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GUEST EDITORIAL

Landscape fluidity – a unifying perspective for understanding and adapting to global change

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ABSTRACT

Rapid, human-induced global change presents major challenges to researchers, policy-makers and land managers. Addressing these challenges requires an appreciation of the dynamics of ecological systems. Here, we propose 'landscape fluidity' as a perspective and research agenda from which to consider landscapes in the process of changing rapidly through both time and space. We define landscape fluidity as the ebb and flow of different organisms within a landscape through time. A range of existing ideas, themes and practical approaches are relevant to landscape fluidity, and we use a case study of scattered tree landscapes in south-eastern Australia to illustrate the benefits of a landscape fluidity perspective. We suggest that a focus on landscape fluidity can bring a renewed emphasis on change in landscapes and so help unify a range of currently separate research themes in biogeography, ecology, palaeoecology and conservation biology.

Keywords

Adaptive capacity, Australia, biological legacies, climate change, conservation science, landscape dynamics, novel ecosystems, palaeoecology, range shifts, resilience.

INTRODUCTION

Imagine being able to observe change in the same landscape over years, decades and centuries. You will see changes in land cover, and you will see species come and go. Woodlands may change into grasslands, only to convert to shrubland centuries later. What you observe is what we term 'landscape fluidity': the ebb and flow of different organisms within a landscape through time.

Since the 1980s, the study of landscapes has benefited from the development of increasingly sophisticated concepts for the analysis of spatial patterns and processes (Forman & Godron, 1986; Turner & Gardner, 1991; Forman, 1995). These developments have resulted in a 'toolbox' of useful ideas, themes and management options, such as metapopulation theory, habitat loss and fragmentation, and wildlife corridors. For land managers, an awareness of these various themes has been useful for helping them in their attempts to guide landscapes towards a desired outcome.

It is widely recognized that landscapes and ecosystems are dynamic, including both equilibrium and non-equilibrium situations (e.g. Huston, 1979; Forman & Godron, 1986; Dunn *et al.*, 1991; Sprugel, 1991; Reice, 1994; Forman, 1995; Gunderson *et al.*, 2002; Nelson *et al.*, 2007). However, major reviews of biodiversity loss in human-modified or fragmented landscapes suggest that research in these landscapes has typically focused on spatial patterns, with little or no emphasis on temporal patterns of landscape change (Debinski & Holt, 2000; Fahrig, 2003). At the same time, palaeoecologists have routinely studied long-term temporal patterns in biodiversity, but this has received limited attention in conservation-related research (Willis & Birks, 2006). Thus, while long-term temporal patterns (palaeoecology) and spatial patterns in biodiversity (landscape ecology) are well researched, short-term temporal patterns are less well studied (Willis *et al.*, 2007a).

The renewed necessity for understanding temporal dynamics is increasingly recognized (e.g. Whittaker *et al.*, 2005). This is because rapid global change poses a series of new challenges for the understanding and management of landscapes and the organisms within them. These challenges include systemic changes in climate and atmospheric composition, cumulative changes in land cover and use, and global-scale changes in socioeconomic processes that influence the way humans

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extract ecosystem services. For the purposes of this editorial we define 'rapid' global change as significant change in key parameters (caused by natural plus anthropogenic drivers) that are occurring within a human lifetime, over a decadal or sub-decadal timeframe. The pace of global change is likely to result in a tendency towards non-equilibrium landscapes that lag in their response to changes in key drivers. In effect, landscapes will be chasing moving targets. Understanding and managing landscapes in this uncertain context, to allow organisms to adapt and respond, requires a concomitant shift in emphasis from stability towards change.

Some aspects of landscape fluidity have been diminished by human actions (e.g. by a loss of connectivity), while other aspects of landscape fluidity have become enhanced (e.g. species extinctions and invasions resulting from landscape change, or changed species interactions resulting from the loss of large predators or other important functional groups). Thus, although landscape fluidity as a phenomenon is value-free, how we guide landscape fluidity can be manifested in outcomes that society may see as good, bad or a mixture of both. Landscape fluidity also has consequences that are species-specific, because in the same landscape change may cause an increase in one species but a decrease in another. The study and management of landscape fluidity as a phenomenon therefore requires an understanding of the underlying factors that affect it.

By emphasizing rapid change in landscapes, and the essential need for organisms to move, the concept of landscape fluidity is intended to provide renewed focus on change through both time and space. At present no perspective or research agenda sufficiently emphasizes the destabilizing effects of continuing rapid change. Landscape fluidity is intended to provide a single concept that alerts practitioners to the need to consider rapid change. To achieve this aim, landscape fluidity encapsulates a range of ideas, themes and practical approaches that are needed to understand and manage changing landscapes. We hope that the concept of landscape fluidity will help researchers to talk more readily with practitioners about the challenges that we collectively face.

In this short editorial, under the banner of landscape fluidity, we briefly summarize a small number of recent themes from the ecological literature that have been treated largely independently of one another, but that share a common focus on organisms' changing distributions and interactions with each other and their environment at a time of rapid global change. We briefly illustrate these themes with a case study of scattered tree landscapes in south-eastern Australia.

THEMES THAT CAN BE INTEGRATED UNDER A 'LANDSCAPE FLUIDITY' BANNER

The following theoretical and practical themes relate directly to the ebb and flow of organisms within a landscape through time – that is, they have a shared focus on landscape fluidity. We argue that, if integrated under a landscape fluidity banner, these themes will be more effective in stimulating debate about how to manage rapidly changing landscapes, and ultimately may help foster a cohesive new research and management agenda. Although our list of themes is by no means exhaustive, it provides support for our view that there are enough concepts with a consistent underlying focus on change to warrant a new unifying perspective. That is, we envisage that these, and other relevant themes, could focus on landscape fluidity (and the processes that influence it) as an integrating concept.

Range shifts and facilitated range shifts

Many species are shifting or will need to shift their ranges to remain within a suitable climate (Root *et al.*, 2003; Parmesan, 2006). Understanding the dynamics of the 'leading edge' and 'rear edge' of populations undergoing range shifts is thought to be critically important, in particular in relation to issues of genetic diversity (Hampe & Petit, 2005; Willis & Birks, 2006). Given rates of climate change and disruptions to connectivity, facilitated range shifts have been suggested as a management tool for some species (Peters, 1990; Hoegh-Guldberg *et al.*, 2008; Hunter, 2008). This poses challenges to management because of the potentially high costs involved, and the risks of negative consequences associated with the establishment of a species in a new location. Despite these challenges, facilitated range shifts may be the only viable management option for some species (Hoegh-Guldberg *et al.*, 2008; Hunter, 2008).

Changed species interactions

The range shifts of individual species will inevitably cause changes in species relative abundances and species composition at any given location. Species interactions may also change and cause feedbacks, which in turn can result in cascading effects in an ecosystem (Breshears *et al.*, 2005). Hence, even when species composition in an ecosystem does not change, species abundance, interaction strength and ecosystem function can change (Fleming & Candau, 1998; Schmitz *et al.*, 2003). These new types of changes pose formidable challenges to researchers and land managers because their consequences will be difficult to predict.

Palaeoecology

Palaeoecology is the study of temporal records such as fossil pollen, seeds and fruits, animal remains, tree rings and charcoal (Willis & Birks, 2006). Thus, by definition, palaeoecology examines landscape fluidity. Temporal perspectives such as those provided by palaeoecology are essential for the development of meaningful conservation strategies that account for rapid global change (Willis & Birks, 2006). However, the palaeoecological record has been under-utilized in conservation-related research, with most data sets in conservation research spanning < 50 years (Willis & Birks, 2006; Willis *et al.*, 2007a). This is a problem because many data sets span only one or a few generations of the organisms studied (Willis *et al.*, 2005; Willis & Birks, 2006). Often,

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long-term ecological perspectives provide a more scientifically defensible basis for conservation decisions than those based only on contemporary data (Willis *et al.*, 2007b). Conservation-related research and palaeoecology can directly complement one another (Willis & Birks, 2006). For example, Martínez-Meyer *et al.* (2004) compared modern ecological niches and distributions for 23 extant mammal species in the USA with those during the Last Glacial Maximum (14,500 and 20,500 BP) based on fossil and palaeoclimatic data. The distributions of nine species were consistent between palaeoecological and modern data. This example of the simultaneous application of conservation-related research and palaeoecology provides evidence of 'niche conservatism' (that ecological niches remain relatively constant over evolutionary time-scales and across space), which in turn has important implications for the anticipation of future range shifts in response to climate change (Martínez-Meyer *et al.*, 2004). Current palaeoecological records can have spatial and temporal resolutions similar to those used in conservation research (Willis & Birks, 2006). This opens the possibility of bridging the gap between the use of long-term and short-term data in understanding landscape fluidity (Willis & Birks, 2006).

Connectivity

Lindenmayer & Fischer (2006) propose that in ecology the term 'connectivity' is an amalgam of three concepts: (1) habitat connectivity – the connectedness of patches of habitat suitable for a given individual species; (2) landscape connectivity – the human perception of physical connectedness of vegetation cover in a landscape; and (3) ecological connectivity – the connectedness of ecological processes at multiple scales. All three concepts of connectivity are relevant to landscape fluidity because each relates to patterns and processes that influence the ebb and flow of organisms. However, from a landscape fluidity perspective (in both research and management), connectivity is most relevant when considered: (1) with an emphasis on trajectories of change in a landscape; (2) from perspectives that incorporate gradients in landscapes (*sensu* Fischer *et al.*, 2004; Manning *et al.*, 2004) rather than a binary (habitat/non-habitat) perception of landscapes; and (3) by adopting an organism-specific perspective in order to understand organisms' individualistic responses, compared with a human 'aerial' view of landscapes (*sensu* Manning *et al.*, 2004).

Ecological memory and biological legacies

Ongoing change in ecosystems is influenced by some level of biological or ecological continuity at a particular location through time. Bengtsson *et al.* (2003) have defined two types of 'ecological memory' – internal memory and external memory. Internal memory occurs at the site level and is manifested as 'biological legacies'. Biological legacies are organisms or organically derived structures that remain at a site after a disturbance and facilitate restoration in the future (Franklin *et al.*, 2000). External memory is the provision of source organisms *between* sites after disturbance (Bengtsson *et al.*, 2003). The explicit consideration of ecological memory will be particularly important in an era of rapid change.

Novel ecosystems

Organisms are expected to respond individualistically to global change, and existing ecological communities are likely to disassemble and reassemble in new ways (Peters, 1990). Invasion by new species, coupled with the extinction or changes in relative abundance of others, will result in 'novel ecosystems' that have not existed in the past (Hobbs *et al.*, 2006). These ecosystems will often include what may be conventionally considered to be 'introduced' species. But if such systems provide certain valued functions should we be concerned about the status of a species as 'introduced'? When do we accept an introduction as irreversible? Novel ecosystems pose an interesting philosophical challenge to ecologists, land managers and society alike because they confront the still widely held preservationist ethic in conservation.

Dynamic reserves and the integration of conservation and production

Only 11.5% of Earth's land mass is formally protected (Rodrigues *et al.*, 2004), and only 5.1% of this is designated explicitly for biodiversity protection (Hoekstra *et al.*, 2005). It is now widely agreed that existing reserve networks by themselves will be insufficient to protect global biodiversity. Climate change, and the dynamic response of landscapes to it, are particular challenges for national legislative frameworks that currently focus on static conservation reservations for particular habitat types or the presence of particular species (Harris *et al.*, 2006). How do we create legislation that accommodates the dynamics of changing landscapes? Does an area need to be 'locked up' for conservation indefinitely, or can desired management outcomes be achieved by creating temporary reserves, or by integrating conservation and production? In the context of a landscape fluidity, 'dynamic reserves' present an innovative management technique (see Bengtsson *et al.*, 2003). Traditional conservation thinking tends to separate conservation and human land uses, whereas dynamic reserves and integrated land use acknowledge the limitations of taking a binary approach to conservation.

Adaptive capacity and ecological resilience

Ecological resilience is 'measured by the magnitude of disturbance that can be absorbed before the system is restructured with different controlling variables and processes' (Gunderson *et al.*, 2002, p. 4). Not all landscapes are equal in their ability to absorb disturbances and adapt through time. Some will change gradually as global change progresses, whereas others will undergo relatively sudden regime shifts as they cross dynamic thresholds. Some regime shifts may not be desirable, e.g. when an agriculturally productive landscape turns saline. While desirability is a value judgement made by society, the possibility of regime shifts that are deemed undesirable can be reduced at least partly by understanding resilience-related concepts and by managing landscapes for diversity and redundancy (Walker & Salt, 2006).

Anticipatory restoration

A focus on change, landscape trajectories and climate adaptation necessarily highlights the need to anticipate the future requirements of organisms. In addition to conventional restoration activities, 'anticipatory restoration' efforts may seek to create certain conditions in anticipation of further changes in the future. For example, habitat may be restored to create the conditions suitable for a particular keystone species, which in turn would facilitate additional changes to the ecosystem further down the line (Manning *et al.*, 2006a). Anticipatory restoration might include, for example, re-establishing gradual transitions between ecosystems and land uses across landscapes.

Anticipatory restoration is important because a management paradigm of 'restoring the past' may not be feasible, desirable or appropriate in many situations. Anticipatory restoration can be used to restore the *properties* of past functional ecosystems, without attempting to create unattainable facsimiles of the past. These properties might include: gradual transitions in time and space, keystone species and structures, key ecological processes (energy flows, nutrient cycles, hydrological cycles), species diversity and interactions, functional redundancy and disturbance regimes. Restoring or enhancing lost properties could range from 'rewilding' (*sensu* Soulé & Noss, 1998), where natural processes are allowed to dominate over large areas to create connected, self-organising ecosystems, through to the targeted return of key ecological processes or properties to an otherwise managed landscape. Therefore, mimicking nature does not preclude commodity production in the same landscape, but requires a revaluation of how we can do this while also allowing adaptation. Thus, in the future, new types of cultural landscapes might emerge where integrated land uses occur alongside areas dominated by natural processes.

CASE STUDY: SCATTERED TREE LANDSCAPES IN SOUTH-EASTERN AUSTRALIA

Scattered trees are recognized as keystone structures in that their positive effect on ecosystems is disproportionate to the small area they occupy (Manning *et al.*, 2006b). In south-eastern Australia, remnant scattered trees are a typical feature of agricultural landscapes. They generally occur in areas of lower topography, and are derived from grassy eucalypt woodlands that occupied the most productive parts of a landscape. These have been preferentially cleared for agriculture – leaving scattered tree cover over large areas. Scattered trees exemplify landscape fluidity in the following ways:

(1) They provide multi-directional connectivity for organisms moving through the landscape (Fischer & Lindenmayer, 2002a,b; Manning *et al.*, 2006c). Thus, they can be expected to facilitate future range shifts of species that will use them.
(2) They provide ecological memory in the landscapes. Many old scattered trees themselves are biological legacies of pre-European vegetation and embody site-level continuity through time. Thus they influence, and are influenced by, the ebb and flow of many organisms over centuries. They also embody external memory between sites through the movement of their own propagules (and genes) on-site and to neighbouring sites, i.e. they ebb and flow themselves, albeit slowly.
(3) They could potentially be used, when grown collectively in a landscape, to create dynamic reserves and to integrate conservation and production, through the careful use of grazing regimes that allow strategic grazing amongst the scattered trees.
(4) The 'whole landscape' distribution and multiple ecological services of scattered trees enhance the ecological resilience and adaptive capacity of landscapes and keep management options open. For example, existing scattered trees could function as foci for ecological restoration (Manning *et al.*, 2006b).

Despite these values, scattered trees are disappearing in south-eastern Australia due to their gradual death, removal and lack of regeneration. Modelling indicates that there is a limited window of opportunity to begin restoring scattered trees in order to avoid a future 'bottleneck' where trees and their functions are absent (Dorrough & Moxham, 2005; Gibbons *et al.*, 2008). The loss of scattered trees would result in a regime shift towards an open grassland system, with negative ecological consequences for many organisms. Thus, anticipatory restoration is required to ensure appropriate levels of landscape fluidity in the future.

Our case study on Australian scattered trees illustrates that, increasingly, researchers and land managers need to consider the ebb and flow of organisms through time and space when addressing issues of landscape management. Australian researchers are not alone in this regard. For example, in the forested landscapes of Sweden, researchers are investigating climate change-induced range shifts (Kullman, 2001), ecological resilience (Chapin *et al.*, 2007), biological legacies (Lindbladh *et al.*, 2007) and the potential use of dynamic reserves (Bengtsson *et al.*, 2003). It is within this context that we suggest landscape fluidity as a focus for unifying congruent research themes.

FUTURE DIRECTIONS

Landscape fluidity provides a unifying perspective that emphasizes the primacy of change through time when addressing ecological issues. Viewing ecology simultaneously through the lenses of time and space will lead to enhanced outcomes for landscape management decisions; as illustrated with our case study of scattered trees. We believe that landscape fluidity could facilitate a seamless integration of the study of long-term and short-term temporal data, where such connections have not previously been made (see Willis & Birks, 2006).

Communicating the breadth of a new idea like landscape fluidity necessarily comes at the expense of detail. We freely accept that whether or not the term 'landscape fluidity' catches on will depend on how well we frame the dynamic imperatives, and whether the term can capture the imagination and perceived needs of researchers and practitioners. If it is considered useful, the next step will be to fill in the detail. Here, the challenge is conceptual clarity to support the move from the theoretical to the practical. From a quantitative perspective, the use of long-term data over large spatial scales will be fundamental to understanding landscape fluidity because such data can capture changes in landscapes and organisms' responses to landscape change through time. Understanding trajectories of change also may require the retrospective analysis of existing data sets and the continuation, establishment or re-establishment of long-term ecological research projects that occur at the landscape scale. Further, to link research with practical management, manipulative experiments at a landscape scale that elicit understanding of causal effects may be useful.

The consideration of landscape fluidity is principally a means of altering our perspective so that the outcomes of our decisions are more applicable in a world that is changing rapidly. Existing ideas, themes and practical approaches of applied ecology remain just as relevant as always, but under a banner of 'landscape fluidity' they may guide us more effectively towards desired outcomes. The boundaries of landscape fluidity as a perspective are therefore inclusive, and are limited only to what is useful to address the central themes of organisms, landscapes and rapid environmental change. We hope the concept can provide a perspective for research and management that facilitates cross-fertilization over a range of themes currently supported by substantial, but often separate, bodies of literature.

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