees like this one, with complicated branching structures, water and chemicals—including insecticides—can be slow to reach some branches. Indeed, one of the Cheoah's four forks has lost most of its needles. But on the whole, the tree looks healthy. "It's the last of its kind," Blozan says wistfully.

He takes some photographs and records health data for the Eastern Native Tree Society, a group that he helped found. At worst, the documentation will help memorialize a remarkable life. But Blozan and others hope it will ultimately enable them to look back on the time when they began to turn the tide against the adelgid. "They'll come back," he predicts. "It's just going to take a long time. Tree time." ■

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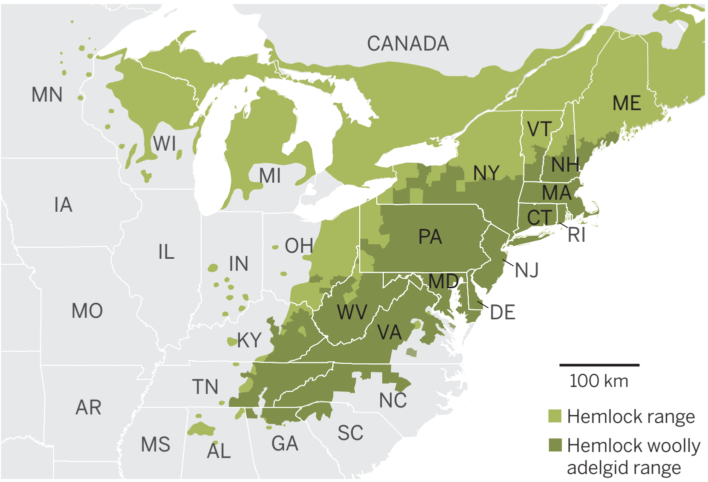
A creeping conflict

The hemlock woolly adelgid now infests about half of the eastern hemlock's range, and has been spreading by about 15 kilometers per year.



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