CLEARING THE AIR
ACID RAIN

Long-Term Data Show Lingering Effects From Acid Rain

Some U.S. ecosystems are recovering slowly from the effects of acid rain, sparking a call for more stringent pollution controls

Acid rain is like the proverbial bad penny: Every time you think you've passed it off, it shows up in your change again. Studies over the past few years have turned up more and more evidence of its lingering effects. Now a major research synthesis provides the most comprehensive view to date—it is not encouraging—and prescribes a drastic cure. This call for more stringent controls comes just in time to fuel what promises to be a ferocious debate over stricter federal regulation of not only acid emissions but also the main greenhouse gas, carbon dioxide.

Progressively tougher pollution rules over the past 3 decades have reduced U.S. emissions of the main acid rain ingredient, sulfur dioxide (SO_2), by about 40% from its 1973 peak of 28.8 metric tons a year. By 2010, SO_2 emissions should be less than half of 1973 levels. But in the March issue of *BioScience,* 10 leading acid rain researchers say victory toasts are premature. They say power plants, the main contributor, must cut SO_2 emissions another 80% beyond the current mandate to undo past insults to sensitive soils and waters in the northeastern United States and, by implication, elsewhere. They also assert that these reductions, which would amount to an overall 44% cut in sulfur emissions, may bring only partial recovery to fish and trees by 2050. At the same time, acidifying emissions of nitrogen oxides (NO_x)—still relatively less regulated—are level or even mounting, causing collateral damage.

"Coming from such a consensus, this study solidifies many things," says Rona Birnbaum, chief of the Environmental Protection Agency's (EPA's) acid rain assessment program. "There was uncertainty especially over long-term soil impacts. Now it's undeniable." James Galloway, chair of environmental sciences at the University of Virginia in Charlottesville, adds that "the old controls were clearly not enough. Acid rain is a lot more complex than we at first thought."

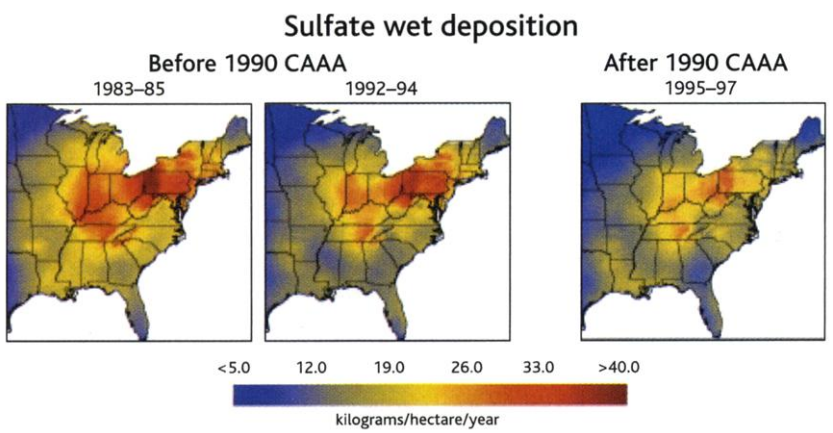
The problem is that acid-causing substances have built up in the ground and are still causing cascading chemical effects that could continue for decades. The first good evidence of acid rain's long-term effects came in 1996 from New Hampshire's Hubbard Brook Experimental Forest, where data have been collected since the early 1960s. That study showed that half the base cations of the nutrients calcium and magnesium, which neutralize acids, had leached from soils in the past few decades; as a result, vegetative growth was near a standstill (*Science,* 12 April 1996, p. 244). The researchers blamed excess acids in the soil for dissolving the cations into drainage waters much faster than weathering bedrock below could replenish them. Adding to the insult, they said, was the fact that smokestack scrubbers installed to reduce particulates were also removing soot rich in calcium that had previously replaced some nutrients the acids were leaching.

Data points. Study co-author Kathleen Weathers collecting water samples in the woods of the Catskill mountains.

The new study, a collation of further Hubbard Brook data and recently published studies from many other sites, adds considerable breadth and detail. Gregory Lawrence, a research hydrologist with the U.S. Geological Survey (USGS) and a co-author, says many northeastern soils "have a long memory" for acid deposition. Residual sulfur and, to a lesser degree, nitrogen are being slowly released by microbes and plants, he says, bumping the cations off the soil particles they normally cling to. This makes the cations highly soluble and easily washed away during rains and snowmelts. As a result, nutrient levels at many sites are showing little improvement, and some are actually worsening. Some of the hardest hit areas overlie calcium-poor sandstones in the Catskill mountains in New York state, where nearly all nutrients have disappeared in places, right down to glacial till and bedrock. Work by Lawrence and others also shows that once nutrients are depleted, excess acids mobilize the soils' abundant aluminum; usually held in harmless organic form, aluminum is poisonous when it dissolves.

Effects on aquatic life have been known since the early 1990s. Some 15% of lakes in New England and 41% in New York's Adirondack Mountains are chronically or episodically acid, says the report, and many such lakes have few or no fish.

Good evidence of effects on trees has been slower in coming, but that too has mounted lately. Although the exact role of acid deposition is unclear, extensive die backs and loss of vigor among red spruces and, more recently, sugar maples have been chronicled for at least 10 years. Co-author Christopher Cronan, a biologist at the University of Maine, Orono, says maples especially in Pennsylvania appear to be malnourished; at some sites, aluminum is glomming onto rootlets, blocking uptake of whatever meager nutrients are left. In spruces the problem is compounded. In 1999 researchers at the University of Vermont in Burlington traced much of their decline to baths of acid fog and rain that leach calcium directly from needles—a reaction that leaves needle membranes unable to cope with winter freezing. It's death by a thousand cuts, says Cronan: Instead of killing directly, acid rain usually leaves trees susceptible to drought or insects, which finish the job. Weakened conifers in southern Appalachia, for instance, are now



A qualified success. Since the 1990 amendments to the Clean Air Act (CAAA) went into effect, levels of acidifying emissions have declined—but not enough, says a new study.

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being defoliated en masse by invading woolly adelgids, exotic parasitic insects. The chain reaction continues. The endangered spruce-fir moss spider, a small tarantula that needs shade from the trees, is now found at just a few known sites, according to entomologists.

This is just one signal that the problem is not limited to the Northeast. Arthur Bulger, a fish ecologist at the University of Virginia in Charlottesville and also a co-author, says that acid rain effects are now becoming more apparent in the Southeast, some 20 years after they appeared in the Northeast. He and colleagues have chronicled these effects in a paper in the *Canadian Journal of Fisheries and Aquatic Sciences* last year and another in press at *Hydrology and Earth System Sciences*. The reason for the time delay, says Bulger, is that southern soils are generally thicker than northern ones and thus able to sponge up far more acid before leaking it to the surrounding environment. But now that soils are saturated, acid levels in nearby waters are skyrocketing. Bulger's colleagues have studied 50,000 kilometers of streams; in a third, he says, fish are declining or are already gone. He predicts another 8000 kilometers will be affected in coming decades.

Until recently, acid rain has been largely off the radar screen in the western states, in part because the population is smaller and the coal that fuels power plants there is much lower in sulfur. But now the region's cattle feedlots are booming, as is the human population. The former churn out lots of manure, and the latter insist on driving more and larger motor vehicles. Both produce acid-causing NO_x. Jill Baron, a USGS ecologist in Fort Collins, Colorado, and colleagues are studying 300- to 700-year-old spruces in the Rockies. In the journal *Ecosystems* last fall, they said trees downwind of populous areas show high levels of nitrogen and low ratios of magnesium in their needles. Nearby streams are also showing dramatic changes in their populations of diatoms, shifting from species that do well in the region's usually nutrient poor waters to those common in overfertilized waters. "Too bad most people get a lot less excited about diatoms than about fish," says Baron. "We're not nearly as bad as the East, but we're beginning a trajectory that will take us there."

The Northeast research team has assembled its data into a model to project the possible impact of various emissions cuts. Lead author Charles Driscoll, director of Syracuse University's Center for Environmental Systems Engineering, says that at current regulatory levels, the most sensitive environments such as Hubbard Brook will probably cleanse themselves, but very slowly. Chemical balances might return by about 2060, he says; after that, lake zooplankton might come back within 10 years; some fish populations, 5 or 10 years after that. If Congress were to call for an 80% SO_2 reduction from power plants below the current target for 2010, streams would probably bounce back by 2025, and some biological recovery in them might come by 2050.

"The question of soil and trees is a lot harder to answer," says Driscoll. In a communication to *Nature* last October, John Stoddard, an EPA scientist in Corvallis, Oregon, suggested that some soils with high sulfur-adsorbing capacities such as those in the Southeast might take centuries to recover.

The *BioScience* study received major attention on Capitol Hill, where momentum for stricter air controls has been building. Just before the study came out, President George W. Bush announced that he was breaking his campaign promise to limit CO_2 emissions—produced largely by the same power plants implicated in acid rain—raising the political stakes in the debate. With the 1990 Clean Air Act amendments up for reauthorization this spring, a half-dozen bills have been knocking around, proposing 40% to 65% reductions in both SO_2 and NO_x. On 15 March, New York Representative Sherwood Boehlert and Vermont Senator James Jeffords, both Republicans, introduced companion proposals calling for a 75% cut in SO_2 below what is currently mandated and a 75% cut in NO_x from recent levels—and a rollback of CO_2 to 1990 levels. Boehlert, head of the House Committee on Science, said the *BioScience* paper "is a wake-up call, and it should lead anyone who truly believes in science-based policy to support acid rain control."

Bush has said he will support stricter acid controls, although he hasn't mentioned any numbers. Moderate Republicans, who are furious that he reneged on CO_2, vow to keep all the pollutants tied together—a strategy that could greatly complicate a solution. Dan Riedinger, a spokesperson for the power industry's Edison Electric Institute, says the call for huge reductions now "is a little premature." He points out that ozone-curbing regulations scheduled to start in 2004 will also cut acid emissions and that some controls mandated in 1990 kicked in only last year. "The current program needs to be given more time to work," he says. "We always knew it would take decades." That last part may be the only thing on which everyone agrees. **–KEVIN KRAJICK**

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OBJECT RECOGNITION

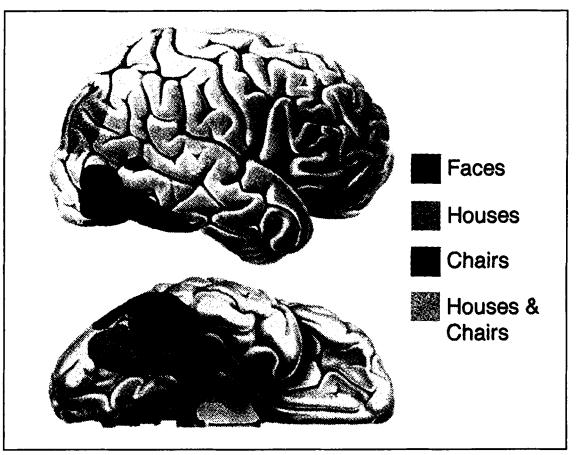
Where the Brain Tells a Face From a Place

Cognitive neuroscientists are beginning to figure out how the brain recognizes a chair as a chair

NEW YORK CITY—It's a complicated world out there, visually, full of things that look a lot alike. Yet people rarely identify a TV remote control as a cell phone or confuse a pencil with a swizzle stick.

The brain makes sense of this jumble of incoming visual stimulation with the help of an approximately 20-square-centimeter patch of tissue called the ventral temporal cortex. It lies just internal to the ears, on the bottom surface of the brain. In the past few years, brain imaging studies have identified one region of this tissue that specializes in recognizing faces and another that processes places. More recently, researchers have found that even mundane objects such as shoes, chairs, and plastic bottles also light up distinct areas in this part of the brain. But as Nancy Kanwisher of the Massachusetts Institute of Technology (MIT) points out, "it's ridiculous to think that there's an area of the brain for every conceivable category of objects."

So just how does the brain know that a chair is a chair? Researchers aren't sure how object recognition works, but several presentations on 27 March at the Cognitive Neuro-



What is it? Faces, places, and chairs activate different areas of the ventral temporal cortex, shown from the side and from below.

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