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.

The most important result to date, says Schlesinger, is that trees in the high-CO_2 plots grew 25% faster than controls did during the first three growing seasons of the experiment (*Science*, 14 May 1999, p. 1177). Last year, however, the difference between the experimental and control stands "was not as great" as it had been from 1997 to 1999, suggesting that the initial boost CO_2 gives to the growth rate of trees may not be sustained once other nutrients such as nitrogen begin to run out.

By November, Schlesinger expects to have results from this year's growing season—and a much better idea of how at least one forest tree species will respond to high CO_2 levels over the long run. The answer is critical to ongoing policy debates. Some partisans argue that faster growing forests will provide a sink for the excess CO_2 humans produce, but "our experiments are suggesting that forests will soak up some of the excess carbon dioxide but nowhere near all of it," says Schlesinger. And Harvard University biologist Fakhri Bazzaz, who also studies vegetative responses to CO_2, estimates that higher levels of the gas will boost the growth rate of the world's plants by only about 10%—far less than what would be needed to balance the global carbon budget.

High CO_2's impact on pine fecundity turned out to be even more dramatic than its impact on growth—onset of reproductive maturity at smaller sizes and 300% more cones and seeds than controls. In addition, trees in the high-CO_2 plots were producing more seeds than were trees of the same size in control plots, suggesting that they were putting a higher percentage of their carbon currency into reproduction.

Early reproduction could also cause the trees to grow old and die sooner, reducing the amount of carbon they sequester. But for *Pinus taeda*, the study's results may be good news—and spell trouble for its competitors. Scientists have hypothesized that faster growing species such as pine will respond more to elevated CO_2 levels than will slower growing hardwoods. If this turns out to be true, "we would expect to see dramatic changes in forest community composition," says LaDeau.

According to Bazzaz, simulation models predicting the effects of elevated CO_2 levels 150 years from now do show a trend of decreasing species diversity over time. And in a still-unpublished meta-analysis of 170 studies of reproduction in herbaceous plants, mostly crops, Curtis found that fast-growing, high-yielding species—equivalent to loblolly pines—profited more from high CO_2 levels than did slow-growing plants. "My suspicion is that forest communities will become less diverse as aggressive, fast-growing trees become more abundant," he says. Such shifts in tree composition would have cascading effects throughout the ecosystem. Some pollinating insects and birds, for instance, may end up with more food and others with less, changing the abundance and distribution of these animals as well as other species that rely on them.

It is way too soon, of course, to say whether any of this actually will happen. Among the Duke researchers' next steps is to examine the viability and quality of the seeds their experimental pines produced. They also are waiting for a handful of hardwoods growing in each plot to reach maturity—as well as those at an all-hardwood FACE site in Tennessee—so they can examine these trees' reproductive responses to CO_2.

But even following through on FACE experiments may never reveal how real forests will react to high CO_2 levels. The Duke plots "are pine plantations, not forest ecosystems," says Bazzaz. Teeri agrees that "what we really need are long-term studies of significant expanses of natural forest." Researchers had hoped to conduct such mega-experiments soon, but Congress last year did not fund a $12 million request from the National Science Foundation to launch a National Ecological Observatory Network. For now, Duke's loblolly pine experiment—and others like it—may offer the best evidence of how forests will respond to CO_2 buildup in the next half-century. —LAURA TANGLEY

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CREDIT: ADAM WILSON

SCIENCE IN BRITAIN

Science Centers Blossom, But How Many Will Survive?

Hands-on science exhibits are springing up across the U.K. Now, they're all part of an unplanned experiment: survival of the fittest

BRISTOL, U.K.—Inside a huge, five-story greenhouse on the waterfront of downtown Bristol, tropical birds and butterflies flit above a botanist's wonderland. Glistening in the humid enclosure are species representing key events during 500 million years of plant evolution—from primitive liverworts and velvety mosses through horsetails, ferns, and conifers, on up to the flowering plants. Scientists laud the "Wildscreen" exhibit, saying that it vividly brings science to life. It's "a marvelous project," says Thomas Eisner, an ecologist at Cornell University. "It's exactly what is needed to kindle an interest in nature and the spirit of conservation."

Wildscreen is part of a phenomenon that's sweeping the United Kingdom. Fueled by $1.4 billion in national lottery revenues and matching funds, 10 science centers—including @Bristol, which houses Wildscreen—have opened their doors to the public since July 1999, and another seven are scheduled to get going in the next year. Created to mark the new millennium, the gleaming new edifices are replacing such urban chancres as derelict steelworks and neglected quays. From the National Space Science Centre featuring a Soyuz rocket to the model ecosystems inside the Eden Project's multiple linked geodesic domes—tall enough to enclose the Tower of London—the science centers offer much more than inner-city renewal, says @Bristol chief executive John Durant. "This is an amazing opportunity to change the scientific culture of a country and connect the community closely ... to the world of science and technology," he adds.

But the science centers must count on a healthy patronage if this budding British renaissance in bringing science to the public is to succeed. The Millennium Commission, a quasi-governmental body that has funded the start-up of the 17 interactive science and technology centers (see table), has stated from the get-go that it will not provide operating money for its progeny. Once the initial funding has been exhausted, the centers are vulnerable to collapse—and that's not neces-

On a roll. The Orange Imaginarium, a planetarium sponsored by the Orange corporation as part of @Bristol.