9. See H. Taylor [*Public Perspect.*, 3 (February–March 1995)] for an informative and thoughtful review of cross-country differences in public opinion polling practices.
10. See (*15*) for extensive evidence on these points and further references. See W. P. Davison and A. Leiserson [in *International Encyclopedia of the Social Sciences*, D. Sills, Ed. (Macmillan and Free Press, New York, 1968), pp. 188–204] for an introduction to the subject of public opinion.
11. Among the nine countries in both surveys, the correlation in the proportion of respondents who rate the environment in their country as very bad (Gallup) or poor (Harris) is 0.67. Given the time and other differences between the surveys, this high correlation is consistent with the view that the data do reflect meaningful and stable preferences.
12. World Bank, *The World Development Report 1992* (Oxford Univ. Press, Washington, DC, 1992).
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14. Multiple regression analysis was also used to examine cross-country associations between the survey responses and per capita income, education, urbanization, region, and population density and growth. However, there are few interesting results to report, perhaps because of small sample sizes. Further study of the covariates of international public opinion on the environment must await the analysis of data on the characteristics and responses of individual survey respondents.
15. B. I. Page and R. Y. Shapiro, *The Rational Public* (Univ. of Chicago Press, Chicago, IL, 1992).
16. The standard errors of the population-weighted averages were computed using the following formula.

$$\left[\frac{n}{n-1}\cdot\sum_{i=1}^{n} p_i\left(y_i-\sum_{i=1}^{n} p_i y_i\right)^2\right]^{1/2}$$

where $n$ is the number of countries in the sample (24 for the Gallup survey, 16 for the Harris survey, and so on for the various developing and industrial country samples), $p_i$ is the ratio of the ith country's population to the total population represented in all $n$ countries, and $y_i$ is the proportion giving a particular response in country i [I. Guttman, S. S. Wilks, J. S. Hunter, *Introductory Engineering Statistics* (Wiley, New York, ed. 2, 1971), pp. 72–74].
17. Reported differences (DCs − ICs) are sometimes not equal to those calculated from the table due to rounding off of the values.
18. Unless otherwise noted, the Gallup surveys were administered from January to March 1992, the Harris surveys were administered from February to July 1988, and all were conducted in person, in local languages, to a representative national sample of the total adult population. Only an abridged version of the Harris survey was administered in the continental United States, by telephone to individuals over the age of 18. The developing countries (sample size) included in the Gallup survey were Brazil (1414), Chile (1000), Hungary (1000), India (4984, urban areas only), Korea (1500), Mexico (1502), Nigeria (1195), Philippines (1000), Poland (989), Russia (964), Turkey (1000), and Uruguay (800); and the industrial countries included in the Gallup survey were Canada (1011), Denmark (1019), Finland (770), (the former West) Germany (1048), Great Britain (1015), Ireland (928), Japan (1434), Netherlands (1011), Norway (991), Portugal (1000), Switzerland (1011), and the United States (1032). The developing countries (sample size) included in the Harris survey were Argentina (400, urban areas only), Brazil (500, urban areas only, conducted during the first half of 1989), China (509, urban areas only), Hungary (500), India (538, urban areas only), Jamaica (300, urban areas only), Kenya (300), Mexico (399), Nigeria (600, urban areas only), Senegal (300, urban areas only), and Zimbabwe (300, urban areas only); and the industrial countries included in the Harris survey were West Germany (513), Japan (510), Norway (1006), Saudi Arabia (398, men only in urban areas), and the United States (1253, conducted during the first half of 1989).
19. Because the Gallup survey in India was administered solely to the urban population, only the urban portion of India's population is used in constructing population-weighted averages. Similarly, because the former East Germany was not in either survey, only West Germany's population was used in calculating the population weight for Germany. Population figures for 1988 and 1992 were used to construct the population weights in the Harris and Gallup surveys, respectively.
20. The values in the tables are population-weighted averages of the percentage of respondents in each of the country samples giving the response indicated. As such they may be interpreted as estimates of the proportion of the total population in the surveyed countries with the specified perceptions or preferences. In the interest of parsimony and conservatism, the focus is generally on the most extreme of the possible responses to each question. For example, statistics are reported on the percentage who say they have "a great deal" of concern about the environment, but not on the larger percentage who say they are concerned either "a fair amount" or "a great deal." The weights used are based on 1992 country population estimates for the Gallup survey results and 1988 estimates for the Harris survey results. For convenience, the populations to which the reported results correspond are referred to in the text as the Gallup and Harris populations, respectively. Analyses were also performed on averages weighted by gross domestic product, which reflect both population and income per capita differences across countries, and simple cross-country averages, which give equal weight to every country. As these alternative measures generally exhibit patterns that are qualitatively similar to those based on the population-weighted averages, they are not reported here. All figures reported include "not sure/don't know" responses in the base.
21. The author is indebted to S. Glied, D. Krane, C. Kyle, W. Noor, B. O'Flaherty, A. Reddy, R. Sah, R. Shapiro, and two anonymous referees for helpful discussions and comments. R. Sah and W. Noor also provided excellent research assistance.

# Environmental Unknowns

Norman Myers

**Among the environmental problems ahead, the most important ones could be those that are still unknown to us. This conceptual article explores this prospect on the grounds that it is important not only to supply answers to recognized questions but to raise appropriate new questions.**

It might seem fruitless to speculate about seemingly unknown problems in the environmental field. But recall that at the time of the first major international conference on the environment in Stockholm in 1972, there was next to no mention of what have now become established as front-rank problems: global warming, acid rain, and tropical deforestation. Environmental scientists could have gone at least partway toward anticipating these problems. They had had 100 years of warning from the Swedish scientist Arrhenius about the possibility of global warming. For decades acid rain impacts were accumulating unseen and unsuspected; could we not have asked whether all of those $SO_2$ and $NO_x$ pollutants would eventually have an adverse effect on biotas? We could readily have alerted ourselves to tropical deforestation through remote-sensing surveys if only we had thought to identify it as a problem. So does the difficulty lie with "ignorance" or "ignore-ance"?

In the midst of much scientific uncertainty about our world—a world on which we are imposing multitudes of simultaneous new insults—we can be all but certain that there are environmental processes at work, or waiting in the wings, with the capacity to generate significant problems and to take us by ostensible surprise. Of course a true surprise is, by definition, beyond our purview. But is it truly beyond our scientific scope to identify a few likely candidates for semisurprises, especially those that could develop into outsize problems? The issue surely ranks as a prominent challenge for environmental science, yet it receives scant research attention (*1*).

Recent portents of environmental problems include the decline of amphibians, the bleaching of coral reefs, the appearance of phytoplankton blooms, the decline of sea urchins, mass mortality among seals and dolphins, and cancer epizootics in fish. All these share several characteristics. First, they are regional or even global phenomena. Second, they are unprecedented in our scientific experience and in our general ecological understanding. Third, there is no immediate or obvious explanation, although a primary or contributory cause is probably widespread pollution. Fourth, this pollution seems to cause the most harm when it works in conjunction with other stresses such as aquatic eutrophication, other forms of habitat disruption, and whatever else can induce immunosuppression, all operating in possibly reinforcing unison (*2*). Most important of all, they may add up to a whole flock of miners' canaries singing.

## Discontinuities

One category of impending problems for environmental processes comprises discontinuities. The classic instance of a discontinuity is when liquid water suddenly changes to ice or steam. Environmental discontinui-

The author is a Visiting Fellow at Green College, Oxford University, Oxford OX2 6HG, UK.

ties occur when ecosystems absorb stresses over long periods without much outward sign of injury, then reach a disruption threshold at which the cumulative consequences finally reveal themselves in critical proportions. For instance, when forest ecosystems undergo "creeping degradation" through acid rain, they manifest slow decline and chronic stress before finally and suddenly displaying severe injury (*3*).

Such discontinuities are especially pertinent to climate change, notably global warming. The most advanced climate models are largely unable, because of their very structure, to encompass the possibility of nonlinear interactions. We scarcely know how to identify and define these interactions, let alone describe their workings across the board. Yet we know that Earth's past climate has often responded in a manner far from smooth, gradual, and hence predictable. It has frequently reacted through sharp changes "which involve large-scale reorganization of Earth's system" (*4*). What if such jump effects were to be triggered, perhaps in multiple forms, by global warming? For instance, what if the Gulf Stream were to be significantly disrupted, even diverted southward, rather than flowing northeastward to warm northwestern Europe (*5*)? More important for the present analysis, what further discontinuities could ensue if that outcome were to interact with potential further disruptions such as soil erosion on croplands, pervasive pollution [for example, low-level ozone, acid precipitation, ultraviolet (UV)B radiation] on crops, and increased pests and diseases—all at a time when we will be trying to feed far larger numbers of people?

Environmental discontinuities can also arise in the socioeconomic sphere. The Philippines' agricultural frontier closed in the lowlands during the 1970s, whereupon multitudes of landless people started to migrate into the forested uplands. The result has been an exceptional increase in deforestation and soil erosion (*6*), deriving from a "breakpoint" in patterns of human settlement and environmental degradation. As long as the lowlands were less than fully occupied, it mattered little whether 50% or 10% of the space remained. It was only when hardly any space at all was left that the situation altered radically and suddenly.

The problem of land shortages is becoming widespread in many if not most developing countries, where land provides the livelihood for some 60% of populations and where most fertile and accessible land has already been taken (*7*). At the same time, populations continue to grow apace. This presents much scope for jump-type increases in land hunger, with all the environmental discontinuities these increases could entail.

Discontinuities can also occur when other natural resources are suddenly overwhelmed by population growth. Fuelwood is the main source of energy for most people in the developing world. As long as the number of fuelwood collectors in a particular area does not exceed the capacity of the local tree stock to replenish itself through regrowth, people can exploit the resource indefinitely. But suppose the number of collectors grows until it finally exceeds the self-renewing capacity of the trees, perhaps by no more than a marginal amount. Suddenly the tree stock starts to decline, and season by season the self-renewing capacity becomes ever more depleted. The vicious circle tightens speedily as soon as the exploitation pressure becomes nonlinear. If the number of collectors continues to grow, the degree of overloading (from an ever-dwindling stock exploited by ever more collectors) becomes compounded. The positive feedback process operates more and more rapidly as the stock is progressively depleted. All too soon, the stock approaches zero (*8*). (True, the situation could be modified by management interventions such as tree plantations and property rights; but the original discontinuity point stands.) An outcome of this sort is likely to occur increasingly, insofar as the number of people with insufficient fuelwood supplies, 1.4 billion in 1985, may well rise to 2.5 billion by 2000 (9).

We encounter a nonlinear relationship between resource exploitation and population growth (the latter is but one possible variable) with respect to many other natural resource stocks, notably fisheries, soil, and fresh water. As soon as the sustainable yield is slightly exceeded, the debacle of resource depletion is precipitated with surprising rapidity (*10*). The same applies to environmental services such as the pollution-absorbing capacity of the atmosphere. Whereas the increase in fossil fuel consumption can be linear, the atmospheric pollution's response often is not.

## Synergisms

A second category of "anticipatable surprises" comprises environmental synergisms—literally, a uniting of energies. These synergisms arise when two or more environmental processes interact in such a way that the outcome is not additive but multiplicative (*11*). For instance, a biota's tolerance of one stress tends to be lower when other stresses operate at the same time. A plant that experiences reduced sunlight, and hence less photosynthesis, is unduly prone to the adverse effects of cold weather, water shortage, insect pests, or diseases. Similarly, plants already injured by one of these factors are exceptionally susceptible to the trauma of reduced sunlight (*12*). The compounding impact of the relationship can be so powerful that the result may be a whole order of magnitude greater than the simple sum of the components (*13*). Despite their obvious importance, however, we know all too little about synergisms. Ecologists cannot even identify and define their main manifestations in nature, let alone document their more important impacts.

Consider the potential for mutually reinforcing interactions between global warming and ozone layer depletion. By cooling the stratosphere through buildup of ice clouds, global warming accentuates ozone layer depletion. Conversely, ozone layer depletion, by increasing UVB radiation, poses an aggravated threat to phytoplankton in the upper ocean layer, as these organisms are unusually susceptible to the radiation. Phytoplankton serve as a sink for roughly half of all anthropogenic emissions of carbon dioxide (*14*). Ozone layer depletion could readily reduce phytoplankton populations to an extent where they sequester less carbon dioxide, thus accentuating global warming—leading to greater ozone layer depletion, more phytoplankton die-off, and so compoundingly forth (*15*).

Or consider global warming from the standpoint of terrestrial plants. In the wake of high-temperature or reduced-moisture stresses, such as are likely to accompany global warming, plants become more susceptible to diseases or insect pests. They then need additional energy, and hence appropriate levels of temperature and moisture, to cope with the stresses (*16*). Conversely, plants that are diseased or otherwise damaged are less able to cope with the onset of elevated temperatures or reduced moisture—or with other types of environmental insults such as UVB radiation and chemical pollutants (*17*). In particular, plants could become subject to pandemic diseases, such as might occur through the environmental disruptions of a greenhouse-affected world; and pathogen-carrying insects may become more numerous as a result of the higher UVB sensitivity of birds and other insect predators (*18*).

Another synergism associated with global warming involves agriculture and biodiversity. The changed temperatures and rainfall regimes expected in a greenhouse-affected world will not prove appropriate for many agricultural crops insofar as they are finely attuned to current climatic patterns. There will be a premium on expanding the genetic underpinnings of our crops in order to increase their resistance to too much or too little rainfall and to other problems arising from global warming. Yet the gene reservoirs of many crop plants are being depleted more rapidly than ever, because plant breeding's emphasis on genetic uniformity leads to the elimination of germplasm variability (*19*). Again: When one problem combines with another problem, the outcome may be not a double problem but a super-problem.

As in the case of discontinuities, and in view of the multiple and simultaneous environmental insults likely in the future, a linear account of synergistic effects will surely—and possibly greatly—underestimate the eventual outcome overall. Each time we fail to discern a synergism at work, our best efforts to tackle environmental problems may fall far short. Regrettably, the amount of synergism-related research planned or under way is all too limited and almost entirely uncoordinated. Herein lies a major (and synergistic?) challenge for environmental scientists (*20*).

## A Research Agenda

Both categories of environmental "surprises," namely discontinuities and synergisms, will often lead to a downturn in the capacity of environmental resources to sustain human communities. As human communities continue to expand in numbers and demands, they will exert increasing pressures on ecosystems and natural resource stocks, whereupon environmental surprises will surely become more frequent. At the same time, degraded ecosystems will enable environmental dislocations to be more dislocating than if the ecosystems still enjoyed stability and resilience. Moreover, the dislocations will, through their aggravating effects, enable still further surprises to exert magnifying effects. If through research we can discern some of the mechanisms at work, we will be better placed to anticipate and even prevent some of the surprises.

We need a research agenda of a character and extent that can address the phenomenon of environmental unknowns. What frontiers of environmental science should we probe with a greater sense of exploratory foresight? The effort will require a shift away from developing more knowledge about what we already know in essence, and toward attempting to learn something about what is virtually a black hole of knowledge and understanding. We are good at analyzing problems when we recognize their existence, but we are sometimes less skilled at reaching out to new problems before they reach out to us.

Plainly, a promising starting point for research would be the generic fields of discontinuities and synergisms. To be more specific, an assessment could be undertaken, both systematic and systemic, of the 70,000 synthetic chemicals we have injected into our environments. So far, minimal testing against only a few known threats has been performed (*21*). Chemical pollutants are thought to have been a cause of some of the large-scale die-offs of seals, dolphins, and other marine fauna cited above, and in humans they are suspected of causing birth defects, neurobehavioral injury, and toxic damage spanning several generations. Yet they remain almost entirely uninvestigated (*2*).

The research challenge is so wide-ranging that it could even entail a reorientation of certain aspects of our "science culture." Many scientists prefer to grapple with problems about which they already know something; it is a strategy that often leads to research breakthroughs, published papers, and career advancement. So part of our response to the research challenge could concern questions of reward structures in environmental science. We need incentive systems that promote rather than discourage research into environmental unknowns.

## Policy Responses

Policy interventions can sometimes constitute constructive dislocations and synergisms. For example, grand-scale tree planting in the humid tropics, undertaken to generate a sink for atmospheric carbon dioxide and thus counter global warming (*22*), could supply many spin-off benefits through, for example, commercial forestry plantations that relieve excessive logging pressure on remaining natural forests. In turn, reduced deforestation helps to safeguard the uniquely abundant stocks of species and genetic resources in tropical forests (sometimes with large agricultural benefits, as when the disease resistance of a wild rice in India's forests saved much of the Asian rice crop from a pandemic blight). Tree plantations and surviving natural forests both supply many hydrological functions with multiplier effects—for example, through their capacity in upland catchments to regulate water flow and thus reduce downstream flooding—and with advantages for irrigation agriculture and domestic water needs.

Many options are available for similar multiple-payoff interventions through policy. Well-known instances include "no regrets" initiatives such as the promotion of energy efficiency and conservation, which is justifiable on both economic and environmental grounds (*23*), and the promotion of female literacy in developing countries, which is justified for its benefits in areas as diverse as employment, family planning, and human rights, and again has no net costs (*24*). The policy challenge lies in identifying the intervention points that offer the greatest leverage. It is a challenge that will engage the social scientist as much as the natural scientist, both of whom have a vital role to play in the pursuit of environmental unknowns.

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