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PERSPECTIVE

Key concepts and research topics in landscape ecology revisited: 30 years after the Allerton Park workshop

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Abstract This year marks the 30th anniversary of a momentous meeting in the history of landscape ecology—the Landscape Ecology Workshop held in Allerton Park, Illinois, USA in 1983. On this special occasion, I am inspired to make some observations and comments on the state-of-the-science of landscape ecology as a tribute to this historic event. One may argue that the workshop galvanized a shift in paradigm and the development of an "identity" for landscape ecology. The field has advanced swiftly and productively during the past three decades, and reviewing the publications in the flagship journal *Landscape Ecology* indicates that the Allerton Park vision has been amazingly influential in shaping the direction of the field. Based on a synoptic analysis of the literature, I discuss the core questions, key topics, and future direction of landscape ecology.

Keywords Landscape ecology · Core questions · Key topics · Future direction · Allerton Park workshop

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Introduction

When one thinks of the history of a scientific field, some events stand out as turning points or game changers. The Allerton Park workshop was certainly one such event in landscape ecology. During April 25–27, 1983, twenty-five ecologists and geographers (23 from the USA, one from Canada, and one from France) gathered in Allerton Park, Illinois, USA to discuss landscape ecology's "directions and approaches." A report, authored by Paul G. Risser, James R. Karr, and Richard T. T. Forman, was consequently published in March 1984, and summarized the major findings of the workshop (Risser et al. 1984).

One may argue that the work shop not only heralded the burgeoning of landscape ecology in North America, but also laid the foundation of what may be called modern landscape ecology. Or, As Wiens (2008) suggested, what the 3-day workshop produced may be regarded as the beginning of a new paradigm in landscape ecology. The workshop report (Risser et al. 1984) explicitly recognized the European roots of the field (citing pioneering works by Carl Troll, Ernst Neef, and others) as well as the importance of recent theoretical and technological developments in ecology (e.g., island biogeography theory, patch dynamics, spatial analysis, and spatial simulation modeling). It was from this document that a new vision for landscape ecology—a vision that hinges fundamentally on spatial heterogeneity—began to emerge. The explicit emphasis on spatial heterogeneity is characterized by, and necessitates, the consideration of the relationships among pattern, process, and scale. As discussed later in this article, these concepts are inherently interrelated theoretically and practically.

On this special occasion of the 30th anniversary of the Allerton Park workshop, I am inspired to make a few observations and comments on the state-of-the-science of landscape ecology. Two insightful reviews on the workshop, written by two of the key participants, have been published in this journal (Risser 1995; Wiens 2008). More fascinating personal accounts of the workshop, and of the early developments of landscape ecology in North America, can be found in a forthcoming book, "History of Landscape Ecology in the United States" (edited by G. W. Barrett, T. L. Barrett, and J. Wu; Springer).So, my intent here is not to provide another retrospective analysis, but rather to focus on two questions inspired by reading the workshop report again: What are the key concepts and salient characteristics of landscape ecology that distinguish it from other related disciplines? What are the key—and "hot"—research topics that form the scientific core of the field?

Key concepts and characteristics defining the identity of landscape ecology

In the Allerton Park workshop report, Risser et al. (1984) stated:

> "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…. The relationship between spatial pattern and ecological processers is not restricted to a particular scale…. Ecological processes vary in their effects or importance at different scales."

It is clear from the quote above that spatial pattern or spatial heterogeneity is the cornerstone concept in landscape ecology. Heterogeneity (neither randomness nor uniformity) begets the consideration of pattern and process which both operate on multiple scales. Pattern is trivial without heterogeneity, and scale matters whenever heterogeneity exists. Pattern and process are often related, and their relationship is scale-dependent. Scale multiplicity frequently corresponds to hierarchical organization, and hierarchy theory simplifies complexity through scale-based modularization. Consequently, heterogeneity, pattern, process, scale, and hierarchy are intrinsically interrelated concepts—all of which are key to the theory and practice of landscape ecology.

If we have to choose one single word to characterize the field of landscape ecology, most of us are likely to pick "heterogeneity." It is probably the only word that can concisely and precisely capture much of the essence of landscape ecology, as defined by the Allerton Park workshop. Although the term was coined in 1939, landscape ecology only began to acquire this prominent characteristic of heterogeneity after the 1984 workshop. Indeed, the workshop report explicitly recognized that the paramount emphasis on spatial pattern or heterogeneity is the feature that most distinguishes landscape ecology from other ecological fields such as population, community, and ecosystem ecology (Risser et al. 1984). This heterogeneity-centered view does not mean that landscape ecology should focus only on bio-ecological patterns and processes (as misinterpreted by some in the literature). In fact, such a view is equally applicable to studies of both ecological and coupled social-ecological systems (Wu 2006).

Paradigm shift does not always have to involve the complete abandonment of existing or "old" paradigms. Indeed, we see more than just bits and pieces of "old" paradigms exemplified by Clementsian (superorganismic) and Gleasonian (individualistic) views in today's ecology (Wu and Loucks 1995). Different ecological fields, such as behavioral, population, community, ecosystem, and landscape ecology themselves may be viewed as representing distinct but related paradigms (Allen and Hoekstra 1992; Wu and Loucks 1995; Pickett et al. 2007). Modern landscape ecology is the result of "the merger of the more or less independently developing European school of landscape geography and the growing body of ecological theory resulting from the study of heterogeneity and instability in ecological systems" (Risser et al. 1984). Landscape ecology is more than just ecology or geography; it is inherently interdisciplinary. The humanistic and holistic perspective, famously associated with the European approach to landscape research, was visible in the "blueprint" of the North American vision (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…, viewing landscape ecology as a branch of ecology, would…tend to exclude the formal analysis of human cultural processes that form landscapes…. Understanding landscapes requires that we deal with human impacts contributing to the landscape phenomenon, without attempting to draw the traditional distinction between basic and applied ecological science or ignoring the social sciences."

During the past 30 years, landscape ecology has made tremendous progress in theory and practice (Naveh and Lieberman 1984; Forman and Godron 1986; Turner 1989; Forman 1995; Turner et al. 2001; Turner 2005; Wiens and Moss 2005; Wu and Hobbs 2007). Some have claimed that the field comes of age, or has matured (Fortin and Agrawal 2005; Turner 2005). It is certain that landscape ecology today is vibrant and well-established. It is also evident, however, that the core questions of landscape ecology are still being formed and coalesced. Thus, landscape ecology is still in the process of rapid development and maturing.

Some trends from the publications in *Landscape Ecology*

In this section, I present some trends that have emerged from the publications in the flagship journal of the field *Landscape Ecology* since its founding in 1987. Admittedly, none of these analyses is on par with rigorous statistical treatments, but I do think that the results are interesting and relevant to the points that I make in this article.

First of all, I have generated a "word cloud" based on the titles, keywords, and abstracts of all the publications in *Landscape Ecology* up to 2011 (Fig. 1). Apparently, spatial, patterns (heterogeneity), species, habitat, forest, vegetation, patch(es), scale(s), structure, processes, fragmentation, and management are among the most commonly used ones.

Second, the top 20 most-cited articles published in the journal (according to the ISI Web of Science) are clearly dominated by topics related to pattern analysis and scale (Table 1). These papers continue to attract a high level of citations (Fig. 2). This trend seems in line

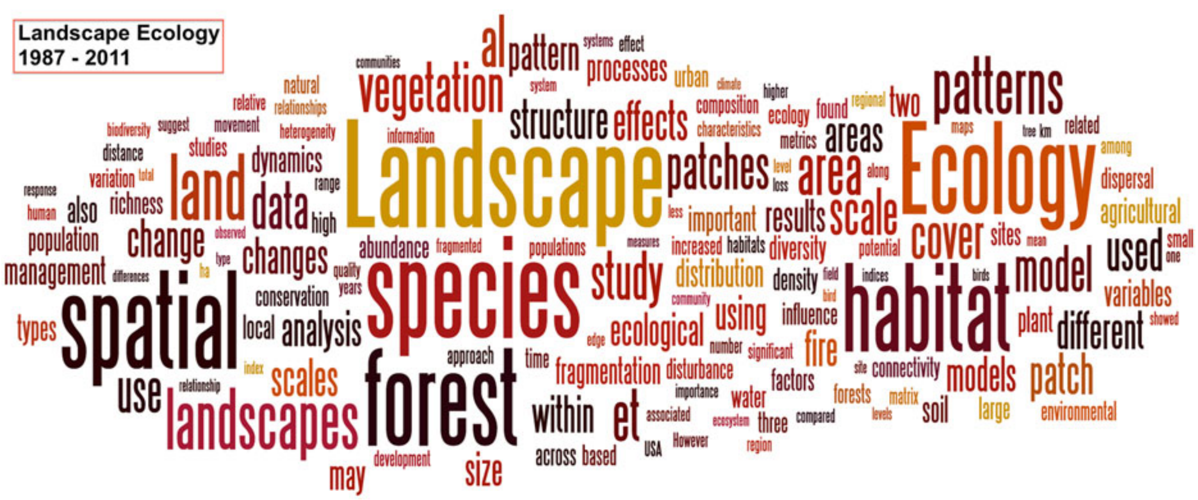

Fig. 1 Word cloud generated with Wordle (http://www.wordle.net/) using words in the titles, keywords, and abstracts of all papers published in the journal *Landscape Ecology* from 1987 to 2011. The size of each word is indicative of the relative frequency of occurrence of the word

with Allerton Park workshop's vision for landscape ecology. After all, quantifying spatial pattern is frequently a necessary first step in studying the causes, processes, and consequences of spatial heterogeneity. As mentioned earlier, scale is inherently linked to heterogeneity and pattern.

Third, using the same dataset as in creating the word cloud, I computed the relative frequency of occurrence for a group of subjectively selected words and phrases that are either well-established terms or ones indicative of important emerging research areas in landscape ecology (Fig. 3). The word "scale" alone was used by 46 % of all the published articles in *Landscape Ecology*, habitat 39 %, patch 31 %, conservation 22 %, fragmentation 21 %, land use 15 %, disturbance 14 %, spatial pattern 13 %, heterogeneity 11 %, modeling 9.4 %, pattern analysis and landscape metrics 7 %, scaling 4.6 %, climate change 3.7 %, sustainability-related terms 3.5 %, and ecosystem services 1.3 %. If we consider all heterogeneity-related words on the list

Table 1 The top 20 most-cited papers published in *Landscape Ecology* (data from the ISI Web of Science, http://apps.webofknowledge.com/; accessed on December 5, 2012)

Order	Author (year)	Title	Vol. (issue)	Total cites	Cites/years
1	O'Neill et al. (1988)	Indices of landscape pattern	1(3)	609	25.4
2	Franklin and Forman (1987)	Creating landscape patterns by forest cutting: Ecological consequences and principles	1(1)	456	18.2
3	Riitters et al. (1995)	A factor-analysis of landscape pattern and structure metrics	10(1)	378	22.2
4	Roth et al. (1996)	Landscape influences on stream biotic integrity assessed at multiple spatial scales	11(3)	374	23.4
5	Gardner et al. (1987)	Neutral models for the analysis of broad-scale landscape pattern	1(1)	352	14.1
6	Turner et al. (1989)	Effects of changing spatial scale on the analysis of landscape pattern	3(3–4)	349	15.2
7	Wu and Hobbs (2002)	Key issues and research priorities in landscape ecology: An idiosyncratic synthesis	17(4)	254	25.4
8	Hargis et al. (1998)	The behavior of landscape metrics commonly used in the study of habitat fragmentation	13(3)	240	17.1
9	Turner and Romme (1994)	Landscape dynamics in crown fire ecosystems	9(1)	237	13.2
10	Gustafson and Parker (1992)	Relationships between landcover proportion and indexes of landscape spatial pattern	7(2)	233	11.7
11	Wu (2004)	Effects of changing scale on landscape pattern analysis: scaling relations	19(2)	226	28.3
12	Andow et al. (1990)	Spread of invading organisms	4(2–3)	225	10.2
13	Wiens and Milne (1989)	Scaling of 'landscapes' in landscape ecology, or, landscape ecology from a beetle's perspective	3(2)	223	9.7
14	Turner (1990)	Spatial and temporal analysis of landscape patterns	4(1)	208	9.5
15	Li and Wu (2004)	Use and misuse of landscape indices	19(4)	205	25.6
16	van Dorp and Opdam (1987)	Effects of patch size, isolation and regional abundance on forest bird communities	1(1)	202	8.1
17	Jelinski and Wu (1996)	The modifiable areal unit problem and implications for landscape ecology	11(3)	188	11.8
18	Ludwig and Tongway (1995)	Spatial-organization of landscapes and its function in semiarid woodlands, Australia	10(1)	186	10.9
19	Opdam (1991)	Metapopulation theory and habitat fragmentation - a review of holarctic breeding bird studies	5(2)	177	8.4
20	Plotnick et al. (1993)	Lacunarity indices as measures of landscape texture	8(3)	174	9.2

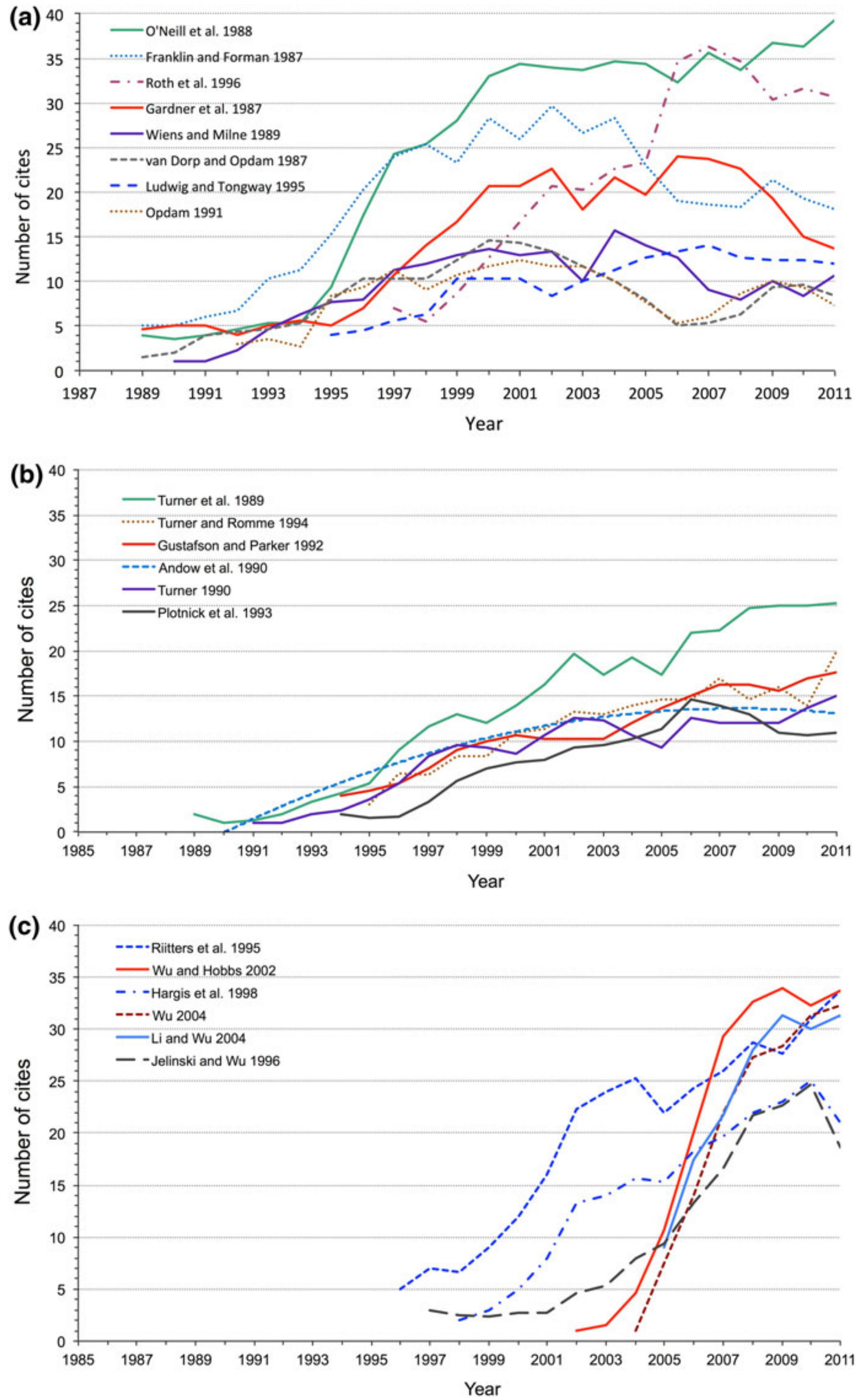

Fig. 2 Temporal changes in the number of citations to the top 20 most-cited papers published in *Landscape Ecology* (data from the ISI Web of Science, http://apps.webofknowledge.com/; accessed on December 5, 2012). Each curve represents a 3-year moving average so as to smooth out annual fluctuations in the number of cites to each article

(heterogeneity, spatial pattern, pattern analysis/metric, patch, and fragmentation), the percentage of papers using these words rises to 84 % (without eliminating double-accounting). Scale and scaling together appeared in about 50 % of the published papers (Fig. 3). These are impressive numbers.

It is also important to notice that, while maintaining their dominant status, most of the well-established terms

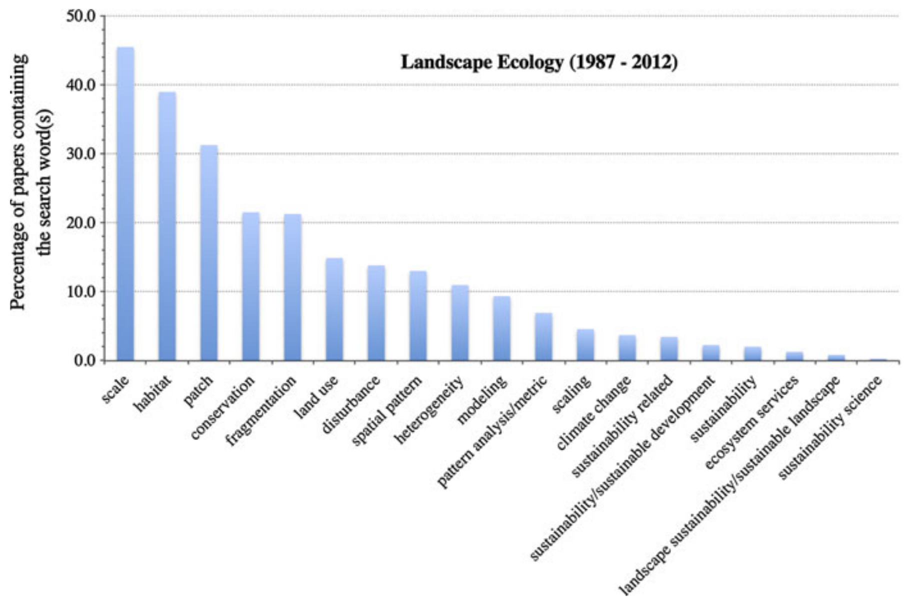

Fig. 3 Relative frequency of occurrencefora group of selected words and phrases that are either well-established terms in landscape ecology or emerging ones indicative of some current development fronts in the field (data derived from the titles, keywords, and abstracts of all the published papers in the journal *Landscape Ecology* between 1987 and 2012). "Sustainability related" refers to terms: sustainability, sustainable development, landscape sustainability, sustainable landscape, and sustainability science

seem to have passed their peaks of occurrence frequency (Fig. 4a). Is this indicative of diversifying research topics or broadening scope of the field during the past decade? Maybe. The substantially increasing number of pages published by the journal since 2000 (especially after 2005) may also be partly responsible ("dilution effect"). On the other hand, though, the preselected terms representing new development fronts (i.e., climate change, ecosystem services, and sustainability) show a rapidly increasing trend in the frequency of occurrence in the published papers in the journal (Fig. 4b).

Taken together, theses results seem to confirm the essential position of the concepts of spatial heterogeneity, pattern and scale in landscape ecology, which corroborates the vision outlined by the Allerton Park workshop report (Risser et al. 1984). They also indicate that many landscape ecological studies have focused on species, vegetation, habitat fragmentation (disturbances in general), conservation, and landscape management (especially for forests). It is encouraging to see the rapid increases in landscape ecological studies of climate change, ecosystem services, and sustainability because the importance of these topics goes far beyond basic research. Indeed, they represent the most challenging issues of our time; they are immediately relevant to society and policy making; and landscape ecology has much to offer for advancing science and practice in these areas through its spatially-explicit principles and methodologies.

Core questions and key topics in landscape ecology

In the Allerton Park workshop report, Risser et al. (1984) stated:

> "Because of the spatial patterning of landscapes, flows and transfers between spatial components assume special importance, and the process of redistribution of organisms, materials, and/or energy among landscape components is thus an essential feature of landscape ecology."

Thus, different from other "ecologies," landscape ecology focuses on the interrelationship among sources, sinks, flows, and redistributions in and across a landscape mosaic that consists of multiple ecosystems (or patches). To advance such research, Risser et al. (1984) further provided four "representative questions:" (1) "How are fluxes of organisms and of materials and energy related to landscape heterogeneity?" (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 disturbance?" (4) "How can conventional natural resource management be enhanced through a landscape ecology approach?"

We have come a long way in addressing these questions since the Allerton Park workshop, but these questions are undoubtedly as valid today as were in 1984. At the turn of the new millennium, there was a perceived "identity crisis" of landscape ecology (Moss 1999; Wiens 1999). In response, a special session entitled "Top 10 List for Landscape Ecology in the 21st Century" was organized during the 16th Annual Symposium of the US Association of Landscape Ecology, held at Arizona State University between April 25 and 29, 2001, to discuss the defining characteristics and key research topics of the field. Synthesizing inputs from 15 leading landscape ecologists who participated in the event in person or by email, Wu and Hobbs (2002) articulated 10 key research topics that help shape the scientific core and identity of landscape ecology: (1) ecological flows in heterogeneous landscapes, (2) causes, processes, and consequences of land use and land cover change, (3) nonlinear dynamics and landscape complexity, (4) scaling, (5) methodological development, (6) relating landscape metrics to ecological processes, (7) integrating humans and their activities into landscape ecology, (8) optimization of landscape pattern, (9) landscape sustainability, and (10) data acquisition and accuracy assessment. This list may be viewed as an update and extension of the representative questions from the Allerton Park workshop report.

During the past decade landscape ecology has made rapid strides in both theory and practice. Here I am tempted to incorporate the recent advances in the field, and revise the top 10 list as follows:

(1) Pattern–process–scale relationships of landscapes.

- Developing and testing hypotheses and principles of the flows and redistributions of organisms, materials, and energy in dynamic landscape mosaics of different types; developing a landscape mosaic theory of population, community, and ecosystem processes.

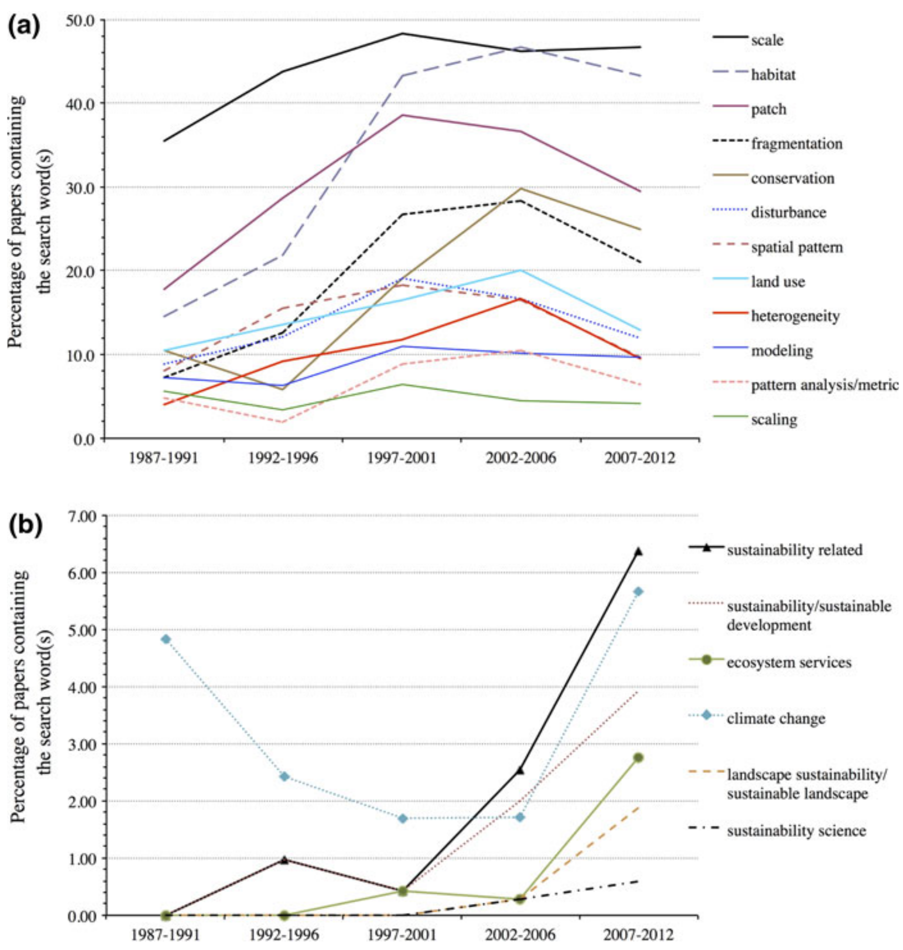

Fig. 4 Changes in relative frequency of occurrence in published papers for a group of important terms in landscape ecology (data derived from the titles, keywords, and abstracts of all the published papers in the journal *Landscape Ecology* between 1987 and 2012). The relative frequency was calculated by dividing the period of 1987–2012 into 5 segments. Terms in the upper panel **a** are a well-established part of the "landscape ecology vocabulary" whereas those in the lower panel **b** represent some new and important research areas

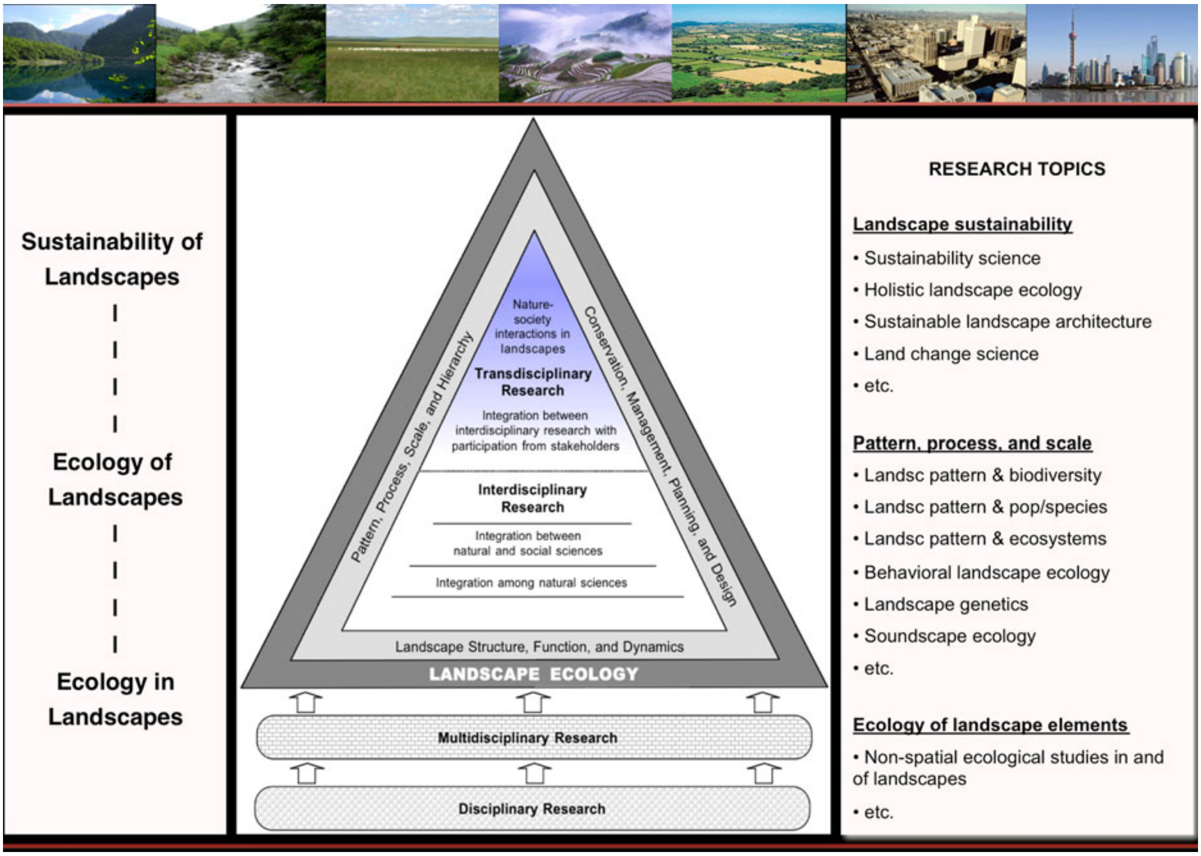

Fig. 5 A hierarchical and pluralistic framework for landscape ecology (modified from Wu 2006). As an interdisciplinary and transdisciplinary science, landscape ecology is focused on research questions concerning pattern–process–scale relationships and landscape sustainability—i.e., questions about the ecology and sustainability of landscapes

(2) Landscape connectivity and fragmentation.

- Typology, measurements, and ecological relevance of different kinds of connectivity (patch, population, habitat, and landscape connectivity, and structural and functional connectivity); ecological (and genetic) effects and mechanisms of connectivity and fragmentation; relative importance of and interactions between habitat loss and fragmentation per se in dynamic landscapes.

(3) Scale and scaling.

- Underlying mechanisms of scale effects; scaling relations; effective scaling methods; hierarchical linkages of patterns and processes across landscapes in space and time.

(4) Spatial analysis and landscape modeling.

- Relating landscape metrics and spatial statistics to ecological functions; developing landscape functional indicators; promoting use-inspired, place-based, and mechanistic landscape models.

(5) Land use and land cover change.

- Developing a general understanding of the relationship among spatiotemporal patterns, drivers, and ecological impacts of land use and land cover change; the relationship of biodiversity, ecosystem function, and environmental conditions to dynamic land use and land cover patterns; understanding and predicting ecological and environmental effects of urbanization on multiple scales.

(6) Landscape history and legacy effects.

 – Documenting and understanding impacts of past land use and historical events on biodiversity and ecological processes in different types of landscapes; developing a general understanding of landscape legacy effects on the composition, configuration, and functions of the present and future landscapes.

(7) Landscape and climate change interactions.

 – Understanding effects of changing landscape pattern on local and regional climate processes; landscape-based approaches to climate change mitigation and adaptation; landscape ecological studies of urban heat islands.

(8) Ecosystem services in changing landscapes.

 – Characterizing and quantifying spatiotemporal patterns, source-sink dynamics, trade-offs, and synergistic interactions of provisioning, regulating, and cultural ecosystem services at the landscape and regional levels; assessing and projecting responses of these ecosystem services to environmental and landscape changes; developing place-based landscape theories of ecosystem services.

(9) Landscape sustainability (defined as the adaptive process of simultaneously maintaining and improving biodiversity, ecosystem services, and human well-being in a landscape).

 – Dynamic relationship between landscape/ecosystem services and human well-being; policy impacts on the relationship; alternative ways of sustaining ecosystem services and human well-being particularly through landscape design and planning as longitudinal experiments; key factors and mechanisms of landscape resilience (capacity to withstand disturbances while maintaining basic structure and functionality) and its relationship to landscape sustainability.

(10) Accuracy assessment and uncertainty analysis.

 – Systematically assessing the accuracy of landscape analysis based on multi-source and multi-scale datasets; quantifying scaling errors; categorizing the kinds, causes, and consequences of uncertainties in landscape studies; developing solutions to uncertainty problems; evaluating implications of uncertainties in landscape research for management and policy making.

I hope this list will stimulate landscape ecologists to think more of the core questions and key topics of our field. One may also want to use it as a guide for the purpose of assessing a manuscript's relevance to *Landscape Ecology*, as either an author or a reviewer. Certainly, the list should be revisited periodically based on inputs representing active landscape ecologists and practitioners around the world.

Concluding remarks

The 1983 Allerton Park workshop marked the beginning of a paradigm shift in the history of landscape ecology. The vision articulated in the workshop report (Risser et al. 1984) has served as an important guide for the development of the field during the past 30 years, and still retains relevance today and into the foreseeable future.

Landscape ecology is a highly interdisciplinary and transdisciplinary science of understanding and improving the relationship between spatial pattern and ecological processes on a range of scales (Fig. 5). Spatial heterogeneity underpins the principles and practices of landscape ecology, and the ultimate goal of this science of heterogeneity is to achieve landscape sustainability (Fig. 5). During the past three decades, research themes and topics that have continued to dominate landscape ecological research include landscape pattern analysis, land use and land cover change, and effects of landscape fragmentation and connectivity on biodiversity and population and ecosystem processes. Landscape ecology has become the leading science in dealing with scale and scaling issues. Most landscape ecology studies have been conducted on broad scales (i.e., human landscapes of hundreds to thousands of square kilometers in area) although key ideas of landscape ecology can be applied essentially to any scale. Landscape ecology increasingly relies on remote sensing data and GIS, and multiple-scale and hierarchical approaches have become the norm in data acquisition and analysis.

Landscape ecology is maturing at a fast pace. Key research topics, core questions, and systematic methodologies have been developed with increasing cohesiveness and integrity. The field remains exceptionally dynamic and vibrant. Several “hot” and new topics are evident from the pages of the field’s leading journal, *Landscape Ecology*. Examples include behavioral landscape ecology (the study of the relationship between landscape pattern and behavioral processes of organisms), landscape connectivity and fragmentation, landscape genetics (relationship between landscape pattern and population genetics), landscape matrix effects, sound scape ecology (the study of patterns, dynamics, and impacts of biological, geophysical, and anthropogenic sounds on organisms and humans in a landscape), urban landscape ecology, landscape-climate change interactions, and landscape sustainability that integrates biodiversity, ecosystem services, human well-being, and landscape planning and design.

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