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PACE, M. L., AND P. M. GROFFMAN [EDS.]. 1998. **Successes, limitations, and frontiers in ecosystem science**. Springer-Verlag. 499 p. \$49.95. ISBN 0-387-98475-5.

What has the study of ecosystems contributed, where is the field going (and why), and what factors challenge its progress? These questions were the focus of the Cary Conference, which was held at the Institute of Ecosystem Studies in Millbrook, New York, in 1997. One product of that conference is this book, which attempts to provide some of the answers to these questions. The book's editors, Mike Pace and Peter Groffman, propose that their readership should include not only practitioners of ecosystem science but also other ecologists, students of ecology, and environmental scientists. The present reviewers fall more or less into the middle two categories.

In addition to the goals of taking stock and of exploring the motivations that underlie ecosystem investigations, Pace and Groffman point out that there is misunderstanding in the ecological community about what ecosystem science actually is. They are right. An early and favorite definition of ecology, which was proposed by Eugene Odum, holds that it is the study of the structure and function of nature. The words structure and function were borrowed from early definitions of physiology and anatomy, which were seen as studies of the structure and function of organ systems. "Function," however, has two distinct meanings: (1) how something works and (2) what purpose something serves. Both definitions have relevance for the components of individual organisms, but for ecosystems, the second holds a peril not entirely avoided by ecosystem scientists during the 1950s, 1960s, and early 1970s. At that time, the loudest voices in ecosystem science suggested, or seemed to suggest, that ecosystems might evolve as distinct units, that some feature (such as energy transfer) should be maximized among all components, and that the "function" of these components was to play a role in this maximization process. This perspective led many ecologists with strong grounding in evolutionary biology to distance themselves from the ecosystem branch of their science. Other factors that, rightly or wrongly, also played a role in this disenchantment were the seeming intractability of the very large computer-simulation models favored during this formative period and the perception that ecosystem science was too closely allied with investigations of applied problems. As a result, for more than two decades some ecologists simply stopped paying attention to advances in ecosystem science. This book makes it clear that by doing so, they missed a lot.

The book is divided into three parts, the first covering areas of research characterized as successful studies in ecosystem science, the second covering some of the difficulties encountered in the pursuit of these studies, and the third discussing areas in which opportunities lie in the future. Given the historical context laid out above, two features of the book's content are striking. The first is the virtual absence of consideration of energy transfers among ecosystem components other than controls of primary production and discussions of carbon cycling. Is it really the case that one of the two traditional pillars of ecosystem analysis (the other being nutrient cycling) does not factor into either its successes or its frontiers? Perhaps so. It is difficult to think of examples (from ecosystem scientists) that were missed. Instead, it has been community ecologists with interests in such questions as "What controls food-chain length?" and "Do trophic levels exist?" who have undertaken much of the recent discussion of energy pathways. The second striking feature, given the history of ecosystem science, is the near absence of computer-simulation models. There is a chapter by William Lauenroth et al. on the role of simulation modeling in ecosystem

science, the intent of which is to raise concern over the absence of simulation studies at the Cary Conference. It is undoubtedly correct that simulation modeling still has important contributions to make: indeed, some specific examples are covered briefly in chapters by Robertson and Paul on agricultural ecosystems, by Burke et al. on regional-scale biogeochemistry, and by MacMahon on restoration ecology. It is equally clear, however, that computer simulation does not hold the central position in the science that it once did. The chapter by Vitousek et al., the only one in the book that presents a model in any detail, is really a heuristic exploration of long-term nutrient limitation that uses simulations only to illustrate key features of the argument. Contrary to the perspective espoused by Lauenroth et al., Tilman's chapter advocates the development of simple mechanistic models that are capable of explaining ecosystem patterns.

In marked contrast to energy relations, nutrient dynamics play a central role in 8 out of 18 contributed chapters. This emphasis reflects the rich body of research that ecosystem science has fostered in understanding element cycling in both natural systems and in predicting and managing the consequences of excess nutrient inputs. In addressing such questions, ecosystem scientists have created an effective toolbox of comparative system approaches, multiscale experiments, creative induction, simulation modeling, and collaborations across scientific disciplines. Val Smith's chapter on aquatic eutrophication is a compelling example of the role that deductive approaches have played in elucidating fundamental patterns and testable hypotheses on the relationship between nitrogen and phosphorus inputs and primary productivity. Vitousek et al.'s inductive model of element cycling formalizes an alternate framework for understanding nutrient limitation on long time scales. Nevertheless, additional challenges lie ahead. As Breitburg et al. argue, ecosystems are exposed to an ever-increasing suite of multiple stressors in addition to excess nutrient inputs, yet organizing frameworks and effective approaches for addressing the effects of multiple stressors have been slow to emerge.

The close connection between ecosystem science and applied environmental problems is an explicit theme of the book: over one-half of the chapters and all of the chapters used as examples of success in ecosystem science directly address applied issues. These include eutrophication (Smith), wetland and riparian zone management (Zedler et al. and Lowrance), and acid precipitation (Weathers and Lovett). Because of the early stigma attached by academic ecologists to mission-oriented research, the nonecosystems branches of our science have been much slower to embrace the need to address applied issues. It can certainly be argued that, to date, they have been much less successful as well. For example, attempts to assign key characteristics for the design of nature preserves have resulted principally in acrimony. Similarly, the slippery connection between diversity and stability (the definitions for which change with distressing frequency and the proposed causal relationships of which have switched sign repeatedly) has left many people in management positions with little of practical use. Tilman's recent contributions to the diversity–stability literature, reviewed in his chapter, employ an ecosystem perspective on the meaning of stability (i.e., constancy of plant biomass and primary production) that is different from—and probably ultimately more useful than—that which was intended by a number of earlier authors (the constancy of species numbers and species identity).

The path between initial scientific findings and necessary changes in environmental policy is rarely direct. How society addresses current and emerging environmental problems depends greatly on how ecosystem scientists communicate their findings to the public, to politicians, and to managers. The two chapters by Likens and Walters in the "limitations" section of the book provide perceptive outlooks on the opportunities and pitfalls associated with this relationship. Likens gives a brief history of acid-precipitation policy

that, though considered a success story of ecosystem science (see the chapter by Weathers and Lovett), nevertheless illustrates the difficulties that scientists face in explaining the increasingly complex science of acid precipitation to the public and to policy makers. Walters further challenges ecosystem scientists to take stock of where the limitations of their science may lie for managers. His critiques on the gaps between what ecosystem science can and cannot do and on how well those messages are communicated to managers are provocative. In addition to communication concerns, Likens discusses a variety of limitations, some of which are perhaps particularly strongly felt among the ecological sciences by the field of ecosystem studies: the multifactor complexity of study systems in time and space and the challenges of supporting and promoting the team-oriented, multidisciplinary approach of the science. Other limitations that he mentions are more generally applicable: lack of time and vision and the question of whether the best and brightest graduate students are being attracted to the field (several of us were relieved to note that Pace and Groffman restated this concern as the need to "continue to attract bright students ...").

Groffman and Pace point out that although only 2 of the 18 contributed chapters are specifically devoted to the limitations of ecosystem science, the book as a whole is more focused on what has not yet been accomplished than on what has been achieved. They assert that the majority of the successes presented in the first section of the book are only partial, while the frontiers, by definition, are tasks that have not to date been adequately addressed. One emerging area is the need to recognize and incorporate human factors into our understanding of ecosystem functioning, including socioeconomic considerations, as Folke discusses in his chapter. In fact, "humans as components of ecosystems" has in the past been the topic of an entire Cary Conference. Most of the chapters in the "frontiers" section point out the need for new experiments and better articulation of the ecosystem approach. Carpenter argues for more large-scale experiments, Zak and Pregitzer discuss the advantages of an ecophysiological approach in studying ecosystem dynamics, and Breitburg et al. attempt to lay out a framework for studying multiple stressors.

One question to which we kept returning as we discussed the chapters (in order) is "Who is this book for anyhow?". The contributions range widely in approach and scientific detail. Some, like those by Smith (on eutrophication), Lowrance (on riparian forests), Zak and Pregitzer (on the integration of ecophysiology and biogeochemistry), Vitousek et al. (on input-output nutrient budgets), and Tilman (on the role of species composition and diversity in ecosystem processes), provide sufficient scientific detail to permit their

chapters to be used to teach about the linkages between ecosystem science and the understanding it provides for environmental issues. Other chapters, such as those by Dale (on managing forests as ecosystems), Zedler et al. (on wetlands protection), and Weathers and Lovett (on acid deposition), while providing annotated lists of studies that address particular problems, make little or no attempt to explain how these problems were discovered or what ecosystem science was carried out so that we could understand and manage them. In these latter instances, it seems that the book was written by ecosystem scientists for ecosystem scientists. The perception that this is the intended audience is especially strong in the parts of the chapters by Zedler et al. and Weathers and Lovett in which considerable space is devoted to evaluating temporal trajectories of the numbers of publications, numbers of Ph.D.s, and the numbers of popular articles written in the field's subdisciplines. These measures of success, useful though they may be, are likely to be of interest only to those within the field.

In summary, this book provides a useful update on where one very influential group of ecosystem scientists believes the field to be at present. The chapters are rather uneven in terms of the detail with which they approach their topics, which makes it difficult to see how the book could be used in teaching a formal course. At the same time, the book provides a great deal of information about the history of ecosystem science, about what the field has achieved, and about where it is likely to go in the immediate future. In the last chapter, Groffman and Pace draw together the somewhat disparate contributions and place them in the context of the conference. It is interesting and revealing that one topic discussed at the 1997 Cary Conference is whether or not ecosystem science as a field of study lacks focus and consensus. After reading the book, it was unclear to us why these were identified as potential problems, since this implies that focus and consensus are desirable for ecosystem science. It would not only be surprising but also somewhat disturbing if such a broadly based discipline were concentrated on a restricted number of questions and approaches. To us, the breadth of topics and the diversity of approaches described in this book speak to the strength of the field rather than to any weakness.

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