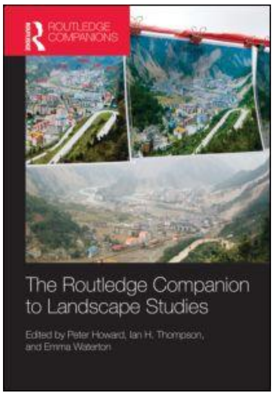

The Routledge Companion to Landscape Studies

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Landscape and ecology

Publication details
https://www.routledgehandbooks.com/doi/10.4324/9780203096925.ch33
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Published online on: 06 Dec 2012

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Landscape and ecology: the need for an holistic approach to the conservation of habitats and biota

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The rationale for landscape ecology

The relationship between people and the natural world is, to say the least, complex. On the one hand, people depend for their very existence on a healthy natural support system. Nature provides us with a suite of goods and services which enable human survival. These include provisioning of food, water and materials, climate and water regulation, nutrient cycling, pollination, primary production, and aesthetic, spiritual and recreational benefits, amongst many others (De Groot et al. 2002). The value of these ecosystem services is indisputable, even if difficult to quantify, and contributes to fundamental constituents of human well-being, including security, basic material needed for a 'good' life, health, and good social relations (Millennium Ecosystem Assessment 2005). Indeed in the overall balance of nature, man is far more dependent on other species than they are on us; as eloquently put by E. O. Wilson, 'If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos' (Wilson 1985 cited in Jarski 2007: 269).

Notwithstanding, the power of the human species to alter its environment is undeniable. No other living being has had as large an effect on the natural world. Sadly, much of that effect appears to have been negative. *Homo sapiens sapiens* was the first species to induce a wave of extinction (Ceballos et al. 2010); the previous five major extinction episodes were all the result of natural factors (primarily related to climate change, tectonics and cometary collisions). Even if precise extinction rates are hard to calculate – given that several millions of species remain unidentified and as a result of problems with extrapolation (He and Hubbell 2011) – there is little doubt that losses are highly significant. Perhaps this human propensity to impact heavily on other species has much to do with the way in which anthropogenic civilizations evolved. Early hunter-gatherer societies had no option but to work 'with' nature, adjusting their lives to the patterns of the seasons, and planning their movements in line with the availability of resources. With the advent of agriculture, people developed the capacity to settle in a single location, made possible by the ability to produce a steady supply (and even a surplus) of food (as opposed to merely harvesting whatever was available). This in turn enabled populations to grow to unprecedented levels, and facilitated the development of conurbations. Whilst present-day cities have undoubtedly come a long way from the earliest riverine civilizations, the fundamental trends established then remain pertinent – people settle in a location, populations grow, and corresponding resource demands increase, with the result that people need to expand their spatial footprint – and so a vicious cycle ensues. Natural landscapes have historically been big casualties of this process, with resource exploitation coming at a heavy cost to the ecosystems that ultimately sustain us.

Perhaps a significant underlying driving force of this unhealthy dynamic between people and the natural world can be found in people's environmental ethic (or lack thereof). One could argue that as our ability to control and exploit nature increased, so correspondingly did our respect for nature decline. The use of natural resources is nothing new; in keeping with the maxim of 'survival of the fittest', humans need to utilize other species to survive. However, contrast a modern-day commercial livestock breeding operation (including high-density intensive breeding of species, extensive use of antibiotics and pesticides, and eventual mass slaughter at an abbatoir), with the limited hunting kills of an indigenous culture, often accompanied by rituals to pay tribute to the animal which gave its life to sustain human survival. Our western lifestyle arguably perpetuates a conception of nature as a commodity, to be used and discarded at will, and lying beyond the remit of our moral concerns. As a result, we now have a gap between 'people' on the one hand, and 'nature' on the other, with the former depending on the latter but often failing to acknowledge the limited capacity of nature to provide resources and absorb waste. In this gap, lies perhaps *the* key constraint to (and challenge for) sustainability. Bridging the gap requires, first and foremost, acknowledging that humans and nature are not two separate entities, but exist together interdependently as elements of a wider Earth system. It is this conception of social–ecological systems that underpins the discipline of landscape ecology.

The emergence of landscape ecology as a discipline

In 'traditional' ecology, the spatial remit of concern is the ecosystem, in itself an ambiguous concept which has been defined in a multitude of different (and not necessarily identical) ways (Naveh 2010). Broadly, ecologists are interested in the biotic and abiotic factors that influence the relations that organisms have with each other and with their surrounding environment, and in related biophysical feedback mechanisms. However, the boundaries and limits of ecosystems are not easily defined, leading biologist Robert O'Neill (2001) to argue that it may be time to bury the ecosystem concept altogether, given two fundamental spatial limitations of the concept:

- the implicit assumption that interactions and feedback loops are necessary and sufficient to explain dynamics occur within the ecosystem boundaries, while in fact the spatial distributions of component populations may be much larger; and
- the assumption of spatial homogeneity within an ecosystem, which rarely holds true.

Landscape ecology was essentially born of this recognition that influences on ecological processes originate from, and extend beyond, the boundaries of the ecosystem itself, and are embedded within a much wider landscape framework. In terms of ecological studies, this can be framed as a distinction between an *area of study* and an *area of influence.* The *area of study* of conventional ecology is limited by ecosystem boundaries (which are fuzzy at best), whilst landscape ecology makes a case for expanding the *area of study* to more accurately reflect the entire *area of influence*. In the case of the latter, the area of influence encompasses entire landscape areas, with all their natural and anthropogenic dimensions, and including the action of man.

The term 'landscape ecology' was first coined in the 1930s by the German biogeographer Carl Troll, who defined landscape as, 'the total spatial and visual entity of human living space, integrating the geosphere with the biosphere and its noospheric [of knowledge] man-made artifacts' (Troll 1971), and advocated a landscape-based approach that would effectively 'marry' biology and geography (Zonneveld 1995). The Landscape Research Group was founded in 1967, and initiated the publication of *Landscape Research*, and the first scientific society for landscape ecology (Werkgroep Landschapsecologisch Onderzoek – Working Group Landscape–Ecological Research) followed in 1972 in the Netherlands (Antrop 2005). It was in the 1980s, however, that the discipline started to come into its own. This is no mere coincidence. The decade of the 1980s was pivotal in highlighting the relevance and significance of broad-scale environmental issues to human well-being, and in confirming the interlinkages between natural systems and people. The first World Conservation Strategy was published by the then International Union for Conservation of Nature and Natural Resources (1980), followed by the UN World Charter for Nature (1982), and later in 1987, by the Brundtland Report (of the World Commission on Environment and Development) (which established what is probably the most oft-quoted definition of sustainable development). More sobering incidents also contributed to the stimulus of the fledgling pro-environment movement, including the Bhopal fertilizer plant disaster (1984), the nuclear accident at Chernobyl (1986) and the Exxon Valdez oil spill in Prince William Sound, Alaska (1989). Less dramatic but no less significant developments during the same decade, included the discovery of the ozone 'hole' over Antarctica by British scientist Joe Farman (1985), providing the stimulus for the adoption of the Montreal Protocol two years later. Concurrently, the 1980s also underlined the strongly social and political aspects of natural resource issues, with, for example, the assassination of Brazilian rubber tappers Wilson Pinheiro and Chico Mendez and the murder of conservationist Dian Fossey in Rwanda. By the end of the 1980s, it was amply clear that people impact on nature but also that they stand to be affected by the health of natural systems, and that environmental concerns cannot be separated from their wider social, cultural, political and economic context.

In parallel to these developments, major paradigmatic shifts were also occurring within the discipline of ecology, as alluded to above. In particular, traditional models of homeostatic stability and equilibrium, where ecosystems are seen to function in a clockwork, machine-like, predictable manner, began to be questioned, with a recognition that many ecosystems fail truly to reflect these traits. The possibility (and likelihood) of non-equilibrium ecosystems started to be acknowledged, and the very concept of an ecosystem began to be characterized more by consideration of dynamics than by aspects of stability (Wu and Loucks 1995). Developments in other fields, such as systems theory and chaos theory, served to further reinforce these altered perceptions. Additionally, the notion that ecosystems are not isolated, neither in space, nor from human activities, began to emerge more strongly, and brought with it an understanding that ecology needs to consider the reality of open systems, with due attention to the flow of energy and material across fuzzy ecosystem boundaries. Real-world issues such as acid rain, where source and effect were found to be separated in space and time, provided further confirmation of this 'new' conception of ecosystems. The practical implications of these intellectual shifts included a realization that ecosystems must thus be understood as embedded within a wider landscape mosaic, and affected by a range of forms, functions and processes occurring at many different scales. Fortunately, the emergence of this conceptual base for landscape ecology was accompanied by technological advances in computing power and in fields such as Geographical Information Systems (GIS), satellite imagery and geo-statistics, thus providing the practical means by which to start evaluating this 'new' ecological model.

Key principles of landscape ecology

Landscape ecology is perhaps best defined by a number of characteristics, including

- its focus on spatial patterns, functions and processes;
- broader spatial extents than those traditionally considered in ecology; and
- the acceptance of humans as agents of landscape change.

Space has, strangely perhaps, been described as 'the final frontier' for ecological theory (Kareiva 1994). This is not, however, as surprising as it might seem because for much of its history, ecology was concerned with inherently non-spatial problems: predator–prey dynamics, for example, or population trends, nutrient cycling, or other functional dimensions that are not geographically determined. However, ecosystems cannot be isolated from their spatial context, as illustrated by the following quotation from Richard Forman, one of the key initiators of the discipline of landscape ecology:

> Look carefully at the big picture out an airplane window or on an aerial photo. The land mosaic displays a distinctive spatial pattern or structure. It works or functions, that is, things flow and move through the pattern. The pattern is dynamic, changing over time. The structure or pattern is normally composed entirely of patches (rounded/elongated, large/small, etc.), corridors or strips (wide/narrow, straight/curvy …), and background matrix (continuous/discontinuous, perforated or not …). Such simple but rigorous attributes opened up the concept of a landscape, well known in other disciplines, to scientists as a research frontier. More to the point, landscape ecology focuses exactly at the scale of human activity.
>
> *(Forman 2011)*

Landscape ecology is fundamentally concerned with this notion of spatial heterogeneity – what it is, how to describe and measure it, what it implies for ecosystems, what it is influenced by, how it changes over time, how humans manage it. Simply put, landscape ecology involves the study of landscape patterns, the interactions amongst the various elements making up a spatial landscape pattern, and how these patterns and interactions change over time. Patterns are understood in terms of different landscape patches, connected through corridors and non-linear linkages, and interacting with a general landscape matrix (McGarigal 2004). Amongst the various themes of the discipline are identifying and describing agents of pattern formation, detecting pattern and the scale at which it is expressed, quantitatively describing patterns and change through landscape metrics, understanding the ecological implications of spatial landscape patterns, understanding the influences of disturbances (both natural and anthropogenic) on landscape patterns, and exploring the implications of landscape patterns for management objectives derived from the demands humans place on landscapes (e.g. Dover and Bunce 1998; International Association for Landscape Ecology 2011; Wiens et al. 2007).

Given this emphasis on landscape patterns, it is then perhaps not surprising that landscape ecology is distinguished by its focus on broader spatial remits than those that have traditionally been the domain of ecology. This is also a result of initial influences on the field from geographers; aerial photography, for example, played a strong part in the formulation of the early landscape ecological ideas of Carl Troll (Antrop 2005), and the discipline approaches the study of landscape patterns from a similar coarse-grained perspective, rather than zooming in on the micro-scale. Landscape ecology is also defined by its focus on the role humans play in creating and modifying landscape patterns and processes. Human beings, as major agents of landscape change, influence practically all types of landscape patterns, whether in predominantly natural, semi-natural or built landscapes, but whilst this fact was recognized early on in ecological theory (e.g. Tansley 1935), it was often overlooked by the main thrust of ecological research. Human influence is now known to be extremely widespread and pervasive – processes of global climate change, for example, impact on even the most seemingly pristine landscapes and there is not a single extensive ecosystem left that is free of this influence (Alberti et al. 2003; Naveh 2010). As a point of interest, it should be noted that two main 'schools' of landscape ecology exist. On the one hand, the American school focuses primarily on natural systems and on heterogeneity within the landscape. It puts emphasis on organism-environment relationships, without necessarily invoking anthropogenic factors into the equation (McIntyre 2001), and is concerned primarily with the ecological consequences of larger spatial patterns of biotic and abiotic resources. The European school, on the other hand, places greater emphasis on typology, classification and nomenclature, and is largely concerned with the cultural dimension and human application of the landscape, reflecting the long history of human modification of the terrain within the European landscape (Cassar 2007; Cassar 2010).

Forman (1995) summarizes twelve main principles of landscape ecology, which establish the premises and remit of the discipline; these are listed in Box 33.1 below:

Box 33.1: General principles of landscape ecology (from Forman, 1995)

Landscapes and regions

1. *Landscape and region:* A mix of local ecosystem or land use types is repeated over the land forming a landscape, which is the basic element in a region at the next broader scale composed of a non-repetitive, high-contrast, coarse-grained pattern of landscapes.
2. *Patch-corridor-matrix:* The arrangement or structural pattern of patches, corridors and a matrix that constitute a landscape is a major determinant of functional flows and movements through the landscape, and of changes in its pattern and process over time.

Patches and corridors

3. *Large natural-vegetation patches:* These are the only structures in a landscape that protect aquifers and interconnected stream networks, sustain viable populations of most interior species, provide core habitat and escape cover for most large-home-range vertebrates, and permit near-natural disturbance regimes.
4. *Patch shape:* To accomplish several key functions, an ecologically optimum patch shape usually has a large core with some curvilinear boundaries and narrow lobes, and depends on orientation angle relative to surrounding flows.
5. *Interactions among ecosystems:* All ecosystems in a landscape are interrelated, with movement or flow rate of objects dropping sharply with distance, but more gradually for species interactions between ecosystems of the same type.

6. *Metapopulation dynamics:* For subpopulations on separate patches, the local extinction rate decreases with greater habitat quality or patch size, and recolonization increases with corridors, stepping stones, a suitable matrix habitat or short inter-patch distance.

Mosaics

7. *Landscape resistance:* The arrangement of spatial elements, especially barriers, conduits, and highly heterogeneous areas, determines the resistance to flow or movement of species, energy, material, and disturbance over a landscape.
8. *Grain size:* A coarse-grained landscape containing fine-grained areas is optimum to provide for large-patch ecological benefits, multi-habitat species including humans, and a breadth of environmental resources and conditions.
9. *Landscape change:* Land is transformed by several spatial processes overlapping in order, including perforation, fragmentation and attrition, which increase habitat loss and isolation, but otherwise cause very different effects on spatial pattern and ecological process.
10. *Mosaic sequence:* Land is transformed from more to less suitable habitat in a small number of basic mosaic sequences, the ecologically best being in progressive parallel strip from an edge, though modifications of this pattern lead to an 'ecologically optimum' sequence.

Applications

11. *Aggregate-with-outliers:* Land containing humans is best arranged ecologically by aggregating land uses, yet maintaining small patches and corridors of nature throughout developed areas, as well as outliers of human activity spatially arranged along major boundaries.
12. *Indispensable patterns:* Top-priority patterns for protection, with no known substitute for their ecological benefits, are a few large natural-vegetation patches, wide vegetated corridors protecting watercourses, connectivity for movement of key species among large patches, and small patches and corridors providing heterogeneous bits of nature throughout developed areas.

Applying landscape ecology: relevance to contemporary issues

The spatial concerns of landscape ecology are highly pertinent to several present-day concerns, in particular those relating to the challenges involved in managing multifunctional landscapes, on which we place multiple, often conflicting, demands. One area of thematic interest, for example, is the impact of land-use change. Habitat destruction is now widely recognized as the leading cause of biodiversity loss worldwide, but issues of concern relate not only to the quantity of habitat being lost (which is very substantial), but also to changes in the spatial patterns that result. In particular, there is much concern about the formation of habitat patches, isolated from other similar habitats, by fragmentation. The characteristics of these small habitat patches vary from those of larger habitat areas, not only because there is a lower extent of continuous habitat cover, but also because of disproportionate exposure to edge effects, i.e. the different biophysical conditions found on the margins of a habitat area, which in turn influence the composition and functioning of biotic communities. Such notions have many practical implications for conservation planning and management. A long-standing debate in protected-area design for example, which was highly prevalent during the 1970s and 1980s, concerns whether it is better to have several small reserves rather than one single large reserve of equivalent size; this is termed the SLOSS (Single Large or Several Small) dilemma (Diamond 1975). The standard species-area relationship, where larger areas support more species, provides evidence in favour of a single large site, with an additional argument in favour being the minimization of edge effects. However, critics point out that this assumes a nested species composition, where a large area would include all species from smaller areas, an assumption that often does not hold (Simberloff and Abele 1982). Additionally, a single large site may be disproportionately vulnerable to natural disasters or disease. Landscape ecology provided the means to add flesh to the bones of these concepts, through empirical research to understand the nesting and flows of species within a landscape.

The SLOSS debate also brought to the fore another key consideration of landscape ecology, i.e. connectivity. Even where habitat areas are small, there are benefits to be had from linking these to one another, to enable flows of matter and energy. Such benefits include genetic exchanges and the facilitation of species movements as these migrate in search of more favourable environmental conditions (Bennett 2003). The latter consideration is particularly relevant in the context of global climate change, which brings about a real risk that protected areas will no longer provide suitable habitat for the species they were designated to protect (Klausmeyer and Shaw 2009). The movements of faunal species are contingent on the availability of suitable linkages, which can take various forms, including corridors and stepping stones (Bennett 2003). Conversely, when seeking to manage issues such as the spread of pests or disease, an understanding of the spatial patterns and features which are facilitating such dispersion comes in extremely useful. Such applications of landscape ecology incorporate biodiversity conservation planning, but also extend to areas such as forestry management, agricultural production and other forms of rural development.

Landscape ecology has also influenced other disciplinary areas, including landscape design and architecture and land-use planning. For example, landscape ecology can provide a strong basis for landscape architecture, guiding and inspiring designers towards landscapes that are both environmentally sustainable as well as culturally and aesthetically appropriate (Makhzoumi 2000). Dramstad et al. (1996) provide several illustrations of the practical applications of landscape ecology in architecture, ranging from the design of road and windbreak barriers, to the shape of boundary areas. Similarly, landscape ecology can provide a solid foundation for strategic land-use planning, based on a holistic review of the multiple functions that a landscape needs to serve, and an understanding of the most efficient and effective spatial patterns that can achieve the relevant planning objectives. In a case study on the island of Gozo (Malta), Cassar (2010) outlines a regional land-use planning model that is based on landscape ecology principles, which juxtaposes and integrates multiple land uses, ranging from urban sites to agricultural areas to conservation core zones, buffer areas and sites with the potential to be ecologically restored.

Future directions

The discipline of landscape ecology has strengthened tremendously over the past years. The International Association of Landscape Ecology (IALE) now has thousands of members and hosts chapters in Africa, Argentina, Australia, Brazil, Canada, China, Czech Republic, Denmark, Estonia, France, Germany, Italy, Japan, the Netherlands, Poland, Portugal, the Slovak Republic, Sweden, Switzerland, Ukraine, the United Kingdom, the United States of America and Vietnam, in addition to a general European chapter. The field has indisputably made great progress in learning to understand, characterize and describe the mechanisms of spatial dynamics at the landscape scale. However, several challenges remain. I focus here on three key issues:

- rigorously enhancing our understanding of spatial dynamics;
- integrating anthropogenic aspects into the discipline; and
- effectively linking landscape ecology to real-world policy concerns.

Starting with the first, notwithstanding the significant strides of the last few years, landscape ecology still needs to better understand the various aspects of spatial dynamics and the linkages between these and ecosystem processes. The 'brief' of the discipline is certainly no walk in the park. Landscape ecology needs to effectively link work in traditional ecology with the wider landscape scale, establishing connections between population and ecosystem processes, and understanding the relationships of many different types of organism to the spatial context in which they exist. The discipline must seek to do this, working within systems that are changing continuously – spatial patterns are characterized first and foremost by their propensity to change – and that exist at multiple nested scales. As per established scientific methods, experimentation is often sought as a means for quantifying and communicating these various aspects, but experimentation is far more challenging at the landscape scale than on a controlled 1 m^2 plot of land. Landscapes are, by their very definition, large all-encompassing spaces, including within them many different natural elements and, more often than not, also including a strong human footprint. Research must continue to address the challenges involved in obtaining scientific knowledge at this scale.

The second major challenge is perhaps an issue of worldview. As noted above, ecology has traditionally been concerned with how natural ecosystems function, 'in spite of' humans, with efforts often being made to exclude human influences in the study of ecosystem processes. Landscape ecology made a quantum leap forward in acknowledging, within its conceptual basis and through its methods, the fact that humans are part of nature and that the study of ecosystem dynamics must proceed accordingly. However, a review of landscape ecology publications will quickly reveal that much research in landscape ecology is biased towards its origin in the natural sciences (Conrad et al. 2011), providing a somewhat one-sided perspective on one of the stated themes of the field which is 'the relationship of human activity to landscape pattern, process and change' (International Association for Landscape Ecology 2011). This is a matter of concern, not only because social systems cannot be effectively analyzed without an acceptance that these are inherently different from natural systems (and thus require different concepts and methods), but also because of the rationale outlined at the start of this chapter. If landscape ecology is to make an effective contribution to sustainability, then it should also work to bridge the people-nature gap, and embed its work within a broader environmental ethic – this cannot be done without truly interdisciplinary and transdiciplinary work.

Finally, and perhaps most significantly, landscape ecology has been criticized for existing in something of an academic vacuum. Notwithstanding its huge potential contribution, it has played little role in significant policy developments of the past decades, such as the formulation and adoption of a European Landscape Convention, or the drafting of the European Union's Birds and Habitats Directives. In a seminal review of the field, Hobbs (1997: 5) noted by its very nature landscape ecology is an applied science, but concluded that the extent to which it really is applied is 'very little', pointing to little cross-fertilization between landscape ecology and other disciplines as a major flaw, and noting 'there is a perception among many in other disciplines that, although the landscape may be the relevant scale at which to study and manage things, landscape ecology has not come up with much that can help' (ibid.: 6). Concerns include the failure of landscape ecologists to move beyond technical jargon to communicate effectively with people outside the field (perhaps Box 33.1 provides an illustration of this), and a lack of emphasis on addressing pragmatic management problems. Whilst fifteen years have passed since these observations were made, they are arguably still relevant. Landscape ecology, despite its potential, still languishes in relative obscurity, exalted by those involved in the field, but largely overlooked by those outside it. The real potential of landscape ecology will only be achieved when the discipline takes a leading role in mainstream efforts for the protection, planning and management of landscapes – and in this aspect, there is still some way to go.

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