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THE LONG VIEW

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Unremembered Intimacies

Beasts of the Earth: Animals, Humans, and Disease. E. Fuller Torrey and Robert H. Yolken. Rutgers University Press, New Brunswick, NJ, 2005. 191 pp. $23.95 (ISBN 0813535719 cloth).

Surrounded long ago by ever better pottery and ever longer epics, our ancestors of almost every cultural lineage began abandoning—as unflattering, irreverent, and implausible—traditional understandings of themselves as being animals *among* animals. Before that, before agriculture anywhere created wealth in sufficient excess to bring forth civilization, humans rating as fully modern in the physical-anthropological sense assumed they were bound to nonhuman animals and could hardly have imagined their bond changing.

But change it did. Human bands following prey and fearing predators may have known other animals behaviorally and even anatomically more expertly than most of us today, but a far greater intimacy was to follow. When a few individuals of a few nonhuman species proved preadapted to living among humans, domestication began and with successive generations progressed. The species domesticated were surprisingly few, but the species—or, more generally, the clades—involved in domestication were amazingly numerous. This paradox, wholly unappreciated until recent centuries and underappreciated still, is easy enough to explain: each domesticated animal carried with it microorganisms amazing in number and tremendous in variety.

Many of these microorganisms helped protect or nourish their hosts, and most proved harmless to humans, but they all now were persistently in contact with new environments: the outer surfaces, inner surfaces, and fluids of humans and nonhuman animals *other* than their hosts. To sufficiently preadapted strains, these new environments were immediately available for colonization, for invasion, and even, as with retroviruses, for genomic incorporation. These new environments, plus surrounding soils and plants, were also already teeming with their own microorganisms, with which newcomers might occasionally exchange genetic material, such as plasmids.

None of this was obvious to neolithic humans, and frighteningly little of it is considered day-to-day even now by governmental and nongovernmental institutions charged with the protection of public and ecological health. *Beasts of the Earth* has been written to explain this problem to sophisticated general readers and to the officials appointed by politicians for whom those sophisticated general readers may or may not have voted.

This book is the work of two physicians. E. Fuller Torrey is associate director of laboratory research at the Stanley Medical Research Institute in Bethesda, Maryland, the largest private US funder of research into schizophrenia and bipolar disorder, and he is codirector of the Stanley Brain Research Laboratory and Brain Collection at the Uniformed Services University of the Health Sciences, where he is a professor of psychiatry. He is also a writer of medical histories and commentaries on psychiatric topics. Robert H. Yolken directs the Stanley Laboratory of Developmental Neurovirology in the Department of Pediatrics, Johns Hopkins University School of Medicine, where he is a professor of pediatrics and holder of the Theodore and Vada Stanley Chair in Neurovirology. Yolken is coeditor of the *Manual of Clinical Microbiology.*

While overall well worth reading, *Beasts of the Earth* does at times adopt an informality of exposition that prompts a check of author qualifications, which are, as described above, impeccable. But are deers and ticks really the only animals involved in Lyme disease? No. Is the agent of bovine transmissible spongiform encephalopathy truly a microbe? Evidently not. Were bacteria really the first forms of life on earth? No. Did hominids separate from primates? No; they *were* primates. Were preadapted bacteria waiting to take possession of anatomically modern people? No, our hominid ancestors and their normal flora and pathogens evolved together into modernity. Coevolution is the theme of this book, but it is often underplayed in a fashion that must leave a lay audience confused, at least subliminally. Evolution and microbial ecology are often miscast, with microbes having to evolve or die, microbes trying to get ahead in life, pathogens "using" and "learning to use" vectors and intermediary hosts to attack humans (pp. 1–7, 19) and microbes and humans locked in an "ongoing war" (p. 12) rather than a lingering coevolutionary embrace that is usually harmless and is in many ways helpful.

Are such problems evidence of editorial pressure to simplify early chapters so as to enhance sales to bookstore browsers? Are they the indiscretions of scientists who know better but forget that many readers do not yet know better and are reading works by scientists to learn what better is? In reference to teleological indiscretions, such as some of the ones cited here, life scientists ruffled by "intelligent design"—natural-history denial's breeze of the moment—should consider the effect that purpose-laden simplifications may have on readers trying to differentiate biology's view from religion's view.

Presentational problems decrease as the authors move on, and readers will find much to reward persistence.

First discussed are heirloom infections, which are shared with our cousin species in molecular-genetic patterns suggesting that *Homo* had them well before becoming *sapiens.* Especially engaging is the herpes B virus, which is passed sexually or orally among macaque monkeys, in whom it causes a mild illness; this same virus, introduced into a human handler by biting, causes severe encephalitis, recalling the problem human newborns have when delivered through a birth canal newly infected with herpes simplex virus 2. Some heirloom infections persist also as zoonoses; urban yellow fever passes among humans through

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mosquitoes, while jungle yellow fever passes from monkeys, which in Africa exhibit no signs of disease, through mosquitoes to humans near the forest edge. Most evocative of the complexity of animal evolution are retroviruses. Some of their remnants have been incorporated into our genomes, where they figure in physiologic and pathophysiologic processes. Other retroviruses as intact microbes have become notorious agents of epidemic disease, perhaps transgenerational epidemic disease.

When humans took to hunting, they took control of their fears and their diets, and they entered an exploitative yet reverential relationship with the animals they followed, ate, and rendered into materials. In a memorable passage, the authors consider the aesthetics of this relationship, as understood from the art and artifacts of our paleolithic ancestors. The authors then turn to the consequences not just of hunting but also of taming, herding, and husbanding animals. Many diseases—cysticercosis, trichinosis, anthrax, brucellosis, Q fever, tularemia, glanders—have been acquired by humans through these activities; AIDS probably was as well. One of these diseases, and not the one so much mentioned after 9/11, is discussed both as a natural factor in war and as a weapon in World War I: glanders, the great leveler of cavalries and impediment to horse-drawn logistics.

When humans took to the land as farmers and, in regions whose animals were suited to domestication, as husbandmen, the intensity and chronicity of exposure to pathogens increased transformatively. Peptic and gastric ulceration, afflictions now attributable to *Helicobacter pylori,* was one result; whooping cough, smallpox, influenza, and tuberculosis were others. Consumption's history in politics and art is told selectively here, but effectively.

When humans took to villages and intervillage trade, the niches and vulnerabilities presented to microbes expanded far beyond those of any single host or single family of hosts. Human society could at last host diseases needing the constant availability of susceptibles, the faithful ambulation of shedders, and the random familiarities of travelers. Many zoonoses came to prominence in these altered conditions: rhinoviruses, measles, and smallpox from cattle, for example. When rats began traveling by sail and then steam, rat-adapted pathogens, including ones highly virulent in humans, moved with their rat-adapted insect vectors from old environments to new.

When humans took pets—or when, in the case of dogs, at least, pets took humans—more exposures became commonplace; many are now well characterized, but doubtless some are left to surprise us. The authors treat this topic in a section sure to be of special interest to many readers. Conscientiously addressed in addition are the benefits pets bestow, not just the risks they embody.

Two chapters—"Humans as Diners" and "Microbes from the Modern Food Chain"—speak to a range of worries: virus-laden shellfish, feculent spring onions, contaminated poultry and eggs, mad cow disease, SARS, putrid fish farming, genetically shifted influenza A, and so on.

A penultimate chapter, "The Coming Plagues," draws lessons from the rapidly changing histories of AIDS, West Nile fever, and Lyme disease and applies these lessons to deficiencies in contemporary policy and practice. Interagency gaps and communications failures and international incoordination are denounced; the interprofessional distancing of veterinarians and physicians is regretted; the underfunding of autopsies is criticized; and the toleration of trade in exotic animals is castigated. Here, in a few pages, is the message the authors may have wanted most urgently to deliver. A short concluding chapter follows.

Beasts of the Earth has its faults, but its faults are dwarfed by the immensity and importance of its subject. It deserves and will hopefully have a wide general readership.

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ENCOUNTERS WITH THE SEERS OF THE UNDERGROUND

Underground: How Creatures of Mud and Dirt Shape Our World. Yvonne Baskin. Island Press, Washington, DC, 2005. 256 pp. $26.95 (ISBN 1597260037 cloth).

Popular science writers chronicling the lives of alluring penguins, elaborate orchids, or toxic mushrooms have a relatively easy time engaging the public with these charismatic macrobiota. These creatures are fuzzy, exotic, and mystifying, making them fine subjects for zoos and botanical gardens, natural history documentaries, coffee-table books, and calendars. Lacking from this lineup of organismal celebrities are the not-so-fuzzy collembola, rhizobia, nematodes, and other members of soil communities. These soil organisms are extremely difficult to popularize, given their small size, yet we indirectly encounter (beneath our feet) and rely on soil organisms more than the well-known charismatic macrobiota. In one of the first attempts to popularize the diversity and function of soil organisms, Yvonne Baskin takes a whirlwind tour of some of the emerging concepts in soil ecology in her engaging new book *Underground: How Creatures of Mud and Dirt Shape Our World.*

Baskin is a freelance science writer based in Bozeman, Montana. She has contributed in the past to *Discover, Natural History,* and other popular science publications. Her previous books include *The Work of Nature: How the Diversity of Life Sustains Us* and *A Plague of Rats and Rubbervines: The Growing Threat of Species Invasions.* Although she is not a practicing scientist, Baskin offers a fresh outsider's perspective on the fields she has written about. More important, in this latest work she demonstrates her ability to explain emerging concepts and issues in a relatively young and sometimes amorphous scientific field. Baskin's nonspecialist viewpoint helps to set her book apart from another recent popular science book on soil organisms, by Cornell Uni-

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versity ecologist David Wolfe, entitled *Tales from the Underground* (Cambridge, MA: Perseus Publishing, 2001).

Underground is structured as a travelogue, describing the author's trip around the world with prominent soil ecologists as her tour guides. Stops along the way include the polar deserts of Antarctica, sugar maple forests in Minnesota, and grasslands in the Netherlands. Instead of trying to convey the importance of specific soil biota and processes, Baskin creatively infuses the personalities of specific soil ecologists with the diversity and function of the soil organisms under study to give life and character to the science of soil ecology. Technical passages are broken up with quirky quotations and descriptions of the eclectic researchers Baskin follows on her journey. In addition to bringing life to a topic that might otherwise be uninteresting to individuals outside the field, Baskin's approach highlights some of the creative twists and turns involved in the scientific process when studying the clichéd "black box" of soil ecology. She describes some of the intended and fortuitous collaborations that have formed within this inherently interdisciplinary field of ecology and refers to some of the methodological obstacles that have beleaguered soil ecologists.

To avoid having readers become entangled in the sometimes overwhelming complexity and elusiveness of soil communities, Baskin begins the book with some of the simplest soil communities on the planet—the polar deserts of Antarctica. In her first field expedition, Baskin follows Diana Wall of Colorado State University (who initially inspired Baskin to write the book) to the lunar landscapes of the McMurdo Dry Valleys. The research Wall and collaborator Ross Virginia conducted in these systems over the past 15 years has demonstrated that without the presence of plants to create a substantial aboveground input, it is easier to discern the controls on populations and communities of soil organisms. These soils are also fairly low in diversity compared with those in other ecosystems, making it easier to describe the overall diversity of soil organisms and the response of this diversity to various experimental manipulations. This is by far the liveliest chapter in the book, with my favorite quotation—"And ruffles! Imagine if you had ruffles!"—coming from the vibrant persona of Diana Wall, in reference to the morphology of the most abundant polar desert nematode, *Scottnema lindsayae*.

In the chapters that follow, Baskin introduces more complex soil communities as she examines the life in marine sediments and upland and wetland soils. She also layers into the discussion the interactions between soil communities and components of aboveground communities, an area of research that has gained substantial popularity within community and ecosystem ecology over the past decade.

As a way to emphasize the importance of soil organisms in human-dominated ecosystems, Baskin highlights many pressing environmental issues that have received significant media attention, including wetland conservation, air pollution, and the preservation of biodiversity.



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For each of these issues, she describes how soil organisms play important but unappreciated roles. In many of the examples in the book, the complete details of the ecological stories described are missing because most of the research discussed throughout the book is ongoing. This open-endedness may annoy some readers, as it will seem as though there are few answers to the questions posed throughout the book. However, this is an accurate portrayal of this field, which still has many more questions than answers.

While in general the author makes many attempts to reach out to audiences who lack a strong background in science, the book is mostly geared toward readers with an interest in biology and with some advanced high school or basic university coursework in the natural sciences. I recommend this book not only to these readers but also to anyone already familiar with the field of soil ecology. Although the book is not a comprehensive reference and only highlights specific research areas within a larger field, soil ecologists and other "seers of the underground" will come away with a unique outsider's perspective on their growing field. This perspective may help these specialists to understand how to convey the many fascinating aspects of soil ecology to broader audiences.

Given that many readers will never have observed most of the creatures or techniques discussed in the book, it is surprising that the only illustrations in the text are basic line drawings. Although Baskin's rich and descriptive writing style can help readers create their own mental pictures, it is here that I think the author and publisher missed an important opportunity to make this science come alive even further, using some of the striking photographs of soil organisms that scientists have accumulated. If publication costs limited the inclusion of such illustrations, it might have been useful to refer readers to a supplementary Web site with photos from the author's travels.

Despite the lack of vivid illustrations, as I read *Underground,* I couldn't stop thinking about how well suited the material in this book is for a science documentary. Perhaps the creators of *Microcosmos* can do for soil organisms what they did for insects, using this book as a framework. Regardless of how they are popularized, nematodes, mycorrhizal fungi, and other soil organisms will never be cute and cuddly to most people. However, Baskin's book successfully gives a face to the rapidly changing field of soil ecology, creating an enjoyable read both for scientists and for anyone else interested in learning more about the life beneath our feet.

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A GENEALOGY OF LIFE ON EARTH

Five Kingdoms: A Multimedia Guide to the Phyla of Life on Earth. Version 2.0. Lynn Margulis and Karlene V. Schwartz. Springer, New York, 2003. $59.95 (ISBN 3540408665 CD–ROM).

In many ways, the *Five Kingdoms* multimedia CD–ROM, authored by Lynn Margulis and Karlene V. Schwartz, is a natural evolution from the text version. Margulis and Schwartz are widely recognized for their contributions to taxonomy through the book *Five Kingdoms: An Illustrated Guide to the Phyla of Life on Earth,* a volume that has graced biologists' shelves for years and is currently in its third edition. Margulis, Distinguished Professor in the Department of Geosciences at the University of Massachusetts in Amherst, is renowned for her work in cell biology and evolution, and her coauthor, Schwartz, is also a recognized biologist at the University of Massachusetts in Boston.

In the print version, *Five Kingdoms* is a genealogy of life on earth, providing diagrams, illustrations, and scholarly text, all organized precisely into the broadest, most inclusive taxonomic classifications: kingdom and phylum. As technology has changed the way we build our family photo albums—from unwieldy books with limited space to CDs with seemingly unlimited photo storage capacity—so, too, has it changed *Five Kingdoms.* The CD reduces bulk (not that the original text was bulky) and offers the reader the chance to engage with a wider spectrum of images and information in a more interactive format. However, the transition from print text to CD brings both benefits and limitations.

The *Five Kingdoms* CD is in tight alignment with the book in both content and structure. In brief, the book and the CD each provide encyclopedic information about the classification and description of organisms in the five kingdoms and in the 96 phyla that these kingdoms subsume. The line-by-line text on the CD was lifted, practically verbatim, from the book text, and the CD even includes some of the more "bookish" elements of the print volume, such as the foreword written by Stephen Jay Gould.

The CD also organizes the science content in a manner that is almost identical to the book. A quick glance at the book's table of contents shows a list of the five kingdoms (and related phyla) in a linear, hierarchical format. The CD replicates this structure by presenting a home page that lists the five kingdoms on the left half of the screen; when one of the kingdom buttons is clicked, a list of phyla appears on the right half of the screen. A click on the name of a specific phylum will take the reader to a page with illustrations, diagrams, and concise, dense, scholarly text about that phylum. In short, if you like the linear, encyclopedic structure of the book, the CD offers the same structure, but in an interactive format.

Because the original book received such wide acclaim in 1998 and has already been reviewed, refuted, and defended, I'm unlikely to contribute anything new by addressing the same content repackaged. Instead, I focus here on the transition from text to CD and highlight features that either enhance or detract from the already established merits of the original print version. The most obvious benefits from the shift to multi-

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media are (a) the added images, video clips, and sound bits made available by increased storage space and (b) the ability to engage in a more creative environment.

The *Five Kingdoms* CD contains hundreds of images, far more than the print version could accommodate; it also includes video clips and a few mouse-over sound bits. The sheer volume of images and diagrams is probably the CD's biggest strength. In the CD's "gallery," the reader can click on thumbnail images and movies, and view the image or movie without changing screens. The downfall of the gallery feature, however, is that it lacks a quick link from a particular image to its corresponding information page. I would have liked a more inquiry-driven format, whereby I could click on a thumbnail image, go to the image or movie, and then have the opportunity to link to the page that contains the image and its related information. Instead, I had to return to the contents page and dig through various listings of kingdoms and phyla to find the right information. Another aside about the gallery: As a science educator, I would have liked to incorporate some of these images into my own multimedia lectures and presentations, but the CD does not allow images to be copied, most likely for copyright reasons.

The CD offers additional features, such as a glossary and a search function (which is a nice bonus for readers with a good grasp of the highly technical, scientific language used throughout the CD). The CD also hosts a section called "Field Trips," although "field trip" is a bit exaggerated: these excursions are actually only links to museum Web sites, many of which were inaccessible when I tried to reach them.

Although the CD version of *Five Kingdoms* does capitalize on the increased storage space available through multimedia, it does not take full advantage of the capacity of multimedia to entertain and draw the reader into the environment—with two exceptions. The first is the movies: though few and short, they add a new dimension to viewing what is otherwise a litany of still images. Second is the initial interface with the product, which opens with some fancy flash and a catchy, rhythmic musical backdrop of jungle drums. Unfortunately, after that short introduction, the rest of the interface is flat and rather regimented. Multimedia environments are essentially nonlinear and fluid—or should be. One advantage that a multimedia format has over print is that it can offer more and different connections between concepts. This CD, however, relies on lists to organize the interface, when a more integrated, organic structure would have worked far better. The linear structure was especially evident when I tried to navigate through the whole program. I found that I had to constantly click back to the contents page to find out where I was among the web of pages. The navigation tool, an unlabeled, generic floating bar, gave me few options other than the contents page, previous page, next page, forward, back, search, and exit.

The information pages, too, were clunky and unrefined. When I located a topic of interest, I could click on the associated text, and a lengthy, scientifically arcane description would appear in a separate window on the desktop, obscuring the image. Because the text box could not be resized, I had to close or move it to see the image. The technical crudeness of this page-level interface contrasted oddly with the complexity of the scientific language.

For individuals who value the print version of *Five Kingdoms,* however, the CD version will be a comfortable fit. Even if the CD does not take advantage of all the benefits of a multimedia experience, the science is solid, well recognized, and cited. The greater number of images and the addition of movie clips enhance the visual experience. I'm sure that the *Five Kingdoms* CD, like the book from which it was derived, will continue to shape the language of taxonomy and to structure the scholarship of these broad biological classifications.

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THE LONG VIEW

Nutrient Cycling and Limitation: Hawai'i as a Model System. Peter M. Vitousek. Princeton University Press, Princeton, NJ, 2004. 232 pp. $35.00 (ISBN 069111580X paper).

Peter Vitousek's *Nutrient Cycling and Limitation: Hawai'i as a Model System* makes an important contribution to the field of biogeochemistry. In this excellent book, Vitousek draws on examples from research he and others have conducted on Hawai'i since the early 1980s to explore general principles about the processes controlling nutrient availability, cycling, and limitation in terrestrial ecosystems. He begins by introducing four fundamental biogeochemical questions that apply to all terrestrial ecosystems. He then moves from the general to the specific, sharing with his readers the "stories that the data have to tell" about nutrient dynamics along a "substrate age gradient" that spans more than four million years and includes six core sites distributed across the Hawaiian archipelago. In the final chapter, Vitousek puts the Hawai'i studies in a global context as he returns to the four fundamental questions raised in the book's introduction.

The four questions that open and close the book have challenged ecosystem ecologists for the past quarter-century: How do biological and geochemical processes that operate on very different timescales interact to cause, sustain, or offset nutrient limitation? How are element inputs to and losses from terrestrial ecosystems regulated, and what are the implications for nutrient cycling and limitation? How do the cycles of different elements interact? Finally, how do genotypes, species, and communities of organisms affect nutrient cycling and limitation in ecosystems? Vitousek argues that these questions can be answered more straightforwardly in Hawai'i than anywhere else. Along with reviewing the natural history of Hawai'i in chapter 2, he describes the attributes of this Pacific archipelago that make it a model system that facilitates research on these questions.

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Often the systems chosen as models for research are relatively simple in structure, a factor that facilitates observation and experimentation. Simplicity is an essential feature of the six core sites at which Vitousek and his colleagues have done much of their field research. Substrate age is the dominant variable across their sites, with the oldest site being 4.1 million and the youngest being 300 years old. The six core sites have developed on rock that varies relatively little in chemistry. They are all forested, with canopies dominated by the tree *Metrosideros polymorpha* and subcanopies dominated by native tree ferns of the genus *Cibotium.* All occur between 1120 and 1210 meters in elevation and share a common climate—each has a mean annual temperature near 15.5 degrees Celsius and receives about 2500 millimeters of precipitation yearly. Additional details on the characteristics of the gradient are given in chapter 3.

Over more than two decades of research, Vitousek and his colleagues, including a cadre of graduate students, have used observational studies and experimental manipulations along the substrate age gradient to test theories and gain new insights about nutrient dynamics during ecosystem development. They use observational studies to reveal patterns, and experimental manipulations to identify the mechanisms responsible for the patterns.

Many of their studies focus on nitrogen (N) and phosphorus (P), two elements required in relatively large quantities by all living organisms. In the book's fourth chapter, Vitousek writes about how he and his colleagues have used observational studies along the gradient to test conceptual models such as the one developed by Walker and Syers (1976) that describes how total P stocks and the bioavailability of P change during long-term soil development. The studies on P done across the Hawai'i gradient generally confirm this model and, when combined with observational studies of N pools and fluxes across the gradient, indicate that young sites have low levels of available P and N, intermediate-aged sites have relatively high levels of P and N availability, and the oldest sites have low P but high N. In chapter 4, Vitousek also uses observational studies to develop the concept of a plant–soil–microbe positive feedback that has different implications for infertile versus fertile sites. The idea is that biological responses to a geochemically driven shortage of nutrients can further reduce nutrient availability and set in motion a positive feedback. The feedback functions to reinforce nutrient deficiency in infertile sites and greater nutrient availability in fertile sites.

While observations along the substrate age gradient in Hawai'i illustrate the feedback, they do not explain why the feedback works as it does. To get at the "why" requires experimental manipulations. In the book's fifth chapter, Vitousek describes several factorial fertilization experiments carried out across the gradient, and uses the results to explain nutrient limitations and controls of plant–soil–microbe feedbacks. With respect to nutrient limitations, responses to fertilization across the substrate age gradient strongly support predictions based on the conceptual model of Walker and Syers—N supply limits tree growth at the young site, N and P supply have equilibrated at a relatively high level at the intermediate-aged site, and P limits growth at the oldest site. On the topic of plant–soil–microbe feedbacks, the effects of P fertilization on P-limited (older) sites were different from those of N fertilization on N-limited (younger) sites. Overall, fertilization with P caused the P-limited 4.1-million-year-old site to function more like a forest on a naturally fertile site, at least with regard to P cycling. In contrast, N fertilization did not cause the forest on the N-limited 300-year-old-site site to function like a forest on a naturally more fertile site. Vitousek sets out several plausible explanations for these differences and explores them further in the book's eighth and final chapter.

Nutrient inputs and outputs are the topics of the sixth and seventh chapters, respectively. I found the discussion of atmospheric transport of P in dust from Asia particularly well presented as an example of an important "teleconnection" operating in the Earth system. Vitousek argues that one of the most striking results of the Hawaiian study is the significance of this continental dust to the P economy of old soils in the archipelago. Near the end of chapter 6, Vitousek states that "were it not for the trickle of P that travels more than 6000 km in dust from Asia, much of it during full glacial periods, I'm not sure it would be possible to maintain forests on the oldest substrates." He goes on to point out the general applicability of this phenomenon to older soils across the globe.

The last chapter is titled "Issues and Opportunities." The first issue that Vitousek explores is the interaction of nutrient cycling processes operating at different timescales—supply and demand for nutrients over minutes to years; feedbacks between nutrient availability, plant growth, and nutrient supply over months to decades; nutrient sources and sinks over years to centuries; and inputs and outputs of nutrients over centuries to millions of years. This is done with a simple model that is available on the Web. One interesting result of this model is that the three fastest sets of processes—nutrient supply and demand, plant–soil–microbe feedback, and nutrient sources and sinks—all reinforce each other in positive feedbacks that reduce nutrient availability in nutrient-poor sites and enhance it in rich sites. An equally interesting model result is that nutrient input–output balances provide a long-term negative feedback to nutrient limitation that can be large enough to offset the three sets of faster processes. I am still pondering the robustness of these insights into the interactions of biogeochemical feedbacks across time scales; that is, do they operate in the same way in most other terrestrial ecosystems? I also find myself wondering about the degree to which Vitousek's interpretations are dependent on the structure of his simple model.

Another issue that Vitousek explores in the final chapter is the influence of changes in populations, species, and diversity on nutrient dynamics over different time scales. He structures his discussion of this issue with two questions: Could relatively subtle differences in biota across the Hawaiian age gradient

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affect the functioning of ecosystems there? And would the functioning of Hawaiian ecosystems across the gradient differ if biological diversity in Hawai'i were substantially greater? While neither question is definitively answered, I found Vitousek's considerations of them stimulating.

Nutrient Cycling and Limitation is essential reading for students and scientists interested in terrestrial biogeochemistry. It is a model of good science writing and a crisp and clear introduction to some of the big ideas that intrigue ecosystem ecologists.

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NEW TITLES

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