Research News

How Fast Can Trees Migrate?

If the climate models are correct, greenhouse warming will spell doom for many forests across the United States

THE FORESTS IN THE SOUTH will go first. Seedlings will wither, the understory plants will be replaced. And over the next century or so, many now-abundant trees will go extinct across much of the United States.

Such are the predictions of Margaret Davis, one of handful of ecologists looking at the effects of the much discussed greenhouse warming on North American forests. As Davis and others who make these predictions readily admit, they are riddled with uncertainties. Data are scarce and have been cobbled together from fossil records, theoretical models, and experiments in controlled environments. Few long-term field studies have been done.

The critical question to Davis is how quickly trees can migrate, for the fate of numerous species in North America will depend on whether they can shift north to cooler climes when their current range becomes uninhabitable.

Speed is of the essence. If the various climate models are correct, within 100 years the earth will not only be hotter than it has been in 1 million years, but the change will be more rapid than any on record. During this time global temperatures are expected to climb 2° to 5°C, and each 1° rise in temperature translates into a range shift of about 100 to 150 kilometers. Trees can migrate long distances, as the fossil record shows, but can they do so in such a short time?

To address this question, Davis and her colleague Catherine Zabinksi have focused on four hardwood species—eastern hemlock, yellow birch, beech, and sugar maple—that are widespread in the Great Lakes region of eastern United States. Highlights of this study were presented at a meeting sponsored by the World Wildlife Fund last fall. This work is also part of a larger Environmental Protection Agency study, "The Potential Effects of Global Climate Change."

Ulf Sjöstedt/FRG

Migrating trees. *Birch will disperse northward when its current range becomes uninhabitable.*

To forecast the future response of each species to climate change, Davis and Zabinski first had to figure out the climatic conditions that determine its current geographical range—essentially, a combination of mean January temperature, mean July temperature, and annual precipitation. With those data in hand, the Minnesota researchers then used two general circulation climate models to calculate where suitable climate for each species will be in the future, when carbon dioxide has doubled from preindustrial levels, the benchmark in calculating greenhouse effects. Doubled carbon dioxide roughly translates into a global temperature hike of some 2° to 5°C.

The GISS model, developed by the National Aeronautics and Space Administration, predicts elevated temperatures throughout the Great Lakes region and slightly increased rainfall. The GFDL model, developed by the National Oceanographic and Atmospheric Administration, shows even higher temperatures in the Great Lakes region, averaging 6.5° as opposed to 4.5°C under GISS, with a decrease in summer rainfall. Such estimates are uncertain, however. Although general circulation models provide reasonable estimates of overall climate trends, they are quite shaky on regional details.

The actual extent and rate of warming will depend, of course, on the future production of not just carbon dioxide but methane, nitrous oxide, and chlorofluorocarbons, and on how the earth's climate will respond to those increases, which is not at all clear. Davis made the conservative assumption that the temperature increase equivalent to doubled carbon dioxide will not occur until 2090. Others predict that it will happen much sooner, perhaps by 2030 or 2040. Davis cautions that doubled carbon dioxide is just a "way station"; carbon dioxide will continue to accumulate, and temperatures will continue to rise, unless action is taken to curb emissions.

Whichever model is used, the results are striking. Both predict conditions under which tremendous northward range shifts—500 to 1000 kilometers—would occur for all four species. Under the milder GISS scenario, sugar maple would disappear across the southern edge of its current range, in a belt 200 to 600 kilometers wide in the middle of the country. Its range would shift eastward in Minnesota by about 100 kilometers, and new habitat would open up to the north, extending some 800 kilometers beyond its current range.

Under the more severe climate scenario predicted by the GFDL model, sugar maple would die out throughout its entire range, except in Maine, eastern Quebec, and Nova Scotia. New potential habitat would extend some 500 kilometers northward into Quebec. Similar patterns emerge for yellow birch and hemlock.

Beech would be hardest hit under either model. It now grows across a wide swath of the United States, from Georgia into southern Canada in areas of high rainfall. Under the GISS model, the population would drop precipitously and perhaps die out over a 1500-kilometer region in the eastern United States. A much smaller area of potential new habitat would open up in Canada. Under the GFDL scenario, beech would disappear from the United States, except in northernmost Maine, and a larger block of noncontiguous habitat would open up in Canada.

Davis cautions that these range shifts are approximate, given the uncertainties in the climate models and the assumptions she and Zabinski made about the species' physiological thresholds and the like. In addition, their calculations do not factor in many variables, such as the direct effects of carbon dioxide enrichment and competition among species, that could make a significant difference. "This is the general direction of change," says Davis, who urges that the details of the forecast nonetheless be "interpreted with a grain of salt."

For all four species, the toll would be greatest on forests near the southern limits of their current range. At first the changes would be subtle, barely detectable to the untrained eye. Almost as soon as temperatures begin to climb, beech, for instance, would produce fewer seeds and reproduction would decline. Within a few decades the vulnerable seedlings would wither and would be replaced by competitors more adapted to the altered climate regime. The hardy canopy trees would persist for many decades, however, giving the illusion that all is well.

Eventually, as temperatures climb and moisture decreases, adult trees would be affected directly, first failing to flower and fruit and eventually dying, though "it is difficult to predict the precise time course for tree death," they say. The most likely scenario is that the weakened trees would fall prey to insects or disease or would be felled by storms or fires, which are expected to increase in frequency under changing climate conditions.

In unmanaged forests near the southern limits of its current range, beech is unlikely to survive for more than 50 years after the onset of noticeable warming, Davis and Zabinski conclude.

Beech growing farther north, in the center of the current range, would get a four- or five-decade reprieve. Reproduction problems might set in by 2040, and trees would begin dying by 2090. Some beech would probably survive in the peaks of the Appalachians, where climate should remain suitable even after carbon dioxide has doubled. Trees will move upslope and perhaps thrive, they predict, provided there is adequate rainfall.

What will happen farther north, where the current and future range coincide? The prevailing assumption has been that beech will continue to grow there because the climate, though warmer, would still support them. But according to Davis and Zabinski, the answer is not so simple.

It all depends on how specifically adapted northern beeches are to the present-day climate in Maine, which Davis says is expected to shift to a climate resembling that of Georgia. Little is known about whether all individuals of a species can adapt to the full spectrum of conditions—varying day length, temperature, and the like—found throughout the entire range. There may instead be distinct ecotypes or subspecies adapted to local conditions and unable to survive in other parts of the range.

Beech, for one, appears to be highly specialized, with perhaps three distinct subspecies that grow in different regions of the country. If that specialization is hardwired in genetically, and if that holds true for other species as well, then the situation may be far worse than anyone has imagined, says Davis. In fact, survival of the species may hinge on transplanting the southern ecotypes to the north.

Davis calls for more research on this ecotypic variation and on each species' physiologic thresholds—actual studies in the field, which have been scarce. "You can put them in a greenhouse, but that is really irrelevant."

Perhaps the critical question is whether beech and other species will be able to migrate even farther north to the new habitats that will open up, or whether they will perish as suitable climate outpaces them.

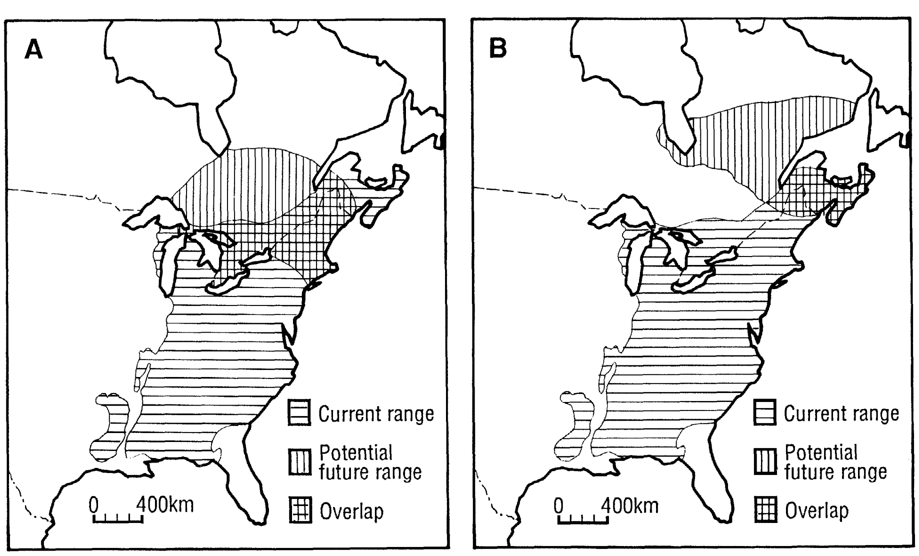
When the climate began warming some 15,000 years ago, North American trees dispersed northward at a rate of about 10 to 45 kilometers a century, the fossil record shows. Beech, which is dispersed by jays, averaged about 20 kilometers a century. Spruce holds the record, 200 kilometers a century, when it migrated into Canada about 9000 years ago.

But what is different now is not just the magnitude of the predicted temperature hike, but the rapidity with which it will occur, which is at least an order of magnitude faster than any previously recorded. If the climate scenarios are correct, beech habitat will shift northward by 700 to 900 kilometers within the next century. That means beech would have to migrate 40 times faster than it did in the past, an unlikely prospect at best. If climate change is as rapid as predicted, Davis concludes, then long-lived species like beech will not make it without massive human intervention.

And just getting the seed there will not necessarily be enough. Whether a new colony becomes established depends on not just climate but on the other types of vegetation present and on the soil chemistry, which is poorly understood at best. "It may fall to humans to convert the soil, in a massive and expensive intervention, if beech is to survive," Davis said at the World Wildlife Fund meeting last fall.

The changes Davis and Zabinski outline are not limited to eastern hardwoods; similar shifts would be occurring across the country for a variety of species, as a recent EPA report made clear. That report drew on six investigations, including this one by Davis and Zabinksi.

Nationwide, EPA foresees a substantial loss of healthy forest area, which now accounts for 33% of U.S. land area, and a net reduction in U.S. forest productivity for



Shifting habitats. *Current and future range for beech under two greenhouse scenarios: (A) the milder GISS scenario and (B) the more severe GFDL scenario.*

several centuries. In the East, spruce and northern pine would decline in the southern parts of their ranges and expand northward. New England coniferous forests would be replaced by hardwoods, especially by oak. Southern pines might shift into the hardwood forests of eastern Pennsylvania and New Jersey. In the Southeast, some 18 tree species may become locally extinct, with forest lands being taken over by scrub or savanna.

In the West, the situation is not as bleak, as Douglas fir, ponderosa pine, and western hemlock can disperse upslope into the Rockies. In California and Oregon, the populations of Douglas fir would shrink in the lowlands and be replaced by western pine. If regional drought persisted and fires increased, total forested area in the West could be dramatically reduced and some species would go locally extinct.

Moreover, these projections are just for the lower 48 states, but as EPA points out, forest effects should be far more pronounced in Canada and Alaska, where the climate warming is expected to be greater. Large boreal forests "could be at significant risk," EPA notes.

All of these studies focus on the dominant canopy trees, for which there are adequate data. But as Davis and Zabinski point out, what happens to them will reverberate throughout the ecosystem. Each of the plants in the forest has its own physiologic tolerances and will respond differently to rising temperatures and changing rainfall patterns. They will scatter, perhaps in different directions, at their own speed. That means, for one thing, that forests as we know them will not simply be duplicated in the north; instead, new plant communities will emerge.

And, says Davis, if the situation looks grim for dominant canopy trees with abundant seed, it could be far worse for understory plants. Many woodland herbs, like *Trillium,* ladies's slippers, and trout lilies, produce few seeds and depend on the wind to scatter them. She calls their chance of dispersing to favorable habitats "disappearingly small."

To save many of these species, Davis and Zabinski call for recreating entire forest ecosystems, including dominant trees, understory plants, and important animals, "on a large scale" in northern locations. They also call for setting up new refuges at all latitudes and for bringing wild plants into cultivation to preserve genetic diversity. EPA, too, envisions "massive reforestation" in the North and perhaps the introduction of subtropical species in the Southeast to replace the forests that have disappeared.

■ LESLIE ROBERTS

Detecting Mutations in Human Genes

New mutation detection methods are giving a boost to efforts to assess the risks of human exposures to environmental chemicals and radiation

FOR THE FIRST TIME, researchers are developing the ability to detect even the smallest mutations caused in human genes by chemicals or radiation. And not just in cells grown in Petri dishes. "You can do molecular analysis of mutations from real, walking people," says Jane Cole of the University of Sussex in Brighton, England.

In the past, only genetic damage sufficient to cause visible chromosomal abnormalities could be spotted in the cells of individuals who had been exposed to some environmental contaminant. Many mutagens do not produce visible chromosome damage, however, and the gene damage they cause therefore goes unnoticed in the older assays.

The new techniques are capable of picking up changes in a single base pair, promising more accurate assessment of the biological consequences of exposure to mutagenic agents, which have been linked to an increased risk of cancer and birth defects. Eventually, the methods may be able to tell not just whether an individual has incurred excess gene mutations, but also what the guilty agent was.

The most common method being used to detect human gene mutations is a T cell assay developed a few years ago by Richard Albertini of the University of Vermont in Burlington and, independently, by Alec Morley of Flinders Medical Centre in Bedford Park, South Australia. The procedure uses the HPRT (hypoxanthine-quanine phosphoribosyltransferase) gene as a mutation indicator, primarily because there is a simple selection method that can distinguish those cells in which mutations have inactivated the HPRT gene from those in which the gene is functional. The T cells themselves can be readily obtained from a sample of an individual's blood.

The assay determines the frequency of T cells that carry HPRT-inactivating mutations. For a normal adult, this is about five T cells in every million, Albertini says. Several groups have recently shown that the mutant frequency goes up in people who have been exposed to a variety of environmental mutagens. These include, for example, the chemotherapeutic drugs used to treat cancer patients and cigarette smoke. "Anyone who smokes has twice as many mutants in their blood as a nonsmoker," Cole declares.

Ionizing radiation also increases the frequency of T cells with HPRT mutations, and its effects can be very long-lived. Masayuki Hakoda of the Radiation Effects Research Foundation in Hiroshima, Japan, and his colleagues have shown that survivors of the 1945 atom bomb blasts in Japan still have higher than normal mutant frequencies more than 40 years after their radiation exposures.

". . . in bacterial and mammalian systems each agent gives its own fingerprint of changes."

The effects of radiation can be seen even with very low dose exposures. For example, Karen Messing and her colleagues at the University of Quebec and Montreal in Montreal have looked at the T cell mutant frequencies in nuclear medicine and x-ray technicians. "We found a dose-related increase in mutant levels that was surprising because these people were exposed to very low doses," Messing says.

Most of these early studies were aimed at establishing the ability of the T cell assay to detect the HPRT mutations caused by environmental or occupational exposures. With that ability now documented, the researchers are moving ahead to characterize the biochemical nature of the mutations produced by the various agents.

This involves cloning individual mutant T cells and analyzing their HPRT genes to identify the particular sequence changes they have undergone. The sequence studies may provide a better understanding of the mechanisms of mutagenesis in humans. They may also provide information about whether a given mutagen leaves discernible "fingerprints" on the HPRT gene that can be used for identification purposes. "We hope to find a correlation between the agent and the