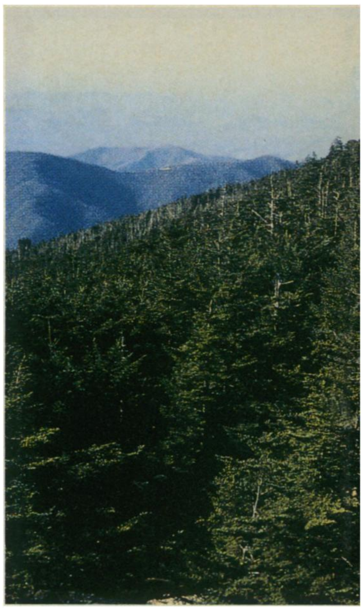
Where Acids Reign



Do dying stands of Bavarian timber portend the future of polluted U.S. forests?

By JANET RALOFF

About 10 years ago, an unhealthy spring yellowing of needles appeared within occasional stands of Norway spruce in a high-elevation Bavarian forest called Fichtelgebirge. That summer, the trees turned green again, their yellow and brown needles littering the forest floor.

Over the next year or two, the blight only spread and worsened. Falling needles and thinning evergreen canopies quickly gave rise to a mysterious increase in tree mortality throughout West Germany's high-elevation timberlands.

Surveys showed that the plague, which affected some 8 percent of all West German trees in 1982, mushroomed to encompass roughly 52 percent just five years later. Today, about a third of West Germany's trees show heavy damage. In some stands, all mature trees have died.

Though Fichtelgebirge is hardly a household name, its devastation warns of a problem facing timberlands throughout the industrial world. It was on its slopes and ridges that scientists first spotted the rapid forest decline now ravaging Central European woodlands. And in this same coniferous forest, a team of ecologists headed by Ernst-Detlef Schulze of West Germany's University of Bayreuth is unearthing new clues to the complex, synergistic web of agents responsible.

It's unlikely that Schulze's latest conclusions, published in the May 19 SCIENCE, will prove the last word on Europe's mysterious "diebacks." But many U.S. forest epidemiologists strongly praise his new assessment, describing it as the most holistic and experimentally grounded piecing-together of the many disparate findings related to the dieback puzzle.

Data on the dieback "have always been confusing," says Dale Johnson, a biologist at the University of Nevada's Desert Research Institute in Reno, who has traveled to West Germany several times to study its dying forests. "It seems there ought to be one common cause — but we just haven't been able to find it."

Numerous German forest analyses make clear, however, "that atmospheric pollution probably plays a decisive role in the development of the decline syndrome," write Bernhard Krahl-Urban and Helmut E. Papke of the Jülich (West Germany) Nuclear Research Center in the book *Forest Decline*. This research report by collaborating U.S. and German scientists will be published in English and distributed by the Environmental Protection Agency later this year.

Though acid rain has received much of the blame for Fichtelgebirge's deterioration, scientists have also considered other agents, including magnesium deficiency, fungi, insects and even weather. Schulze's report finds no one agent responsible. Industrial pollutants initiated the problem, he believes, but his data indicate that West Germany's dead and dying trees reflect a problem far more complex than direct pollutant poisoning. Sickened and severely weakened by a

Karl Peters/Res. Ctr. Jülich

The first symptom of forest decline is a yellowing of interior (older) needles, here indicating severe magnesium deficiency. Tip needles are seldom visibly damaged except in trees near death. Photographed in the field, this branch is from a several-year-old Norway spruce.

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Shortle/USFS

Red spruce on Mt. Mitchell, N.C., often encounter pollution-acidified cloud water 100 times more acidic (pH 3) than in pre-industrial times.

chemical imbalance throughout their ecosystem, these forests appear to be dying from opportunistic blights.

Nitrogen compounds and sulfates – both the stuff of acid rain – initiated the imbalance by acidifying the soil, Schulze contends. As the forest floor's acidity rose, it freed toxic aluminum – normally present throughout soil – to compete with other cations (positively charged ions) for portals into the thread-like, nutrient-absorbing roots of trees. Some of these cations, most notably calcium and magnesium, are crucial to tree nutrition.

Fichtelgebirge's trees gradually developed serious deficiencies of magnesium, potassium, manganese and iron, particularly in their stems and needles. Alone, the cation deficiencies should do no more than stunt the growth of towering conifers, Schulze points out. But an accelerating rain of nitrogen aerosols onto the trees' foliage and into their roots acted as a fertilizer, he says, spurring the cation-starved trees to attempt further growth. In this highly stressed state, the conifers are now succumbing to otherwise nonlethal ravages of pests and weather, including drought.

Compounding the problem is an unusual abundance of soil ammonium at Fichtelgebirge, according to Schulze's new data. In soil, ammonium (NH_4^+) and nitrate (NO_3^-) are the principal forms of nitrogen available to plants. Unlike nitrate, however, ammonium interferes with a tree's uptake of magnesium. And Schulze's work with seedlings now suggests that spruce roots preferentially absorb ammonium over nitrate. Richard D. Bowden and his colleagues at Yale University reported a similar finding with red spruce seedlings in the March CANADIAN JOURNAL OF FOREST RESEARCH.

While researchers have not quantified the amounts of nitrogen contributed by various sources of this excess, Schulze suspects major sources include West Germany's intensive animal husbandry, with its ammonia-laden "stable fumes" and offgassing of liquid-manure fertilizers, and the nation's relatively new "ammonification" systems for treating human sewage. In addition, he says, soil acidification may kill off some of the microbes that normally convert ammonium to nitrate in the forest floor.

Because Schulze's observations suggested an evolving soil chemistry endangered rooting, he excavated roots from the more mature trees in dieback areas. And indeed, he found the deepest roots had died. The shallower roots that took their place, susceptible to acute droughts, "may account for the strong decline of European forests following dry years in the early 1980s and for some of their recovery in recent wet years," he notes.

Finally, Schulze observed "no detectable long-term direct harmful effect" from air pollutants and pesticides. His field studies, for example, showed that needles on trees in the declining Fichtelgebirge stands – exposed to substantial sulfur dioxide, smog ozone and nitrogen oxides – photosynthesize at the same rate as healthy spruce needles growing in the pristine air of Craigiburn, New Zealand.

The greatest value of Schulze's interpretation of how air pollutants subtly foster Europe's forest diebacks may lie in winnowing out many tantalizing but false research leads, says David Van Lear, a forest-soils specialist at Clemson (S.C.) University. And the implications of Schulze's work may extend far beyond Europe. "The same processes that [Schulze] identified," says Van Lear, "are happening in the United States" – just at a much slower pace.

How much slower depends on the site and its elevation. Eastern U.S. forests at about 3,000 feet or higher from New England to South Carolina "are dying in large numbers – and look much worse than some of these Bavarian sites," notes Walter C. Shortle of the U.S. Forest Service science laboratory in Durham, N.H. In these forests, as at Fichtelgebirge, acidic pollutants initiated nutrient imbalances that have weakened the trees to the point where all it takes to finish them off are insects, fungal infections or such vicissitudes of weather as heat, drought and ice storms, he suggests.

Until now, Shortle says, no one had "done a really good job in pointing out that forest decline is likely a multiple-nutrient effect taking place over two or three decades." Schulze, he says, "comes closer than anyone has before in describing what the real mechanisms are."

Forester J. (Dev) Joslin describes Schulze's finding "that an excess of nitrogen is the primary factor" in these forest declines as one of the report's more significant contributions. Working for the Tennessee Valley Authority, Joslin studies pollutant effects in high-elevation spruce forests on White Top Mountain, straddling the Virginia-North Carolina border, where clouds bathe trees in mists five to 10 times as acidic as the local rains.

He says acidifying nitrogen pollutants – largely from cloud droplets – have contributed not only to very high soil-nitrate concentrations but also to the leaching of nutrients from spruce needles

Schulze/Univ. Bayreuth

This stand of 130-year-old trees growing on Fichtelgebirge's highest mountain – Schneeberg – looked fine and robust in 1978. By 1983, however, heavy needle loss heralded their decline. When this photo was taken three months ago, nearly all the trees were dead.

Karl Peters/Res. Ctr. Jülich

Serious infestation of needle fungus ravages spruce weakened by potassium deficiency. Browning and loss of older needles typify the decline syndrome.

and a mobilization of soil aluminum to "levels approaching toxicity." A dieback in red spruce has already become visible at White Top, especially in the last three to four years. Joslin hopes to begin quantifying that mortality later this year.

Shortle, too, has witnessed signs that nitrogen emissions pose a growing threat to U.S. forests. In the May 20, 1988 SCIENCE, the New Hampshire researcher and his coauthors described an aluminum-induced calcium-deficiency syndrome that can result from excessive nitrogen.

Trees need lots of calcium to manufacture new twigs and leaves, more massive stems and heftier trunks. And unlike some nutrients, calcium can't be recycled from woody tissues; once bound, it tends to remain there. "We've found that where you have a calcium imbalance, the area of the functional sapwood keeps getting smaller," Shortle says. As this food-storage zone shrinks, the tree becomes generally less vital.

Older trees, the least able to adapt, respond by suppressing production of new wood. Their crowns thin and tree rings narrow. Already, Shortle notes, stunted growth is the norm in eastern high-elevation forests. In examining tree-ring data, "you see growth suppression in spruce from Maine down into the Carolinas," he says. "It's pretty widespread."

While researchers have yet to establish the cause, Shortle worries that chronic growth suppression may signal these trees' initial response to the evolving soil chemistry Schulze describes.

If Schulze has underplayed any aspect of this scenario, Shortle says, it's the importance of calcium and the soil water's "ionic strength" – the number of acidic ions present per unit of water. While the pH shift fostered by a decades-long rain of wet or dry acidic pollutants "is essential for these evolving chemical imbalances to take place," Shortle says, "it [pH] is not sufficient in itself." Many of the major soil-bound metal ions that normally will not dissolve in water – including magnesium, calcium and aluminum – will go into solution only if the pH is in the right acidic range *and* the ionic strength is high enough.

Ordinarily, these mineral cations remain bound to "exchange sites" – negatively charged regions – on soil particles or plant-cell walls, Shortle explains. Under the right chemical conditions, however, they come unbound – but only briefly. Almost immediately, they begin searching for new exchange sites on which to lodge.

"Since aluminum has a stronger affinity for these sites than does calcium, it can knock the calcium off [the sites]," Shortle notes. And the freed calcium ions, lacking aluminum's affinity for the exchange sites, can't easily regain them. Forests suffer when freed aluminum binds to exchange sites in the tips of fine tree roots, essentially shutting out crucial nutrient cations like calcium and magnesium.

Shortle recently examined the absorbing tips of fine roots at New England sites with sick and dying trees, and indeed found aluminum in greater concentrations than calcium. From a number of studies conducted in Germany, he says, "we know that when these conditions exist, the uptake of calcium and magnesium will be suppressed."

Karl Peters/Res. Ctr. Jülich

Transpiration and photosynthesis recorded in spruce branches. Such field data helped show that needle symptoms in declining trees were not a direct effect of air pollutants.

The slower decline of U.S. forests suggests the United States, unlike Europe, may have time to avert a wholesale dieback of woodlands, Van Lear says. But data from Schulze and others suggest such intervention will require stricter controls on air pollutants, especially nitrogenous ones.

Schulze notes that West Germany appears to have traded one serious nitrogen problem for another over the past 20 to 30 years as most of its cities and villages have switched from sewage-treatment systems that spew nitrogen (primarily as nitrate) into water to ones that release it (primarily as ammonia) into the air. And manure-application practices in his nation of intensive farming have probably compounded the problem, he says. Once spread on fields in dry form, manure today is more commonly sprayed as a fine mist – and so is more prone to lofting and distant transport by winds.

In many other industrial nations, growing levels of nitrogen oxides – among the most recalcitrant combustion emissions to control – represent the major source of atmospheric nitrogen. In the United States, motor vehicles and fossil-fueled power plants and industrial furnaces spew out most of the nitrogen oxides.

Are Americans willing to adopt the tough pollution controls and lifestyle changes needed to substantially curb their nitrogenous emissions? If not, Van Lear worries, Fichtelgebirge may represent a premonitory nightmare of what's in store for many U.S. woodlands. □

Joslin/TVA

Aluminum toxicity stunted year-old red-spruce seedlings grown for 3 months in soils acidified (from pH 4.3 to about 3.8) by calcium sulfate (far left) or hydrochloric acid (center). Water in soils with the higher acid levels contained 20 to 25 times more aluminum than did control's soil water.