15

Landscape ecology: the state-of-the-science

15.1 Introduction

Good science starts with precise definitions because clearly defined terminology is a prerequisite for any fruitful scientific discourse. For rapidly developing interdisciplinary sciences like landscape ecology, unambiguous definitions are particularly important. Contemporary landscape ecology is characterized by a flux of ideas and perspectives that cut across a number of disciplines in both natural and social sciences, as evidenced in the previous chapters of this volume. On the one hand, after having experienced an unprecedented rapid development in theory and practice in the past two decades, landscape ecology has become a globally recognized scientific enterprise. On the other hand, more than 65 years after the term "landscape ecology" was first introduced, landscape ecologists are still debating on what constitutes a landscape and what landscape ecology really is (e.g., Wiens 1992, Hobbs 1997, Wiens and Moss 1999, Wu and Hobbs 2002).

Two major schools of thought in landscape ecology have widely been recognized: the European approach that is more humanistic and holistic and the North American approach that is more biophysical and analytical. To increase the synergies between the two approaches, not only do we need to appreciate the values of both approaches, but also to develop an appropriate framework in which different perspectives and methods are properly related. Toward this end, in this chapter we shall compare and contrast the European and North American approaches through several exemplary definitions (see Table 15.1). We shall argue that both approaches can be traced back to the original definition of landscape ecology, and that recent developments seem to show a tendency for unification of once diverging perspectives. Then, we shall propose a

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TABLE 15.1. *A list of exemplary definitions of landscape ecology*

Definition	Source
The German geographer Carl Troll coined the term "landscape ecology" in 1939, and defined it in 1968 as "the study of the main complex causal relationships between the life communities and their environment in a given section of a landscape. These relationships are expressed regionally in a definite distribution pattern (landscape mosaic, landscape pattern) and in a natural regionalization at various orders of magnitude" (Troll 1968; cited in Troll 1971).	• Troll, C. 1939. Luftbildplan and okologische bodenforschung. *Zeitschraft der Gesellschaft fur Erdkunde Zu Berlin* 241–98. • Troll, C. 1968. Landschaftsokologie. Pages 1–2 in *Pflanzensoziologie und Landschaftsokologie – Symposium Stolzenau*. Junk: The Hague. • Troll, C. 1971. Landscape ecology (geoecology) and biogeocenology – a terminological study. *Geoforum* 8, 43–6.
"Landscape ecology is an aspect of geographical study which considers the landscape as a holistic entity, made up of different elements, all influencing each other. This means that land is studied as the 'total character of a region' , and not in terms of the separate aspects of its component elements" (Zonneveld 1972).	• Zonneveld, I. S. 1972. *Land Evaluation and Land(scape) Science*. Enschede, The Netherlands: International Institute for Aerial Survey and Earth Sciences.
"Landscape ecology is a young branch of modern ecology that deals with the interrelationship between man and his open and built-up landscapes" based on general systems theory, biocybernetics, and ecosystemology (Naveh and Liberman 1984). "Landscapes can be recognized as tangible and heterogeneous but closely interwoven natural and cultural entities of our total living space," and landscape ecology is "a holistic and transdisciplinary science of landscape study, appraisal, history, planning and management, conservation, and restoration" (Naveh and Liberman 1994).	• Naveh, Z. and A. S. Lieberman. 1984. *Landscape Ecology: Theory and Application*. New York: Springer-Verlag. • Naveh, Z. and A. S. Lieberman. 1994. *Landscape Ecology: Theory and Application*, 2nd edn. New York: Springer-Verlag.
"A landscape is a kilometers-wide area where a cluster of interacting stands or ecosystems is repeated in similar form; landscape ecology, thus, studies the structure, function and development of landscapes" (Forman 1981). Landscape structure refers to "the spatial relationships among the distinctive ecosystems;" landscape function refers to "the flows of energy, materials, and species among the component ecosystems;" and landscape change refers to "the alteration in the structure and function of the ecological mosaic over time" (Forman and Godron 1986).	• Forman, R. T. T. 1981. Interaction among landscape elements: a core of landscape ecology. Pages 35–48 in S. P. Tjallingii and A. A. de Veer (eds.). *Perspectives in Landscape Ecology*. Wageningen: Pudoc. • Forman, R. T. T. and M. Godron. 1986. *Landscape Ecology*. New York: John Wiley & Sons Inc.

"Landscape ecology focuses explicitly upon spatial pattern. Specifically, landscape ecology considers the development and dynamics of spatial heterogeneity, spatial and temporal interactions and exchanges across heterogeneous landscapes, influences of spatial heterogeneity on biotic and abiotic processes, and management of spatial heterogeneity" (Risser *et al.* 1984). "Landscape ecology is not a distinct discipline or simply a branch of ecology, but rather is the synthetic intersection of many related disciplines that focus on the spatial-temporal pattern of the landscape" (Risser *et al.* 1984).	• Risser, P.G., J.R. Karr, and R.T.T. Forman. 1984. *Landscape Ecology: Directions and Approaches*. Special Publication 2. Champaign: Illinois Natural History Survey.
"Landscape ecology emphasizes broad spatial scales and the ecological effects of the spatial patterning of ecosystems" (Turner 1989).	• Turner, M.G. 1989. Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics* 20, 171–97.
"Landscape ecology is the study of the reciprocal effects of the spatial pattern on ecological processes," and "concerns spatial dynamics (including fluxes of organisms, materials, and energy) and the ways in which fluxes are controlled within heterogeneous matrices" (Pickett and Cadenasso 1995).	• Pickett, S.T.A. and M.L. Cadenasso. 1995. Landscape ecology: spatial heterogeneity in ecological systems. *Science* 269, 331–4.
"Landscape ecology investigates landscape structure and ecological function at a scale that encompasses the ordinary elements of human landscape experience: yards, forests, fields, streams, and streets" (Nassauer 1997).	• Nassauer, J.I. 1997. Culture and landscape ecology: insights for action. Pages 1–11 in J.I. Nassauer (ed.). *Placing Nature: Culture and Landscape Ecology*. Washington, DC: Island Press.
Landscape ecology is "ecology that is spatially explicit or locational; it is the study of the structure and dynamics of spatial mosaics and their ecological causes and consequences" and "may apply to any level of an organizational hierarchy, or at any of a great many scales of resolution" (Wiens 1999).	• Wiens, J.A. 1999. Toward a unified landscape ecology. Pages 148–51 in J.A. Wiens and M.R. Moss (eds.). *Issues in Landscape Ecology*. Snowmass Village: International Association for Landscape Ecology.
"Landscape ecology emphasizes the interaction between spatial pattern and ecological process, that is, the causes and consequences of spatial heterogeneity across a range of scales" (Turner *et al.* 2001). "Two important aspects of landscape ecology . . . distinguish it from other subdisciplines within ecology": "First, landscape ecology explicitly addresses the importance of spatial configuration for ecological processes" and "second, landscape ecology often focuses on spatial extents that are much larger than those traditionally studied in ecology, often, the landscape as seen by a human observer" (Turner *et al.* 2001).	• Turner, M.G., R.H. Gardner, and R.V. O' Neill. 2001. *Landscape Ecology in Theory and Practice: Pattern and Process*. New York: Springer-Verlag.

hierarchical and pluralistic cross-disciplinary framework for promoting interactions and synergies between different perspectives and methods. Finally, the relevance of this framework to the admirable but elusive goal of unification will be discussed.

15.2 Two dominant approaches to landscape ecology

15.2.1 The European approach

The term landscape ecology was coined by the German geographer, Carl Troll (1939), who was inspired especially by the spatial patterns of landscapes captured by aerial photographs and the ecosystem concept put forward by Arthur Tansley (1935). This new field of study was proposed to combine the horizontal–geographical–structural approach with the vertical–ecological–functional approach, in order to meet the needs for geography to acquire ecological knowledge of land units and for ecology to expand its analysis from local sites to the region (Troll 1971). For example, information obtained from local sites through ground-based work can be "extended areally by means of knowledge of the distribution of the ecosystems derived from air photograph study" (Troll 1971). From its very beginning, landscape ecology evidently had a close conceptual relationship with ecosystem ecology. In a formal definition, Troll (1968) described landscape ecology as "the study of the main complex causal relationships between the life communities and their environment in a given section of a landscape. These relationships are expressed regionally in a definite distribution pattern (landscape mosaic, landscape pattern) and in a natural regionalization at various orders of magnitude" (Troll 1968, 1971). While the above definition seems semantically indistinguishable from that of ecosystem ecology, Troll's explanation of the "complex causal relationships" points to three important characteristics that distinguish landscape ecology from ecosystem ecology: (1) broad spatial scales, (2) spatial pattern, and (3) multiplicity of scales.

In addition, a landscape as perceived by Troll (1939, 1971) includes humans in addition to its physical and biological components, as does the ecosystem by Tansley (1935). Like other holistic geographers in Europe and Russia of that time, Troll considered a landscape as something of a *Gestalt* (a German word referring to a configuration of elements or an integrated system organized in such a way that the whole cannot be described merely as the sum of its parts). Zonneveld (1972) further emphasized the holistic totality of the landscape while defining landscape ecology as part of the applied science of land evaluation and planning (Table 15.1). Oddly, he claimed unequivocally that landscape ecology was not part of the biological sciences, but a branch of geography. The

holistic landscape perspective culminated in Naveh's and Liberman's (1984, 1994) work which described a landscape as a biocybernetic subsystem of the so-called "Total Human Ecosystem" – "the highest level of co-evolutionary complexity in the global ecological hierarchy" (Naveh 2000). Naveh (1991) further stated that "Landscape ecology deals with landscapes as the total spatial and functional entity of natural and cultural living space. This requires the integration of the geosphere with the biosphere and the noospheric human-made artifacts of the technosphere." This is essentially what is called the "holistic landscape ecology," often described as a transdisciplinary environmental science (Naveh 2000).

In general, most landscape ecological studies in Europe since the 1930s have reflected more of the humanistic and holistic perspective, involving landscape mapping, evaluation, conservation, planning, design, and management (Zonneveld 1972, Naveh and Lieberman 1984, Schreiber 1990, Bastian and Steinhardt 2002). However, it should be pointed out that, influenced by geographic and socioeconomic settings as well as academic and cultural traditions, European landscape ecological studies do vary in terms of the research focus and methodology, ranging from tedious technical mapping of heavily populated areas and systematic land evaluation, to philosophical (and sometimes enigmatic) discourses of the wholeness of landscapes. Some of the fine traditions and exciting new developments in European landscape ecology are well reflected in several chapters of this volume (e.g., Antrop, Chapter 10, Voss *et al.*, Chapter 13, Fry *et al.*, Chapter 14).

15.2.2 The North American approach

Landscape ecology was introduced to North America in the early 1980s (Forman 1981, Risser *et al.* 1984, Forman and Godron 1986), more than 40 years after it had been practiced in central Europe, focusing on the human–land systems. In the following decade, landscape ecology quickly flourished in North America with a stream of new perspectives and methods (Forman 1990, Turner 2005; also see Iverson, Chapter 2 of this volume for an interesting and personable account of the early days of North American Landscape Ecology). Consequently, landscape ecology became a well-recognized scientific discipline around the world by the mid-1990s. In their ground-breaking book, Forman and Godron (1986) defined landscape ecology as the study of the structure, function, and change of landscapes of kilometers wide over which local ecosystems repeat themselves (also see Forman 1995). Landscape structure refers to "the spatial relationships among the distinctive ecosystems"; function refers to "the flows of energy, materials, and species among the component ecosystems"; and change refers to "the alteration in the structure and

function of the ecological mosaic over time" (Forman and Godron 1986). This definition of landscape ecology is consistent with Troll's original definition in that both aim to integrate the spatial pattern of landscapes with ecological processes within them. However, Forman and Godron (1981, 1986) provided the first systematic conceptual framework for studying landscape pattern and processes, signified by the patch–corridor–matrix model. As a convenient spatial language, this model has played an important role in promoting the development of landscape ecology worldwide since the 1980s.

Several other definitions of landscape ecology have been developed in North America (see Table 15.1). In particular, the report by Risser *et al.* (1984) was an important landmark publication because it reflected the collective view by North American ecologists on what landscape ecology should be and because it has served as a blueprint for the development of landscape ecology in North America in the past decades. The document is a synthesis of a workshop on landscape ecology held in the USA in April 1983, with 25 participants many of whom were leading ecologists and geographers (23 from the USA, 1 from Canada, and 1 from France). Risser *et al.* (1984) defined landscape ecology as the study of the development, management, and ecological consequences of spatial heterogeneity, or "the relationship between spatial pattern and ecological processes [that] is not restricted to a particular scale." They further identified four "representative questions" in landscape ecology: (1) How does landscape heterogeneity interact with fluxes of organisms, material, and energy? (2) What formative processes, both historical and present, are responsible for the existing pattern in a landscape? (3) How does landscape heterogeneity affect the spread of disturbances (e.g., pest outbreaks, diseases, fires)? (4) How can natural resource management be enhanced by a landscape approach? These earlier ideas of landscape ecology in North American were significantly influenced by the theory of island biogeography (MacArthur and Wilson 1967, Wu and Vankat 1995) and patch dynamics (Levin and Paine 1974, Pickett and White 1985, Wu and Loucks 1995).

In line with Risser *et al.* (1984), the different definitions developed in North America all have considered spatial heterogeneity as the cornerstone of landscape ecology. Of course, this does not mean that all North American landscape ecologists hold the same view on landscape ecology. Their major differences seem to hinge on how a landscape is perceived. In the seminal work of Forman and Godron (1981, 1986), a landscape is a kilometers-wide land area with repeated patterns of local ecosystems (also see Forman 1995). But most landscape ecologists consider landscape simply as a spatially heterogeneous area whose spatial extent varies depending on the organisms or processes of interest (Wiens and Milne 1989, Wu and Levin 1994, Pickett and Cadenasso 1995, Turner *et al.* 2001). In this case, landscape is an "ecological criterion"

whose essence is not its absolute spatial scale, but rather its heterogeneity relevant to a particular research question (Allen and Hoekstra 1992, Pickett and Cadenasso 1995).

As such, the idea of "landscape" is also applicable to aquatic systems (Steele 1989, Turner *et al.* 2001, Poole 2002, Wiens 2002, Turner 2005). This multiple-scale or hierarchical concept of landscape is more appropriate because it is consistent with the scale multiplicity of patterns and processes occurring in real landscapes, and because it facilitates theoretical and methodological developments by recognizing the importance of micro-, meso-, macro-, and cross-scale approaches. Today, the most widely used definition of landscape ecology in North America, and arguably worldwide, is simply the study of the relationship between spatial pattern and ecological processes over a range of scales (Pickett and Cadenasso 1995, Turner *et al.* 2001, Turner 2005). Reflective of this dominant ecological paradigm in contemporary landscape ecology are several chapters in this volume, addressing a series of key issues focusing on the interrelationship among spatial pattern, ecological processes, and scale (see Chapters 2 to 9, this volume).

15.3 The elusive goal of a unified landscape ecology

It is evident that the European and North American approaches to landscape ecology have differed historically. On the one hand, the European approach is characterized by a holistic and society-centered view of landscapes, the focus on user-inspired and solution-driven research, and the combination of qualitative empirical methods with surveying and mapping techniques. On the other hand, the North American approach is dominated by an analytical and biological ecology-centered view of landscapes, the focus on basic science-oriented and question-driven studies, and the emphasis on the use of quantitative methods (particularly spatial pattern analysis and modeling). This dichotomy, of course, is an oversimplification of the reality because neither of the two approaches is internally homogeneous in perspectives and because both have been changing as an inevitable consequence of increasing communications and collaborations among landscape ecologists worldwide.

Both European and North American approaches can be traced back to the original definition of landscape ecology by Carl Troll (1939, 1968, 1971). The focus of the North American approach on the interrelationship between spatial pattern and ecological processes is not only consistent with Troll's original definition, but also represents a significant advance in implementing Troll's proposal to integrate the geographical and structural approach with the ecological and functional approach. Also, as noted earlier, the emphasis on large geographic areas, spatial patterns, and scale multiplicity that characterizes the

North American approach was evident in Troll's earlier writings. One may argue that Carl Troll was inspired as much by landscape patterns revealed in aerial photos in the 1930s as contemporary landscape ecologists are by those displayed in GIS. Indeed, it was the resurgence of interest in linking ecological processes with spatial pattern in the 1980s that led to a revitalization of the entire field of landscape ecology. Studies of spatial heterogeneity have laid an important foundation for landscape ecology as a scientific enterprise. On the other hand, landscape ecological studies in Europe have epitomized the ideas of landscapes as human-dominated *gestalt* systems, which were also evident in the early works of Troll and other holistic landscape ecologists (Troll 1971, Naveh and Lieberman 1984, Bastian and Steinhardt 2002). They have promoted the development of interdisciplinary and transdisciplinary approaches that transcend natural and social sciences. Undoubtedly, these studies provide valuable methods and exemplary solution strategies for dealing with various complex landscape issues, which must also be considered as an integral part of landscape ecology.

The simplistic dichotomy of landscape ecology approaches also obscures the fact that North American landscape ecology has recognized the important role that humans may have in shaping landscapes from its very beginning. In most cases, humans have been treated as "one of the factors creating and responding to spatial heterogeneity" (Turner *et al.* 2001, Turner and Cardille, Chapter 4, this volume), but perspectives from landscape architecture and planning are quite prominent in other instances (e.g., Nassauer 1997, Ahern 1999, Vos *et al.*, Chapter 13, this volume). In contrast, human society becomes the focus in European landscape ecology as presented by Naveh and Lieberman (1984, 1994). While advocating this holistic landscape ecology perspective, Naveh (1991) claimed that North American landscape ecology was merely "a ramification and spatial expansion of population, community, and ecosystem ecology," and that Risser *et al.*'s (1984) vision of landscape ecology as "the synthetic intersection of many related disciplines which focus on spatial and temporal pattern of the landscape" was inadequate. However, although the North American approach does not always consider landscapes in "their totality as ordered ecological geographical and cultural wholes," even the most ardent holists cannot deny that studies using this approach "are important and of great theoretical and epistemological value to the science of landscape ecology" (Naveh 1991). On the other hand, few would doubt that a holistic landscape ecology approach is essential for resolving problems of biodiversity conservation and ecosystem management.

During the past decade, there have been an increasing number of books and articles attempting to unite the two primary approaches to landscape ecology (Farina 1998, Wiens 1999, Bastian 2001, Wu and Hobbs 2002, Burel and

Baudry 2003). While landscape ecologists converge on the desire for a unified landscape ecology, they differ significantly as to how to achieve the goal. How can different perspectives be unified? There is no simple way to add them up to form a coherent scientific core of landscape ecology even if such a "core" exists. One common approach that many ecologists have adopted is to include humans and their activities as factors influencing and responding to landscape heterogeneity. In this case, landscape ecology is viewed as a branch of ecology, and issues of land use, biodiversity conservation, ecosystem management, and landscape planning and design belong to the domain of practical applications of landscape ecology, or "applied landscape ecology" (Turner *et al.* 2001).

Others do not seem to agree. For example, Naveh (1991) asserted that "landscape ecologists cannot restrict themselves merely to the study of the ecology and/or geography or history of landscapes, projected according to the definition of Forman and Godron (1986)," and that "landscape ecological studies have to be carried out along multidimensional, spatio-temporal, functional, conceptual and perceptional scales by multidisciplinary teams, using innovative interdisciplinary methods and having a common systems approach and transdisciplinary conception of landscape ecology." We agree that interdisciplinarity and transdisciplinarity are critically important to landscape ecology (Wu and Hobbs 2002), and this point has been made clear and loud in most of the chapters of this volume (e.g., Hof and Flather, Chapter 8, Mackey *et al.*, Chapter 11, Bowman, Chapter 12, Fry *et al.*, Chapter 14). However, we do not believe that each and every landscape ecological study has to be done "along multidimensional, spatio-temporal, functional, conceptual and perceptional scales by multidisciplinary teams." Interdisciplinarity and transdisciplinarity are not monolithic, but hierarchical. Thus, we argue that the unification of landscape ecology needs a complementary framework that clearly recognizes and takes advantage of the hierarchical structure in cross-disciplinarity.

15.4 A hierarchical and pluralistic framework for landscape ecology

When a group of leading scientists from around the world was asked about the future of landscape ecology, they unanimously agreed that the field is characterized, most prominently, by its interdisciplinarity or transdisciplinarity (see Wu and Hobbs 2002). It is logical, then, to take this consensus as a point of departure for exploring the possibility of unifying different landscape ecology perspectives. However, we need to understand what landscape ecologists mean by the terms interdisciplinarity and transdisciplinarity because they have been used rather ambiguously in the literature. Particularly, transdisciplinarity sometimes sounds like "a mystic supra-paradigm" that can hardly be understood in practical terms, much less implemented (Tress *et al.* 2005). Thus, we

believe that clearly defined terms for cross-disciplinary interactions are a prerequisite for effective discussions on the possible unification of landscape ecology approaches.

Based on an extensive review of the literature, Tress *et al.* (2005) and Fry *et al.* (Chapter 14, this volume) have provided a much needed clarification on four frequently used terms with increasing degrees of cross-disciplinary integrations: disciplinarity, multidisciplinarity, interdisciplinarity, and transdisciplinarity. Disciplinary research operates within the boundary of a single academic discipline with no interactions with other disciplines, thus producing disciplinary knowledge; multidisciplinary research involves two or more disciplines with loose between-disciplinary interactions and a shared goal but parallel disciplinary objectives, thus producing "additive" rather than "integrative" knowledge; interdisciplinary research involves multiple disciplines that have close cross-boundary interactions to achieve a common goal based on a concerted framework, thus producing integrative knowledge that cannot be obtained from disciplinary studies; and transdisciplinary research involves both cross-disciplinary interactions and participation from nonacademic stakeholders or governmental agencies guided by a common goal, thus producing integrative new knowledge and uniting science with society (Tress *et al.* 2005, Fry *et al.*, Chapter 14, this volume). According to these authors, both interdisciplinary and transdisciplinary, but not multidisciplinary, studies are "integrative" research, and transdisciplinarity is essentially interdisciplinarity plus nonacademic involvement. Of course, disciplines or sub-disciplines are relative and dynamic terms that depend necessarily on the classification criteria used. Thus, it is important to recognize that cross-disciplinarity (i.e., multi-, inter-, and transdisciplinarity) may be discussed in different domains, such as within biological sciences, among natural sciences, or across natural and social sciences.

Before we discuss our cross-disciplinary framework for landscape ecology, let's make some general observations of the science of ecology first. Ecology has often been described as an interdisciplinary science because the relationship between organisms and their environment involves a myriad of biological, physiochemical, and geospatial processes. Thus, ecological concepts, theories, and methods come from a number of different disciplines, including botany, zoology, evolutionary biology, genetics, physiology, soil science, physics, chemistry, geography, geology, meteorology, climatology, and remote sensing. Without a common ecological context, some of these disciplines may seem rather unrelated. Various interactions among these disciplines characterize different ecological sub-disciplines (e.g., molecular ecology, chemical ecology, physiological ecology, ecosystem ecology, geographical ecology, etc.). Arguably, the most popular way of classifying ecological sub-disciplines, at

least among bio-ecologists, has been based on the hierarchical levels of biological organization from the organism to population, community, ecosystem, landscape, and the biosphere. Although this is not a nested hierarchy (meaning that the levels do not always correspond to spatial and temporal scales in a consistent order), some general patterns of cross-disciplinarity emerge along the hierarchy.

Moving up the hierarchy of biological organization from physiological ecology at the level of individual organisms to global ecology that focuses on the entire Earth system, research questions and methodologies, in general, become increasingly multidisciplinary and interdisciplinary, spatial and temporal scales characterizing each field tend to increase, and mechanistic details of phenomena under study tend to get increasingly coarse-grained. The need and actual frequency of explicitly considering human activities in research also tend to increase. For example, interdisciplinary studies that involve both natural and social sciences are much more frequently encountered in ecological studies at the landscape and global levels than those focusing on individual organisms and local biological communities. As different ecological disciplines provide different perspectives and approaches to the study of nature, they all contribute crucial knowledge to understanding how nature works in the multiscaled and diversely complex world. Generally, studies at lower levels of the ecological hierarchy provide the mechanisms for patterns observed at higher levels, whereas higher-level studies provide the context and significance for lower-level processes. For instance, it is impossible to understand how terrestrial biomes respond to global climate change without invoking the knowledge of plant ecophysiology and ecosystem ecology. On the other hand, global climate change has provided tremendous impetus and new directions for physiological and ecosystem ecology.

The above general patterns suggest that the interdisciplinarity of ecology is quite heterogeneous. We argue that landscape ecology has similar disciplinary characteristics in that landscape ecology involves essentially all the levels of ecological organization and as diverse disciplines as ecology itself. Although the landscape sometimes is considered as a level of ecological organization, it is fundamentally a hierarchical concept that is operational on a wide range of scales in space and time. Different from the traditional ecological disciplines, landscape ecology focuses explicitly on the relationship between spatial pattern and ecological processes on the one hand and nature–society interactions on the other, with the human landscape as arguably the most common scale of research activities.

To promote synergies and unification in the extremely heterogeneous field of landscape ecology, we argue that interdisciplinarity and transdisciplinarity should be interpreted in a hierarchical and pluralistic view (Fig. 15.1).

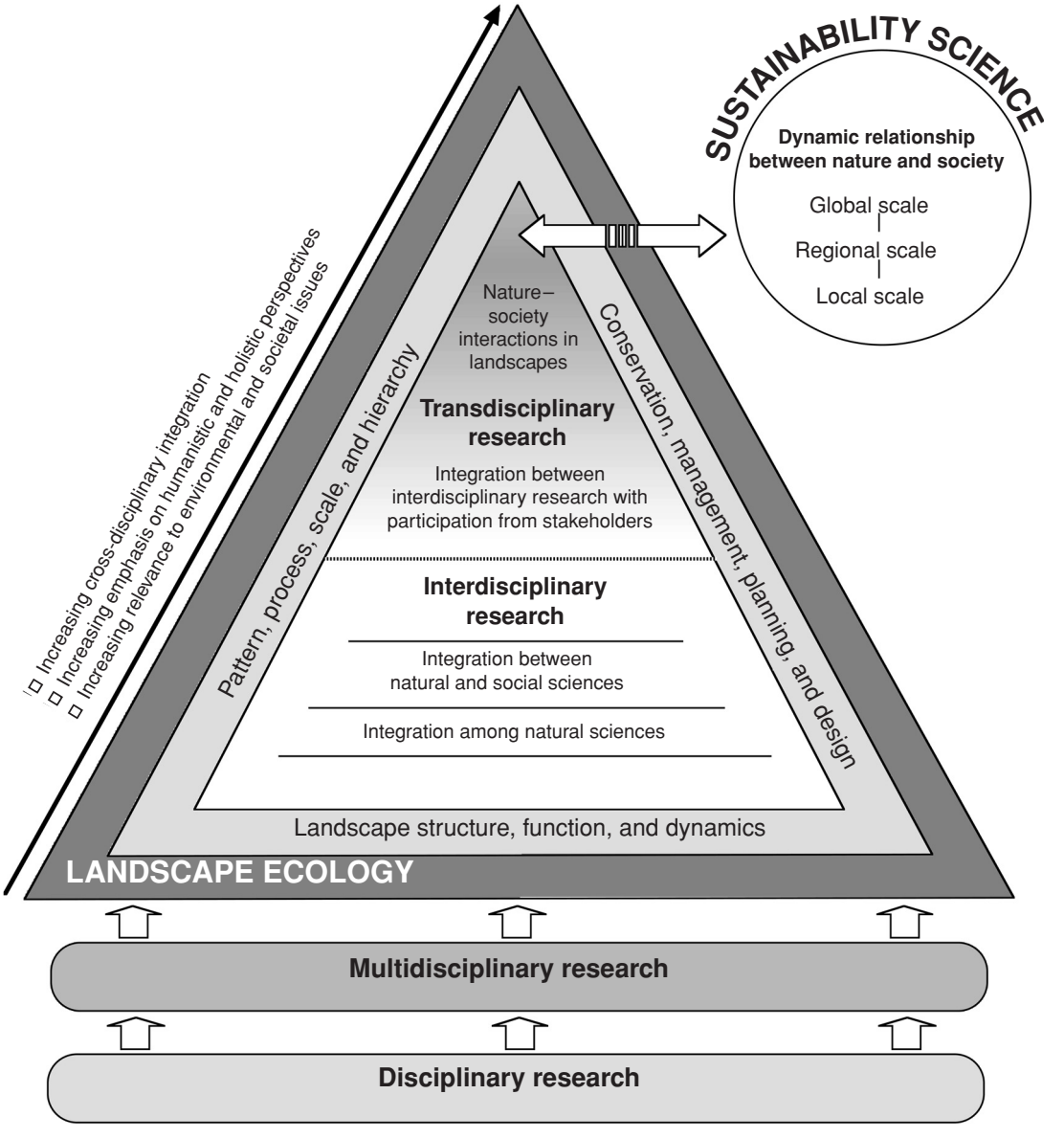

FIGURE 15.1
A hierarchical and pluralistic view of landscape ecology as an interdisciplinary and transdisciplinary science. Landscape ecology is composed of research with various degrees of cross-disciplinary integration from interdisciplinary studies involving multiple natural sciences (e.g., bio-ecology and physical geography) to transdisciplinary studies that include natural and social sciences as well as active participation by stakeholders. Relevant multidisciplinary and disciplinary studies can also provide important contributions to the science of landscape ecology. The definitions of cross-disciplinarities are based on Tress *et al.* (2005)

"Hierarchical" here refers to the multiplicity of organizational levels, spatiotemporal scales, and degrees of cross-disciplinary interactions as well as the relativity of the definition of discipline. As a whole, landscape ecology is an integrative science that consists of studies with different degrees of interdisciplinary and transdisciplinary integration. This basic cross-disciplinary structure is not only reflective of what landscape ecology has been, but also germane to its future development. For example, it seems consistent with the general theme emerging from a list of major research directions and challenges suggested by a group of leading landscape ecologists (Wu and Hobbs 2002), as well as the chapters in this volume. In addition, it is hard to imagine how a credible transdisciplinary science can be developed without resorting to interdisciplinary and multidisciplinary efforts as well as solid disciplinary bases. "Pluralistic" here indicates the necessity to recognize the values of different perspectives and place them in a proper context characterized by a hierarchical cross-disciplinarity. This is indispensable for landscape ecology because of its diverse origins and objectives.

In this hierarchical and pluralistic framework, various approaches and perspectives correspond to different levels in the pyramid of cross-disciplinary integration (Fig. 15.1). In reality, landscape ecological studies usually have varying degrees of cross-disciplinary integration that are determined by specific research goals and questions. Many influential landscape ecological studies have involved different degrees of interdisciplinarity concerning primarily natural sciences, such as biological, ecological, physical, and geographical disciplines. The research topics include the effects of landscape pattern on animal behavior or "behavioral landscape ecology," metapopulation dynamics, spread of disturbance across landscapes, spatial ecosystem processes, patch dynamics, and neutral landscape models (e.g., Turner 1989, Farina 1998, Burel and Baudry 2003, Turner and Cardille, Chapter 4, Fahrig, Chapter 5, Gardner *et al.*, Chapter 6, this volume). In general, moving from the bottom to the top of the cross-disciplinarity pyramid in Fig. 15.1, landscape ecology increases the degree of integration among disciplines, prominence on humanistic and holistic perspectives, and relevance to environmental and societal issues (e.g., Hof and Flather, Chapter 8, Ludwig, Chapter 9, Mackey *et al.*, Chapter 11, Bowman, Chapter 12, Vos *et al.*, Chapter 13, this volume). Correspondingly, human–environment interactions increasingly become the focus of landscape ecology towards the transdisciplinarity end. There are outstanding examples from Europe and elsewhere in which natural and social sciences are successfully integrated with direct involvement of stakeholders, policy-makers, and governmental agencies (see Fry *et al.*, Chapter 14, this volume). Such transdisciplinary research ultimately unites science with society, and is an indispensable part of landscape ecology. In this case, landscape ecology is a critical part

of the emerging sustainability science that focuses on the dynamic interactions between nature and society from the local to global scale through place-based and problem-driven projects (Kates *et al.* 2001, Clark and Dickson 2003).

15.5 Discussion and conclusions

Landscape ecology is the science and art of studying and influencing the relationship between spatial pattern and ecological processes across hierarchical levels of biological organization and different scales in space and time. The relationship among pattern, process, and scale is as essential in human-dominated landscapes as in natural landscapes, and is as important in theory as in practice. The "science" of landscape ecology focuses on understanding the dynamics of spatial heterogeneity and the relationship among pattern, process, and scale in natural as well as human-dominated landscapes. The "art" of landscape ecology emphasizes the necessary use of humanistic and holistic perspectives for integrating biophysical with socioeconomic and cultural components in general, and design, planning, and management in particular.

As we discussed earlier, two salient approaches have evolved, both of which can be traced back to the original definition of landscape ecology by Carl Troll (1939, 1968, 1971). The pattern–process–scale perspective that characterizes the North American approach is a continuation and indeed a breakthrough of realizing Troll's aspiration to integrate the geographical (structural) and ecological (functional) approaches. On the other hand, inspired and constrained by the close interactions between land and human society, scientists particularly in European and the Mediterranean countries have transformed the early holistic ideas into a transdisciplinary vision for landscape ecology. Differences in perspectives have apparently caused some landscape ecologists to worry about an identity crisis for landscape ecology (e.g., Moss 1999, Wiens 1999), and others have increasingly called for a unification of different approaches to landscape ecology (Wiens and Moss 1999, Bastian 2001, Wu and Hobbs 2002). Nonetheless, landscape ecology has been maturing as a science in recent years as it has apparently become more quantitative and precise with increasing use of modeling and statistical approaches, more concentration on methodology, and more concerted efforts to bring together different perspectives (Hobbs 1997, Wu and Hobbs 2002).

We believe that the diversity, but not divergence, of perspectives is an essential characteristic and strength of landscape ecology. The hierarchical and pluralistic framework proposed in this chapter help unite the different approaches to landscape ecology and allows for the continuing development of diverse perspectives and approaches. Unification is not to make certain views more prominent by diminishing others, but rather to join different perspectives

complementarily in order to produce a whole that is larger than the sum of its parts. This is especially true for broadly interdisciplinary and transdisciplinary sciences such as landscape ecology that cut across natural and social sciences. Landscape ecology may never have a monolithic disciplinary core, and it should not in view of its diverse origins and goals. As a science of spatial heterogeneity, landscape ecology can benefit from its disciplinary heterogeneity. On the one hand, landscape ecology will continue to improve our understanding of the relationship among pattern, process, and scale; and on the other hand, it should play an increasingly important role in sustainability science in years to come.

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