Landscape Ecology

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What Is Landscape Ecology?

Landscape ecology has been defined in various ways partly because the word 'landscape' means quite different things to people with different scientific and cultural backgrounds. Landscapes are spatial mosaics of interacting biophysical and socioeconomic components (**Figure 1**). Just as in other ecological disciplines, a spectrum of views exists as to the relative salience or prominence of the two aspects of landscapes. The diversity of perspectives can often be related to the philosophical underpinnings of reductionism versus holism. Nevertheless, few would disagree that landscapes are compositionally diverse and spatially heterogeneous. A general definition of landscape ecology may be the science and art of studying and improving the relationship between spatial pattern and ecological processes on a multitude of scales and organizational levels. Landscape ecology is not only a field of study, but also represents a new scientific perspective or paradigm that is relevant to a range of ecological, geophysical, and social sciences.

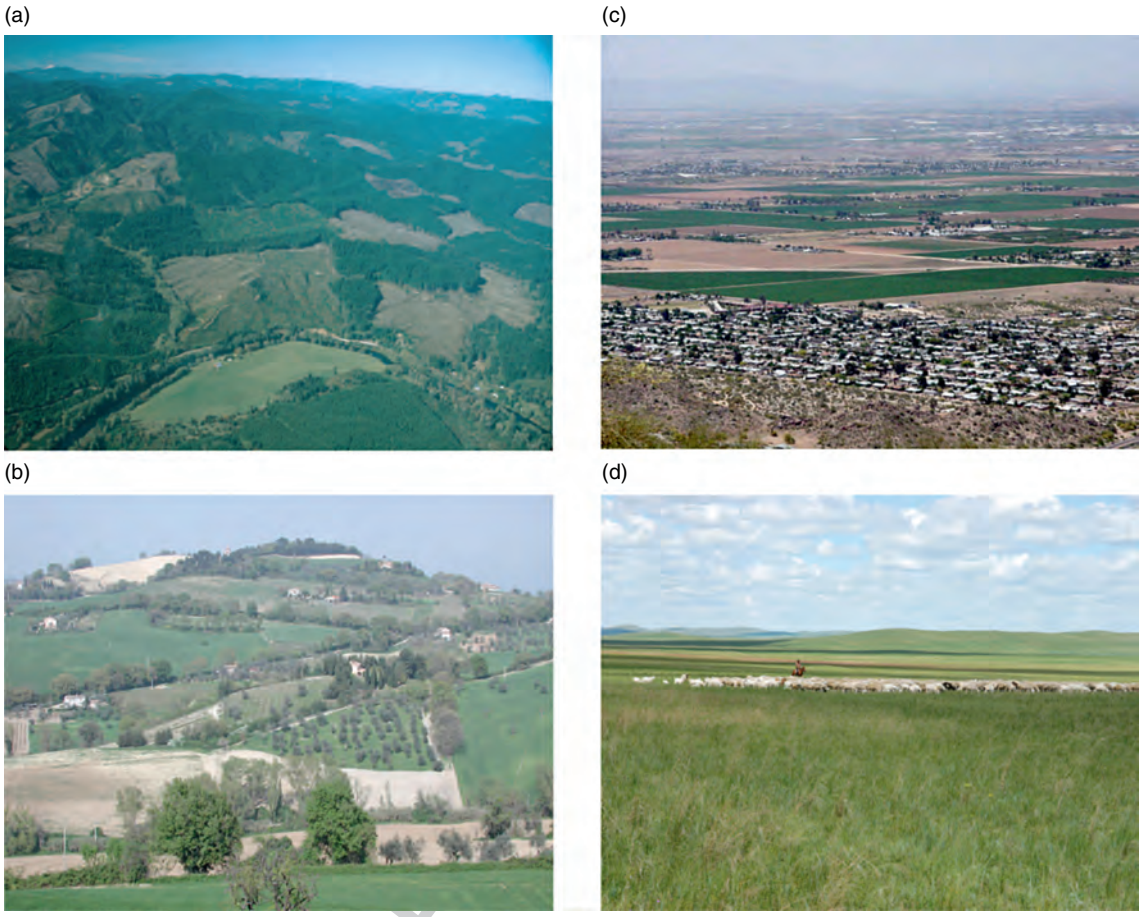
Heterogeneity, scale, pattern–process relationships, hierarchy, disturbance, coupled ecological–social dynamics, and sustainability are among the key concepts in landscape ecology. Typical research questions include: How can spatial heterogeneity be quantified so that it can be related to relevant ecological processes? What are the processes and mechanisms responsible for existing landscape patterns? How does spatial heterogeneity influence the flows of organisms, material, and energy? How does landscape pattern affect the spread of disturbances such as pest outbreaks, diseases, fires, and invasive species? How do patterns and processes on different scales relate to each other? How can ecological information be translated from fine to broad scales and vice versa? How can the knowledge of spatial heterogeneity help improve biodiversity conservation, planning, and management? How can sustainable landscapes be developed and maintained?

Studies in landscape ecology usually involve the extensive use of spatial information from field survey, aerial photography, and satellite remote sensing, as well as pattern indices, spatial statistics, and computer simulation modeling. The intellectual thrust of this highly interdisciplinary enterprise is to understand the causes, mechanisms, and consequences of spatial heterogeneity, while its ultimate goal is to provide a scientific basis and practical guidelines for developing and maintaining ecologically, economically, and socially sustainable landscapes (**Figure 2**).

Evolving Perspectives in Landscape Ecology

Contemporary landscape ecology is characterized by a flux of concepts and perspectives that reflect the differences in the origins of ideas and the ways of thinking, both of which are shaped by physical and cultural landscapes. The term 'landscape ecology' was coined in 1939 by the German geographer, Carl Troll, who was inspired by the spatial patterning of landscapes revealed in aerial photographs and the ecosystem concept developed in 1935 by the British ecologist, Arthur Tansley. Troll saw the need for combining the more structurally oriented geographical approach with the more functionally centered ecosystem approach, in order to allow for geography to acquire ecological knowledge of land units and for ecology to expand its analysis from local sites to larger regions. Thus, he defined landscape ecology as the study of the relationship between biological communities and their environment in a landscape mosaic on various spatial scales. At the same time, Troll also emphasized the holistic totality of the landscape which was perceived as something of a gestalt (an integrated system organized in such a way that the whole cannot be described merely as the sum of its parts). This holistic and humanistic landscape perspective, focusing on landscape mapping, evaluation, conservation, planning, design, and management, was embraced and further developed primarily in Europe, and has become a hallmark of landscape ecology.

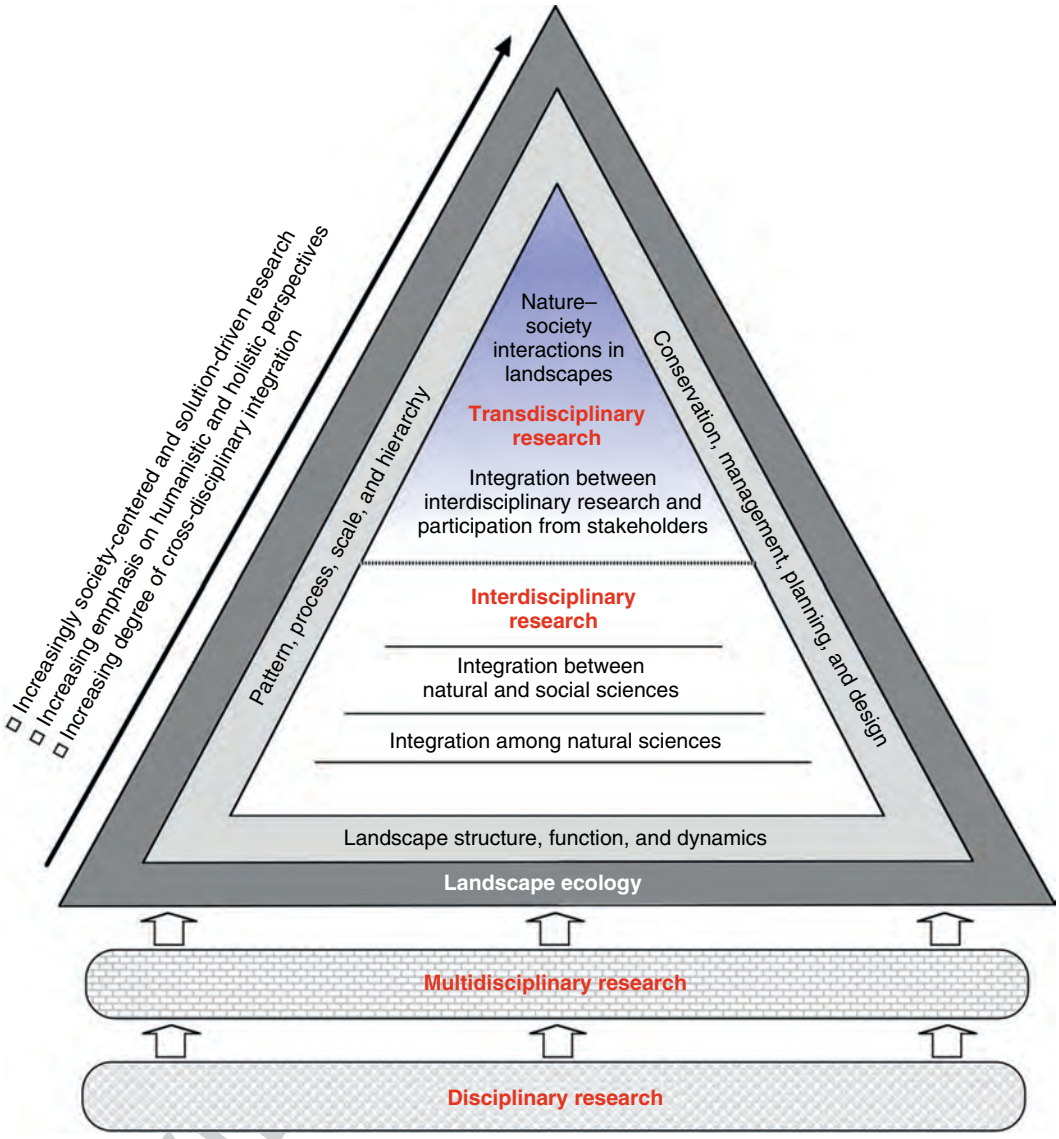
The concept of landscape ecology was introduced from Europe to North America in the early 1980s, and subsequently stimulated the rapid development of a stream of new ideas, theories, methods, and applications. As a result, the field of landscape ecology quickly flourished in North America, and became a widely recognized



f0005 **Figure 1** Different kinds of landscapes as spatial mosaics of various patches on a range of scales. (a) A forested landscape from North America (photo by Tom Spies), (b) an agricultural landscape in Europe (photo by Almo Farina), (c) a metropolitan landscape in the Sonoran Desert, USA (photo by Jianguo Wu), and (d) a grassland landscape in the Mongolia Plateau, China (photo by Yongfei Bai).

scientific discipline by the mid-1990s around the world. Some of the early publications in North America defined a landscape as a kilometers-wide land area with repeated patterns of local ecosystems. However, most landscape ecologists now consider such definition too narrow and rigid. Instead, the most widely accepted definition of landscape is simply a spatially heterogeneous area whose spatial extent varies according to research questions and processes of interest. This multiple-scale concept of landscape is more appropriate as it facilitates the theoretical and methodological developments of this interdisciplinary field by promoting micro-, meso-, and macroscale approaches. Despite their variations in details, the definitions of landscape ecology in North America all hinge on the idea of spatial heterogeneity. In particular, the North American landscape ecology focuses on the relationship between spatial pattern and ecological processes on multiple scales ranging from tens and hundreds of square meters to thousands of square kilometers in space and from a particular point to a period of several decades in time. Its primary goal is to understand the causes, mechanisms, and ecological consequences of spatial heterogeneity.

p0030 More specifically, North American landscape ecology has had a distinct emphasis on the effects of spatial pattern on biodiversity, population dynamics, and ecosystem processes in a heterogeneous area. This research emphasis is practically motivated by the fact that previously contiguous landscapes have rapidly been replaced by a patchwork of diverse land uses (landscape fragmentation), and conceptually linked to the theory of island biogeography developed in the 1960s and the perspective of patch dynamics that began to take shape in the 1970s. Island biogeographic theory relates the equilibrium-state species diversity of islands to their size (area effect on species extinction rate) and distance to the mainland (distance effect on species immigration rate). The heuristic value of the theory is apparent for understanding the ecology of habitat patches submerged in a sea of human land uses. The patch dynamics perspective, on the other hand, treats ecological systems as mosaics of interacting patches of different size, shape, kinds, and history,



f0010 **Figure 2** A hierarchical and pluralistic view of landscape ecology. 'Hierarchical' refers to the multiplicity of organizational levels, spatiotemporal scales, and degrees of cross-disciplinarity in landscape ecological research. 'Pluralistic' indicates the necessity to recognize the values of different perspectives and methods in landscape ecology dictated by its diverse origins and goals. Modified from Wu J (2006) Cross-disciplinarity, landscape ecology, and sustainability science. *Landscape Ecology* 21: 1–4.

emphasizing the transient dynamics and cross-scale linkages of such patchy systems. In this view, a forest is no more than a dynamic mosaic of tree gaps of various age, species composition, and biophysical properties; thus the dynamics of the forest can be adequately predicted by aggregating the behavior of individual tree gaps. The perspective of patch dynamics has been evident in the conceptual development of landscape ecology in the recent decades.

p0035 In summary, the European approach is more humanistic and holistic in that it emphasizes a society-centered view that promotes place-based and solution-driven research. In contrast, the North American approach is more biophysical and analytical in that it has been dominated by a biological ecology-centered view that is driven primarily by scientific questions. Here the author hastens to point out that this dichotomy most definitely oversimplifies the reality because such geographic division conceals the diverse and continuously evolving perspectives within each region. In fact, many ecologists in North America have recognized the importance of humans in shaping landscapes for several decades (especially since the Dust Bowl in the 1930s). Although humans and their activities have been treated only as one of many factors interacting with spatial heterogeneity, more integrative studies have been emerging rapidly in the past few

decades with the surging interest in urban ecology and sustainability science in North America. On the other hand, the perspective of spatial heterogeneity has increasingly been recognized by landscape ecologists in Europe and the rest of the world. Thus, the current development of landscape ecology around the world seems to suggest a transition from a stage of diversification to one of consolidation (if not unification) of key ideas and approaches.

p0040 In fact, both the European and North American approaches can be traced back to the original definition of landscape ecology. Carl Troll's proposal to integrate the geographical and structural approach with the ecological and functional approach is best reflected in the pattern–process–scale perspective, which enhances the scientific rigor of landscape ecology. The holistic and humanistic perspective, on the other hand, epitomizes the idea of landscape as a nature–society coupled system embraced by Troll and others. This perspective is entailed by any attempt to tackle practical problems in real landscapes on broad scales. Both the European and North American perspectives are essential to the development of landscape ecology as a truly interdisciplinary science.

s0015 Some Key Topics in Landscape Ecology

p0045 Landscape ecology, as a relatively young scientific enterprise, is quite comprehensive and dynamic in its scope. As with other interdisciplinary fields, it is impossible to define precisely the domain of landscape ecological studies. To get a sense of what the scientific core of landscape ecology is, a series of key research topics based on the collective view of leading landscape ecologists and recent publications in the flagship journal of the field, *Landscape Ecology* (http://www.springeronline.com), are discussed here. Five key topics are highlighted in this section.

1. *Ecological flows in heterogeneous landscapes.* Understanding how organisms, matter, and energy affect, and are affected by, the spatial pattern of landscape mosaics is a fundamental problem in landscape ecology. Much progress has been made in unraveling the effect of spatial heterogeneity on the spread of disturbances (e.g., fires and diseases) and the influence of landscape fragmentation on population dynamics, particularly through studies of metapopulations (structurally discrete and functionally connected population ensembles). Research into the effects of landscape pattern on ecosystem pro-
AU3 cesses, while still in their infancy, is currently a rapidly developing area. Important areas for future research also include the spread of invasive species, the effects of landscape structure on population genetics (known as landscape genetics), and the effects of socioeconomic processes on ecological flows in landscape mosaics.

2. *Mechanisms and consequences of land-use and land-cover change.* Land-use and land-cover change, driven primarily by socioeconomic processes, exerts the most pervasive and profound influences on the structure and functioning of landscapes. Thus, quantifying the spatiotemporal pattern of landscape change and understanding its underlying driving forces are essential. More effort is needed to couple biophysical with socioeconomic approaches and to integrate ecological with historical methods in the study of land change.

3. *Scaling.* Spatial pattern and ecological and socioeconomic processes in heterogeneous landscapes operate on multiple scales, and thus understanding the totality of landscapes requires relating different phenomena across domains in space and time. The process of translating information from one scale or organizational level to another is referred to as scaling. Landscape ecologists are leading the way in developing the theory and methods of scaling, which is essential to all natural and social sciences. However, many challenges still remain, including establishing scaling relations for a variety of landscape patterns and processes as well as integrating ecological and socioeconomic dimensions in a coherent scaling framework.

4. *Coupling landscape pattern analysis with ecological processes.* Quantifying spatial heterogeneity is the necessary first step to understanding the effects of landscape pattern on ecological processes. Various effects of the compositional diversity and spatial configuration of landscape elements have been well documented, and a great number of landscape metrics (synoptic measures of landscape pattern) and spatial analysis methods have been developed in the past two decades. The greatest challenge, however, is to relate the measures of spatial pattern directly to the processes and properties of biodiversity and ecosystem functioning. To address these challenges, well-designed field-based observational and experimental studies are indispensable, and remote sensing techniques, geographic information systems (GIS), spatial statistics, and simulation modeling are also necessary.

5. *Landscape conservation and sustainability.* Because of the emphasis on broad- and multiscale patterns and processes with interdisciplinary approaches, landscape ecology is uniquely positioned to provide a comprehensive theoretical basis and pragmatic guidelines for biodiversity conservation, ecosystem management, and sustainable development. These real-world problems cannot be adequately addressed by species-centered or individual ecosystem-based approaches. How do spatial processes occurring in landscapes (e.g., urbanization, agriculture, flooding, fires, biological invasion) affect the biodiversity and ecological functioning of landscapes? How does landscape heterogeneity affect the relationship

between biodiversity and ecosystem functioning? How do ecological, economic, and social processes interact to determine the resilience and vulnerability of landscapes? What are the design principles for sustainable landscapes? These are only a few of many challenging questions landscape ecology will continue to address in decades to come.

s0020 Concluding Remarks

p0050 Emphasis on heterogeneity begs questions of the relationship between pattern and process. Simply put, heterogeneity is about structural and functional patterns that deviate from uniform and random arrangements. It is this pervasively common nonhomogeneous characteristic that makes spatial patterns ecologically important as it suggests nontrivial relationship to underlying processes. Thus, studying pattern without getting to process is superficial, and understanding process without reference to pattern is incomplete. Emphasis on heterogeneity also makes scale a critically important issue because heterogeneity, as well as the relationship between pattern and process, may vary as the scale of observation or analysis is changed. Thus, whenever heterogeneity is emphasized, spatial structures, underlying processes, and scale inevitably become essential objects of study. From this perspective, landscape ecology is a science of heterogeneity and scale. On the other hand, with increasing human dominance in the biosphere, emphasis on broad spatial scales makes inevitable to deal with humans and their activities. As a consequence, humanistic and holistic perspectives have been and will continue to be central in landscape ecological research.

p0055 The above arguments also, in part, explain the two seemingly disparate views that have become known as the European and North American perspectives in landscape ecology. The world is already too fragmented ecologically, economically, and socially, and we certainly do not need a landscape ecology for each continent! As discussed earlier, the two perspectives should be viewed as being complementary rather than contradictory. To increase the synergies between the two approaches, not only do we need to appreciate the values of each, but also to develop an appropriate framework by which different perspectives and methods can be integrated. This requires a pluralistic and multiscale perspective (**Figure 2**). Landscapes out there are messy and are increasingly being messed up. Landscape ecology not only is expected to provide the scientific understanding of the structure and functioning of various landscapes, but also the pragmatic guidelines and tools with which order and sustainability can be created and maintained for the ever-changing landscapes.

See also: 00677; 00659; 00672; 00293; 00633; 00502; 00192; 00062; 00193; 00804.

Further Reading

Forman RTT (1995) *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge: Cambridge University Press. b0005

Gutzwiller KJ (ed.) (2002) *Applying Landscape Ecology in Biological Conservation*. New York: Springer. b0010

Naveh Z and Lieberman AS (1994) *Landscape Ecology: Theory and Application*. New York: Springer. b0015

Pickett STA and Cadenasso ML (1995) Landscape ecology: Spatial heterogeneity in ecological systems. *Science* 269: 331–334. b0020

Turner MG (2005) Landscape ecology: What is the state of the science? *Annual Review of Ecology and Systematics* 36: 319–344. b0025

Turner MG, Gardner RH, and O'Neill RV (2001) *Landscape Ecology in Theory and Practice: Pattern and Process*. New York: Springer. b0030

Wiens J and Moss M (eds.) (2005) *Issues and Perspectives in Landscape Ecology*. Cambridge: Cambridge University Press. b0035

Wu J (2006) Cross-disciplinarity, landscape ecology, and sustainability science. *Landscape Ecology* 21: 1–4. b0040

Wu J and Hobbs R (eds.) (2007) *Key Topics in Landscape Ecology*. Cambridge: Cambridge University Press. b0045

Relevant Website

http://www.springeronline.com – Landscape Ecology Journals, Books, and Online Media, Springer.

Wu, J. 2008. Landscape ecology. In: S. E. Jorgensen (ed), Encyclopedia of Ecology. Elsevier, Oxford. pp. **2103-2108**

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Abstract

Ecological systems are diverse and heterogeneous. Landscape ecology is the science and art of studying and improving the relationship between spatial pattern and ecological processes on a multitude of scales and organizational levels. In a broad sense, landscape ecology represents both a field of study and a scientific perspective or paradigm. As a highly interdisciplinary and transdisciplinary enterprise, landscape ecology integrates biophysical and analytical approaches with humanistic and holistic perspectives across natural and social sciences. Landscapes are spatially heterogeneous geographic areas characterized by diverse interacting patches or ecosystems, ranging from relatively natural terrestrial and aquatic systems such as forests, grasslands, and lakes to human-dominated environments including agricultural and urban settings. The most salient characteristics of landscape ecology are its unequivocal emphasis on the relationship among pattern, process, and scale and its focus on broad-scale ecological and environmental issues that necessitates the coupling between biophysical and socioeconomic processes. Key research topics in landscape ecology include ecological flows in landscape mosaics, land-use and land-cover change, scaling, relating landscape pattern analysis with ecological processes, and landscape conservation and sustainability.