Toward a Synthesis of the Newtonian and Darwinian Worldviews

Physicists seek simplicity in universal laws. Ecologists revel in complex interdependencies. A sustainable future for our planet will probably require a look at life from both sides.

John Harte

Physicists and ecologists approach their crafts from different intellectual traditions, as exemplified by the differing values they attach to the search for simplification and universality. As a particle theorist by training, currently engaged in the study of ecology and global change, I have witnessed dysfunctional consequences of this bimodal legacy. I argue here for a synthesis of what I call the Newtonian and Darwinian approaches to science. Such a synthesis, I believe, offers opportunities for progress at the intersection of physics and ecology, where many critical issues in Earth system science reside.

Two quotes aptly frame the discussion. The first is from the 1948 book *Sand County Almanac*, by the ecologist and conservationist Aldo Leopold:

> In terms of conventional physics, the grouse represents only a millionth of either the mass or the energy of an acre. Yet, subtract the grouse and the whole thing is dead.

The other quote is from the 1940 book *Wind, Sand and Stars*, by the aviator and writer Antoine de Saint-Exupéry:

> In anything at all, perfection is finally attained not when there is no longer anything to add, but when there is no longer anything to take away.

Leopold speaks for ecologists and their craft, for the intellectual tradition that blossomed with Darwin's remarkable insights into evolution and natural history. Saint-Exupéry, by contrast, eloquently describes the sword that physicists from Galileo and Newton onward have sought to extricate from the stone of Nature. The box on this page is only a slight oversimplification of the dichotomy between the two sciences as they are practiced today.

Physics	Ecology
The more you look, the simpler it gets	The more you look, the more complex it gets
Primacy of initial conditions	Primacy of contingency and complex historical factors
Universal patterns; search for laws	Weak trends; reluctance to seek laws
Predictive (chaos and quantum mechanics notwithstanding)	Mostly descriptive, explanatory
Central role for ideal systems (ideal gas, harmonic oscillator)	Disdain for caricatures of nature

There is also an important difference in the actual practice of scientists from these two traditions. Ecologists frequently focus decades of study around a particular habitat, and even a specific place and species. The unique aspects of the chosen system are often what motivate such intensely narrow focus and endow it with significance. A too general theory or model that ignores the unique aspects of the object of study is unlikely to be met with enthusiasm. By contrast, few nuclear physicists would devote their careers to a particular isotope, or astronomers to a particular distant star. Physicists seeking the extraordinary do not hope to see it confined to a single location or material. Theories of unique events are not generally of interest. (One might cite the Big Bang as a counterexample. But cosmologists are also looking for general principles that might predict multiple big bangs.)

John Harte *is a professor in the energy and resources group and in the division of ecosystem sciences at the University of California, Berkeley.*

Earth system science

So what's the problem? Do we really need a synthesis? Can't we just enjoy this epistemological and cultural diversity? I believe that striving toward a synthesis of these two traditions would benefit science for a number of reasons. One reason was recently articulated by molecular biologist Steven Benner.[1] He noted that attention to the evolutionary history of proteins has become a critical ingredient in our understanding of the physics of protein folding. In a sense, that development has brought biology back to biology. It shows that, despite the remarkable contributions of physicists and chemists to molecular biology, one cannot do without the contingent evolutionary perspective at the core of biology.

A synthesis might achieve even more, by including the

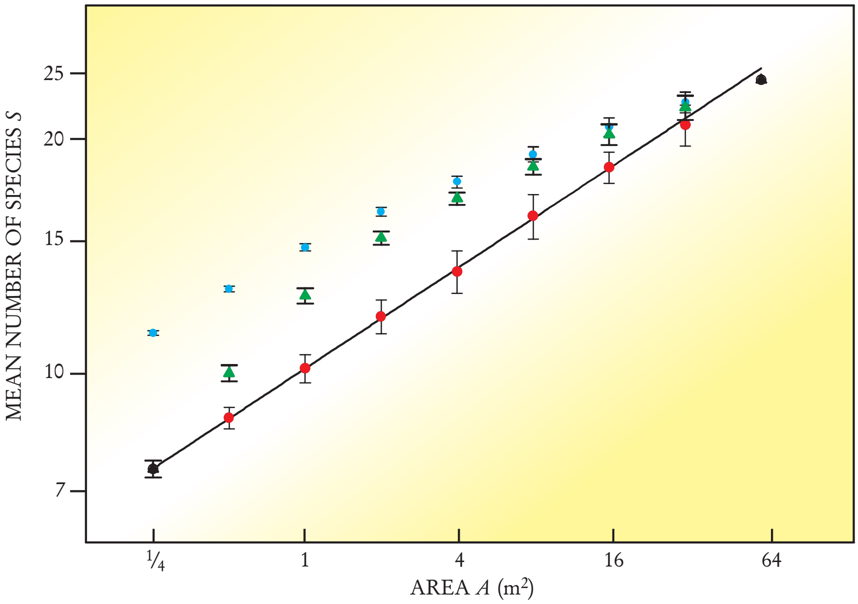

Figure 1. Species–area relation for all plant species in a 64-m² grassland ecosystem. The average number S of species found in a square subcell of that system is plotted (red points) against A, the area of the subcell. The straight line indicates a good fit to the power-law form $S = A^z$ expected for a self-similar distribution pattern. (The best fit yields $z = 0.215$.) The empirical power-law dependence is clearly spoiled if one randomly alters the data by redistributing pieces of the subcells (green) or exchanging species labels of individuals (blue). (Adapted from J. Green, PhD thesis, University of California, Berkeley, 2001.)

epistemological equivalent of emergent phenomena (for example, superconductivity) as understood by condensed matter physicists. More urgently, the synthesis could expedite progress in Earth system science. ESS attempts to answer questions that are at once deep, grand, and practical. It seeks no less than a predictive understanding of the complex system comprising organisms, atmosphere, fresh water, oceans, soil, and human society. It builds on the basic disciplines of physics, biology, and chemistry, which provide the foundations of ecology, climatology, hydrology, oceanography, geology, and biogeochemistry. Moreover, ESS cannot avoid confronting policy-laden scientific issues.

Here are some examples of questions being actively addressed by current ESS research:

How will climate warming alter life? Will global climate change alter terrestrial ecosystems in ways that cause feedback to the climate, for example, by causing a release of soil carbon to the atmosphere or by changing the albedo of the land surface as a consequence of changes in dominant plant species? How can we reliably forecast the sign and magnitude of climate–ecosystem interactions over a range of spatial and temporal scales?

How important is biodiversity? Is diversity of life forms necessary for maintaining essential Earth system processes such as soil formation, pest control, and climate regulation? Is there redundancy among the multitude of species? What general patterns, if any, govern the distribution and abundance of species, and how can we use these patterns to predict more accurately the effects of human activities on biological diversity?

What is needed for a sustainable future? Our planet is too small to absorb the wastes of profligate societies and too small to permit the wealthy to hide from the poor. What, then, might a future that is sustainable, and that we would all like to live in, look like? And how could we get there?

Difficulties

Several key facets of the Earth system make ESS particularly formidable:

▶ The global scale of human activities and the historically unprecedented magnitude of human disturbance of the planet mean that past experience is often not a reliable guide to predicting the consequences of our actions.

▶ The Earth system is rife with feedback, nonlinear synergies, thresholds, and irreversibilities that confound our intuition.

▶ Conducting large-scale experiments on this system is impossible—except, unfortunately, for those unbidden and uncontrolled experiments that befall us in real time. Thus, efforts to identify causative mechanisms are bedeviled by the conundrum that correlation does not necessarily imply causation. In one sense, this is similar to what astrophysicists confront. But they can base predictions on established or hypothesized physical laws and then test them against future observations. For ESS, that's a limited option, because the future state of the Earth system is contingent on future human activity. Such contingency weakens our ability to test theory against phenomena not yet observed. Moreover, because accidents of history play so central a role for living systems, the Newtonian approach to prediction on any spatial scale often demands inaccessible or impossibly detailed data on initial conditions.

▶ Attempts to carve out spatially and temporally delimited subsystems often founder because drawing space-time boundaries large enough to mark out an effectively closed system entails bringing in unnecessary and unmanageable complexity. Furthermore, the various disciplines frequently draw system boundaries differently and communicate poorly with one another about implicit boundaries.

To add to the difficulties, ecologists (like anthropologists and linguists) often witness the progressive deterioration and sometimes extinction of the objects of their study. Imagine if physicists had to fear the impending extinction of high-temperature superconductivity or the Higgs boson. Cosmology is sometimes compared to ecology; both fields have to deal with unique events and systems that cannot be replicated. But think what cosmology would be like in a universe where people are artificially speeding up stellar death rates and moving clusters of galaxies around.

What are the possible solutions to these formidable challenges? Here are some conceivable responses that have been suggested by various scientists (*and my concerns about these responses*):

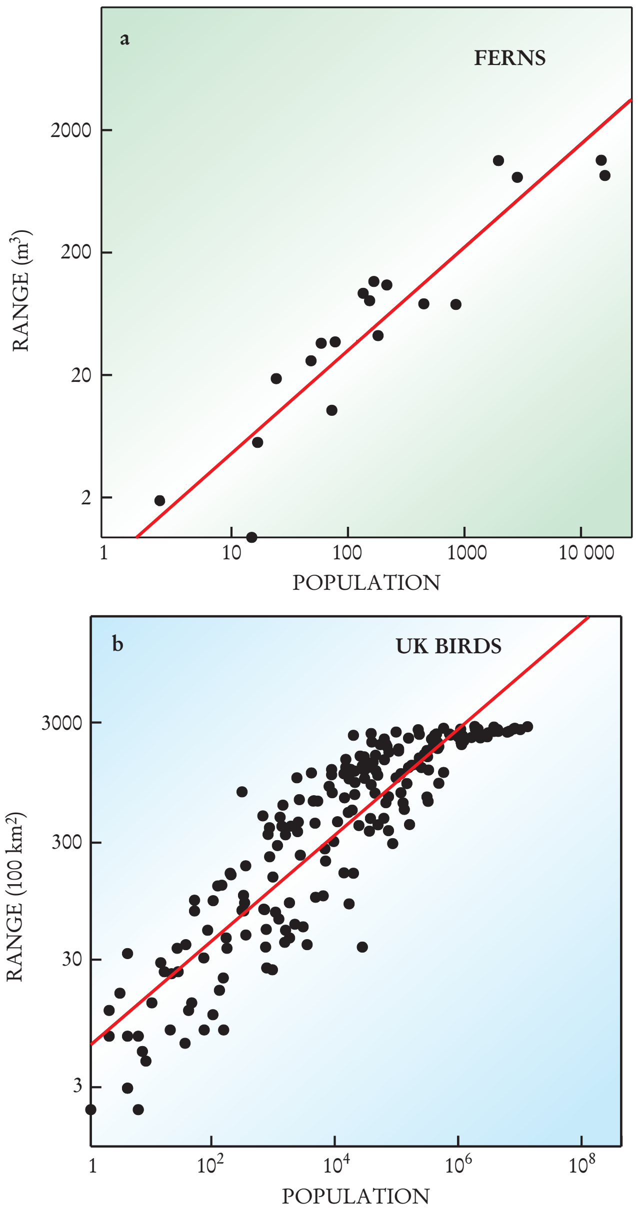

Figure 2. How range size of a species relates to its population. Each point represents a distinct species **(a)** of ferns in a 1 hectare (10^4 m^2) plot of Quebec forest, and **(b)** of native-breeding birds in all of the United Kingdom. The forest plot is subdivided into 1-m^2 cells, and the UK is divided into cells 10 km on a side. The range of a species is defined, in the fractal sense, as the total number of cells in which at least one species member is found. Self-similarity theory predicts power-law exponents of 0.89 for the ferns and 0.42 for the birds. The empirical fitted exponents, indicated by the lines, are 0.85 and 0.43, respectively. (Adapted from ref. 9.)

▶ Give up the goal of prediction. Be content with scenario building, pattern identification, and historical analysis.

I disagree. People will *predict and the public will pay attention, regardless of the merits of the predictions. Policymakers cannot escape the need for reliable predictions.*

▶ Bypass the messy interface between science and policy. Set policy by assembling panels of technical experts and letting them weigh evidence and prescribe responses.

The risks to both democracy and science would be unacceptable.

▶ Force the science into a Newtonian framework. That is, build detailed predictive models of ecosystems, climate, and the other coupled components of the Earth system. Determine the needed initial conditions and measure the model parameters. Learn how to couple the models, and then improve computational capability and simulate the future.

Attempts to carry out such an agenda are under way. But, as appealing as this approach may seem, it will probably founder for the very reasons that make ESS so formidable. I doubt that we will ever have physics-level confidence in such predictions before we actually experience the future that is being predicted.

▶ Cleverly find algorithms that generate output resembling complex natural phenomena, and use such simulations as a basis for prediction.

That wouldn't be convincing. It's too easy to generate patterns that look like whatever you want.

▶ Scrap efforts to further improve scientific understanding on the grounds that we already know enough about the magnitudes and consequences of climate warming, habitat loss, and other global changes, to justify policy responses.

Yes, we do know enough to justify policy responses to many recognized global threats such as climate change. But it is, nonetheless, crucial to pursue the science aggressively, because we need to anticipate and deal with future problems that we haven't yet recognized. Moreover, the policy responses that we make in response to problems we already understand will undoubtedly trigger new problems we have not yet identified.

Elements of a synthesis

None of these proposed responses is ambitious enough. None accepts the challenge of seeking a synthesis of the Newtonian and Darwinian traditions. I do not know how such a synthesis might come about, nor where it would lead. But here are a few ingredients that I believe could play a useful role:

Simple, falsifiable models. There is, in ESS, a growing infatuation with ever more complex models. It's gotten to the point where some models look as inscrutable as nature itself. With numerous adjustable parameters, these models are generally unfalsifiable, so that the opportunity to learn from a wrong prediction is shortcircuited. A "Fermi approach" based on models that capture the essence of the problem, but not all the details, might get us farther. We need to develop simple, mechanistic models. They will, perforce, be caricatures of the Earth system, but they must be falsifiable. Coupled with the development of such models, it is critical to identify appropriately lumped system variables that can substitute for subsets of the detailed variables in traditional complex models. My pedagogic contribution to this effort has been to write two textbooks that teach, via examples, the power of such models, as well as the tools needed to construct and analyze them.[2] This Fermi approach to ESS will only be effective, of course, if decision makers can be weaned from their awe of computer-simulated complexity.

Search for patterns and laws. That's a touchy subject among ecologists. Many would consider such a search a waste of effort, time, and money. But, in a thoughtful essay, ecologist John Lawton of Imperial College, London, has put forward a more favorable opinion.[3] The study of spatial scaling in ecology affords a fruitful way to search. Our most detailed small-scale knowledge of ecosystems comes from studies carried out on experimental plots of land no larger than a few hundred square meters, over time periods dictated by the durations of NSF grants. Coarser, larger-scale field surveys reflect processes occurring over longer time scales. At the largest spatial scales, we have satellite data. And paleobiology unearths information about past changes over huge time scales. If simple, robust scaling patterns exist, they will let us connect and extend insights from these different scales. Identifying such patterns—and the mechanisms that generate them—could improve our ability to predict. Of course, laws in ecology will not have the exactness and universality of physical laws. There will be approximations and exceptions in their formulation and application. Our knowledge, however, could increasingly resemble physics far more than it does a collection of idiosyncratic case studies, let alone unfalsifiable just-so stories.

Embrace the science of place. Searching for laws and deploying simple models nudges ecology toward looking more like physics. But traditional ecology offers equally important ingredients to a synthesis that ESS can profitably build on. Paradoxically, the admittedly limited extent to which ecology is *already* a predictive science, capable of formulating broad and reliable generalizations, is largely attributable to the intense effort ecologists have made to understand very specific environments. That's because place-centered studies provide the best means we have for going beyond pattern to process—for identifying the actual mechanisms at work. The knowledge of those mechanisms then provides the basis for formulating reliable generalizations at larger scales. In ecology, certain place names are associated with the gold standard of in-depth, integrative investigations. One fine example is Hubbard Brook, New Hampshire, which has given us fundamental insights into the biogeochemistry of disturbed and undisturbed watersheds. Another is the Experimental Lakes Area in northwestern Ontario, where the biology and chemistry of lake acidification have been most clearly elucidated. Successful place-centered investigations emphasize methodological pluralism: They combine purely observational long-term data acquisition, which represents the natural-history component of ecology, with the experimental manipulations that are essential to testing putative mechanisms.

I cite here three examples of the application of such syntheses to ESS.

Lake eutrophication

The first example is a historic case: determining the cause of lake eutrophication. Several decades ago, there was a debate about whether excessive algal growth (eutrophication) in lakes throughout the midwestern US was caused by runoff containing phosphates from fertilizers and detergents. Many ecologists and other environmental scientists blamed the phosphates. But the phosphate industries claimed that eutrophication was a natural effect or, if not, that it stemmed from land-use practices, thermal pollution, or the buildup of atmospheric carbon dioxide.

Attempting to settle the matter, scientists on both sides of the debate trundled out enormously complex models, often containing hundreds of parameters that described everything from planktonic feeding rates, to hydrologic circulation, to reaction rates for a host of abiotic and microbially-mediated chemical reactions. In the absence of measured values for the numerous model parameters, knob twiddling was rampant. Needless to say, the result was a variety of answers. Often, one could predict a particular result from the politics of the modeler. And so the debate continued.

The starting point for the breakthrough that came in the late 1970s was a pattern that had emerged from the analysis of survey data on largely uneutrophied lakes from around the world. The lake survey data showed that peak midsummer chlorophyll concentrations (a measure of the algal concentration) correlated well with a critical parameter: the average concentration of phosphorus in stream flow into a lake, multiplied by a simple empirical function of the so-called hydraulic load.[4] (Hydraulic load is the rate, per unit surface area, at which water flows out of the lake.)

Of course, correlation does not necessarily imply causation. And there was no guarantee that the relationship would hold up for heavily eutrophied lakes. The next step was taken in 1979 by environmental engineers Steven Chapra and Kenneth Reckhow. They constructed a simple coupled-box model of the network of the five Great Lakes, one of which—Lake Erie—was severely eutrophied. The input data to their model were the volume of water in each lake, the flow rate of each major stream into or out of each lake, and the concentration of phosphorus in each inflow stream.[5] This mass-balance model successfully predicted the phosphorus concentrations in each of the Great Lakes. And then the empirical phosphorous–chlorophyll correlation correctly gave each lake's eutrophication state. When the model was run with reduced phosphorus inputs, estimated by assuming that the major sources of detergent-laden sewage had been cleaned up, it predicted dramatic improvement in lake quality. Furthermore, the model yielded rough estimates for the time constants characterizing the improvement of water quality following such a cleanup.

The Chapra–Reckhow model was admirably simple; it could be explored either analytically or with a small spreadsheet. Because the model's handful of parameters were all readily measured, its output could not be fudged. And the model was falsifiable, in the sense that its unambiguous prediction of existing lake phosphorus and algal concentrations could well have been contradicted by the measurements. By combining hydrologic and chemical observation at one locale with patterns deduced from observations at sites around the world, this simple model exemplified methodological pluralism. And it extended a biological pattern widely seen in relatively pristine lakes to other lakes that were heavily affected by human activity.

This fine example of methodological synthesis has led to political action. The plausibility of the approach cut through the confusion of earlier analyses. It convinced decision makers that phosphorus loading was indeed the cause of the problem, and that achievable remedial action would, in fact, greatly improve lake water quality. Most US lakes are now less eutrophied than they were several decades ago.

Scaling laws in ecology

The second example of synthesis in ESS involves scaling laws. Two important, yet unresolved, questions in ecology are: How many species are there in a given habitat? And how many of them will go extinct when that habitat is destroyed? Answering these questions requires knowledge of spatial patterns of species diversity. In Sweden in the 1920s, Olaf Arrhenius discovered an empirical relationship between the number of species found in a census

NATALIE DEMONG

SCOTT SALESKA

FIGURE 3. EXPERIMENTAL subalpine meadow at the Rocky Mountain Biological Laboratory near Gunnison, Colorado. Shown here from different vantage points in summer and winter, the site is used by the author and coworkers to study climate–ecosystem feedback. The hanging metal strips are overhead heaters that continuously warm the 30-m^2 experimental plots. The winter photo shows three of the plots with the snow melted by the heaters.

patch, and A, the area of that patch.[6] The number of species, Arrhenius found, grows with area like A to a power z that appears to remain remarkably constant over an ecologically significant range of areas, although the extent of that constant range, and the numerical value of z, vary with habitat and species. Figure 1 shows an example of this species–area relation, which is the ecologists' most powerful tool for determining the total number of species in areas too large for a direct census, and for estimating extinction rates under habitat loss. Arrhenius's famous father Svante, the 1903 chemistry Nobel laureate, carried out the first plausible calculation of the climatic effect of increasing atmospheric carbon dioxide (see the article by Spencer Weart in PHYSICS TODAY, January 1997, page 34).

More generally, the relationships among the number, range, abundance, and distribution of species within a habitat patch, and the dependence of these quantities on the patch's area, are of fundamental, as well as practical, interest in ecology. They tell us about the processes that allow species to coexist and to partition resources. Like the species–area relation, these dependences are often observed to have a power-law form,[7] as we see in figure 2.

Such power-law relationships, with fractional exponents, often indicate underlying self-similar structures or mechanisms. A self-similar pattern, as the phrase is used in the study of fractals, is one that looks the same on all spatial scales. It involves no characteristic size. Self-similarity is quite different from true randomness.

My students and I have been employing a variety of analytical methods, including renormalization-group techniques developed for the study of scaling in self-similar phenomena in physics, to understand better the origins, implications, and interconnections of the power-law and self-similar relationships one finds in ecology.[8,9]

The search for scaling laws has also been very fruitful in the investigation of the physiological and life-history traits of individual plants and animals. It has led to a more unified understanding of relationships among organism size, metabolism, life span, biomass allocation, home range size, and total species biomass.[10] Here too, the assumption of self-similarity has proven useful. On the frontier of scaling research in ecology there awaits a "grand unification" between scaling patterns at the ecosystem level and such patterns at the level of the individual organisms.

Feedback and the carbon cycle

The third example of synthesis involves feedback between ecosystems and climate. The 2-km-long Vostok ice core, extracted from the East Antarctic ice sheet by international teams in the 1970s and 1980s, has provided evidence that past climate change involved positive feedback mechanisms. The reconstruction of several hundred thousand years of surface temperatures and atmospheric gas concentrations from various ice cores indicates a strong positive temporal correlation between atmospheric CO_2 and average surface temperature. During interglacial periods,

CO_2 levels have been about 50% higher than those during glacial episodes.

These elevated CO_2 concentrations undoubtedly contributed to the warming events, but the pacemaker was a combination of periodic variations in Earth's orbit and its axis of rotation. Thus we have carbon–climate feedback: The net effect of surface warming on the planet's very complicated carbon cycle was the release of more CO_2 into the atmosphere. And that, in turn, further enhanced warming. The implication of such positive paleofeedback for us is the likelihood that whatever caused it is operating today. With global warming, we can expect that some combination of terrestrial and marine processes will release more carbon into the atmosphere.

The problem is that we don't know the mechanism causing this feedback, nor how strongly and rapidly it will operate. Its existence, however, suggests that our present general-circulation models, which ignore this positive feedback, are probably underestimating the magnitude of impending global warming. Thus it is important to understand the feedback mechanism and its relevance to the climate change we are causing. (See the article by Jorge Sarmiento and Nicolas Gruber in PHYSICS TODAY, August 2002, page 30.)

To that end, my colleagues and I began an experimental study of climate–ecosystem feedback 12 years ago in a subalpine meadow at the Rocky Mountain Biological Laboratory (see figure 3). Using overhead heaters to continuously warm five 30-m^2 experimental plots, we have been routinely monitoring responses in soil microclimate, biogeochemical processes (including carbon sequestration), and the species abundance and dynamics of the vegetation. Among the observed responses to heating has been a sizable decrease in the amount of organic carbon stored in the soil. Soil organic carbon is a potential source of climate feedback, because soils worldwide house roughly three times as much carbon as does the atmosphere or the totality of living organisms.

By combining this field investigation with laboratory experiments and observations along a natural climate gradient, we have been able to develop and validate a very simple mathematical model that attributes the loss of soil organic carbon to a warming-induced shift in the relative abundance and growth rates of various species of meadow vegetation.[11] Moreover, the model allows us to project the sign and magnitude of this feedback into the near future, yielding predictions that we are now gearing up to test.

Going still further, Lindsey Rustad (US Forest Service) and coworkers have performed what they call a meta-analysis, in which they compare the findings of several dozen ecosystem warming experiments, like ours but in differing habitats and using a variety of warming technologies.[12] Their analysis is a partial step in the right direction, but even here the comparisons are all among experiments carried out on small field plots, so that its relevance beyond the scale of the experimental plots remains an open question. There might, after all, be emergent spatial phenomena not captured by these small-area studies.

To understand the global carbon cycle better, ecologists have undertaken many global modeling studies. Among them is a recent analysis of the rate at which forests are sequestering atmospheric carbon that makes use of satellite data, ground-based forest inventories, and mathematical models.[13] But missing from that type of analysis is consideration of how climate change might alter rates of carbon sequestration in the future. Clearly, we need to integrate experimental climate manipulations on small-plot scales with landscape-scale observations along large natural climate gradients, satellite data, and a variety of mathematical modeling approaches if we hope to comprehend the real implications of the Vostok ice-core data for the present episode of warming.[14]

What more is needed?

Might a synthesis of the Newtonian and Darwinian traditions lead to the kind of paradigm shifts that have punctuated the history of physics? In physics, such lightning strikes are rare, but their overall influence has been profound. ESS has also had its true revolutions. The theories of evolution and plate tectonics have been the most influential. Is such a revolutionary paradigm shift a prerequisite for further major advances toward understanding the deep, grand, and practical questions discussed here? I hope not, because finding answers to critical environmental problems is of such great urgency. On the other hand, scientific revolutions are thrilling, and the opportunity to participate in one would be a privilege.

Whatever the answer, many of the current puzzles in Earth system science will undoubtedly yield to patient work within existing paradigms. The solutions are less hindered by the absence of novel scientific ingredients than by a general failure to adequately stir existing ingredients together. I suggest that particularity and contingency, which characterize the ecological sciences, and generality and simplicity, which characterize the physical sciences, are miscible, and indeed necessary, ingredients in the quest to understand humankind's home in the universe.

This article is based on a talk prepared for the acceptance of the American Physical Society's 2001 Leo Szilard Award.

References

1. S. A. Benner, *Nature* **409**, 459 (2001).
2. J. Harte, *Consider a Spherical Cow: A Course in Environmental Problem Solving,* University Science Books, Sausalito, Calif. (1988); J. Harte, *Consider a Cylindrical Cow: More Adventures in Environmental Problem Solving*, University Science Books, Sausalito, Calif. (2001).
3. J. Lawton, *Oikos* **84**, 177 (1999).
4. R. A. Vollenweider, *Mem. Ist. Ital. Idrobiol.* **33**, 53 (1976).
5. S. Chapra, K. Reckhow, *J. Fish. Res. Board Can.* **36**, 225 (1979); K. Reckhow, in *Perspectives on Lake Ecosystem Modeling*, D. Scavia, A. Robertson, eds., Ann Arbor Science, Ann Arbor, Mich. (1979), p. 193.
6. O. Arrhenius, *J. Ecol.* **9**, 95 (1921).
7. K. Gaston, T. Blackburn, *J. Anim. Ecol.* **65**, 701 (1996); W. Kunin, *Science* **281**, 1513 (1998).
8. J. Harte, A. Kinzig, J. Green, *Science* **284**, 334 (1999); A. Ostling, J. Harte, J. Green, *Science* **290**, 671 (2000); J. Banavar, J. Green, J. Harte, A. Maritan, *Phys. Rev. Lett.* **83** 4212 (1999); H. Martin, N. Goldenfeld, *Phys. Rev. E* **65**, 032901 (2002).
9. J. Harte, T. Blackburn, A. Ostling, *Am. Naturalist* **157**, 374 (2001).
10. W. A. Calder III, *Size, Function, and Life History*, Harvard U. Press, Cambridge, Mass. (1984); G. West, J. Brown, B. Enquist, *Science* **276**, 122 (1997); B. Enquist, K. Niklas, *Nature* **410**, 655 (2001).
11. J. Harte, M. Shaw, *Science* **267**, 876 (1995); S. Saleska, M. Shaw, M. Fischer, J. Dunne, C. Still, M. Holman, J. Harte, *Global Biogeochem. Cycles* (in press).
12. L. Rustad, J. Campbell, G. Marion, R. Norby, M. Mitchell, A. Hartley, J. Cornelissen, J. Gurevitch, *Oecologia* **126**, 543 (2001).
13. S. Pacala et al., *Science* **292**, 2316 (2001).
14. G. Shaver et al., *Bioscience* **50**, 871 (2000). ■