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Tree of Life

To save the most species, conservationists might do best to save the common ones they depend on

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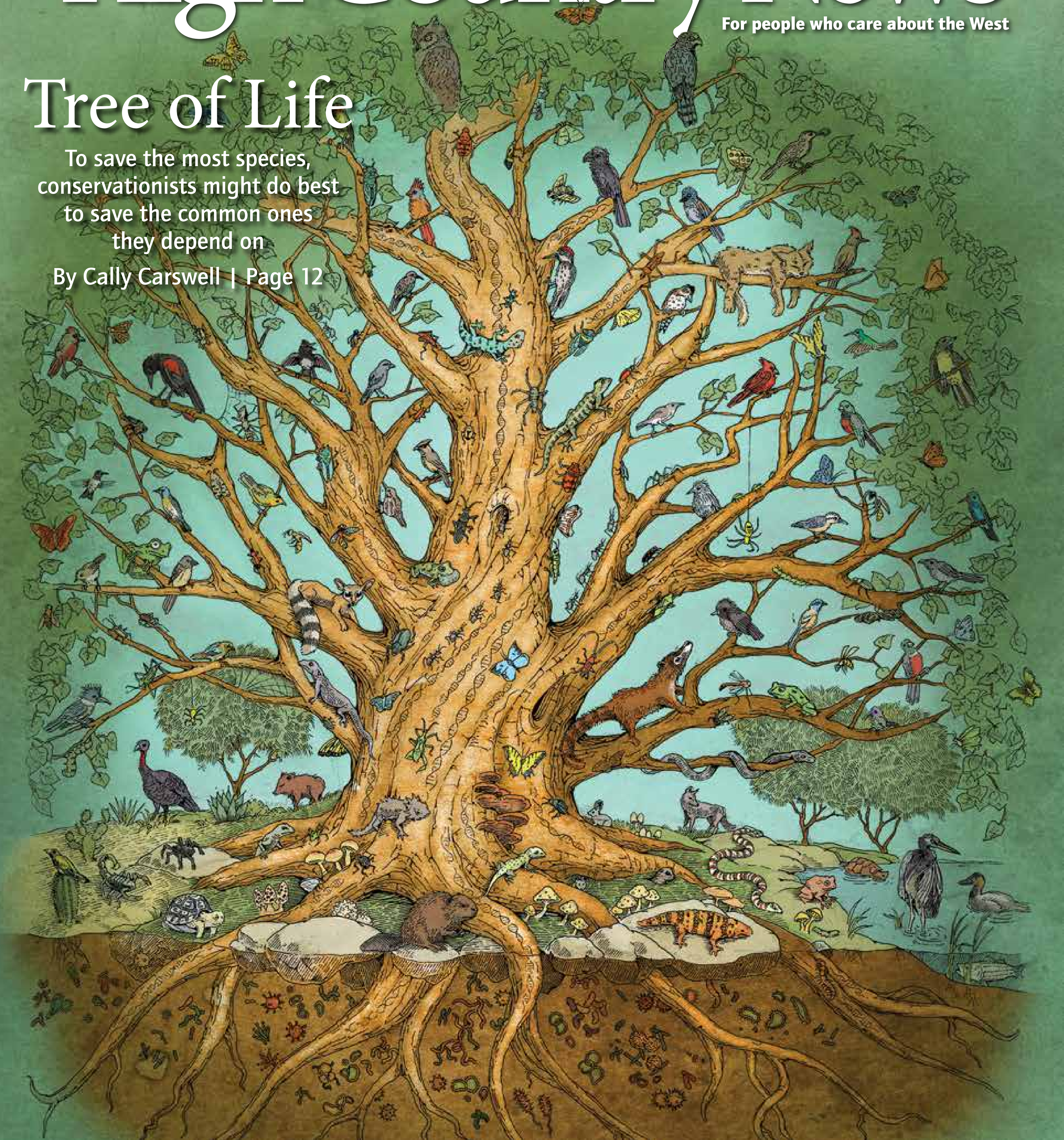

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TREE OF LIFE

To save the most species, conservationists might do best to save the common ones they depend on

FEATURE BY CALLY CARSWELL

Back when he was in his 30s, Tom Whitham would have been leery of the meddlesome approach to conservation that he is laying the foundation for today. Whitham came out West in 1973 to pursue a doctorate in biology at the University of Utah. He had just finished a tour as an Army photographer at a hospital in Hawaii filled with soldiers injured in Vietnam, a difficult experience that had one positive result: He encountered buzzing, singing and tangled rainforests, and became enchanted with wild places, which were rare in his native Iowa. He decided to move to the American West because, he says, "we hadn't plowed it under yet."

He imagined it as an untamed frontier. Though not naive about the human tendency to damage the environment, he thought the West was still too big and sparsely populated to be threatened in any existential sense. One good way to protect or heal the environment, he believed, was to leave it alone. Given time and space, nature could often fix itself.

Today, Whitham is a meticulous and accomplished ecologist based at Northern Arizona University in Flagstaff. He wears round glasses, a gray goatee and, when outdoors, an oiled leather cowboy hat. His love of nature hasn't wavered. At last count, his home garden boasted 120 species of native conifers, poplars, shrubs and grasses. In the field, he always carries a camera, and even at sites he's studied for decades, he still finds things worth photographing. But he thinks the frontier is dead. He is no longer optimistic about nature healing itself. The challenges — a climate in disorder, a looming sixth extinction, and people, always more people, always seduced by short-term gain — have grown too big, too fast. "We live everywhere and we're affecting everything," Whitham says. "My senior colleagues, some of them use the 'f-word.' Some of them think we can't do anything."

Whitham, however, prefers not to dwell on the negative. "We don't need another study to tell us how bad things are," he says. Lots of damaged landscapes need help right now, and that need will only increase as global temperatures rise and warp the local conditions to which organisms are adapted. What we need to know is: *How* do we take action to sustain plants and animals through the turmoil ahead?

Whitham believes the answers lie in an unexpected place: The DNA of species so common we usually take them for granted. As Whitham and his colleagues have researched the Southwest's cottonwoods and piñon pines, they've introduced groundbreaking new ideas about how these trees' genetic traits influence the community of surrounding organisms, and even shape entire ecosystems. If their discoveries hold true in kelp beds, coral reefs, tropical forests and desert shrublands — and so far, they have — they may transform our understanding of how everything in the web of life is connected.

That could make today's restoration efforts more successful, and even help managers take the kind of radical leaps that conservationists increasingly say are necessary to prevent extinctions: Moving species to more favorable habitats, for example, without making things worse in the process. But for now, the most revolutionary idea to emerge from Whitham's work is perhaps the simplest: Saving a large number of species has everything to do with saving the few they all depend on.

WHITHAM GREW UP IN THE TINY TOWN OF AGENCY, IOWA, with an oak and hickory forest nearby. His father, Lloyd, ran a wholesale nursery, selling big trees to banks, which paid good money for the image of stability that they imparted. Lloyd also bred new varieties for landscaping, including a frost-resistant yew that could survive a couple hundred miles farther north than other varieties. A green thumb ran in the family: Whitham studied nursery management and plant pathology in college. And though he decided not to take over the family business, his interest in trees — an inheritance, of sorts — inspired his future research.

A little way north of Salt Lake City, where the University of Utah is located, flows the Weber River. It originates high in the Uinta Mountains and gurgles through small farming and mining towns before draining into the Great Salt Lake. Whitham wandered the Weber's banks, which were lined with sun-speckled cottonwood galleries. The trees were familiar, though in Iowa the cottonwood was considered "kind of a lowly tree," he remembers. "It produces a lot of debris, it's not really long-lived. If you plant one next to your house, the wind could blow it over."

In the Southwest, however, the tree is special. Cottonwoods are one of the few big deciduous trees that grow wild in the

Cottonwoods at the Northern Arizona University greenhouse, where seedlings with different genetic signatures are grown for field trials at experimental gardens under varying conditions. JEREMY WADE SHOCKLEY

Tom Whitham plants cottonwood seedlings for an experiment at Cibola National Wildlife Refuge in Arizona. COURTESY ARIZONA BOARD OF REGENTS

region, and, together with willows, they anchor native riverside habitat. Cottonwood galleries are home to insects, birds and animals, and the trees themselves are beautiful — flushing a brilliant, glittering gold every fall. Though not endangered, they are vastly depleted, thanks to overgrazing by cattle, overzealous cutting, and the damming and diversion of wild rivers, whose seasonal ebbs and flows are critical for cottonwood reproduction.

Whitham began to look closely at the Weber River's two resident species — Fremont and narrowleaf cottonwoods — searching for interesting patterns. A milky, soft-bodied aphid caught his eye. The bug attacks the trees each spring, forming a hollow gall just below the leaf, where it feeds, reproduces and hides from predators. Whitham noticed that one cottonwood might attract millions, while another tree of the same species, only feet away, had none.

There were two possible explanations: There could have been something different about the trees' environment, with one spot slightly drier or warmer, creating some change that the aphid preferred, perhaps in leaf shape or size. Or something in the trees' DNA could have conferred natural pest resistance on some trees. "The trees were so close together, it almost had to be genetic," Whitham says. "But I was still kind of surprised to see it in nature, because it was so striking. I always expected it to be more subtle."

He took cuttings from 81 cottonwoods and planted them all in a "common garden." A few acres in size, it would ensure consistent growing conditions, removing the possibility that any differences that emerged were caused by soils, temperature or water supply. Sure enough, aphids swarmed clones of the same trees they attacked in the natural forests. The insects were responding to the trees' genes.

Whitham noticed other things, too: The aphids attracted other bugs that didn't visit the resistant trees, and those bugs drew an unusual number of hungry birds. He began to wonder if a tree's genetics might not only determine the presence of one measly aphid, but indirectly, the panoply of creatures that frequented its canopy.

For the next two decades, he and a formidable group of collaborators intensively studied that first garden and others, planted with diverse genetic variants, or genotypes, with each tree DNA fingerprinted. They saw the influence of the trees' genes almost everywhere they looked. Birds of various species preferred to nest in genotypes with particular branch and canopy architectures, for example, while spiders favored one with thickets of dead branches and dense foliage. Beavers selected a "sweet" genotype, with low tannin levels. Lichen attached to the trunks of a genotype with rough, topographically complex bark. On a stretch of the Weber where Fremont and narrowleaf cottonwoods naturally hybridized, the two species supported two distinct insect communities, while the hybrids hosted elements of both.

The researchers dug into the soil and analyzed leaf litter in streams. Eventually, they demonstrated that a single group of genes influenced not only the community, but the invisible ecological processes that helped sustain it. Tannin-poor and tannin-rich leaves decomposed at different rates, causing variability in soil fertility. The two leaf types similarly affected the nutrient cycle in streams, and with it the bacteria and bugs at the bottom of the food chain. Genotypes even differed significantly in their ability to sequester carbon in their roots.

Based on the researchers' hundreds of studies, it appeared that genetic diversity within cottonwood species influenced the composition and function of the entire riparian system — accounting for between 39 and 78 percent of the total biodiversity in the researchers' cottonwood gardens. Parallel research in aspen, eucalyptus and piñon pine forests suggests that "foundation species" — that is, the dominant, habitat-forming plant on the landscape — do the same in other ecosystems.

Genetic diversity — the raw material of evolution — had long been seen as important, but scientists and conservationists primarily considered it when trying to protect rare and endangered species. Without it, small populations are especially vulnerable to extinction. In the event of a disease outbreak, for instance, genetic diversity acts as an insurance policy: The more diversity there is, the better the odds some individuals will carry genes that confer some resistance. But for common species, beyond recognizing genetic diversity's importance in keeping them healthy and abundant, nobody paid it much mind. Now, there was new incentive to care.

"Almost everyone thinks a species is a species is a species," says Jessica Hellmann, a biologist at the University of Notre Dame who specializes in the ecological impacts of climate change. "Tom has shown that there are differences between cottonwoods that matter. The identity of an organism influences every other member of its community." That means that maintaining genetic variation in a foundation species is "going to be critical for the associated community's biodiversity and ecosystem function," adds Gery Allan, a plant geneticist and a member of Whitham's research group at NAU. "We know it's all tied together."

It's necessary, then, not only to understand how a foundation species' genes influence the whole community of living things around it, but also to parse out what traits hidden in its DNA might ensure its persistence, even as its world shifts. After all, species that are common today might not be so common decades from now. Some models predict that within this century, torturously hot, dry spells could kill off or significantly beat back some of the Southwest's most familiar tree species.

In the region's piñon woodlands, the crippling 2002 drought offered a grim preview, with 57 percent of the mature piñon in northern Arizona perishing. But there was a sliver of hope in the die-off, and it taught scientists a new version of the lesson they'd learned among cottonwoods: When it comes to who lives and dies, a tree is not a tree is not a tree.

ON A WARM SEPTEMBER MORNING, Whitham and Kitty Gehring, an NAU colleague who studies soil microbes, take me to see a special stand of piñon trees, a foundation species that, at this site, supports roughly 1,000 species of birds, rodents, bugs, bacteria and fungi. The stand is about 30 minutes from Flagstaff, in Sunset Crater Volcano National Monument. The volcano erupted nearly 1,000 years ago, smothering an 800-square-mile area in lava, ash and cinder. Life rose from the rubble, but its existence still feels improbable. The sandy "soil" the trees live in has all come from somewhere else, an accumulation of dust deposited by the wind. There's just a thin layer of it, no more than one or two inches thick, sandwiched between layers of jet-black basalt pebbles that radiate the day's building heat. Growing here must be sort of like trying to eke out a living on a hot tar roof.

Right around the time Whitham planted his first cottonwood garden, he came to this place with a group of graduate students. They immediately noticed that the piñon grew in two distinct shapes. One resembles a classic tree, with a canopy, a trunk and admirably upright posture. The other has a form reminiscent of a fat, laughing Buddha, reclining lazily on one elbow, looking perhaps a little drunk, its branches sprawled across the cinder.

Research pegged the difference to the Buddha trees' genetic susceptibility to a moth that attacked each year's new shoots. The moths acted like hedge-clipper-wielding suburbanites, cutting the trees down to shrubs. Not only did the trees grow painfully slowly, there was also the matter of the sex change: Piñon produce female, seed-bearing cones in their crowns and male pollen-dusted cones down their sides, but the moths chewed only the crowns, eliminating most of the trees' lady bits. "You look at them and go, 'Poor things,' " says Gehring.

Gehring also found what appeared to be a subtler disadvantage. The moth-munched trees had much less — and different types — of a helpful kind of fungi than the resistant trees. Called *mycorrhiza*, these fungi form little hairs around the trees' roots and, in exchange for a supply of sugar, deliver nutrients from the soil. Experiments showed that the trees' genes determined which kind they ended up with. Because moths were attacking the shrubby trees, they couldn't afford to give their fungi much sugar. Thus, Gehring assumed, the fungi would be "cheap and not very good." She dubbed them "Wal-Mart mycorrhiza."

"These resistant trees seemed so superior," Whitham recalls, "that I would have bet that they would have taken over the piñon world."

But he would have lost that bet. After the 2002 drought, nearly 70 percent of the "superior" trees perished, while less than 30 percent of their moth-attacked neighbors did. Gehring suspects the fungi made the difference. She's discovered that the susceptible trees' fungi stay

Environmental Genetics and Genomics Lab Director Gery Allan studies plant genetics at the molecular level. Above, a hole punch is used to extract samples of cottonwood leaf for DNA sequencing. JEREMY WADE SHOCKLEY

Kitty Gehring at Sunset Crater Volcano National Monument near Flagstaff, Arizona, where she studies moth-resistant piñon pines that look healthy (right) and those that are more susceptible to hungry moths (far right) — and are more resistant to other environmental stresses. Below, a piñon rises from the volcanic soil.
JEREMY WADE SHOCKLEY

active and abundant when it's dry, while others die or go dormant, perhaps depriving trees of critical nutrients. "Maybe it's cheap," she says of the Wal-Mart mycorrhiza, "but it's really good."

It was an encouraging sign: The piñons had vulnerabilities, sure, but also wells of resilience. The dramatically higher survival rate of one genetic variant suggested that drought-hardiness was embedded in its DNA. "If you find populations like this one," Gehring explains, "and if they reproduce or if you breed them intentionally, then you may not have a species that goes extinct in Arizona in 2080. It could survive."

But for Whitham, the scale of the die-off also underscored the urgent need for action: Since trees live for hundreds, even thousands, of years, they have to be adapted to a wide range of environmental conditions. "If you see mortality in these really long-lived species, that suggests something fundamental is changing," Whitham says. Climate change was no longer a distant threat: "It's occurring right now."

THIS SPRING, the journal *Science* published a study that predicts one in six species globally will go extinct if carbon emissions continue climbing on their current trajectory. Some scientists say that estimate is low; the number "may well be two to three times higher," one told *The New York Times.* Neither estimate accounts for the species that will die out in parts, but not all, of their range, thanks to local variations that pound some areas with much more extreme climatic changes.

The scale of the crisis seems well beyond the scope of laws like the Endangered Species Act. As the national climate change policy advisor for the U.S. Fish and Wildlife Service, Mark Shaffer, wrote in a recent editorial in the journal *Conservation Biology*: "Tending to one species at a time in the face of thousands in need promises a long journey to closure." Protected areas are one way to safeguard lots of species at once, but our current collection wasn't designed to withstand a turbulent climate. Joshua Tree National Park, for instance, may become unsuitable habitat for Joshua trees. And without protected corridors between these islands of preserved habitat, creatures may not be able to move or connect to other populations as their environments change.

So conservationists need new strategies. Shaffer's editorial introduced a group of papers focused on a novel approach dubbed "conserving nature's stage." It suggests ensuring that a wide array of geophysical features are protected — soils, topography, geology — "as 'stages,' " Shaffer writes, "for the evolving cast of players sure to be on the move in an era of climate change." Another option is "assisted migration," where people pluck species or populations out of habitats they're no longer suited to, and plop

Coral bleaching in Kaneohe Bay, Hawaii, last October. As in the Arizona piñon and cottonwood trees, researchers have found genetic variation among corals that leave some healthy in the face of stress (brown in the photograph) and others bleached white and more likely to die.
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them down in more hospitable ones. Yet another is the idea of preserving genetic diversity within foundation species.

With any of this, there are practical problems. In a lot of places, we don't yet know what the foundation species are, nor can — or should — we relocate every struggling species. We don't know whether it would even work. And there are risks. A transplanted species could become invasive in a new environment, crowding out others that were doing fine before humans intervened. "The idea of assisted migration comes up all the time," says Notre Dame's Hellmann, a leading thinker on the approach. "But the leap from starting to think about it to actually implementing it is a big one. We probably have five, 10, 15 years we can spend thinking about it," before it becomes much more common for species to blink out in parts of their range. "We don't have much more time than that."

Scientists are thus rushing to understand whether species can move quickly enough to friendlier climes on their own, or adapt quickly enough to stay where they are. And for critical species that are already dying at alarming rates — such as corals — scientists are at the same time trying to devise ways to help them adapt.

"Corals are foundation species, just like trees," says Ruth Gates, a marine biologist at the University of Hawaii. Scientists are only beginning to study how genetic variation among corals might affect all of the algae, fungi, plants and fish associated with them. What they already know, however, is that — just like Whitham and Gehring's piñon — some corals within the same species withstand stress better than others.

"When you go on a reef that is in a stress event, usually from high temperatures, you'll see some are completely colored, and the one next door will be bleached," which often leads to death, Gates explains. She and a collaborator in Australia, Madeleine van Oppen, are now working to understand the survivors' biology in order to develop stock able to endure and adapt to future climate conditions, an approach they've dubbed "assisted evolution."

"We need to see if we can manipulate the system using selective breeding," Gates says. "Or create environmental treadmills, giving them experiences that will turn on certain genes." It appears, for example, that stress flips on genes in some coral that help them survive bleaching events, and that once those genes are "on," they stay on and can be passed on to offspring. That's an exciting prospect, Gates says, because "these changes happen in the same timeframe that these radical environmental changes are occurring."

If Gates and her collaborator can develop resilient stock that can be successfully planted in the wild in Hawaii and Australia, they will then hurry to see whether their methodology can be applied to a wide array of coral species around the world. "We'd have to make this a viable restoration strategy," she says. "We're all in the race against time."

IT WAS WITH THE GOAL of winning that race that Whitham refocused his research around enabling conservationists and land managers to figure out how to keep critical species like piñon and cottonwood, along with a little, or maybe a lot, of the insects, birds, microbes and mammals they support.

Today, he and a laundry list of collaborators — including the Bureau of Land Management, the U.S. Forest Service, The Nature Conservancy, the Flagstaff Arboretum and the Arizona Game and Fish Department — are creating a climate-focused network of 10 common gardens in Arizona, plus a number of satellite sites around the region, called the Southwest Experimental Garden Array. The 10 core gardens will span elevations from 5,000 to 9,000 feet above sea level — a gradient that can be used to mimic the effects of climate change — and feature a range of soil and habitat types, from desert scrublands to aspen and mixed conifer forests.

Northern Arizona University graduate student Hillary Cooper, above, and her study of drought-resistant grasses, such as native grama grass and Arizona fescue, at the Flagstaff Arboretum, part of the Southwest Experimental Garden Array. Michael Ingraldi, right, of the Arizona Game and Fish Department at the Chevelon State Wildlife Area, where invasive tamarisk and other exotics thrive in the riparian area. JEREMY WADE SHOCKLEY

They'll be big enough to support multiple studies, and offer ready-to-go infrastructure — fencing, data management, irrigation systems that can be controlled from afar — to encourage as many researchers as possible to use them.

The methodology is not so different from that of field trials to develop new seed varieties in corn country. But where agricultural experiments might focus on increasing the harvest from each acre, here the metrics of success involve biodiversity and long-term survival.

"The huge power of genetics is that you can take a species like piñon or cottonwood and look at the variation over their whole range," Whitham says. "You can find areas where they're adapted to much more severe conditions that reflect what another area will become in the next 50 years." And you can quantify how much environmental change different genotypes and populations can tolerate. "Genetic differences," Whitham explains, "are the difference between life and death in a given environment."

One of the gardens in the new experimental array will sit on the bank of a Little Colorado River tributary called Chevelon Creek, just south of Winslow, Arizona, on Arizona Game and Fish Department land. The day after visiting Sunset Crater, Whitham and I meet Michael Ingraldi on the creek, where similar work is already underway in an established garden. Ingraldi, youthful-looking at 50, inquisitive, a constant jokester, is a research biologist with the state agency. Both men, it turns out, have species of flies named after them, gifts of a kind from the friends who first identified them. Whitham's namesake eats poop, Ingraldi's sucks blood.

Ingraldi is in charge of removing tamarisk from some 55 acres around the creek and restoring its native cottonwoods and willows. Sounds routine enough, but it's no small task. Though the tamarisks at the garden's edge are now thick enough to hide a meth lab — which they have, in fact, been known to do — they are probably on their way out. In 2001, federal officials introduced a beetle to the West to kill the riparian invader, and it is making its way into Arizona. Ingraldi must ensure that native vegetation becomes established in its wake rather than tumbleweeds, which now grow so big here they look ready to collapse under their own weight.

Plus, trees planted for restoration projects often die. "People say it's because of salty soils," Ingraldi explains, or because the water table has dropped too low. Climate change doesn't help, he adds. "That's why we're partnering with these guys. We want it to work." After all, they're on the hook. Once his agency replants the area, it must maintain it in perpetuity. Moreover, this restoration work will be a demonstration project for a larger vision: To restore the cottonwoods and willows that have been lost in much of the 27,000-square-mile Little Colorado River watershed. "This is going to be the jewel of the Little Colorado," Ingraldi says. "Hopefully."

Until now, restorations like this have typically been done with cuttings from local trees, on the theory that they are the most likely to thrive, or with plants of unknown provenance bought from a nursery. But "this place is probably going to get drier," Ingraldi explains. "And if it gets drier and warmer, you would assume cottonwoods and willows from a drier climate would do better here. Well, is that true?"

To find out, researchers have planted local cottonwood and willow genotypes in the garden, along with genotypes from lower and higher elevations, and more southern and northern climes. They track their growth and survival rates, and how different combinations of willow and cottonwood fare together, among other things. As Whitham explains it to Ingraldi, citing data collected at other sites: "If you tell me, 'I want a tree that supports the greatest diversity,' I can guarantee you that we can select trees that maximize biodiversity. If you want to maximize growth, we can do that."

That might sound like a potentially dangerous level of meddling. But Dan Simberloff, an invasive species expert at the University of Tennessee and a sharp critic of assisted migration, says there's little risk in moving cottonwood and willow genotypes around across relatively short distances, and to already highly disturbed sites, within their native range. There's not a lot to mess up on the tamarisk-lined banks of Chevelon Creek, as Whitham puts it, but there is a lot of opportunity to learn "the tools of a new trade."

His confidence that this kind of restoration can work comes in part from a proof of concept project on the Weber River 13 years ago. Simply planting strategically selected cottonwoods has helped shift a site that was completely consumed by invasive weeds to one composed of nearly 40 percent native plants, and with some 700 species of bugs living in the trees alone. The lesson of this project: If you build it, they *may* come.

Things were a bit different on the Weber, though: Creatures didn't have to go far to colonize the restoration site; they had intact habitat nearby. If managers plant genotypes from a hundred miles away, or in places without cottonwoods and willows nearby, it's unclear how much of the life they supported in one place would follow them. Kevin Grady, a restoration ecologist at NAU, is just beginning to tackle these additional layers of complexity in large research sites on the Little Colorado River, transferring understory grasses and even microbial communities with trees.

Already, it seems likely that economically expedient one-and-done plantings won't last indefinitely. Climate models predict that the Chevelon Creek site could warm by 6 degrees Celsius this century, but new results from the garden show that cottonwoods adapted to those higher temperatures don't thrive here now. They leaf out too early and set their buds too late, often getting nipped by frost, and they are more vulnerable to pathogens; some have died. Conversely, data from a garden to the south show that the trees that do well here now won't thrive under radically warmer conditions. That means that land managers may have to consider planting new genotypes incrementally.

"The genetics stuff is getting sort of science-fictiony," Ingraldi observes after a while. Whitham nods. The pie-in-the-sky goal, he explains, would be to have the genome of everything sequenced and functionally parsed apart — the natives, the invasives, the soil microbes. "Then we could say, 'This is the gene in the tree that's interacting with the gene in the willow interacting with the gene in the tamarisk, and if you take this gene away it's going to have these effects, negative or beneficial.' "

Ingraldi works it over in his mind: "Once you understand these interactions, you're saying then, we can play God, in a way. If I want this, just tweak this gene here, or move this from the system, and you'll get it."

"That's true," Whitham says. "And I think it's actually possible" — eventually. That kind of precise understanding of the genetic basis of everything, as another NAU biologist touring the site with us quips, is "Tom's Death Star."

AFTER INGRALDI DEPARTS for a tango lesson in Flagstaff, Whitham and I sit on a cooler a few hundred yards from the creek, waiting for a group of grad students scrambling to collect their last data of a research project. Cottony clouds on the horizon begin to blush purple and pink.

Whitham pulls out a graph, determined to make sure I understand it. It's based on data from a garden in Yuma, planted with Fremont cottonwoods from across the species' Southwestern range. It plots their reproductive success against the temperature shift they've experienced going from their native environment to their new home.

"So let's say we're down at this low-elevation garden, and it increases 4 degrees," he explains, moving his finger four steps down the graph. "According to our research, you can't find a cottonwood that would tolerate a 4 degree increase down here. This would predict, well, they're dead." The only way to maintain cottonwoods at that hot, dry edge, then, might be to genetically engineer them, like a soybean. Unlike the near-term efforts to shuffle cottonwoods and willows around, "that is a controversial thing to do," Whitham acknowledges. "But then, I have a choice. Would I rather have a genetically engineered one, or none at all?"

Whitham doesn't want to make that choice. But the climate is already changing faster than many scientists expected, and our emissions remain on a trajectory that promises extreme future warming. If nothing big changes — and soon — that's bad news for a lot of life on earth. It makes Whitham think that the day could very well arrive when we have to make many such decisions. It will be imperative, he believes, to have good science to inform them. Saving species may "require moving things around, and upsetting the natural order of things," he says. "But we made this problem. Now we've got to do our best to fix it." □

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