FEATURE BY CALLY CARSWELL | PHOTOGRAPHS BY MICHAEL CLARK

The Tree Coroners

To save the West's forests, scientists must first learn how trees die

There are few better places than Frijoles Mesa to study the mortality of trees. This tongue of land lies partly within the grounds of Los Alamos National Laboratory in northern New Mexico's Jemez Mountains. To the west rises Cerro Grande, a mountain riddled with the charred skeletons of fir and pine trees. To the southwest are the lingering scars of another fire, one so intense that its heat alone killed trees that weren't consumed by the flames themselves.

The mesa itself is an exceptionally tough place to be a tree, even where the land has escaped conflagration. This summer, many ponderosas were so short of water that their weakened limbs snapped like pretzel sticks. The trees that sit behind a padlocked gate off State Road 4 were also struggling. This is tree physiologist Nate McDowell's outdoor laboratory. Here, he's enclosed piñon and juniper trees in transparent silos, cranked up the heat and deprived many of water — in order to watch them die.

McDowell spent his early career studying the towering conifers of his native Pacific Northwest and came to Los Alamos in 2003, eager to begin a U.S. Department of Energy job that would allow him to set his own research agenda. But looking out his office window at New Mexico's characteristic piñon-juniper woodlands, he had second thoughts. "This is *not* a forest," he scoffed. The stout, pear-shaped junipers — one of the most common species here — resembled ill-kept hedges more than trees, all arms and twisted torsos, barely showing any leg. "They were like a weed to me," he remembers.

Like weeds, junipers are durable. Those outside McDowell's window were still green, but the piñon around them were dead. During the deep drought of 2002 and 2003, piñon died throughout the Southwest in historic numbers. Had the Old Testament told stories of forest die-off, as it did of floods, the carnage around Los Alamos would have been called "biblical": More than 90 percent of the area's piñon succumbed. "What a bummer," McDowell sulked. "I'm a tree physiologist, and the trees are all dead. What am I gonna do?"

At first, the cause of the trees' demise seemed obvious. The punishing drought badly weakened them, and when beetles bored through their bark, the trees couldn't muster enough sap to pitch them out. Once inside, the beetles mated, multiplied, dug tiny tunnels and spread a fungus that cut off the flow of water and nutrients, killing the tree.

Nate McDowell, a tree physiologist at Los Alamos National Laboratory, pushes trees to the limits of moisture deprivation and heat in his outdoor laboratory in order to learn more about how trees die.

> Why do trees die? It's a deceptively simple question in urgent need of answers: Trees are dying at alarming rates across the West.

But Dave Breshears, a University of Arizona professor and arid lands ecologist who had studied the woodlands for years, suspected that the truth was more complicated. During the 1950s drought, tree death seemed less extensive, even though that drought was longer and drier than the more recent one. What was different about this drought was temperature: It was a degree or two hotter.

Breshears' observations inspired McDowell to take a second look at the struggling forest. It's common knowledge that trees die during and after a drought, McDowell says, but "nobody can predict where it will happen, when it will happen, what trees it will happen to. That means we don't understand it. That was exciting to me — there's a science question there."

Why do trees die? It's a deceptively simple question in urgent need of answers: Trees are dying at alarming rates not only in the Southwest but in Colorado, the Northern Rockies, Alaska and elsewhere. This summer in northern New Mexico, even junipers began to expire in droves.

IT MIGHT SEEM SURPRISING that, in 2013, we don't know how trees die. We understand tree growth so well that we can decipher its code — tree rings — and reconstruct droughts thousands of years in the past. So why is tree mortality such a mystery?

"There has been a long tradition in plant science where, if your plant died during your experiment, you were bummed out," McDowell explains. "It was like, 'Ugh, we've gotta start over.' The question was never, 'Why did it die?' " Besides, he adds, tree death didn't seem particularly pressing. "I think people inherently look at trees as these stable things in our lives, like mountains. We didn't know there was a problem."

Western forests are confronting new versions of familiar foes. In the 1990s, a series of warm winters and summers in south-central Alaska allowed bark beetle populations to explode and kill millions of old spruce trees. Beetles gained similar strength in the Rockies during mild winters in the late '90s and early 2000s, killing not only their usual victims but also entire hillsides of ancient whitebark pines, which live at altitudes once too frigid to support the insects.

Farther south, piñons were also attacked, but by a beetle that, unlike its fellows in the Rockies, typically preys only on the weak. Here, scientists believed the industrious insects were less the cause of death than the final straw: a strong shove to trees with one foot already dangling over the cliff.

The piñons died during what Breshears dubbed a "global-change-type-drought." It's impossible to blame any particular weather event on climate change. Still, the drought was a glimpse of the future, when droughts are predicted to be hotter and drier. Breshears and his colleagues found that it took 15 months in extremely dry soils to kill the piñons around McDowell's office. The heat, they believed, had increased the overall death toll by siphoning more water from soil and plants, though they couldn't yet prove it.

Dramatic changes in Southwestern forests had been expected — eventually. Desert edges are already marginal tree habitat, and were predicted to become especially vulnerable to the future's hotter, more intense droughts. Still, the amount of dead wood around Los Alamos was startling. Piñons didn't die only at the ecological boundary between woodland and grassland, the dry end of their range where Breshears and others believed climate change impacts would first become visible. Instead, piñons died almost everywhere they grew.

No community can comfortably afford to lose its forests. Besides being nice places to hike and ski, forests provide food and shelter for birds and wildlife. Leaves scrub the air of pollutants humans saturate it with. And forests shelter winter snow, the source of most Westerners' water supply, filtering it to rivers and streams in spring.

More important from a global perspective is the fact that forests ingest an estimated quarter to a third of the carbon dioxide released by fossil fuels, effectively keeping the earth's burner turned down. When trees die, they not only stop absorbing CO_2, but they also decompose, gradually releasing the carbon stockpiled in their wood. If enough forests collapse, the flame on the planetary heating ele-

The conifer forests in New Mexico's Jemez Mountains near Los Alamos National Laboratory still bear scars from the 2011 Las Conchas Fire. While the damaging side effects of warm temperatures, from drought to insect infestation to fires, have long been recognized as threats to forests, new research indicates that hotter temperatures alone will kill trees.

ment could turn from "low" to "high." Instead of slowing global warming, forests could start to make it worse.

Computer models either don't account for future tree death caused by climate change, or they do so simplistically. These shortcomings worry scientists, and with good reason: The most troubling thing it could mean is that the dramatic forecasts the models currently produce — the ones predicting not only a warmer climate, but also the fundamental transformation of life on earth — are understated.

Before scientists can more accurately predict our future climate, they have to complete a simpler task — at least, one that sounds simpler. They need to understand, in mechanistic detail, how trees meet their end.

AFTER NATE MCDOWELL spent a few years studying the inner lives of junipers, his attitude toward the trees softened. What junipers lack in majestic height and open, shady understories, they make up for in pluck and perseverance. McDowell, a spry, 41-year-old former endurance runner, began to appreciate these qualities. "They're just so tough," he says. "You have to respect someone who's tough."

Juniper doesn't cower in the face of drought. Even when extremely short on water, it doesn't close its stomata — the tiny pores on its needles that regulate the tree's basic bodily functions. Stomata allow trees to consume carbon dioxide and photosynthesize. They also let water escape, creating the tension that pulls water upward through the tree's circulatory system. If there's too little water in the soil, a tree's pipes can fill with air and break.

To prevent this, many trees close their stomata during droughts. Juniper, with its deep roots and sturdy build, doesn't. When extremely stressed, it begins severing the water supply to entire limbs — reducing the amount of water the whole tree needs to survive. This is why smooth, naked branches — the desert's version of driftwood — often protrude from living junipers otherwise covered in stringy bark and sharp needles.

Piñon is more cautious, slamming its stomata shut during drought. Perusing data Breshears and another colleague collected during the drought, McDowell had an epiphany: For a year, the piñons that died endured a level of water stress that should have kept their stomata shut. Photosynthesis is to trees what cooking is to people. It's how they eat. In trying to protect themselves from dying of thirst, he thought, maybe piñons had starved to death instead.

McDowell hypothesized that drought could kill trees either through thirst or starvation, and that owing to their different coping strategies, juniper would die of thirst while piñon would starve. Since the hypothesis is based on fundamental plant biology, and because juniper and piñon manage risk so differently, studying them could reveal basic mechanisms of death that can be tested and tweaked to model mortality elsewhere.

McDowell first tested his hypothesis in a drought experiment in central New Mexico. One set of trees was irrigated, another deprived of water, a third received whatever the sky provided, and all were poked and probed. The piñons in the "droughted" plots, nudged by beetles, perished first, but within a few years junipers, which beetles ignored, died too. Apparently, neither strategy was enough to protect the trees from long-term drought. Rather than perishing of thirst or hunger alone, both species died from some combination of both.

The Frijoles Mesa experiment adds another variable: heat. On the mesa in mid-August, McDowell pried open an acrylic cylinder enclosing a diminutive, maybe 6-foot-tall juniper, and invited me to wedge myself inside. The tree was alive, but had the scrappy look of Charlie Brown's Christmas tree. A fan roared on and off. The air was warm, the experience claustrophobic. After a minute or two, I showed myself out.

The chambers are kept at a consistent 9 degrees Fahrenheit above ambient temperatures, the sort of weather all these trees may have to cope with in the latter half of this century, especially during a drought. The study is young, but McDowell has found evidence of heat's disruptive effects. Elevated temperatures seem to cause both piñon and juniper to devour their carbohydrate reserves more quickly, for instance. "But it's not that clean," he says. During winter, extra warmth can boost photosynthesis.

Tree mortality is a complex and dynamic process. But despite all the remaining questions, a flurry of research over the last five years has helped crystallize an important message, says Breshears. "We have gained a huge amount of confidence that, under warmer conditions, we're going to get a lot more mortality."

IN MID-AUGUST, I hiked into the Sangre de Cristo Mountains outside Santa Fe with Park Williams, a 32-year-old climatologist who, until recently, worked out of the Los Alamos National Laboratory with McDowell. When we strolled past Hyde Park Lodge, his eyes began to dance. In two weeks, the California native would marry his girlfriend at the lodge. He had proposed to her underneath a coast redwood, his favorite tree.

A half-mile or so up a steep trail, we gained a sweeping view of the fortresses

What's happening in other Western forests?

Aspen

After hundreds of thousands of acres of aspen in the West perished during the 2000s, William Anderegg, a Princeton University forest and climate researcher, set out to test tree physiologist Nate McDowell's hypothesis that drought killed trees in one of two ways: thirst or starvation. Anderegg found that aspen primarily died of thirst, but it wasn't an "instantaneous failure." Mortality peaked six years after the drought did, suggesting that, even when precipitation improved, the trees couldn't repair drought-damaged plumbing systems and slowly died. He also found that the dead stands were unlikely to regrow. After fires kill aboveground growth, surviving aspen roots usually send up new shoots. However, after the drought, root systems also died.

Aspen are water-loving trees, drinking primarily from the topsoil, where moisture is controlled by the timing of snowmelt and the heat and dryness of summer air. Earlier snowmelt, and hotter, drier summers are both expected to become more common, and further reduce that water supply. "The climate," Anderegg says, "is leaving aspen behind."

Boreal Forest

In the past, cold temperatures limited the growth of the boreal forests that cover Northern latitudes. Climate change, it was thought, might increase growth in these forests. But that's not turning out to be the case in Western Canada. A 2011 study found that in forest plots unaffected by beetle outbreaks, wildfire or logging, background mortality rates have increased by about 5 percent a year since 1963. The pattern was not counterbalanced, as it was in Eastern Canada, by new growth or faster growth in surviving trees. The increase in mortality seems tied to an increase in water stress due to declines in precipitation and increases in summer temperature — a drought double-whammy.

Boreal forests are globally important because they are gigantic carbon sinks, absorbing more carbon dioxide than they emit. Disturbingly, the 2011 study suggested that if the mortality trends continue, Western Canada's boreal forest could become a net source of carbon, emitting more over time from its decaying wood than it can absorb.

Redwoods

The growth rates of coast redwoods and giant sequoias have surged since the 1970s, according to preliminary results of ongoing research. But this seemingly good news should be taken with a lump of salt. As temperatures continue to rise and water availability decreases, the trees could reach a threshold beyond which growth declines.

California's ancient giants are resilient in ways many trees aren't. They have massive food reserves, are resistant to insects and fungi, and have thick bark that doesn't burn easily. The trees can even resprout crowns after losing all limbs and foliage to wildfire. "It's going to be really hard to outright kill these things," says Anthony Ambrose, a redwood physiologist at the University of California-Berkeley. But if they become stressed by drought in the future, they may become vulnerable to pests and disease they currently tolerate. "That's one of those big unknowns."

White Spruce

White spruce, one of the most common species in Western North America's boreal forests, are responding unevenly to warmer winters and summers. In interior Alaska, white spruce reacted positively to warmer temperatures until the mid-20th century. Then, as temperatures kept going up, tree growth rates started to decline, sparking concern that the trees might start to die. The exact mechanisms that are harming white spruce are still uncertain, but temperature-induced water stress is a prime suspect.

Where the forest meets the tundra farther north, some white spruce have shown the same pattern, but others are growing faster, according to a high-profile 2011 study. Interestingly, temperature no longer seems to be the primary factor controlling tree growth here, as it was before 1950. "There is now a new sheriff in town regulating annual growth," physiologist Nate McDowell and climatologist Park Williams wrote in an analysis of the 2011 study. That sheriff's identity remains unknown, however, highlighting scientific uncertainty about the mechanisms that control growth, survival and death in the boreal forest.

BY CALLY CARSWELL

Juniper trees are tough, McDowell says. "You have to respect someone who's tough."

of pine and fir on facing hills. Williams wore a navy trucker hat and aviator sunglasses with blue-blocking lenses. "When I first look at this mountainside, it looks totally green," he remarked, handing me his sunglasses. The lenses made it easier to see red-orange flecks in the blanket of green, like the first autumn leaves snagged in a lawn. "I think we're seeing the beginning of something that in another one or two years will be much more widespread."

Williams hasn't studied this forest, but his offhand prediction has some basis. Last fall, he authored a high-profile study concluding that if climate models' temperature projections are correct, and if carbon emissions remain at current levels, most mature conifers in the Southwest could die by 2050 or soon after. The tall ponderosa haunted by Mexican owls? Mostly gone. The old piñon that produce sweet nuts prized by New Mexicans? For the most part, toast. Douglas fir, the largest conifers native to Arizona and New Mexico? Them, too.

Williams made a convincing — and frightening — case that warmer temperatures alone could kill the trees, even without changes in rain and snowfall. Using tree rings from piñon, ponderosa and Doug fir — the species that occupy the Southwest's warm and dry, and cool and wet niches — Williams created something called a "forest drought stress index." It showed, surprisingly, that drought stress is driven as much by growing season temperatures as winter snowpack.

Drought is not always a problem of scarce rain or snow, though that's how we usually think of it. Hot weather can also impose drought conditions on plants. Minor temperature increases have an outsized effect on the amount of water the atmosphere can hold: When the temperature goes up, the atmosphere gets a lot spongier. The relationship is exponential. Stubbornly set on fulfilling its potential, warm air sucks water more greedily from both plants and soil. If the water supply it's drawing on becomes depleted, the tension begins to strain a tree's water columns. Picture an eager child sucking the last drops of a milkshake from a straw: The water columns, like the straw, collapse. That's bad news for trees, no matter their coping strategy.

Williams also found a strong correlation between water stress and the forested acreage killed by beetles and wildfire in the past 30 years. "Even if we think of a couple degrees of warming as relatively minor," Williams says, "forests notice a couple of degrees, and they express it by dying."

Because the atmosphere's sponginess is so strongly dictated by temperature, climate models can help predict how fast it will climb. "I considered a scenario where we begin curbing emissions significantly yesterday," Williams says. "Even in that most optimistic scenario, we're looking at megadrought conditions by the 2070s." In other words, even if we began to aggressively control carbon pollution tomorrow, the heat guaranteed by past and ongoing emissions could still devastate Southwestern conifers.

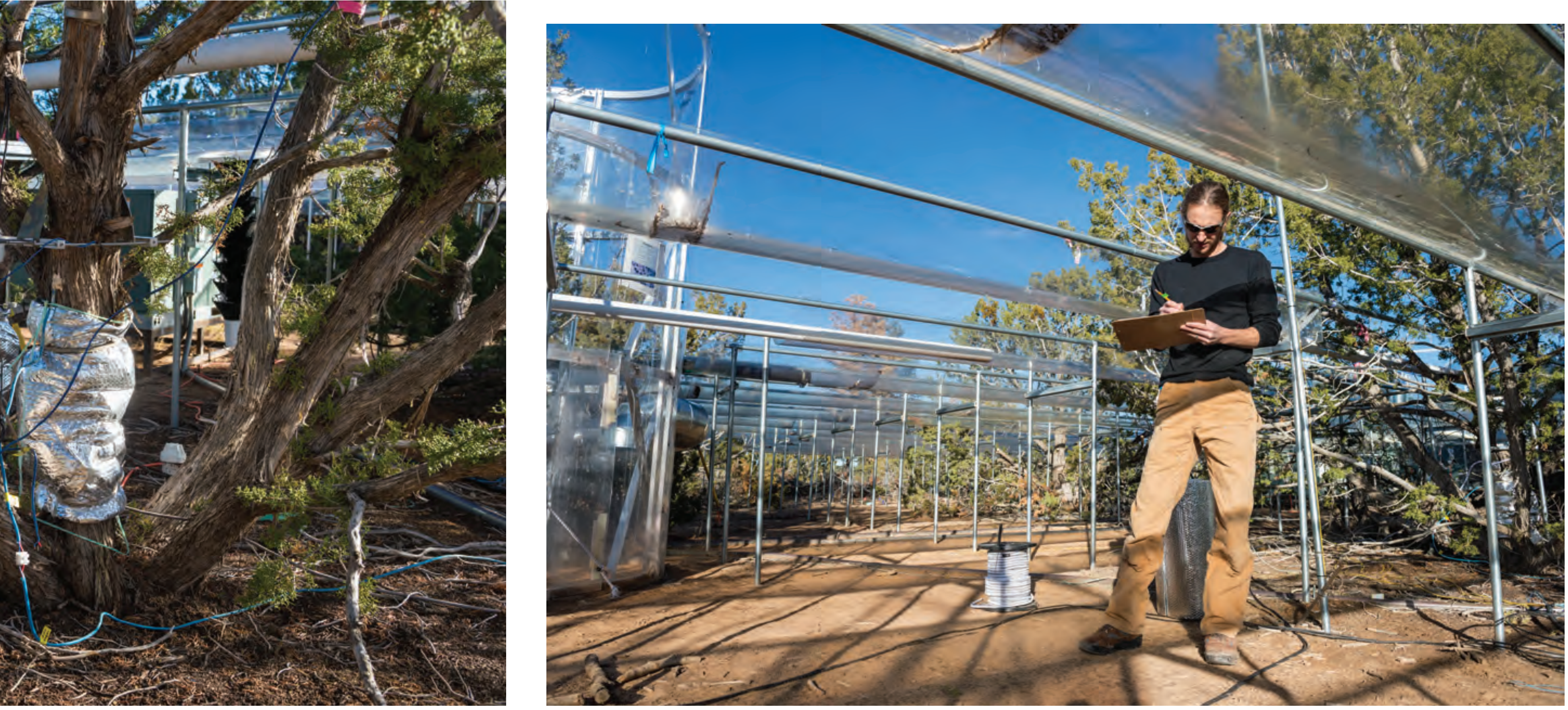
"By 2050, it doesn't matter if it's wet or dry, it's just too damn hot out," McDowell explains. The sense of inevitability that accompanied Williams' conclusions changed how McDowell views his work. At first, he was intrigued by the novel scientific questions involved in tree mortality. "Now I feel like I have a moral obligation to speak up," he says. "We're not just going to lose a bunch of trees, we're going to lose most of them in the Southwest. By 2050, we could be looking at Albuquerque vegetation in Los Alamos," a landscape now surrounded by forests. "Albuquerque has grass and creosote bush."

Such radical changes are unlikely to be confined to the Southwest. A newer modeling effort that Williams and McDowell participated in estimates that the Pacific Northwest could lose 60 percent of its conifers to heat-induced water stress by 2100 — an especially sobering finding for McDowell, whose love of forests was lit at an early age by the old Doug firs on Puget Sound and the Olympic Peninsula. "Can you imagine the Olympic Peninsula without trees?" he asks.

SUCH A FUTURE *is* hard to imagine. Many Western forests still look healthy, with plump, verdant canopies. But even some of the healthiest-looking stands may already be stressed.

In mid-July, U.S. Geological Survey forest ecologist Nate Stephenson drove me to a long-term forest-monitoring plot in Sequoia National Park, a few hours north of Los Angeles. As we left the shrubby foothills, where one could break a sweat standing still at 9 a.m., the temperature dropped 20 degrees, shadows painted the pavement, and giant sequoia appeared — the titans of the Sierra Nevada. The plot itself was blanketed with ferns, and full of soaring sequoias and lichen-covered sugar pines.

Stephenson helped establish the network in 1982, measuring off the first plots with string. He is wildly passionate about the Sierra Nevada: In graduate school, he designed a thesis project that allowed him to hike 500 "glorious" miles a summer in Sequoia's backcountry. After he earned his Ph.D., he returned to Sequoia with no promise of permanent employment. He wasn't interested in going where the jobs were. Stephenson has now studied this place for 34 years. But it can still surprise him. When he expanded the plot network across different elevations in the early '90s to study how climate affects forests, he says, "It didn't occur to me that by the mid-2000s, we would already be able to detect an



Researchers in Nate McDowell's research facility at Los Alamos check on a tree inside a chamber that allows them to keep the temperature 9 degrees Fahrenheit warmer than ambient air, far left. Trees in the facility are wired to monitor health, center, and some are deprived of water by plastic troughs that divert rainfall, right.

increase in tree mortality."

Around that time, Phil van Mantgem, a scientist who worked in Stephenson's shop, began analyzing growth and mortality in the plots. He expected dull results — birth and death rates usually reach equilibrium in old growth — but something peculiar appeared in his data: Background mortality rates — the rate at which trees die in a healthy forest — had doubled. "We thought we did something wrong," Stephenson says. "We tried to make it go away. We couldn't." The only possible cause they couldn't eliminate was the average temperature, which had risen almost 2 degrees F since the 1980s.

Stephenson and van Mantgem ran the same analysis for old-growth forests West-wide. They found the same pattern: At many high-, mid- and low-elevation plots, from California to Idaho, Arizona and Colorado — even in Washington's Hoh Rainforest — conifers were dying at double the rate they used to.

"Every year, you expect some people to die in your hometown," Stephenson analogizes. "If that death rate started to creep up slowly, it doesn't create a dead landscape all at once, but you would sit up and go, 'Oh my gosh, what's happening?' "

As in so many ecological stories, what's happening is complicated. "There is something tied to temperature that is probably responsible for what we're seeing," says van Mantgem. But exactly what that something is may vary from forest to forest. At mid-elevations in the Southern Sierra, where the sugar pines and sequoias live, the increase in mortality seems to be tied primarily to a temperature-induced increase in the atmosphere's demand for water — the same thing Park Williams expects to happen more in the Southwest. But at higher elevations and in wetter forests, like the Hoh, warmer temperatures may instead be favoring the fungi and insects that attack trees.

What the uptick in background mortality ultimately portends is also uncertain. But the forests' response to mild temperature increases, van Mantgem says, indicates their vulnerability. "(The results) might be telling us that they have chronic stress as things get warmer. Then if you get an acute stress, like a severe drought, it might be something that hits you over the head." That is, it might be something that takes out a centuries-old forest in a year, or two — or, in the case of a forest fire, overnight.

The Southwest has already experienced such sudden shocks. One of the most dramatic occurred just a few miles from McDowell's outdoor lab. There, in 2011, an aspen tree fell onto a power line, sparking a fire stoked by hot, dry weather and drought-seasoned fuels that burned 43,000 acres in its first 14 hours. The Las Conchas blaze raged through pine and fir canopies on the Jemez Mountains' eastern flank, killing entire stands. Some are unlikely to regenerate, ever, and are already being replaced by oak and locust shrubs. The worst-hit and driest areas have yet to sprout much of anything at all.

"That is the land manager's worst nightmare," Stephenson says of the Las Conchas Fire. "The biological potential has been lost, there's going to be soil loss, erosion, the trees' seed source has been killed off. That was not an easy transition."

If the warming trend continues — as it surely will without heroic intervention — Stephenson hopes land managers can slow the pace of change and influence its outcome for key forests in the Sierra. The Giant Forest in Sequoia National Park, for instance, contains the most massive tree on the planet — known the world over as the General Sherman. "It's a place of high social value," Stephenson says. To help protect the Giant Forest from sudden death in an insect outbreak or a big wildfire, managers can thin trees and set small, controlled fires to reduce competition and increase the resilience of individual trees. If research begins to show that certain species can't survive the future climate, Stephenson says, managers may decide to let those trees go, assisting their migration to more hospitable terrain and perhaps planting new species in their place.

So far, though mortality among many of the area's tree species is increasing, the giant sequoias seem unchanged. There's too little information to draw strong conclusions about the whole population, but preliminary studies suggest that, in their prime habitat, the trees are actually thriving, benefiting perhaps from an extended growing season. Coast redwoods also appear to be growing vigorously, perhaps basking in extra sunlight as coastal fog declines.

Of course, this trend could change. These two iconic giants slurp more water than any other trees on earth, and future changes in water supply could hurt. Desperate measures to save them — like installing sprinkler systems — are already being discussed. "Mortality of big trees is a one-way street," says Stephenson. "You can't replace them once they're gone."

MODELS ARE USEFUL in planning for the future, but we needn't wait for them to be perfected in order to start grappling with the effects of climate change on forests. The mechanisms and trends scientists like Nate McDowell, Park Williams and Nate Stephenson are uncovering are already in motion — and gaining momentum. The future is all around us, plain to see.

That's especially true in the Jemez Mountains. USGS research ecologist Craig Allen has spent his career in this landscape, never growing bored. Allen is

Going forward, the question is: How fast can new trees colonize landscapes as the old trees die?

During periods of drought, piñon trees like this one near Tres Piedras, New Mexico, close their pores to conserve energy and water, while junipers under extreme stress cut off circulation to some limbs. These tactics may not save New Mexico's piñon-juniper forests if the warming trend continues, putting old forests around the West — and the world — at risk.

a whip-smart man with boyish, straight-cut bangs whom McDowell calls "one of the godfathers of tree mortality." Like Stephenson, a colleague and friend, he's studied the same place for 30-plus years.

Change itself does not surprise him. But some of the changes he's seeing now are painful. "Because trees live longer than we do, we tend to view them as timeless," Allen says. "It's unsettling when these landscapes flip overnight." Asked about his favorite tree species, Allen deflects the "unfair question," but acknowledges that he loves old trees the most. The longer a tree lives, the more visible its history becomes — in gnarled bark, fire scars, and in the case of conifers, flattened tops. "You can feel this sense of endurance," Allen remarks. "In human terms, we would call it wisdom."

Allen has spent a lot of time thinking — and publishing papers — about the global significance of the rapid changes in the Jemez. "I don't want to overstate the lessons of the Southwest for the rest of the world," he says. "But it's a preview of what could happen." Drought won't kill all of the world's trees; some forests may get wetter and grow better. Still, the expected increase in global temperature is so extreme that it could easily convince most trees that they've moved to a new planet, and outweigh the potential upsides of climate change for plants, such as more carbon dioxide to consume.

Forests' widespread vulnerability is already evident. A hot, dry spell in Europe in the mid-2000s wiped out oak, fir, spruce, beech and pine. Drought has picked off aspen, jack pine, and black and white spruce in Western Canada's boreal forest — at both high and low elevations. A once-in-a-century drought in 2005, followed by another five years later, killed vast numbers of trees in the Amazon rainforest.

"One thing we are going to lose, and it might be in most places later this century, is old trees," Allen says. "Even if the system can still grow abundant vegetation, the historically dominant old trees are dominant because they're tuned to that historic climate window — which is already not the climate that we're in."

As grim a prospect as that is, it is also an opportunity to make the forests we still have more resilient — and to start doing so now. It is possible, even in the Southwest. The region goes through natural wet and dry cycles, and within the next 10 years, says Allen, the current dry spell is likely to let up. That will ease the pressure on trees from wildfires, beetles and the weather itself, and allow land managers to more safely thin forests with low-intensity fires. Combined with landscape-scale mechanical thinning, these measures could soften the blow of the next drought, and reduce the risk of future catastrophic fires or insect outbreaks. If managers want to plant trees — perhaps more drought-hardy species from other places — the wetter cycle will give seedlings an opportunity to establish themselves.

Most of the old trees we love may still perish, but there are better and worse ways for that to happen. When landscapes change incrementally, they are more likely to maintain species diversity, soil health, and basic functions like erosion control. Past droughts that killed trees in what seemed like apocalyptic fashion, Allen says, in fact caused a gradual reshuffling of the landscape. The 1950s drought, for instance, killed most ponderosa at the dry end of the tree's range, but not all. It didn't leave a treeless landscape, prone to the kind of erosion and soil loss that follows severe wildfire. "It didn't leave a desert," Allen says. Piñon and juniper replaced the dead ponderosa. Going forward, change of this sort may represent a best-case scenario. The question is: How fast can new trees colonize landscapes as the old trees die?

If his daughter or his twin boys have children, Allen wonders, what will they want to know about the forests he knew? He is brainstorming a new project: documenting the size, age, diversity and three-dimensional structure of trees in old forests, archiving tree-ring samples and the histories they hold, and recording the sounds of birds and wind blowing through the canopy. He also hopes to document what ancient forests mean to people by involving artists, poets, ethnographers and the elders of cultures for whom forests are important. Such a project, he is starting to think, might be just as important as scientific research. Someday, even if only through a virtual experience, his grandchildren could still walk through the Jemez Mountains' ponderosa or the Olympic Peninsula's rainforest, and hear the whisper of the breeze through the treetops. ☐

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