Ecosystems (1998) 1: 1–5

ECOSYSTEMS

EDITORIAL

At Last: A Journal Devoted to Ecosystem Science

The science and management of ecosystems together is one of the most dynamic fields of contemporary ecology. Ecosystem science has developed into a well-established diverse discipline that bridges fundamental research and applied problem solving, employs a wide variety of approaches, and draws upon linkages to a number of other ecological disciplines. The scope of ecosystem science encompasses bounded systems like watersheds as well as spatially complex landscapes and even the earth itself. Temporally, ecosystem science crosses scales ranging from seconds to millennia. The focus of ecosystem science is characterized increasingly by issues that cross spatial and temporal scales as well as the boundaries of traditional ecological disciplines.

Despite the steady development of ecosystem science, there has been no flagship journal devoted to the study and management of ecosystems. Rather, the literature of ecosystem science has been dispersed among a variety of journals that either reflect broadly the discipline of ecology in all its facets or focus upon more specialized aspects of ecosystem-level ecology. Now *Ecosystems* is poised to unify the field. We are grateful to Hal Mooney and other members of Springer-Verlag's Advisory Board for Ecological Sciences for their vision of this new journal, and to the staff of Springer-Verlag for helping to make it a reality. We wish to thank the members of our distinguished Advisory and Editorial Boards for their hard work and useful suggestions as plans for the journal took shape. We hope that *Ecosystems* can serve as the focal journal for the presentation of original research in ecosystem ecology as well as editorials, minireviews, and special features that consider current topics of interest to ecosystem scientists. In this essay, we briefly review the development of ecosystem science, highlight some of its accomplishments, outline a few key frontiers in the discipline, and sketch some of the topics to be addressed in the first few issues.

Development of Ecosystem Science

Ecosystem is among the ecological terms most familiar to the public (Belden and Russonello Research and Communications, presentation in East Madison, NH, USA, October 1995). The concept of ecosystem services is bridging ecology and economics and creating a new rationale for the value of biodiversity (Daily 1997). Ecosystem management is advanced as a new framework for natural resource policy (Christensen and others 1996), but awareness of the scientific content of ecosystem science is lagging far behind the popularization of the term. Much of the literature on ecosystem management is written by nonecologists who are not familiar with the basic concepts or knowledge of ecosystem science. For example, some recent papers have grappled with the definition of "ecosystem" and the boundary problem, essentially reinventing the conceptual basis of ecosystem ecology without reference to the original papers! The absence of a central, unified forum for ecosystem science has probably contributed to this sort of problem. We hope that *Ecosystems* is part of the solution.

Tansley (1935) first defined ecosystems, recognizing them as "the basic units of nature on the face of the earth." Tansley's ideas are preserved in the modern definition of an ecosystem as "a spatially explicit unit of the earth that includes all of the organisms, along with all components of the abiotic environment within its boundaries" (Likens 1992).

From this definition, it is clear that an ecosystem is a place. While theory can proceed in the abstract, in order to measure properties of ecosystems we must first define their boundaries. Because most ecosystem processes are scale dependent, the choice of boundaries has profound effects on the outcome of a study and the inferences that can be drawn from it (Levin 1992). Although ecosystem boundaries may seem arbitrary, they are no more so than other boundaries considered by biologists (Allen and Hoekstra 1992). A muscle cell may seem like a convenient unit of study, but its intimate connections with other cells may mean that certain questions are best answered by experiments that consider a larger unit than the muscle cell itself. Similar problems arise in studies of fungal hyphae with their intimate connections to soil particles and roots. Every entity studied by biologists—cells, organs, organisms, populations, communities, ecosystems, landscapes—requires that scientists consider scaling questions and define boundaries.

Ecosystem science weaves together many lines of thought, but some are especially notable (McIntosh 1985; Golley 1993). The trophic–dynamic concept (Lindeman 1942) established organic energy flow as an organizing framework for ecosystem ecology that lasted for decades. Fundamental ideas of nutrient cycling began to crystallize at about the same time and, beginning about 1960, were greatly advanced by studies of radionuclides and persistent chemical contaminants in ecosystems. Biogeochemistry is now one of the best-developed branches of ecosystem science (Schlesinger 1991). Simulation modeling brought a new appreciation of ecosystem dynamics. New spatial tools gave ecologists unprecedented capacity to understand spatial heterogeneity and spawned landscape ecology as a self-conscious branch of ecosystem science. Now ecosystem ecology is several decades old with a rich conceptual framework, diverse technological tools, and a strong information base for understanding and management.

ACCOMPLISHMENTS OF ECOSYSTEM SCIENCE

A comprehensive review of the accomplishments of ecosystem science is beyond the scope of this brief editorial. Examples contained within the References, particularly Pace and Groffman (1998), provide a great diversity from which to choose. Here we highlight a few accomplishments that help define the breadth of the science. Ecosystem scientists have made great strides in

- Understanding the flow of water, chemical elements, and compounds through watershed ecosystems, flowing waters, lakes, estuaries, and oceans.
- Analyzing feedbacks between plants and animals and their biophysical environment.
- Understanding the causes of eutrophication and contributing to correctives.
- Analyzing the transport and transformation of contaminants, such as mercury and organochlorine compounds.
- Understanding the biophysical basis of production and expanding the spatial scales for coupling production to climate.
- Assessing the importance of below-ground processes in terrestrial ecosystems.
- Recognizing the scale dependence of most ecosystem processes and searching for scaling rules that may enable us to translate results across scales.

FRONTIERS IN ECOSYSTEM SCIENCE

Prompted by the dual demands for basic knowledge and environmental problem solving at multiple scales, ecosystem science is poised to tackle some of the most important scientific questions of our time. What are the frontiers likely to drive research and lead to new insights during the coming decade? Applied problems will continue to offer new frontiers; although terms like “sustainability” and “ecosystem management” are often used as buzzwords, the challenges they present to ecosystem science are quite real (Lubchenco and others 1991; Christensen and others 1996). Resource managers and policy makers often are seeking guidance from ecological scientists in subject areas where basic knowledge is incomplete. Integrating across scales remains another widely acknowledged research frontier that receives considerable discussion, yet we are only beginning to deal with cross-scale studies in a substantive way (Levin 1992). Here, we highlight four general areas that represent important frontiers in ecosystem science: people and ecosystems, spatial scale shifts, cross-disciplinary linkages, and temporal scale shifts. Our discussion is designed to be illustrative rather than comprehensive, and we certainly do not wish to eliminate other possibilities or directions.

People and Ecosystems

Homo sapiens is the dominant species of earth. Humans have settled most of earth’s ecosystems, and pollution of the atmosphere now affects all ecosystems. Humans appropriate a substantial percentage of earth's terrestrial primary production (Vitousek and others 1986), marine primary production (Pauly and Christensen 1995), and available renewable fresh water (Postel and others 1996). At the current annual growth rate, the human population will double in a little over 40 years (Cohen 1995). It is unlikely that the current high growth rate can be sustained, but, even so, there will be a lot more people on earth in coming decades. Given current levels of resource use per capita, this population will appropriate well over half the terrestrial primary production, most of the aquatic primary production that flows to industrially harvestable fisheries, and most of the available renewable fresh water on earth. Substantially less of these resources will be available for other ecosystem components. How can social systems and ecosystems be integrated in sustainable ways? Ecosystem science has much to contribute.

Sustainability is a challenge to ecology, institutions, and economics. Resource collapses are often institutional failures (Hilborn and others 1995). In sustainable systems, institutions and economics will act to preserve ecosystem services. How can sustainable systems be created? This is a challenging frontier for ecosystem science. Early work in this area is cross-disciplinary, integrative, and exciting (McDonnell and Pickett 1993; Costanza and others 1993; Gunderson and others 1995; Hanna and others 1996; Berkes and Folke 1997).

All ecosystems have a history, and humans are often a component of that history. The relative importance of past land use compared with other abiotic and biotic factors in influencing biotic community composition and ecosystem processes is a subject that demands increased attention. Land use has changed tremendously over the past several centuries, yet the ecological legacies of these changes are poorly known. This is being addressed for some areas [for example, see Foster (1992)], but we are often missing an important piece of the puzzle in explaining the structure and function of contemporary ecosystems. Linkages to paleoecological studies are of particular importance here, as well as studies that focus on the more recent historic record.

Spatial Scale Shifts

There is an ongoing need to enhance our understanding of the spatial heterogeneity. Just how spatially variable are ecosystem processes? How do the controls on processes and rates operate across space? Are there thresholds in rates beyond which qualitative shifts in processes occur? Despite tremendous advances in understanding ecosystem processes in relatively small study areas, little theory exists for predicting variability in ecosystem processes across broader spatial scales. This is a subject ripe for development.

We must develop a more synthetic understanding of spatial heterogeneity than we presently have in hand. Thus, ecosystem scientists should be cautioned against a naive view of spatial heterogeneity. The concept of "the patch" has emerged as a useful construct in landscape and population ecology and one that clearly still maintains an important role in our science. However, patches are defined at particular scales and for particular questions; for example, the definition of habitat patches in the same landscape varies for different species (Wiens 1989) and may be quite different again if one considers variability in the rates of ecosystem processes. In addition, the interstitial areas may be as important as the patches for some ecological functions (Franklin 1993).

We must continue to expand the spatial scales considered by ecosystem scientists—for example, to develop understanding of the structure and function of entire river systems, and to incorporate disturbance dynamics into the functioning of larger regions. Most ecosystem studies have been oriented toward particular problems and sites, and few have addressed the fluxes of energy or materials across spatial units. A major component of this scaling up should be the enhancement of our knowledge of the movement of materials and energy across heterogeneous systems by combining both theory development and empirical study.

Cross-Disciplinary Linkages

Although ecology is inherently a synthetic science, both disciplinary and subdisciplinary cultures can sometimes impede the cross-fertilization sorely needed to achieve synthesis. Consideration of spatial dynamics may encourage cross-disciplinary linkages among subdisciplines of ecology. For example, scientists can take advantage of a spatial ecological approach to link the actions of species to ecosystem processes. The need for integration between population/community ecology and ecosystem ecology has been widely noted [for example, see Schulze and Mooney (1993) and Jones and Lawton (1995)].

When we consider space explicitly, there is a tremendous opportunity to link the heterogeneity present in ecosystems (for example, primary and secondary productivity, community composition, and nutrient dynamics) with the responses of populations and then with the feedbacks of the populations to the ecosystem. Understanding of the ecosystem will be incomplete without considering these linkages across the domains of traditional ecological disciplines.

Temporal Scale Shifts

Interactions across time scales appear to be key to ecosystem dynamics, temporal variability, and surprise. Slow processes like evolution and pedogenesis provide the foundation or template for ecosystem dynamics. However, human experience and management of ecosystems tend to focus on faster processes like productivity or population interactions. Surprises occur when gradual change in slow processes profoundly alters fast processes that people care about. Examples include atmospheric carbon dioxide and climate change; buildup of fertilizers in soil, and nonpoint nitrogen and phosphorus pollution of surface waters; biodiversity loss and changes in ecosystem process rates; loss of coarse woody debris and changes in recruitment of trees and fishes; exploitation of piscivorous fishes and increasing algal blooms. What are the key time scales of temporal variability in ecosystems? How can we recognize and forecast situations in which gradual change in slow processes will abruptly alter fast variables? Where are the thresholds for the constraints on the fast processes? These questions are fundamental to understanding and predicting ecosystem dynamics.

Contents of This and Future Issues

For this inaugural issue and coming issues, we have invited contributions from research groups that represent the breadth of the discipline. We encourage submission of manuscripts in all areas of ecosystem science.

In this issue, Peterson and colleagues describe a new conceptual framework linking biodiversity and ecosystem processes. Fisher and coworkers present a new model that integrates understanding of material processing by flowing waters and lateral linkages in river corridors. These two papers are syntheses that create new ideas for future research. Papers of this nature should appear regularly in *Ecosystems.* Ives and colleagues consider the approaches to spatial heterogeneity adopted by landscape ecologists and theoretical population ecologists, and discover opportunities for productive exchange across these disciplines. Moen and coworkers integrate effects of alternative foraging strategies by moose on spatial patterns of vegetation and the feedbacks from vegetation back to foraging choices. DeAngelis and colleagues present a spatial model of the Everglades landscape that spans ecosystem processes, vegetation dynamics, and organisms and can be exercised to gain insight for both research and management. This trio of papers establishes a theme of integration between ecosystem ecology and other branches of ecology that we hope will be continued in *Ecosystems.* Fuller and colleagues and Foster and coworkers provide a long-term perspective on how human activity has influenced a regional landscape over both the paleoecological and historical periods, illustrating how important it is to understand the past to explain the present. Elser and colleagues present an ecosystem experiment with surprising results, and suggest that the stoichiometry of ecosystems can determine whether keystone predators are present or absent. Focused ecosystem analyses, as represented by these three papers, should be well represented in *Ecosystems* in the future.

Due to short deadlines, some aspects of ecosystem ecology that should be central to the journal are not represented in this issue. *Ecosystems* is an international journal and future issues will include contributions from many nations.

People and nature is an emerging theme of ecosystem ecology that will be represented more strongly in future issues. For example, studies of ecological economics, property-rights systems, and institutions for integrating human systems and ecosystems are important topics that will be addressed.

Concluding Comments

A new journal should be substrate for primary succession of the discipline. Just as newly opened space creates the opportunity for reorganization and new development of an ecosystem, *Ecosystems* should lead to new ways of thinking and a new era of progress in ecosystem science. As was well stated by Risser (1987) for landscape ecology, now is a time when ecologists must "think bravely and with contemplative recklessness." Too often our productivity and creativity are canalized by intensive competition for funding or journal space. *Ecosystems* is an opportunity for competitive release, expansive creativity, and insightful integration. We look forward to seeing an exciting phase of growth and innovation in ecosystem ecology develop on the pages of this new journal.

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