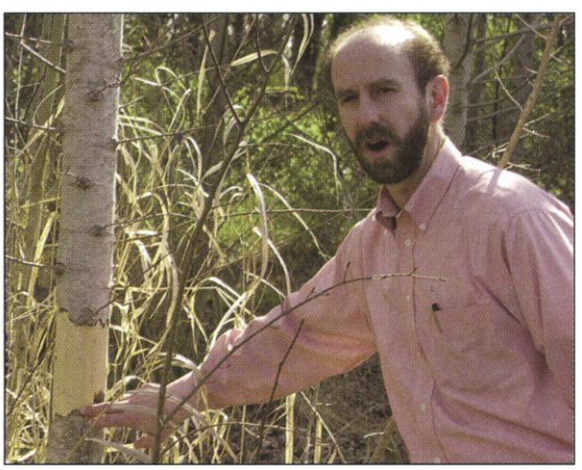
The battle over genetically modified crops is being replayed as transgenic trees enter field trials

Words (and Axes) Fly Over Transgenic Trees

Forest geneticist Steve Strauss just lost some of his idealism. He thought he was making the world a better place when he began working on genetically engineered trees 16 years ago at Oregon State University (OSU). If transgenic tree farms could help meet demand for pulp and paper, he thought, then natural forests might be spared. But 2 weeks ago, vandals attacked more than 800 young trees at Strauss's experimental plots near Corvallis, either hacking them down or condemning them to death by stripping off a ring of bark. A shadowy antibiotech group at OSU issued a letter claiming responsibility for destroying what it called "a dangerous experiment."

"It feels absolutely terrible," says Strauss. "We're doing research we regard as a net environmental good." Fortunately, he adds, his team had finished studying most of the trees, some of which were transgenics.

Tree-chopping fringe activists aren't the only threat to transgenic tree research. Forest biotechnologists are also coming under fire from influential environmental groups such as the World Wildlife Fund (WWF), which claim that genetically engineered trees may wreak havoc on natural ecosystems and want a moratorium on their use. Indeed, transgenic trees may well be the next battleground in the war over biotechnology.



Under siege. Steven Strauss's lab at Oregon State is reeling from an attack by eco-terrorists that damaged hundreds of transgenic and other experimental trees.

CREDIT: RYAN GARDNER/*CORVALLIS GAZETTE-TIMES*

Unlike genetically modified (GM) crops, which are already widely planted by farmers and consumed in foods, GM trees are still at least 5 years from commercialization in North America. Their developers say these trees, with traits ranging from fast growth to herbicide tolerance, could help solve environmental problems such as chemical pollution and the loss of wild forests. Critics, however, say the altered trees could do more harm than good—especially because they live much longer than crops. "I think this is a very risky approach," says Faith Campbell of American Lands, a conservation organization in Washington, D.C.

Although it's still early days, debate is flaring up worldwide: in New Zealand, where the government has been holding hearings on GM trees and other plants, to Canada and the United Kingdom, where experimental trees have also been vandalized. Hoping to avoid the brouhaha over GM foods, some researchers and companies are reaching out to their critics, inviting them to a meeting in Oregon in July. And industry groups, led by a nonprofit organization funded by the state of North Carolina, are launching a new think tank to debate and try to defuse societal issues before they explode. "I have to be optimistic that we're going to get past this phase," says Strauss, who helped plan the think tank.

The next battleground

Forest biotechnology has taken off in the past decade despite scientific hurdles such as the slow growth rate of trees and their giant genomes, ranging up to 10 times the size of the human genome (*Science*, 9 February 1996, p. 760). Much work focuses on gene mapping and function, but plant molecular biologists have also added foreign genes for herbicide tolerance and the production of a bacterial insecticide called Bt to such mainstays as poplar, pine, and fruit trees. Working within labs and greenhouses, researchers are also developing trees that yield more energy when burned, and others with lignin modified so that the trees are easier to break down for paper. Plans afoot to sequence the first tree genome—the poplar, the model organism of forestry—should spur more such work.

Like Strauss, many academic researchers say they got into this field because of its environmental benefits. Trees with less lignin should save on chemicals in paper factories, they say, while Bt trees could reduce the use of pesticides, and fast-growing trees could produce more wood on less land. At the same time, they were well aware of the ecological risk of these introduced traits spreading to natural forests. "We in the community talked about that from the get-go," says David Neale of the U.S. Department of Agriculture (USDA) Institute of Forest Genetics in Berkeley, California. So research has also gone into developing sterile trees to minimize the risk; such sterile trees could also offer the bonus of faster growth, because they don't devote energy to flowering or producing seed. And even if sterilization isn't perfect, proponents argue that GM trees are unlikely to invade wild ecosystems, because their new traits won't give them a long-term advantage.

A combination of government and private funds has supported GM tree development, with the dozen or so companies involved worldwide often collaborating with academic researchers such as Strauss. The reasons for commercial interest are clear: Traits such as faster growth and insect resistance could reduce the cost of growing trees on plantations. The industry heavyweight is Arborgen, a joint venture of International Paper, Fletcher Challenge Forests, and Westvaco Corp. formed in 1999. Arborgen is putting $60 million over 5 years into developing GM trees. All told, more than 300 field trials have been approved by the USDA, as well as a dozen or more by other countries, according to Campbell of American Lands, who checked public databases last year. But so far, nobody in the United States has applied to grow trees on a commercial scale, aside from virus-resistant GM papaya trees that are credited with saving the industry in Hawaii.

Until 1999, this work attracted little atten-

tion outside scientific circles. But in July of that year, demonstrators picketed a forest biotech conference at Oxford University, and activists hacked down a nearby field of lignin-modified poplars being tested by AstraZeneca. The WWF, followed last year by American Lands, then put out scathing reports calling for more research on risks and a moratorium on commercialization. Perhaps the biggest blow to forest biotechnologists is opposition from a coalition that certifies timber as sustainably harvested. The Forest Stewardship Council, which includes companies such as Sappi Forest Products and activists such as Greenpeace, refuses to certify any GM plantations, Strauss notes.

Risky business

Environmentalists' main concern parallels that about GM crops: They're worried that pollen containing Bt proteins may harm nontarget insects such as monarch butterflies, and they're concerned that sterility won't work perfectly, resulting in gene "leakage." In this scenario, transgenic trees might pollinate natural relatives and pass on traits such as pest resistance or modified lignin that could alter ecosystems in unpredictable ways. "Trees live a lot longer [than crops], and they're more integrated into natural systems," Campbell says, so they pose a much greater threat. She also predicts that companies will abandon fields if they don't perform as expected. Because many GM plants are no longer regulated once they've been approved for commercial use, there's little to prevent that from happening, Campbell asserts. Stewart Maginnis of WWF also fears that plantations of fast-growing GM trees could add to environmental problems caused by some nontransgenic tree farms, such as depleted water tables and fertilizer runoff, while there's no evidence that they will do anything to slow global forest loss.

As the debate heats up, it is attracting attention from the broader community of ecologists. Peter Kareiva of the National Oceanic and Atmospheric Administration says he started to take notice when a European study of ornamental woody plants showed that although they spread very slowly, over the course of 150 years they had made substantial progress. "These woody plants could look harmless for 50 to 100 years and then become a pretty severe problem," Kareiva says.

Strauss, who says the activists' two reports are "hysterical in places" and contain "scientific distortions," argues that the ecological threat from GM trees is actually less than that posed by many of the trees already grown on plantations, which include exotic species that can become invasive weeds if not managed properly. "These things are not mortally dangerous compared to everything else we're doing," he says. In a commentary in the December 1999 issue of *Nature Biotechnology*, endorsed by members of the International Union of Forestry Research Organizations (IUFRO), Strauss and several colleagues argued that GM trees would be unlikely to infiltrate natural forests because they could be made highly infertile and would be planted on managed farms and harvested after 3 to 25 years. The commentary also laid out the benefits of transgenic trees for meeting wood demand. "I'm not proposing that GM trees are a panacea, but I think they're part of the solution," says Malcolm Campbell of Oxford University, a co-author.

Still, GM tree backers agree that gene escape is impossible to prevent entirely, and several groups are investigating the risk. For example, Steve DiFazio of Strauss's group has looked at gene spread from commercial plantations of nontransgenic hybrid poplar to nearby wild poplars. When DiFazio analyzed the DNA of seeds from wild trees growing close to the hybrids, he found that on average 0.2% of the seeds had been fathered by the hybrid trees, suggesting that the risk of pollen spread is real, although low. And insect ecologist Kenneth Raffa of the University of Wisconsin, Madison, has found that insect pests could develop resistance to Bt trees if the trees are not interspersed with a buffer zone of non-GM trees that would harbor populations of insects without resistance. The risks of GM trees, says Raffa, "depend on how they're used."

One of the few points of agreement among advocates and critics is that there aren't enough of these kinds of studies.

SELECTED TRANSGENIC TREES APPROVED FOR FIELD TRIALS

Species	Institution	Traits
Poplar	Oregon State Univ.	herbicide tolerance, insect resistance, sterility
Eucalyptus	Monsanto do Brasil Sappi Forests, South Africa	herbicide tolerance
Aspen	Michigan Tech.	modified lignin
Sweetgum	Westvaco Corp.	herbicide tolerance
White spruce	Canadian Forest Service	insect resistance
Walnut	Univ. of California, Davis	altered root formation
Apple	Agritope (now Exelixis)	altered fruit ripening

Spruced up. Scientists say transgenic trees such as these spruce in Canada, which make their own Bt pesticide, could help cut chemical pesticide use and reduce pressure to log natural forests.

USDA funds some work through its $1.5-million-a-year Biotechnology Risk Assessment Research Grants Program; a new USDA extramural grants program has supported studies of GM tree risks as well. That's small potatoes compared to the tens of millions being spent on tree development. Besides, review panels tend to reject proposals on "more complex questions" such as effects of Bt trees on a whole array of insect species, says Raffa. Companies are just beginning risk studies, and the public tends to distrust industry trials anyway, he notes. But Strauss argues that companies need to co-sponsor risk studies if they're to be done on a large enough scale to be meaningful. The problem, Strauss and others say, is whether field tests will escape the axes of the eco-terrorists, who have attacked at least a half-dozen experimental tree plots in the past 2 years.

In search of consensus

To explore such issues and reach out to their critics, Strauss and other forest biotechnology researchers hope to bring all sides together at a July symposium to be held in conjunction with a meeting of the IUFRO. The list of questions ranges from whether research should be put on hold, to whether allowing the public to monitor commercial plantations would make them more acceptable, to how best to study ecological risks. "We want to get as wide a group as possible to sign off on a scientific agenda," says co-organizer Toby Bradshaw of the University of Washington, Seattle. Representatives from a few environmental groups will be there, along with ecolo-

CREDITS: (TOP TO BOTTOM) SOURCES: ISB ENVIRONMENTAL RELEASES DATABASE (WWW.NBIAP.VT.EDU) AND LINKED COUNTRY DATABASES; CANADIAN FOREST SERVICE

gists and company scientists.

The National Academy of Sciences' standing committee on ag biotech is expected to launch a study of the ecological risks of trees, ornamental grasses, and shrubs. And the forestry industry is reaching out to critics as well, motivated by a desire to save transgenic trees from the fate of GM crops. "A world with transgenic trees raises an entire range of very complicated issues," concedes Steven Burke, senior vice president of the North Carolina Biotechnology Center, a state-funded nonprofit that promotes biotech. "This has been a big wake-up call to the forestry companies to say, 'What can we do to make this palatable?' " notes Malcolm Campbell.

The North Carolina biotech center is launching a new institute this year that will bring together respected representatives from companies, government, academia, and environmental groups. "We will only commercialize these technologies if there is a clear agreement to doing such," says Daniel Carraway of International Paper, who was also on the planning task force. But some environmental groups are not convinced. Companies haven't indicated they'll take a precautionary approach and weigh the pros and cons before deploying trees, asserts Rebecca Goldburg of Environmental Defense: "It's not if, it's when."

Not necessarily, counters Strauss, who worries not only about the activists but also about how restrictive upcoming regulations on GM trees will be. "Nearly all the scientists I know believe that GM trees have a lot of potential," Strauss says. "But if the whole process of moving them to the field is too expensive and legally risky, then scientists are going to walk away from this. ... It would be a shame to foreclose the possibilities."

–JOCELYN KAISER

GREENHOUSE EFFECTS

High CO_2 Levels May Give Fast-Growing Trees an Edge

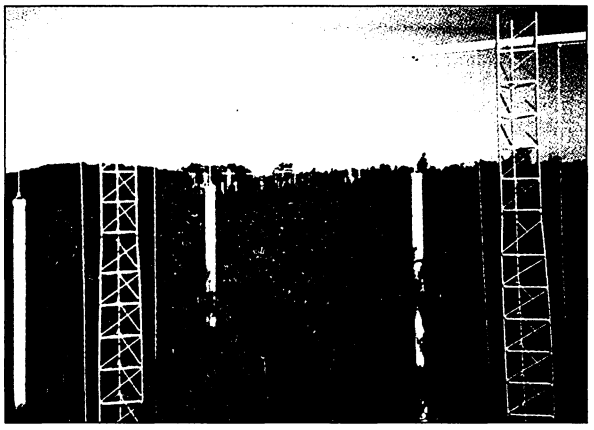
Loblolly pines may reproduce earlier—and more abundantly—in a future environment pumped up with carbon dioxide, according to a new study

Take a walk through a southeastern U.S. forest half a century from now, and it may look, or at least smell, a lot like Christmas: Loblolly pines, fed by rising levels of carbon dioxide, fill the air with their scent. Spurred to early maturity, the pines are challenging slower growing species such as oak and hickory. As forest composition shifts, it affects animals, too, making life more difficult for some seed-eating birds and mammals while providing a boon to others.

Although the scenario is hypothetical, it could happen, suggests a new study of CO_2's effects on tree fecundity, reported on page 95. The research, conducted by Duke University biologists Shannon LaDeau and James Clark, shows that loblolly pines (*Pinus taeda*) grown for 3 years at the CO_2 levels expected by 2050 are twice as likely to be reproductively mature, and produce three times as many cones and seeds, as trees in today's environment.

This work marks the first time that a CO_2 experiment has resulted in forest trees grown all the way to reproductive maturity. The conclusions are among several now beginning to emerge from an ambitious, decade-long project—launched 5 years ago in loblolly stands within a North Carolina Piedmont forest—that aims to predict the effects of high CO_2 levels on both the trees and the ecosystem as a whole (*Science*, 5 May 1995, p. 654). Already, the project has confirmed one key result of earlier small-scale experiments—that high CO_2 levels can spur faster photosynthesis and growth. As the first such experiment to look at forest tree fecundity, the new report is an "elegant demonstration that CO_2's stimulatory effect on photosynthesis and growth carries over to reproduction," says Peter Curtis, a biologist at Ohio State University in Columbus.

Predicting the effects of high CO_2 levels on natural ecosystems is more than an academic exercise, though. The answers are likely to fuel public policy debates on global warming. Because CO_2 is a plant nutrient as well as a greenhouse gas, some researchers argue that faster growing trees of the future will absorb and sequester increasing amounts of CO_2, making it unnecessary to impose new controls on the gas. Other scientists warn that the effects may not be benign and could include dramatic changes in the composition of ecosystems worldwide.



Gas propelled. Loblolly pines get an extra dose of CO_2 released from vertical towers in a large open-air experiment at Duke.

CREDIT: DEPARTMENT OF BIOLOGY/DUKE UNIVERSITY

Although heated debate continues over how much, or even if, the globe is warming, no one disputes the fact that atmospheric CO_2 has increased—from about 270 parts per million (ppm) in 1870 to about 370 ppm today—and that it will continue to rise in the future. For more than 2 decades, biologists have been working to understand how plants respond to increasing CO_2 levels—focusing first on crops (which clearly respond with faster growth and higher yields), then moving on to plants in natural ecosystems. But these experiments, conducted in greenhouses or growth chambers, have been hampered by artificial conditions. According to James Teeri, an ecologist at the University of Michigan, Ann Arbor, scientists discovered early on that "pot effects" skewed their results. That realization led to the development of outdoor open-top chambers, in which plants surrounded by polyvinyl chloride cylinders are fed extra CO_2 but receive natural sunlight and grow freely in the soil. Yet these chambers hold only about a dozen small, immature trees.

By contrast, the Duke experimental system can test the responses of an entire stand of adult trees. It relies on a technology—called Free Air Carbon Enrichment, or FACE—designed in the early 1990s by scientists from Brookhaven National Laboratory on Long Island. At Duke, large vertical pipes that release CO_2 tower over six plots of mature loblolly pine, each 30 meters in diameter. Half grow at ambient CO_2 levels and the other half at the 560-ppm concentration expected by 2050. Except for this extra CO_2, conditions in the experimental and control stands are identical, and all trees are exposed to whatever Mother Nature decides to dish out. "If a deer wants to run through a plot and eat something, so be it," says William Schlesinger, co-director of the Duke project. He adds that all the plots have experienced drought, record-level snowfall, and even a hurricane since they were established in August 1996. Today, there are 12 FACE sites up and running worldwide. Duke's is the oldest of three forest sites.