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By Karen Charman

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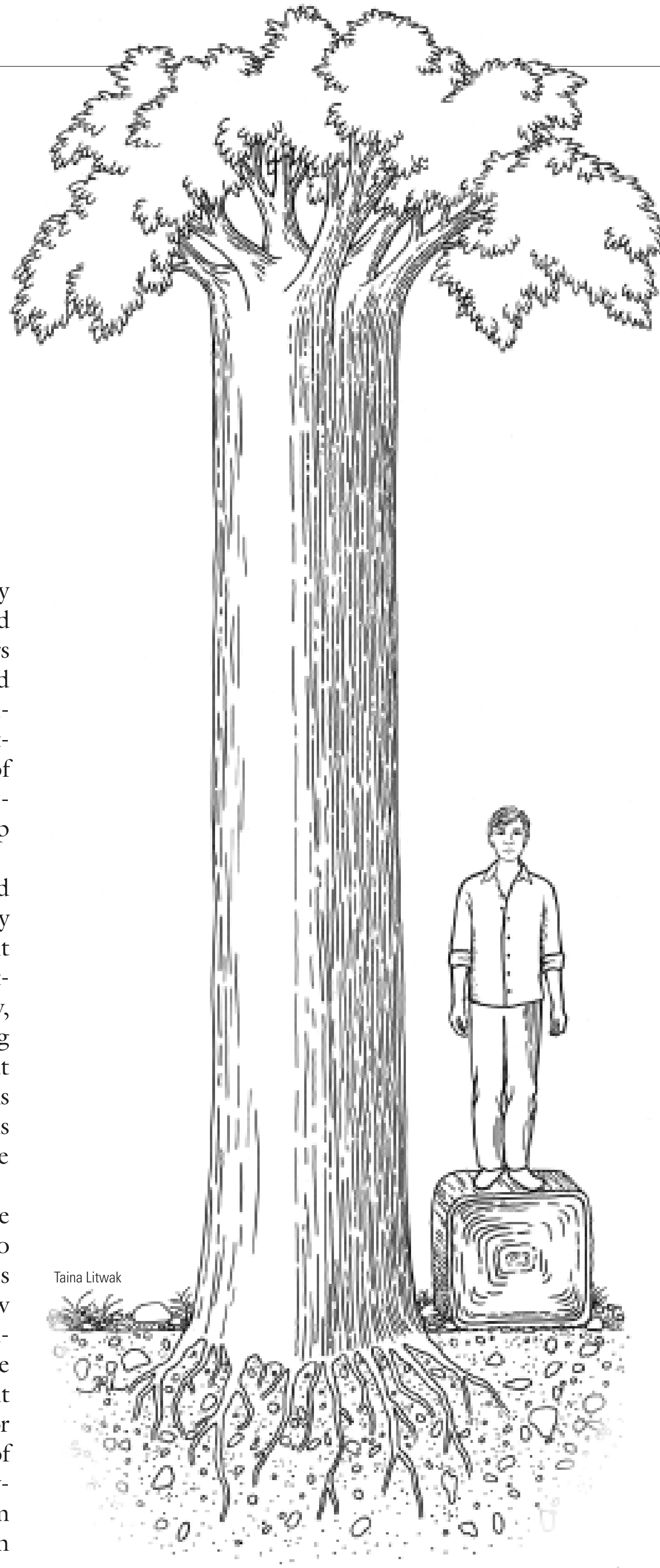
At the turn of the last century, nearly one out of every four trees in the eastern deciduous forests of the United States was an American chestnut. Averaging 30 meters tall and 2 meters wide, these majestic beauties ranged from Maine down through the Appalachian mountains and west to Michigan. The fast-growing and naturally rot-resistant chestnut was an important part of early American life, its timber widely used for log cabins, posts, and railroad ties and its abundant nut crop sustaining wildlife as well as livestock.

But within 40 years, a fungal blight had spread throughout the tree's range, felling virtually every chestnut it touched—some 3.5 billion in all. Brought in by a New York nurseryman on imported Asian chestnut seedlings that were then sent all over the country, the blight moved stealthily from tree to tree, entering through a break in the bark and producing an acid that lowered the tree's pH to toxic levels. Because it attacks new shoots before they can mature, the fungus has reduced the once dominant chestnut to little more than a short-lived shrub.

Ever since chestnut blight was first described at the Bronx Zoo in 1904, scientists have been struggling to defeat it. One of several efforts is going on in the labs of Chuck Maynard and Bill Powell, directors of New York State's American Chestnut Research and Restoration Project. The two scientists have been working since the late 1980s to genetically engineer a blight-resistant American chestnut. In the fall of 2004, they made a major breakthrough: shoots finally appeared on a handful of blight-resistant chestnut embryos in petri dishes in Maynard's lab. Each of the tiny embryos had a gene from wheat to give it an extra enzyme, oxalate oxidase, which neutralizes the oxalic acid produced by the blight.

Genetically engineering the chestnut (or any other plant) involves not only inserting foreign DNA into its cells but getting the altered, or "transformed," cells to regenerate into a whole plant. This is particularly difficult with chestnut, because unlike species such as poplar, it won't regenerate from leaf tissue. So Maynard and Powell had to work with immature embryo



Taina Litwak

THE FUTURE: Could a future genetically modified tree look like this?

tissue, which is much more difficult. Unlike the natural transformation a tree seed undergoes in the forest, the method plant biotechnologists use—somatic embryogenesis—is a multi-step, highly sterile, precision operation. It demands vigilant monitoring, special chemical solutions, and filtering equipment to prevent contamination of the fledgling embryos and coax them into seedlings that can survive outside the lab.

Barring unforeseen problems, Maynard and Powell hope to have potted plants by this summer, to begin field tests in either the fall or spring, and then to do three years of field trials. If all goes smoothly, they expect to begin deploying genetically modified (GM) American chestnut seedlings to forests in the United States in about four years. Because their goal is to reestablish this tree in its natural range, the two scientists want the Animal and Plant Health Inspection Service (APHIS), the branch of the U.S. agriculture department that regulates biotech plants, to allow their transgenic chestnut genes to spread as far and mix with as many chestnut stump sprouts as possible. In fact, they propose that transgenes from *any* GM tree in a forest restoration or disease eradication project be granted such regulatory freedom. (In addition to the chestnut, they've engineered transgenic elm seedlings to fight Dutch elm disease, field tested GM hybrid poplars, and identified other pathogens that affect butternut, white pine, beech, dogwood, and oak.)

But it's impossible to know in advance what kind of impacts transgenic trees will have on wild forests. Maynard and Powell see only a minuscule risk of ecological disruption (if any) with their GM chestnut, since it will contain just three or four foreign genes—the target trait plus a few others needed for the desired transformation. The scientists say greater unknowns exist with the conventionally bred and backcrossed American chestnut, which draws one-sixteenth of its genes from its naturally blight-resistant relative, the Chinese chestnut.

Others, however, aren't convinced that ecological safety depends merely on how many foreign genes a transgenic organism contains, particularly when GM organisms may include genes that didn't evolve together and have never existed in nature. Faith Thompson Campbell, a former advocate with American Lands who is now at The Nature Conservancy, summarized the views of many skeptics in her 2000 report "Genetically Engineered Trees: Questions Without Answers." Here, she warns that GM trees planted near large populations of wild relatives will inevitably spread their genes and alter the genomes (the full complement of an organism's genetic material) of wild trees, including those in national parks, wilderness areas, and other reserves. Since the introduced genes have not evolved with those of wild trees, they could have unpredicted impacts and be unstable over the long lifespan of a tree. Moreover, trees modified to exhibit desired traits such as drought or pest resistance may be able to outcompete native vegetation and spread as weeds in wild forests. As a result, Thompson Campbell argues, changing the genetic codes of some trees could have significant impacts on the ecological functioning of an entire forest.

At the same time, large gaps in scientific understanding of forest ecosystems make it difficult to predict, or even recognize, the wider impact of engineered trees. Two leading proponents of GM trees reaffirmed this at a biotech tree conference in North Carolina in November 2004. After describing the monumental effort of sequencing the genes in the Nisqually poplar, Jerry Tuskan, a senior scientist at the Department of Energy's Oak Ridge National Laboratory, said, "So I stand here looking at the poplar genome data set and realize we know nothing about how trees grow." Later, on a panel discussing current knowledge gaps, Ron Sederoff, co-director of the Forest Biotechnology Group at North Carolina State University—and one of the most outspoken advocates for GM trees—admitted, "We don't know a few important things.… We don't know what a genome really is.… We don't know how many genes there are, because we don't know what a gene really is. We don't know the extent of something that I call epigenomics—the non-genetic changes that occur in genomes that are unstable."

Plant pathologist Doug Gurian-Sherman, a former scientist with the U.S. Environmental Protection Agency who now works at the International Center for Technology Assessment, explains some of the complexities. He notes that trees, and plants in general, produce an array of compounds whose primary purpose appears to be warding off pathogens and harmful insects. This occurs through a sophisticated system of biochemical and metabolic pathways—functions that aren't fully understood by plant physiologists who specialize in the subject, let alone by the molecular biologists manipulating tree DNA. "As biologists, we have to be a little humble and say 'Look, these are complex interactions,'" Gurian-Sherman says. "Frankly, we can't predict how they're all going to play out."

Like many, Gurian-Sherman sees the appeal of wanting to restore the dominant tree in eastern forests. He says there's even a reasonable chance that Maynard and Powell's transgenic chestnuts won't cause harm in the wild because the target trait—the enzyme that neutralizes oxalic acid—is not as obviously disruptive as, say, inserting an insecticide like *Bacillus thuringiensis* (Bt), which could kill large numbers of non-target insects. But the only way to really know GM chestnuts won't cause harm, he notes, is to study in a controlled setting how different forest animals, birds, insects, and microorganisms respond over several generations of the tree's lifetime. Different growth cycles in the tree, environmental and climatic changes, and numerous other factors could trigger unintended impacts over time. Avoiding such mistakes is important because, once released, it won't be possible to recall the GM chestnut trees back to the lab.

So far, however, there's no indication that federal regulators will require the GM chestnut to undergo the kind of full environmental risk assessment Gurian-Sherman is calling for, and he's concerned this will set a dangerous precedent. He also predicts the biotech industry will use the example of the transgenic chestnut to say that all genetically engineered trees are safe. "But different transgenes will have very different impacts," he says. "It's like doing a crash test with a Volvo that passed with flying colors. That tells you nothing about how a little Kia will perform in the same test."

Gurian-Sherman's suspicions appear well placed. At the North Carolina biotech meeting in November, forest industry veteran Scott Wallinger, who recently retired from paper giant MeadWestvaco, was one of many speakers who acknowledged the public relations value of the blight-resistant GM chestnut: "This pathway can begin to provide the public with a much more personal sense of the value of forest biotechnology and receptivity to other aspects of genetic engineering."

SKINHEAD EARTH?

Like their colleagues in agriculture, proponents of forestry biotech use the rationale of looming scarcity and environmental preservation to argue their cause. In a 2000 *Foreign Affairs* article widely quoted in forestry circles, David Victor and Jesse Ausubel offer two visions for the future. In one, "quaint and inefficient agriculture and forestry" lead to a "Skinhead Earth" scenario, where the planet's forest cover shrinks by 200 million hectares by 2050, and lumberjacks regularly shave 40 percent of what remains. Alternatively, "efficient farmers and foresters" who grow "more food and fiber in ever-smaller areas" herald a "Great Restoration" that adds 200 million hectares of forest by 2050 and requires cutting only 12 percent of the world's woodlands to meet global demand for forest products.

Genetically engineered trees grown in intensively managed plantations, or "fast forests," fit into the latter scenario. Today, forest plantations produce one quarter of the world's industrial wood. Though still a tiny percentage of the Earth's nearly 4 billion hectares of forests, they are expanding rapidly, especially in Asia and South America. According to the United Nations Food and Agriculture Organization, between 1990 and 2000, plantations increased 51 percent from 124 million hectares to 187 million hectares. At current rates of planting, they are projected to produce one billion cubic meters of wood—half of the world's supply—by 2050.

The American South, the nation's wood basket since the late 1980s, produces 15 percent of the world's pulp and paper products, primarily from 13 million hectares of intensively managed loblolly pine plantations. Timber companies have invested up to $1 billion for each of the pulp and paper mills that pump out reams of paper, newsprint, and cardboard, says Conner Bailey, a rural sociologist at Auburn University who studies the timber industry. Yet mounting competition from low-cost pulp and paper producers in places like Indonesia and Brazil is putting these investments at risk, because the mills aren't easily converted to other uses. The industry's solution to safeguarding their profits? Increase efficiency through technological innovation, including by genetically engineering the raw material.

High on the pulp and paper industry's wish-list is a tree with reduced lignin, the cellular glue that holds wood fibers together and gives a tree its structure. Lignin, which accounts for about 30 percent of the dry weight of a tree trunk, is good for lumber, but removing it for papermaking is messy, toxic, and costly. Engineering trees with less lignin could mean significant cost savings for paper manufacturers.

Unresolved issues remain, however. Former MeadWestvaco executive Wallinger points out that in the U.S. South, paper mills buy about one-third of their fiber from private forest owners who typically grow some trees for pulp and others for saw timber. Gene flow from low-lignin transgenics could alter the timber trees, which are about four times as valuable. On the manufacturing side, separate processing lines for the two would have to be set up, requiring yet more capital investment. Meanwhile, studies have linked high lignin content with greater resistance to diseases and pests, suggesting that weakening this trait could make trees more vulnerable to these threats.

BIG STUMPS OF WOOD

Scientists are testing genetically engineered trees with several other traits of interest to forestry companies, including faster growth, tolerance to drought and salty environments, herbicide resistance, insect resistance (primarily Bt), and altered flowering. More complicated—and more financially risky—traits include straighter-grained and knotless pines, and cold-tolerant eucalyptus trees for plantations in the United States and other places too cold for eucalypts. One of the stranger visions comes from University of Washington molecular biologist Toby Bradshaw, a leading proponent of transgenic trees, who told *Science* in 2002 that trees could one day be "rearchitected" to be, basically, big stumps of wood—"short, wide, almost branchless organisms without extensive root systems" that could pack super-intensive tree plantations.

Experience with GM crops—from Bt corn to Roundup Ready canola—has proven that transgenes spread widely in the environment. But key differences between annual agricultural crops and forest trees make the risks of transgenic contamination in forests even

Courtesy of CIFOR/Christian Cossalter

THE PRESENT: Four-year-old eucalyptus plantation in Congo.

greater. Because of the size of trees, the amount of seeds and pollen they produce, and the updrafts that occur in forests and tree plantations, the scale of gene flow among trees is "unprecedented" compared to food crops, says Claire Williams, a forest geneticist at Duke University. And while most annual agricultural crops cannot survive outside the comparatively simple ecosystem of a farm field, long-lived trees are designed to exist in complex, but poorly understood, wild environments.

Tom Whitham, an ecologist at Northern Arizona University, works with other scientists to document how certain genetic traits affect relationships between trees, understory plants, insects, animals, and micro-organisms. His research shows that genes in individual organisms and populations have "extended phenotypes"—identifiable effects on an ecosystem beyond the organism. Extended phenotypes are particularly important when they occur in dominant plants and keystone species like trees, he says, because they can affect as many as a thousand other species. In addition, traits that may be beneficial under one set of circumstances can become problematic under another. For example, in ongoing research of pinyon pine ecology, Whitman's team discovered that some of the trees are naturally resistant to the stem-boring moth, an insect that eats away at the woody stems. In the first 19 years of their study, the insect-resistant trees did much better. But in a record drought in the twentieth year, about 70 percent of the insect-resistant trees died, while 80 percent of the non-resistant trees survived. "That was a real shock," he says.

In a survey of hundreds of published studies, Whitham found that the more factors a study considered, the greater the likelihood of observing such "ecosystem reversals." He says this is important because changes (including those likely to be induced by genetic engineering) that ignore interactions over time, space, and numbers of species run a high risk of having the opposite effect from what was intended.

Tree biotechnologists acknowledge that GM trees could threaten native forests. But they believe they can solve the problem by making the seeds and pollen sterile, so they cannot reproduce and spread transgenic traits. Yet there is no guarantee a transgenic tree will remain sterile throughout its life. Moreover, many trees, like the American chestnut, also reproduce by sending suckers up from their roots or by re-growing from broken twigs.

FUTURE PROSPECTS

So far, GM trees have not been released commercially, except in China, where more than one million Bt poplars are reported to have been planted nationwide. The reforestation is part of the Chinese government's plan to cover 44 million hectares with trees by 2012 to prevent flooding, droughts, and the spread of deserts. Meanwhile, hundreds of field trials have taken place in the open environment—mostly in the United States, but also in Canada, Europe, New Zealand, Japan, and a handful of other countries—though researchers in most places are currently required to cut down any GM trees before they flower.

Despite their enthusiasm, tree biotechnologists face some challenges before transgenic trees march across the American landscape. The large investments required over long periods are a tough sell in a world where time is money. (Forestry veteran Scott Wallinger laments that the first biotech tree products from 20 years ago are still being tested.) Changing trends in timberland ownership are adding further uncertainty. Investment companies are buying up large tracts of land from forestry corporations, and their commitment to the

Courtesy of the Forest History Society, Durham, NC

THE PAST: Posing with American chestnuts before the blight, North Carolina, c. 1920.

Sciences study faulted the agency for not having the resources, staff, or expertise to adequately assess the environmental impact of GM releases, especially as the technology progresses. According to Lee Handley, who works for the Risk Assessment Branch of APHIS's Biotechnology Regulatory Services, the agency is considering scrapping the current system of notifications and permits in favor of a new multi-tiered system, where the regulations for a particular GM plant (including both trees and crops) would depend on the environmental risk the agency thought it posed. For example, insect resistant trees might be required to be sterile, while GM trees with other traits might not. APHIS is also considering adding a category of "conditional release" that would require additional data to be collected on a given planting over time.

The proposed rules are expected sometime in 2005, and final regulations will come out following the agency's review of comments. Handley, a forest industry veteran, has strongly urged industry members to make their voices heard by participating in the public comment period. At the North Carolina conference he warned participants that GM trees "are definitely on the radar screen" of environmental groups, which are "very well organized and sophisticated"—which suggests just how nervous biotech tree proponents are, since most mainstream environmental groups have not addressed this issue, and very few people know genetically engineered trees even exist.

In their *Foreign Affairs* piece, David Victor and Jesse Ausubel remind us that "forests matter": they host much of the planet's biodiversity, protect watersheds and provide clean drinking water, and remove carbon dioxide from the atmosphere. "Forests count—not just for their ecological and industrial services but also for the sake of order and beauty," they write. A key question as we consider genetically engineered forests is what to do to preserve wild forests, and who gets to decide.

technology, or even how long they'll own the land, is unknown. After witnessing public resistance to agricultural biotech, GM tree proponents are also very concerned about how the public will react to their plans.

Nevertheless, GM forestry is likely to get a substantial boost from a decision in December 2003 by parties to the UN Framework Convention on Climate Change, the international treaty aimed at reducing emissions of carbon dioxide and other greenhouse gases that contribute to global warming. Under the convention's Kyoto Protocol, which sets specific targets for these reductions and entered into force this February, countries will be allowed to offset their carbon emissions by planting tracts of GM trees, which would absorb and store atmospheric carbon. According to Heidi Bachram of the Transnational Institute, millions of dollars in public subsidies are being used as incentives to establish such plantations, despite the questionable benefit of establishing them in lieu of forcing polluters to reduce their emissions up front. Moreover, in order to keep the stored carbon from entering the atmosphere, the plantations would have to be prevented from burning, being destroyed by pests or diseases, or being cut down.

Meanwhile, the USDA's APHIS, which oversees field tests and grants permits for the unrestricted commercial release of transgenic plants, is revamping its biotech regulations. In 2003, a National Academy of

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