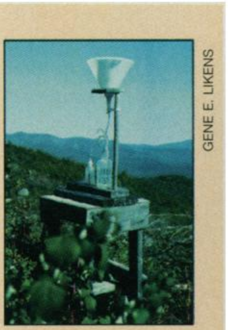
LETTERS

Ah, wilderness!

Are changes in the chemistry of stream water and forest soil a result of "the natural processes of soil acidification" or of the "anthropogenic emissions" in acid rain? (At right, rainwater sampling at the Hubbard Brook Experimental Forest, New Hampshire.) Elsewhere, the herbivorous appetite of certain soft corals is measured. How robust is the evidence that human activity is accelerating the rate of species extinctions worldwide? And the difference between ion transport in membrane channels and the diffusion of molecules through zeolites is explicated.


GENE E. LIKENS

Acid Rain Revisited?

The continuous record of the chemistry of bulk precipitation and stream water since 1963 at the Hubbard Brook Experimental Forest in New Hampshire is unique (*1*). It affords an invaluable insight into the effects of acid rain on the acidic forest soils of New England. It is difficult, however, to separate the effects of acid rain from the natural processes of soil acidification.

E. C. Krug and I (*2*) argued in 1983 that the amount of acid in acid rain is trivial compared with that produced by soil weathering. Acid rain did not increase the rate of cation export from soils, according to earlier reports from Hubbard Brook (*3*). Johnson (*4*) subsequently reported that acid rain had not increased cation export from soils throughout the northeastern United States. Gene Likens, Charles Driscoll, and Donald Buso (Reports, 12 Apr., p. 244) have revisited the data from Hubbard Brook and now conclude that acid rain has leached large amounts of calcium and magnesium from the soil. They also report a decrease in acid neutralizing capacity (ANC) in the stream.

Calcium is a major proportion of the cations in ANC; hence, this is not an independent parameter. The natural processes of soil acidification provide an equally plausible alternative for the observed changes in ANC. Because the pH of the stream has increased only slightly in the past 30 years, it appears that neither acid rain nor soil weathering has had any significant impact on the acid soils at Hubbard Brook. The rhetoric in the accompanying Research News article by Jocelyn Kaiser (12 Apr., p. 198) is but one more example of the scare tactics that responsible scientists should eschew.

Charles R. Frink
Connecticut Agricultural Experiment Station,
123 Huntington Street,
New Haven, CT 06504, USA

References

1. G. E. Likens and F. H. Bormann, *Biogeochemistry of a Forested Ecosystem* (Springer-Verlag, New York, ed. 2, 1995).
2. E. C. Krug and C. R. Frink, *Science* **221**, 520 (1983).
3. N. M. Johnson, R. C. Reynolds, G. E. Likens, *ibid.* **177**, 514 (1972).
4. N. M. Johnson, *ibid.* **204**, 497 (1979).

Likens *et al.* argue that acid rain is leaching base cations from the soils of Hubbard Brook Experimental Forest, leading to slower-than-expected recovery of soils and streamwaters in response to reduced acid deposition. This result should be considered in the context of previously published data from other sites, and previously published analyses for Hubbard Brook itself.

Four years ago, I proposed (*1*) that the declining base cation concentrations in Hubbard Brook were caused by depletion of exchangeable bases from the catchment's soils, in combination with the direct effects of declining acid deposition. Likens *et al.* confirm this, using a longer and more detailed data set. I derived a simple mathematical relationship linking soil base cation depletion to base cation declines in streamwater and calculated that soils at Hubbard Brook were losing 40 ± 12 micromoles of calcium and magnesium (consisting mostly of calcium) per square meter per year. Likens *et al.* independently estimate calcium depletion rates at 31 to 46 micromoles per square meter per year.

Hubbard Brook is just one of many acid-sensitive sites where catchment base cation depletion has been observed (*2*, *3*). At several Norwegian watersheds, where surface

water quality has not measurably improved despite marked reductions in acid deposition, rates of soil base cation depletion are clearly correlated with acid loading (*3*). Although water quality has not improved at these sites, reductions in acid deposition have been beneficial, because they have compensated for ongoing acidification resulting from base cation leaching (*3*).

These observations indicate that, at many sites, acid deposition is leaching bases from soils faster than they are resupplied by mineral weathering, thus impeding the recovery of soils and surface waters from acidification. Emission controls on acid precursors are yielding measurable environmental benefits, but we should not expect the acid rain problem to go away any time soon.

James W. Kirchner
Department of Geology and Geophysics,
University of California,
Berkeley, CA 94720–4767, USA
E-mail: kirchner@moray.berkeley.edu

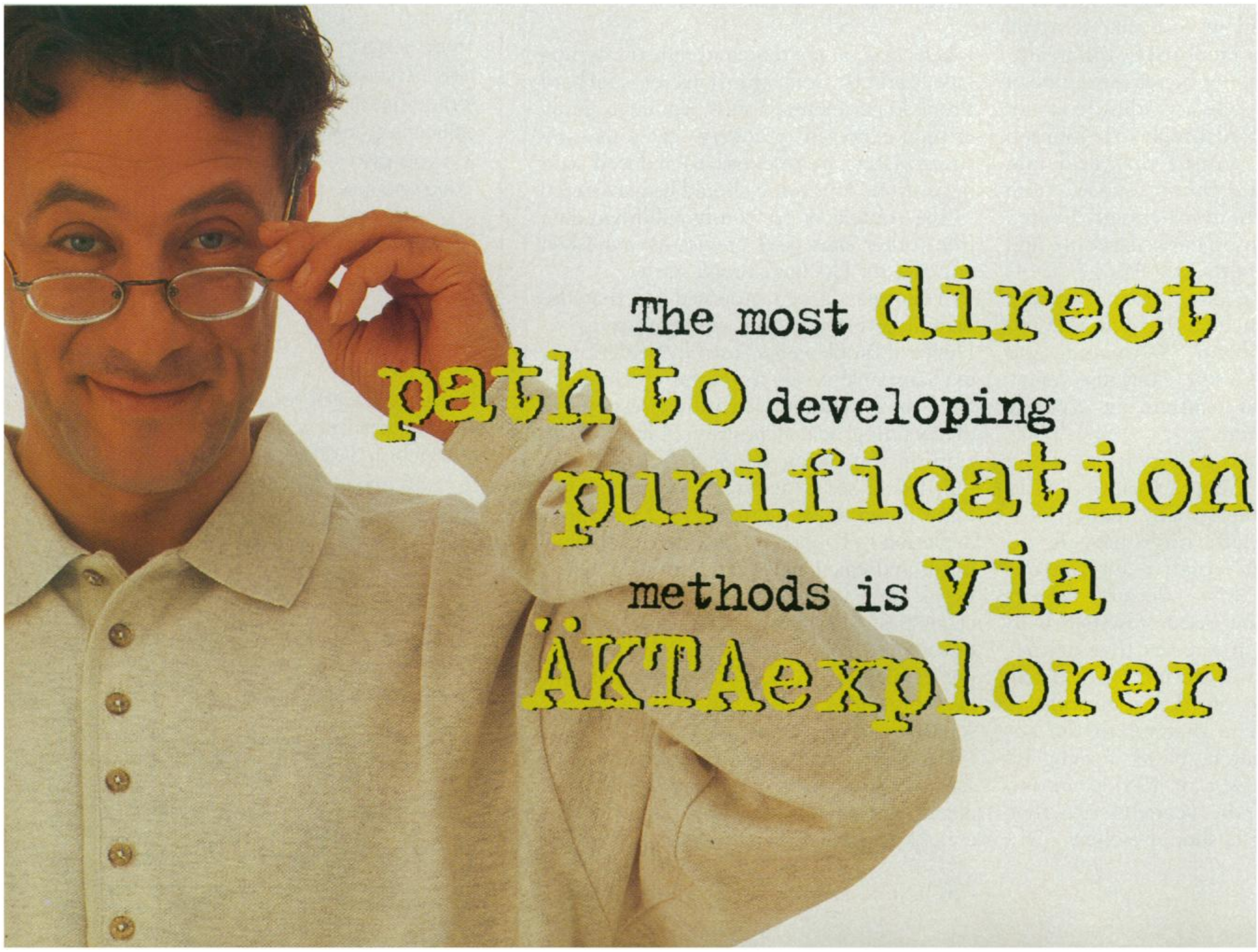
References

1. J. W. Kirchner, *Geochim. Cosmochim. Acta* **56**, 2311 (1992).
2. P. J. Dillon, R. A. Reid, E. de Grosbois, *Nature* **329**, 45 (1987); L. G. Wesselink, K.-J. Meiwes, E. Matzner, A. Stein, *Environ. Sci. Technol.* **29**, 51 (1995); N. Christophersen *et al.*, *J. Hydrol.* **116**, 63 (1990).
3. J. W. Kirchner and E. Lydersen, *Environ. Sci. Technol.* **29**, 1953 (1995).

Response: Frink raises an old "red herring" (*1*) of acid rain research. We agree that soils (spodosols) like those at the Hubbard Brook Experimental Forest are naturally acidic because of the limited supply of base cations from weathering, the accumulation of nutrient cations by vegetation, and the large production of organic acids from litter decomposition. Nevertheless, atmospheric inputs of acidic sulfate and nitrate are anything but trivial and clearly have had major chemical consequences on soil and drainage water in acid-sensitive watersheds of eastern North America. Sulfate is the major anion associated with elevated acidity in precipitation at Hubbard Brook. Wet and dry deposition of sulfate and associated acidity at this site are derived largely from anthropogenic emissions of sulfur dioxide (*2*). Streamwater and soil solutions there are also highly acidic. The major anion associated with drainage water acidity is sulfate, and this sulfate is derived largely from atmospheric deposition (*3*). Indeed, annual losses of base cations in streamwater during the past 32 years are highly correlated ($r^2 = 0.94$) with losses of sulfate plus nitrate in streamwater (*4*). We have quantitatively evaluated the total sources of acidity (internal and external) to the forest ecosystem at Hubbard Brook, finding that atmospheric deposition represented 52% of the total during 1963–1980 (*5*).

The relationships in our long-term data are clear. Our data do not represent "scare tactics," but clearly demonstrate the effects of acid rain and the subsequent slow recovery of forest and aquatic ecosystems in response to air pollution controls.

Our comprehensive ecosystem approach for analyzing changes in base cations during more than five decades was different from Kirchner's approach (*6*), which was based on streamwater chemistry for 1971 through 1980. Because of space constraints, it was not possible to refer to several important papers in our report, including those dealing with conceptual analysis [for example, (*7*)], historical measurements of soils [for example, (*8*)], model calculations [for example, (*9*)], strontium isotope studies [for example, (*10*)], proton budget studies [for example, (*5*)], and changing nitric acid levels [for example, (*11*)]. Other issues that would have warranted discussion include the long-term patterns of nitrate loss in streamwater and changes in the biogeochemistry



and toxicity of aluminum. We welcome the opportunity to have attention called to papers showing the effect of acid rain on base cation leaching at other sites in the Northern Hemisphere.

Gene E. Likens
Institute of Ecosystem Studies,
Millbrook, NY 12545, USA
Charles T. Driscoll
Department of Civil and
Environmental Engineering,
Syracuse University,
Syracuse, NY 13244, USA
Donald C. Buso
Institute of Ecosystem Studies

References

1. M. Havas, T. Hutchinson, G. E. Likens, *Environ. Sci. Technol.* **18**, 176A (1984).
2. T. J. Butler and G. E. Likens, *Atmos. Environ.* **25A**, 305 (1991).
3. G. E. Likens, *The Ecosystem Approach: Its Use and Abuse, Excellence in Ecology*, vol. 3 (Ecology Institute, Oldendorf/Luhe, Germany, 1992); ———, F. H. Bormann, L. O. Hedin, C. T. Driscoll, J. S. Eaton, *Tellus* **42B**, 319 (1990); C. T. Driscoll, G. E. Likens, L. O. Hedin, J. S. Eaton, F. H. Bormann, *Environ. Sci. Technol.* **23**, 137 (1989).
4. G. E. Likens *et al.*, in preparation.
5. C. T. Driscoll and G. E. Likens, *Tellus* **34**, 283 (1982).
6. J. W. Kirchner, *Geochim. Cosmochim. Acta* **56**, 2311 (1992).
7. J. N. Galloway *et al.*, *Environ. Sci. Technol.* **17**, 541A (1983).
8. E. A. Bondietti and B. McLaughlin, in *Atmospheric Deposition and Forest Nutrient Cycling*, D. W. Johnson and S. E. Lindberg, Eds. (Springer-Verlag, New York, 1992), pp. 358–377.
9. S. A. Gherini *et al.*, *Water Air Soil Pollut.* **26**, 425 (1985).
10. S. Bailey *et al.*, *Water Resour. Res.* **32**, 707 (1996).
11. G. E. Likens *et al.*, *Ecol. Monogr.* **40**, 23 (1970).

■

Herbivory in Soft Corals: Correction

We have demonstrated the ability of several azooxanthellate soft corals to feed on phytoplankton (Reports, 7 Apr. 1995, p. 90) (*1*). The conversion of gut fluorescence values to chlorophyll concentrations yields nanograms of chlorophyll in the gastrovascular system of *Dendronephthya hemprichi*, not micrograms, as we erroneously stated. Hence the data presented in our "third line of evidence" for herbivory, and in figure 1B, should have read "Chlorophyll a content (nanograms per polyp)" instead of microgram. Gut chlorophyll contents of well-fed *D. hemprichi* are thus comparable to those of herbivorous copepods with similar body weight (*2*). As these corrections could change our conclusion with regard to herbivory in *D. hemprichi*, we have estimated the coral's feeding rate using a new approach, based on in situ measurements of chlorophyll removal from natural seawater. Chlorophyll a concentrations in seawater upstream of large *D. hemprichi* colonies were compared with those downstream of the corals with a time lag between pairs of samples equal to the water passage time through the coral thicket. On average, *D. hemprichi* removed 0.035 microgram per liter ± 0.064 (SD) or 6.4% ± 11.6 of chlorophyll at a mean flow speed through the colonies of 3.5 centimeters per second. This removal rate is equivalent to an uptake of 16.34 milligrams of phytoplankton carbon per gram of ash-free dry weight (AFDW) of the coral per day, which is 2.5 to 3.6 times the corals' daily respiratory carbon demand (*3*). The chlorophyll depletion of the water and recent electron microscopic documentation of digested algal cells within the endodermal tissue of the polyps suggest that our finding of herbivory in these soft corals is valid. However, our initial method of analyzing gut fluorescence underestimated the actual rates of intake and digestion of phytoplankton by *D. hemprichi*.

Katharina Fabricius
Australian Institute of Marine Science,
Private Mail Bag 3,
Townsville Q4810, Australia
