

# 16

## The Science and Practice of Landscape Ecology

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In his essay, "Second thoughts on paradigms," Thomas Kuhn (1974) illustrated the power of paradigm shifts in the sciences with an analogy to the child's puzzle in which one is asked to find the animal shapes or faces hidden in a drawing of shrubbery or clouds. The child, Kuhn observed, "seeks forms that are like those of the animals or faces he knows. Once they are found, they do not again retreat into the background, for the child's way of seeing the picture has been changed." In the same way, a shift in paradigms changes forever the way scientists view the phenomena they study. Previous theories and methodologies are replaced by new ones. This change is more than a simple shift in emphasis—the scientific worldview and, ultimately, the way scientists conduct their investigations have been altered.

The emergence of landscape ecology as a discipline has catalyzed a shift in paradigms among ecologists and (to the extent that they care about such things as paradigms) resource managers and land-use planners. Having now seen the faces of spatial patterning and scale—the features of landscapes—lurking in our pictures of natural or human-dominated systems, we can never go back to the old ways of viewing things. We can no longer ignore spatial variation and pattern, nor can we continue to cling to the belief that the scale on which we view systems does not affect what we see. We may consider whether the effects of spatial variation and scale are likely to be important in a particular situation (e.g., Kareiva and Wennergren 1995), but we must begin with the presumption that they *do* matter. This is quite a different way of viewing the world than that which was in vogue a decade ago, and it is by no means yet widely embraced by everyone (see, e.g. the statistics on scale awareness compiled by Wiens 1992; Schneider 1994; Chapter 11). But the paradigm shift is inevitable, if we are to further our understanding of ecological systems and their management and sustainable use.

It is remarkable that landscape ecology has played such a role, in view of its ongoing identity crisis and its immaturity as a discipline. This chapter provides some perspective for the other contributions to this volume, first

by considering what I mean by an “identity crisis” and “immaturity,” and then by exploring some aspects of the relationship between landscape ecology as a science and as a practice. I will conclude by noting some themes of the emerging paradigm of landscape ecology, which, if Kuhn’s (1970) thesis applies, will guide our thinking and research into the next millennium.

## The Identity of Landscape Ecology

As Klopatek and Gardner have noted, “landscape ecology” means different things to different people. To some, it is characterized primarily by the tools that are used, especially geographical information systems (GIS; Johnston 1990; Haines-Young et al. 1993). To others, particularly many Europeans, it represents a holistic integration of human geography and ecology with land systems; humans are considered as an integral part of functioning landscape ecosystems (Naveh and Lieberman 1994; Zonneveld 1995). Even within a more strictly biological frame of reference, there are differing views. Thus, the “landscape” may be a level of organization falling somewhere between the community or ecosystem and the biome (O’Neill et al. 1986; Gosz 1993; Lidicker 1995), or a scale somewhere between “local” and “regional” (i.e., tens to thousands of ha; Forman and Godron 1986; Hobbs 1994), or the templet on which spatial patterns influence ecological processes, regardless of scale (Turner 1989; Pickett and Cadenasso 1995; Wiens 1995).

In some ways, this diversity of views about what landscape ecology is represents a strength of the field. It enhances a cross-fertilization of ideas and approaches that contributes to the vitality of the discipline, and it serves to integrate basic science with applications and with humanistic perspectives on landscapes (e.g., Bissonette 1997; Nadenicek 1997; Nassauer 1997). This diversity is much in evidence in the contributions to this volume. There is little doubt that, at a time when “interdisciplinary” science has become the fashion, landscape ecology is among the most interdisciplinary of the sciences. Yet landscape ecology continues to suffer from something of an identity crisis. With so many faces, which one is the “real” landscape ecology? Some European landscape ecologists disparage what they perceive as the “narrow bioecological conceptual and methodological framework” of North American landscape ecology (Naveh and Lieberman 1994), while some North Americans complain (at least in private) about the absence of “science” in the more humanistic approaches the Europeans bring to landscape ecology. Landscape ecology remains, in Hobbs’ (1994) words, “a science in search of itself.” Why is this?

## The Conceptual Immaturity of Landscape Ecology

Scientific disciplines are distinguished by their concepts and theories rather than their “facts.” In a mature discipline, these concepts and theories are unified into a framework that provides a foundation for both research in

and applications of the science. Fields such as genetics, biochemistry, molecular biology, and geology have such conceptual unity. Ecology, on the other hand, does not, and it has therefore been accused of being intellectually immature (Strong et al. 1984; Peters 1991). Hagan (1989) has attributed this apparent immaturity to the historical development of ecology about differing intellectual perspectives, one focused on population processes, the other on flows of materials and energy through ecosystems. Much in the manner of paradigms, these perspectives influence the types of questions ecologists ask and the types of explanations they find acceptable. They are now well established and institutionalized perspectives, and, recent attempts (e.g., Allen and Hoekstra 1992; Jones and Lawton 1995; Ulanowicz 1997) notwithstanding, they continue to defy conceptual integration.

Landscape ecology is a much younger discipline than ecology. Although nascent threads (as well as the name) existed much earlier, the real emergence of landscape ecology as a recognizable field of study dates only from the 1970s (Schreiber 1990; Zonneveld 1995). Nonetheless, Zonneveld (1995), Forman (Chapter 4) and Hobbs (Chapter 2) have suggested that landscape ecology has already developed a solid conceptual and theoretical foundation. The recent development of new technologies and tools for describing, analyzing, and modeling the spatial patterns and dynamics of landscapes (some of which are illustrated in the previous chapters) has also provided a degree of methodological unity to the discipline. Several authors (e.g., Forman 1995; Lidicker 1995; Turner et al. 1995; Golley 1996) have even identified general principles of landscape ecology.

Does landscape ecology therefore have the conceptual unity we expect of a mature science? I think not. In my view, the diversity of approaches and viewpoints in landscape ecology has yet to coalesce about a clear central theme or unifying conceptual structure, much less a body of predictive theory. Thus, although the concept that “scale matters” is a central concern of landscape ecology, we have only fragments of a theory of scaling (Meetenmeyer and Box 1987; Wiens 1989, 1995), and few studies have gathered empirical information that directly addresses scaling effects. Neither are principles such as “all ecosystems in a landscape are interrelated” or “different species may respond differently to a given patch array” really theories. Rather, they are provisional statements that may or may not have an empirical foundation. While they may call attention to particular aspects of landscapes that merit investigation, they do not generate predictions or testable hypotheses. To do that, we need coherent concepts and formalized theories, at least according to conventional views of scientific progress.

## Landscape Ecology as a Science

One can argue, however, with the premise that conceptual unification and the development of predictive theories are really valid measures of the intellectual maturity of a science (e.g., Laudan 1977; Hagan 1989), espe-

cially one that deals with complex relationships such as those that exist in landscapes (Pickett et al. 1994; Hobbs 1997). Landscape ecology is rapidly developing a methodological foundation for dealing with this complexity. As the chapters in Part IV of this volume demonstrate, we now have powerful ways to describe the spatial patterns of landscapes over multiple scales, to conduct rigorous statistical analyses of these patterns, and to incorporate landscape complexity into spatially explicit computer simulation models. But being a science involves more than methods. Landscape ecology also requires a consistent philosophy that stipulates how we should go about gaining knowledge of landscape systems while maintaining rigor.

Following the example of physics, most contemporary scientific disciplines are firmly rooted in causality—the belief that the phenomena and patterns that we see are founded upon simple cause-effect relations and that the power of science lies in deriving the rules or theories (“principles”) that capture the essence of this causation. This philosophy is the basis for Urban’s (1993) observation that “ecological processes generate patterns, and by studying these patterns we [landscape ecologists] can make useful inferences about the underlying processes” (see also Wiens 1997). This philosophy is the basis for the central role of hypothetico-deductive approaches and experimentation in science. A well-designed experiment can factor out potentially complicating sources of variation and permit the investigator to isolate key elements of a proposed process-pattern (i.e., causal) linkage. In this way, incorrect explanations can be falsified and new theories and hypotheses proposed.

The systems studied by landscape ecologists, however, are characterized by complexity and scale dependencies. The complexity means that the potential process-pattern linkages are likely to be sensitive to the details of the spatial configuration of a mosaic and that simple experiments are likely to omit key components among a web of interacting elements. Scale dependency means that it is logistically difficult to conduct experiments at the broad scale of many landscapes. More importantly, it means that what happens at a particular scale may be strongly influenced by the character of the broader-scale landscape as well as by events occurring at finer spatial scales. Hierarchy theory (O’Neill et al. 1986; Ahl and Allen 1996) has called attention to these complicating effects of scale, but it has not developed an effective recipe for dealing with them. Although our ability to discern cause-effect relationship in such complex systems will probably be enhanced if we consider patterns and processes that vary on similar spatial and temporal scales (Meentemeyer and Box 1987; Wiens 1989; Withers and Meentemeyer, Chapter 11), this approach does not ensure that the complicating effects of cross-scale influences will be considered.

The difficulty of establishing simple cause-effect relationships in landscape systems does not mean that we should abandon a philosophy of causality, but it does imply that a strict falsificationist and experimental

model of “proper” scientific investigation may be inappropriate for landscape ecology. Following the arguments of ecologists such as Macfadyen (1975), McIntosh (1987), and Pickett et al. (1994), Hobbs (1997, Chapter 2) has argued for a pluralism of approaches to studying landscapes that embraces their complexity rather than imposes simplicity upon them. Thus, while studies on experimental model systems occupying fine-scale “microlandscapes” (e.g., Wiens and Milne 1989; Barret et al. 1995; Wiens et al. 1995; McIntyre 1997; With 1997) may yield useful insights, they are inevitably limited by their scale and by the particular features of the systems that lend themselves to experimentation. Broad-scale experiments or anthropogenic landscape modifications (e.g., Saunders et al. 1987; Settele et al. 1996; Laurance and Bierregaard 1997) may have greater realism but generally suffer from both a lack of replication and from the confounding effects of covarying factors (Nicholls and Margules 1991; Hargrove and Pickering 1992). Other existing approaches, such as spatial simulation modeling or GIS modeling, or some of the novel techniques described in this volume, need to be combined with new and innovative ways of assessing landscape interrelationships that do not attempt to simplify the complexity that is the essence of landscapes. And, because we still know relatively little about the variety of patterns that exist in landscapes, careful description still has an important role to play (Burke 1997). A relaxation of adherence to a philosophy of strict and simple causality, coupled with a diversity of scientific approaches, probably means that a “conceptual unification” of landscape ecology is still some time away, if indeed it is even a desirable goal.

The problem with such a pluralism of approaches, of course, is that it does not conform to the image of science-as-experiments held by the public as well as by many other scientists. The work of landscape ecologists may therefore be perceived as lacking in rigor or “soft,” being “just descriptive,” or as offering only uncertainty instead of useful predictions. But science does not need to be experimental to be good. What it *does* need is clear logic, sound design, careful measurement, quantitatively rigorous and objective analysis, and thoughtful interpretation. These features are all the more critical if landscape ecology as a science is to mold landscape ecology as a practice.

## Landscape Ecology as a Practice

In the Conclusion to her book, *Placing Nature: Culture and Landscape Ecology*, Joan Nassauer (1997) observed that “landscape ecology should be as much about doing as it is about thinking.” Landscape ecology, from its very beginnings, has been a discipline that transcends the boundary between science and application. Its focus, to varying degrees, is on human land use and its effects, and on how scientific findings and principles can be applied to real-world problems in natural resource management and land-

use planning. Notwithstanding the view that the ecosystem level is an inappropriate level for landscape planning (Zonneveld 1995; Ahern, Chapter 10), landscape ecology has become an important component of ecosystem management (Bartuska, Chapter 3; Coulson et al., Chapter 5; see Christensen et al. 1996). Perhaps because of its relative youth as a science, however, the “principles” that landscape ecology offers are general statements that provide only vague predictions. They do not specify the ways in which spatial phenomena are contingent not only upon landscape structure, but on other features of the environment, the organisms or systems involved, the management objectives, and (of course) the scales of interest. It is fine to argue for the benefits of large natural patches in a developed landscape, as Forman (Chapter 4) has done, but it is important to realize also that these benefits vary as a function of the above features and that bigger is not invariably better. Depending on the characteristics of the organisms and systems considered and one’s objectives (e.g., conservation of an endangered species, enhancement of biodiversity, reduction of soil or nutrient loss), the scales of land management may or may not coincide with the scales on which landscape patterns and processes are actually important.

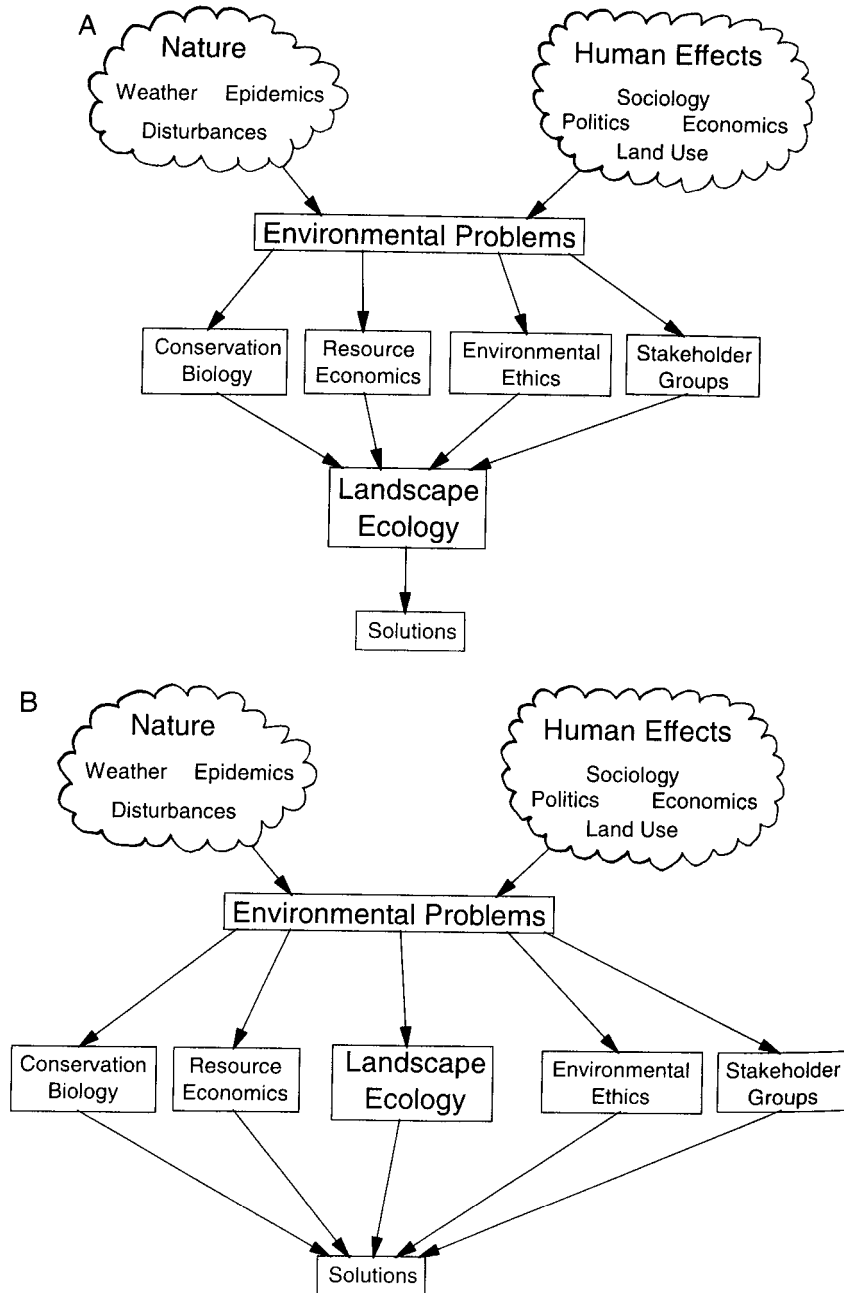
This is not to say that landscape ecology has not yet had important applications. The very recognition that land management or conservation efforts might be directed toward entire landscape mosaics rather than isolated parcels of “habitat” (e.g., McKelvey et al. 1993; Bissonette 1997) is a major advance. Forest ecologists and managers are now considering the spatial consequences of various management activities (Franklin and Forman 1987; Gustafson, Chapter 7) or are incorporating information on natural patterns of landscapes or disturbances into their practices (Lämås and Fries 1995; Forman, Chapter 4). Perhaps the greatest success in putting landscape thinking into practice is in the area of designing nature reserves. Beginning with simple patch-matrix conceptualizations of landscapes derived from island biogeography theory, reserve design has progressed to incorporate the structure of entire landscape mosaics into specifying the properties, configuration, and placement of reserves, as well as recommending compatible uses of the surrounding landscapes (Margules et al. 1988; Pressey et al. 1993; Settele et al. 1996; Csuti et al. 1997; White et al., Chapter 8; Polasky and Solow, Chapter 9).

Landscape ecology, of course, is more than simply a branch of ecology and more than ecologically based land-use management. Its historical roots are, in fact, much broader. In Chapter 1 Paul Risser argues forcefully that landscape ecology must broaden its reach even further, to include economic analysis and social and political forces as explicit components of its structure. For landscape ecology to avoid becoming a science of marginal importance, it must undergo a fundamental reconstruction. A discipline that is arguably not yet even mature is already undergoing a midlife crisis!

As a counterpoint, I would argue that there are real dangers in further diffusing the focus of a discipline that already has some difficulty in establishing its identity. Yes, decisions affecting landscapes *are* made within a social, political, and economic setting, and yes, landscape ecology *must* contribute its findings and expertise and principles (such as they are) to such decisions. The question is, How should this be done? Two (of many) alternatives are depicted in Figure 16.1. Environmental problems, broadly considered, arise from the ways in which the natural patterns and processes of ecological systems interact with an amalgamation of human factors and forces that affect land (or water; Naiman 1996) use. In one view (Risser’s; Fig. 16.1A), landscape ecology should function as an umbrella discipline, integrating the perspectives on environmental problems held by traditionally separate disciplines such as conservation biology, resource economics, environmental ethics, and the like to produce a cohesive picture of the forces that affect landscapes and, from that, possible solutions to the environmental problems. In another view (mine; Fig. 16.1B), landscape ecology represents one of several ways of addressing environmental problems. Each of these disciplines brings to the debate a particular perspective on the problems and a particular set of values, and developing potential solutions involves integrating and balancing information from each. The distinction between the two views represented in Figure 16.1 is important, because it affects how we identify landscape ecology as a discipline, how we do landscape ecology, and how we train students and practitioners.

The reality, of course, and the impetus behind Risser’s appeal, is that traditionally separate disciplines usually approach environmental problems independently of one another. The power of Risser’s thesis is that landscape ecology could act as an integrating discipline, bringing together disparate viewpoints to produce a broad-based and unified approach to environmental problems. I maintain, however, that this breadth will weaken landscape ecology, leading to a loss of rigor and credibility. The strength of landscape ecology lies in the distinctiveness of its approach—its emphasis on spatial patterns and relationships, scaling, heterogeneity, boundaries, and flows of energy and materials in space. This approach should not be diluted, but should be brought to bear on major issues in a coherent way, with a strong foundation in science. Landscape ecology can have this impact, however, only if there is vigorous communication among the various disciplines addressing environmental problems. This will not happen without an active effort to break down the boundaries of traditional disciplines and to make the ideas and findings of landscape ecology clear and comprehensible to workers in other arenas (and vice versa). As Joan Nassauer (1997) has observed, we must cross disciplinary boundaries to ask cultural questions informed by science and to ask scientific questions informed by culture.

Being “scientific,” however, does not mean that landscape ecology should focus exclusively or even primarily on scientific questions. I concur



with Risser's concern that landscape ecology should not stand aside dealing with traditional science while landscapes are converted to urban sprawl and parking lots or are planned or managed in ways that clearly are not sustainable. Even at its present stage of development, landscape ecology has ample insights to offer to those charged with land or resource management or involved in land use or urban planning or concerned about conservation issues.

### Conclusions: Elements of the Emerging Paradigm

"Embrace complexity" might well be the mantra of landscape ecologists. In fact, landscape ecologists have little choice but to deal with complexity. It is what comes of an explicit focus on spatial patterning and scale. If anything serves to unify the various approaches to landscape ecology, it is the shared concern about the causes and consequences of spatial heterogeneity and the effects of changes in scale on these relationships. Beyond this focus, it may not matter much whether or not landscape ecology develops "conceptual unity" (there are some advantages in never growing up!). What is important, however, is that the discipline develop formalized concepts and predictive theories of some sorts, and that answers to questions be founded upon a firm base of science. Clearly, there is no single "best" way of doing landscape ecology. The questions landscape ecologists ask require a diversity of tools and methods to answer, and they may be approached from a variety of directions. The key point is that the methods and approaches must be quantitatively rigorous and logically sound.

And what are the questions? In 1983, a workshop was held at Allerton Park, Illinois, to develop recommendations concerning the current and future status and the importance of landscape ecology (Risser et al. 1984; see Risser 1995). The workshop participants identified four central questions of landscape ecology:

- How are fluxes of organisms, or material, and of energy related to landscape heterogeneity?

FIGURE 16.1. The role of landscape ecology in contributing to solutions to environmental problems. Environmental problems arise from a conflict between nature and land use, which in turn is influenced by factors such as politics, sociology, and economics. In (A), different disciplines or interest groups respond to the environmental problems from particular perspectives. Landscape ecology then serves as an integrating discipline, pulling together the separate perspectives to produce comprehensive solutions. In (B), landscape ecology is viewed as making its own distinctive contribution to solutions, in concert with the perspectives of other approaches or interest groups.

- What formative processes, both historical and present, are responsible for the existing pattern in a landscape?
- How does landscape heterogeneity affect the spread of disturbances?
- How can natural resource management be enhanced by a landscape ecology approach?

To see how things have changed, consider the questions posed by Turner in a chapter on landscape ecology in a current undergraduate ecology text (1998):

- How does the spatial arrangement of habitat influence the presence and abundance of species?
- Does the surrounding landscape influence local populations?
- Do landscape patterns affect the transport of materials from land to water?
- How do ecosystem processes vary spatially?
- How are disturbances an integral part of landscapes?

There is a slight difference in emphasis, perhaps reflecting an increased influence of conservation issues in landscape ecology, but not much has really changed. Both sets of questions stress the ecological aspects of landscape ecology, and people interested in land use policy, landscape geography, or landscape architecture would frame the questions using different terms. But the thrust of the questions, I suspect, would be similar. They define the central themes of landscape ecology: spatial variation, scaling, boundaries, and flows. These are, indeed, the core elements of the emerging paradigm of landscape ecology—a science *and* a practice.

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