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PERSPECTIVE

Spatial resilience: integrating landscape ecology, resilience, and sustainability

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Abstract Landscape ecology has a high potential to contribute to sustainability in the interactions of people and nature. Landscape ecologists have already made considerable progress towards a more general understanding of the relevance of spatial variation for ecosystems. Incorporating the complexities of societies and economies into landscape ecology analyses will, however, require a broader framework for thinking about spatial elements of complexity. An exciting recent development is to explicitly try to integrate landscape ecology and ideas about resilience in social–ecological systems through the concept of spatial resilience. Spatial resilience focuses on the importance of location, connectivity, and context for resilience, based on the idea that spatial variation in patterns and processes at different scales both impacts and is impacted by local system resilience. I first introduce and define the concepts of resilience and spatial resilience and then discuss some of their potential contributions to the further interdisciplinary integration of landscape ecology, complexity theory, and sustainability science. Complexity theorists have argued that many complex phenomena, such as symmetry-breaking and selection, share common underlying mechanisms regardless of system type (physical, social, ecological, or economic). Similarities in the consequences of social exclusion and habitat fragmentation provide an informative example. There are many strong parallels between pattern–process interactions in social and ecological systems, respectively, and a number of general spatial principles and mechanisms are emerging that have relevance across many different kinds of system. Landscape ecologists, with their background in spatially explicit pattern–process analysis, are well placed to contribute to this emerging research agenda.

Keywords Resilience · Spatial resilience · Complexity · Landscape ecology · Framework · Social–ecological system · Vulnerability · Robustness · Social exclusion · Fragmentation

Introduction

In recent years, landscape ecology has increasingly been seen as a pluralistic area of research that both can and should contribute to the sustainable management and development of landscapes (Wu 2006; Musacchio 2009; Pearson and McAlpine 2010). Landscape ecologists have produced solid documentation of the relevance of many broad-scale conservation heuristics, such as maintaining habitat connectivity, paying attention to habitat complementarity, and thinking about landscape functionality for organisms that move through and use landscapes over a range of different

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scales (e.g., Poiani et al. 2000; Lindenmayer and Fischer 2006). We are now at a point in the development of landscape ecology where many of these principles can be confidently applied to the broad-scale management of ecosystems, and landscape ecologists have been broadening their scope to think about implementation as well as documentation (e.g., Opdam et al. 2001; Opdam and Wascher 2004).

In expanding from its largely pattern-oriented origins into an interdisciplinary arena, landscape ecology faces a number of challenges. One of the greatest of these is the incorporation of the complexity of social, ecological, and social–ecological systems (SESs) into a cohesive spatial framework. We often tend to think of landscapes as sets of patches that are arranged along biophysical and anthropogenic gradients. Anthropogenic influences have a spatial outcome, which may be measured by its impacts on patches; but spatial patterns in societies and economies are often harder to map and more dynamic than spatial patterns in land cover, and landscape ecology has not yet been well integrated with sociologies of place and geographies of human societies (e.g., see discussion in Abbott 1997).

Achieving effective interdisciplinary integration will rely heavily on our ability to conceptualise and frame questions about the interactions between people and nature as elements of a cohesive system with spatially located components, flows, interactions, and perturbations. The systems approach is already implicit in many landscape ecological analyses but the move from a fundamentally pattern-oriented view of the world to a more mechanistic, process-oriented view requires something of a paradigm shift (Cumming 2007). Even in areas of landscape ecological and biogeographic research that have a strong sociological history, such as network analysis, there are still relatively few published analyses that combine spatial approaches to societies and ecosystems in a compelling, dynamic way (Cumming et al. 2010).

When considering how to expand the scope of landscape ecology to better deal with questions of sustainability, one obvious approach is to introduce a stronger spatial component (as derived from and informed by landscape ecology and related ideas about the importance of spatial variation) to existing bodies of interdisciplinary knowledge. In what follows I will first introduce the concepts of resilience and spatial resilience, and then discuss some of their potential contributions to the further interdisciplinary integration of landscape ecology and sustainability science, focusing on the relatively new field of spatial resilience and its relevance for analysing and understanding landscape sustainability.

Resilience concepts

The concept of resilience has been used in ecology and interdisciplinary science for nearly 40 years (Holling 1973, 2001), with considerable confusion existing over its definition and usage (Grimm et al. 1992). Contemporary definitions consider resilience to consist of (1) the amount of disturbance that a system can absorb while still remaining within the same state or domain of attraction; (2) the degree to which the system is capable of self-organization (versus lack of organization or organization forced by external factors); and (3) the degree to which the system can build and increase its capacity for learning and adaptation (Carpenter et al. 2001).

A complementary perspective on resilience focuses on system identity; resilience equates to the maintenance of key components and relationships and the continuity of these through time (Cumming and Collier 2005). If resilience is low, identity may be lost; and correspondingly, if identity is lost, we can conclude that resilience was low. Resilience can thus be operationalized by quantifying identity and assessing the potential for changes in identity (Cumming et al. 2005).

As discussed by Cumming and Collier (2005) in relation to the ancient philosophical problem of Theseus's ship, identity has a strong subjective element. As with resilience (Carpenter et al. 2001), it must be defined in relation to a given perspective and problem. For example, while a sailor might view a boat as an entity that floats on water, a legal definition of a boat may depend only on the presence of part of its hull. In studies of social–ecological resilience and sustainability, defining identity requires a clear statement of exactly what constitutes the system and which of its components and relationships—social, ecological, and economic—we are interested in. For example, the identity of a hunter-gatherer resource system may depend heavily on the presence of hunters, a persistent population of their prey, and an environment in which hunting by traditional means can occur. If the hunters become farmers, or stock-brokers, the relationship of people to their prey items will be broken and the system can be considered to have lost its identity. Without a clear system definition, both resilience and sustainability become meaningless concepts because there is no baseline against which to measure change and no criterion against which (in the case of 'sustaining' or 'conserving') to define success or failure.

Although identity must be defined subjectively, based on what people agree on as being essential to the system, the definition of identity can itself be quantitative (e.g., a threshold level beyond which identity is lost). For example, in the traditional hunter-gatherer system mentioned above, system identity might be defined by the presence of at least 10 hunters (or some other theoretical prediction about minimum viable group size); and system changes that are considered to threaten identity can be quantified using changes in the number of hunters as one of a set of indicators.

Resilience theory has largely focused on understanding how and when complex adaptive systems undergo fundamental changes in their structure and function (e.g., Scheffer et al. 2001, 2009; Folke et al. 2004). It offers a number of principles for the fostering and development of resilience in SESs. In considering these generalities, it is important to note that resilience is not necessarily desirable per se. As a case in point, some highly resilient configurations of landscapes, such as the still-evident imprint of apartheid-era zoning policies in rural South Africa, may be negative for the people who live in those landscapes (Ramutsindela 2007).

Resilience is most rigorously quantified in very specific contexts, with the resilience *of* what *to* what clearly specified within known system boundaries, at known scales of analysis, and in relation to specified perturbations (Carpenter et al. 2001). Generalities about resilience, such as those that I present below, thus require the further qualification that these are 'average' expectations that may not be applicable in every instance.

In ecosystems, the key components are species and their biophysical environment (Tansley 1935; O'Neill et al. 1986; Pickett and Cadenasso 2002). The key relationships are structural (e.g., through habitat provision) and trophic; system memory is derived from seed banks, old-growth woodlands and trees, soils, and long-lived animals; and regimes are driven by a combination of biotic and abiotic factors such as herbivory, fire, and drought. Ecological resilience is generally thought to be enhanced by having or maintaining higher biodiversity, including a full complement of functional groups and natural levels of heterogeneity (patch mosaics); maintaining the capacity for broad-scale responses and system inputs and outputs, such as migration, colonization, and spatial subsidies; and the maintenance of natural disturbance regimes, especially fires and floodplain dynamics (e.g., see Walker 1992; Holling and Meffe 1996; Levin 1999; Kinzig et al. 2001). Spatial elements of ecological resilience are evident in the many well-documented pattern–process interactions that comprise the core of landscape ecology (e.g., Tscharntke et al. 2005; Harlan et al. 2007).

The key components of social systems are people, their livelihoods, and their rules, laws, customs, and attitudes. Key relationships include governance, social networks, economic transactions, and kinship; long-term memory is derived from older people, libraries, and other artefacts (e.g., aerial photographs, long-term data sets). Regimes are driven by politics, laws, and history. Social resilience is (in general) thought be enhanced by increased financial capital, the diversification of livelihoods, increases in trust and community cooperation, higher levels of education, the enhancement of local response capacity through appropriate institutions and organizations, and the creation of appropriate social and economic incentives for abiding by laws (e.g., see Ostrom 1990, 2007; Scheffer et al. 2000; Norberg et al. 2008). Spatial variation in each of these variables occurs within landscapes but can be difficult to map out and quantify in a spatially explicit manner, although some relevant data sets, such as census data, are collected in ways that are highly amenable to spatial analysis.

Social–ecological systems are not simply 'social plus ecological systems'; they exhibit a range of unique emergent properties and have their own varieties of complex behaviour (Westley et al. 2002). Their key components are people and other organisms and a set of essential maintenance components or ecosystem services, such as water quality and quantity, timber production, and soil fertility. Key relationships are those that link the two systems; for example, land tenure, land use, management, agriculture, and hunting. Long-term memory derives from both social and ecological sources, and social–ecological regimes (in the sense of forms of local stability) result from a complex interplay of social and ecological drivers, often with top-down (e.g., politics and governance) and bottom-up (population growth, ecological change) controls playing a central role (Norberg and Cumming 2008).

Although social–ecological resilience is generally thought to be enhanced by increases in both or either of social and ecological resilience, the two may also be in conflict. Focusing solely on ecosystems can reduce social resilience (e.g., game farms in Zimbabwe were invaded by people who felt dispossessed); and exploiting ecological capital in unsustainable ways (e.g., overfishing) can still create financial capital and increase short-term social resilience. Ultimately the resilience of SESs will depend heavily on the tightness (and speed) of feedbacks between ecosystems and people and the processes that lead to self-organization (Levin 1999, 2003). Local system dynamics may be greatly complicated by processes that occur at higher (more inclusive) hierarchical levels, such as the interference of central government in local governance, remittances from "external" family members to impoverished communities, global societal attitudes and external markets, and so forth.

Nearly all of the elements, relationships, and regimes discussed in this brief summary have spatial locations and spatial attributes. Even supposedly 'dimensionless' social interactions occurring over telephones or the internet involve two agents who have specific locations in space and time; and the wide range of technologies that human society has developed have reshaped societal concepts of space and distance (Cronon 1992), making them harder to map in geographical space. The explicit details of the role of space and spatial variation in system resilience are captured by the concept of spatial resilience, to which I now turn.

What is spatial resilience?

The concept of spatial resilience has its roots in meetings and discussions of the Resilience Alliance (http://www.resalliance.org), an international consortium of researchers and practitioners with interests in developing and applying resilience-related concepts in the context of social–ecological sustainability. Its first published usage was by Nystrom and Folke (2001), but it has taken on a broader meaning in subsequent discussions. A comprehensive definition is offered in the first book-length treatment of spatial resilience (Cumming 2011):

> Spatial resilience refers to the ways in which spatial variation in relevant variables, both inside and outside the system of interest, influences (and is influenced by) system resilience across multiple spatial and temporal scales. It has elements that are both internal and external to the system.
>
> The primary internal elements of spatial resilience include the spatial arrangement of system components and interactions; spatially relevant system properties, such as system size, shape, and the number and nature of system boundaries (e.g., hard or soft, and whether temporally variable or fixed over time scales of interest); spatial variation in internal phases, such as successional stage, that influence resilience; and unique system properties that are a function of location in space.
>
> The primary external elements of spatial resilience include context (spatial surroundings, defined at the scale of analysis); connectivity (including spatial compartmentalization or modularity); and resulting spatial dynamics, such as spatially driven feedbacks and spatial subsidies.
>
> Both internal and external elements must be considered in relation to other aspects of system resilience, including such things as the number and nature of components and interactions, the ability of the system to undergo change while maintaining its identity, system memory, and the potential inherent in the system for adaptation and learning.

Spatial resilience can thus be seen as an interplay, at different scales (Fig. 1), between spatial attributes of the system and the different system constituents (such as elements, interactions, adaptive capacity, memory, and history) that are typically included in definitions of resilience.

If resilience is thought of as the ability of a system to maintain its identity, spatial resilience deals with spatial variation in both internal and external

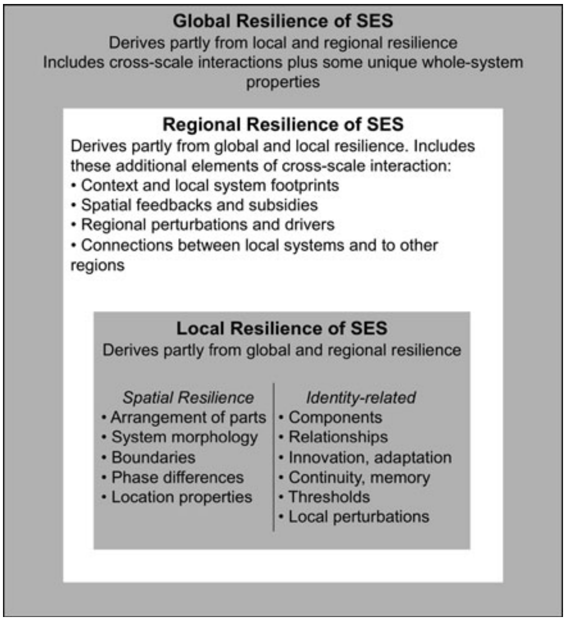

Fig. 1 Conceptual summary of hierarchical influences on the spatial resilience of a SES. The local resilience of a SES both influences and is influenced by its global, regional and internal resilience. Spatial variation and relationships are important at each of these scales. Reproduced with permission from Cumming (2011)

influences on identity. As argued by Cumming et al. (2005), a focus on identity and identity-related thresholds (i.e., points beyond which the identity of the system is lost) provides a way of linking tangible management goals and resilience theory. For example, the manager of a protected area in Zimbabwe might take the essential ecological elements of the system to include the maintenance of canopy cover and a set of processes that relate to pollination, seed dispersal, and woody plant recruitment. Management might then entail keeping the system away from the (example) thresholds defined in Table 1.

If there is a substantial human presence in the area, the definition of system identity can be expanded to include the provision of ecosystem or cultural services (e.g., thatch grass, cattle forage, drinking water, access to burial sites) to local communities, as well as elements of human wellbeing (e.g., health care, food security, economic benefits from the park). In this example the system as a whole is a spatially structured SES, with human elements located around the periphery of the park and ecological elements located along biophysical gradients both inside and around the park. The subtleties of spatial arrangement, both internal and external, may play a large role in the overall resilience of the system. For instance, it makes a huge difference to the manager's task if the headwaters of local streams are within the park (and hence under her control) or if the park sits downstream of other intensive water users, such as industry or agriculture. Viewing the park and its surrounding communities as a single, interdependent SES with a well-defined spatial structure provides the conceptual framework for starting to connect typical 'landscape ecology' variables—such as heterogeneity in land use and land cover distributions, woodland cover, and the spatial configuration of surrounding green spaces—with socioeconomic networks, trade, and feedbacks between social and ecological elements of the system at several different scales.

Exporting spatial concepts

How can the concept of spatial resilience be used to achieve better integration between landscape ecology

Table 1 Examples of potential identity thresholds for Miombo woodlands in southern Africa

Property	Ecological example	Zimbabwean example	Identity threshold example
Components (essential)	Habitat amount	% area of Miombo woodland	Loss of >40% of area
Relationships (functionally relevant)	Food webs	Pollination, nest cavity excavation	>30% population decline in sunbirds or barbets
Innovation (sources)	Biodiversity	Species or population loss	>20% reduction in insect species richness
Continuity	Seed banks, disturbance legacies	Recruitment post fire	Loss of >50% in year class of trees

The different system properties that contribute to identity are associated with specific examples that are then tracked and measured to explore overall system resilience and other disciplines? One answer is that it can contribute to developing better ways of applying some of the spatial principles and concepts that have been developed in landscape ecology to social, economic and geographic contexts, and to identifying generalities and synergies between different ways of looking at superficially different complex systems. The underlying assumption behind this view is that all complex systems reflect, at some level of analysis, the fundamental structure and physical principles of our universe. For instance, the concepts of symmetry and symmetry-breaking have interesting applications in fields as diverse as physics, chemistry, architecture, business, evolution, animal behaviour, and landscape ecology (e.g., Middleton 1989; Acemoglu and Scott 1997; Cooper et al. 2000; Mayes 2002; Portha et al. 2002; Brading and Castellani 2003; Cumming et al. 2008).

An interesting example, which is discussed in more detail by Cumming (2011), concerns the parallels between social and ecological fragmentation processes. Most landscape ecologists will be familiar with the idea that habitat loss can cause the fragmentation of formerly continuous landscapes into a series of smaller patches. Isolated patches have different properties from a continuous landscape, resulting in changes in both their internal ecological dynamics and the ways in which organisms disperse, interact, and meet their basic life history requirements (Debinski and Holt 2000; Lindenmayer and Fischer 2006). It is important to note that the strongest forms of fragmentation result in spatial separation of elements of both pattern *and* process; the physical division of one forest patch into two, for instance, does not inevitably translate into a change in ecological processes (Debinski and Holt 2000).

In social systems, people derive many benefits from belonging to a social network. These benefits are collectively termed social capital (Portes 1998). The converse of social capital, being left out or cut off from a socioeconomic network, is termed social exclusion (Silver 1995, 2007). Social exclusion is driven by a range of factors including inequities in wealth and power, as well as with differences in culture, education, and race. It is a social process with a strong spatial element. Socially excluded communities tend to live in their own isolated ghettos or homelands [‘fragments’ within a larger societal ‘matrix’; (Schierup 2001; Ramutsindela 2007; Szczepanski and Slezak-Tazbir 2007)]. Excluded communities may be linked to higher levels of poverty and crime, as in Cape Town, where murder rates are highest in some of the poorest suburbs (Gie 2009); but they may also be sources of cultural and ideological diversity, and can be forces for positive change, as in the case of the black civil rights movement in the USA. Social capital within an excluded community may be high, and may help to reduce risk and enhance collective action. The physical separation of many excluded communities from the rest of society can set in place further feedbacks, reinforcing a group identity and emphasizing other forms of exclusion (Dangschat 2009). Societies often have rigid rules about residency and work, for example, and these rules may further reinforce social segregation between long-time residents and new arrivals.

While there are important differences between ecological and social fragmentation processes, a spatial resilience framework serves to clarify some of the commonalities and general principles that underlie both cases. Just as isolated habitat fragments may lack important ecological processes relating to diversity and connectivity, socially excluded groups tend to be more vulnerable to many kinds of disturbance, often have below-average health and child survival rates, and may be less resilient to physical or socioeconomic perturbations because they do not have easy access to coping mechanisms and support systems (e.g., Acevedo-Garcia et al. 2003; Chaves et al. 2008).

Cumming (2011) identified at least three fundamental similarities between fragmentation concepts across different disciplines. The first is that process-related separation of any sort, including social and economic exclusion, almost always has a spatial component. In social systems this component is often ignored, but it may be fundamental to understanding the dynamics of a society or human community of interest and their interaction with natural resources. In many urban green spaces, for example, social and ecological values are positively correlated (Dooling 2009) because more affluent neighbourhoods often have taller, older trees and more recreational opportunities.

Second, while many differences exist in the relationships between fragmentation and diversity (where diversity is defined as the abundance and number of different elements in a given class, such as species, ethnic groups, land cover types, or kinds of organization) in social and ecological systems, respectively, there are some marked similarities between social and ecological systems in the relevance of higher-level systemic properties such as diversity and productivity (Walker and Langridge 2002; Norberg et al. 2008). Social exclusion can itself be viewed as an outcome of a lack of resilience to spatial fragmentation processes. It may be less likely in a more diverse community in which human interactions occur regularly across cultural and economic boundaries. Diversity can play a role in social systems in maintaining the viability of fragments; within excluded communities, for instance, shared knowledge and experience can improve coping strategies. And as in ecosystems, intermediate connectivity is perceived as an important component of the long-term resilience of societies, with medium levels of connectivity facilitating innovation and knowledge transfers without leading to excessive homogeneity in attitudes and technologies (Granovetter 1973; Portes 1998) and the resulting loss of adaptive capacity.

Third, issues of scale and the scaling relationships between the different holons (i.e., elements of a hierarchy, such as country, state, and county) within different kinds of hierarchy—social, institutional, economic, and ecological—can have a large influence on the overall performance of a SES, with a wide range of spatial consequences (Levin 1992, 1999). Hierarchy theory has been extremely useful within landscape ecology (e.g., Lambin 1996; Wu and Levin 1997; Wu 1999) but its roots lie in complexity theory (Koestler 1967; Allen and Starr 1982; Allen and Hoekstra 1992) and it has broad relevance for interdisciplinary research (Holling 1994, 2001). Top-down controls in hierarchical systems appear to act similarly, regardless of the kind of system that is being considered (Holling 2001). For example, just as ecological processes (such competition, succession, predation and dispersal) at different scales structure ecological communities (Levin 2000), ‘sorting effects’ resulting from regional policy can induce the highest productivity firms to move to the economic core of a region while lower productivity firms tend towards the periphery (Baldwin and Okubo 2005). Scale mismatches, in which the scales of governance or management and the scales of ecological or sociological problems are poorly aligned, can greatly reduce the resilience of SESs (Cumming et al. 2006). For example, the decision of CITES (the Convention in Trade in Endangered Species) to prevent trade in products from African elephants at a continental scale, with one-size-fits-all regulations, created difficulties for southern African countries that were relying on sales of elephant ivory from burgeoning populations to support elephant conservation (Cumming et al. 1997).

General principles for spatial resilience

Cumming (2011) reviewed relevant literature across a range of disciplines and identified a further 20 general principles relating to the spatial resilience of SESs. While the list is too long and requires too much additional explanation to reproduce here in full, some of the more important principles that apply across nearly all kinds of social, ecological, and SES can be summarized succinctly (note that all of these points are discussed in more detail, and with more complete referencing, in Cumming (2011)).

In ecological systems in particular, but also in many social systems, system size is fundamental to overall resilience. The probability of extinction, or localised component loss, correlates with habitat and population size, with larger areas and populations usually being more resilient (Holt 1992; Bruhl et al. 2003). The relationship between regional spatial properties (e.g., connectivity, mean patch size, amount of edge) and habitat amount is non-linear; habitat loss and spatial variation in habitat composition thus introduce the potential for thresholds and other complex behaviours, particularly where landscape structure determines the outcomes of contagious processes such as fire or the spread of disease (e.g., see Stauffer 1985; With and Crist 1995; Boswell et al. 1998; He and Mladenoff 1999; With and King 1999).

Spatial processes, such as limited dispersal and differential mortality, can produce spatial patterns independently of variation in the abiotic environment (e.g., see Schurr et al. 2007). Spatial variation often, but not always, stabilizes system dynamics (Pascual et al. 2001); and localised interactions and uneven mixing help to maintain diversity in interactions, contributing to spatial resilience at a system level.

Since the tradeoffs that exist between dispersal and stationarity are environmentally contingent (Levin 1992; Bakun and Broad 2003), resilient long-term strategies for individuals and populations will often include varying and/or flexible dispersal behaviours.

Since different system components generally respond to changes in spatial patterns and processes in different ways, spatial resilience at the level of an ecological community is heavily influenced by the nature of the ecosystem components that are present (Debinski and Holt 2000). Patch surroundings (local context, matrix) influence within-patch outcomes (Prugh et al. 2008); apparently fragmented landscapes may not be fragmented for all system components, and apparently continuous landscapes may be fragmented for others. As fragments and communities become smaller, the idiosyncracies of the local community become more important and the consequences of fragmentation become harder to predict. This principle is nicely illustrated by the work of John Terborgh and others on forest fragments on islands created by flooding in Venezuela; various bizarre outcomes occurred on different islands, depending on the degree to which intact food webs were present (Terborgh et al. 2001).

Many obvious parallels exist in socioeconomic systems. Spatial fragmentation may drive both market failures (including failures of economic solutions due to violations of neoclassical assumptions, such as a failure of the market in solving urban sprawl because of negative interaction effects between residential developments) and political failures (e.g., see Brueckner 2000; Irwin and Bockstael 2002). In situations where local and regional benefits are in conflict (e.g., resolving income inequities may not be in the immediate interests of the upper class), there is a tradeoff in the degree to which institutions and management are decentralised; local governance may be more responsive, but regional governance may be more able to ensure equity and sustainability (see example in Irwin and Bockstael 2002). Social exclusion and marginalization typically have a strong spatial component, as discussed above, and spatial patterns of exclusion can interact with other social processes to create feedbacks that may further entrench inequities (e.g., Gordon and Monastiriotis 2006). Social exclusion can also increase the likelihood of conflict (Ostby et al. 2009), thus providing an example in which spatially structured social diversity makes a system less resilient. Resilience to conflict appears to reside primarily in institutions, such as treaties, that govern spatial interactions. System resilience may be enhanced by the formation of spatially structured social networks that build social capital across several different scales (Olsson et al. 2004; Hahn et al. 2006).

Since social networks are often built around and strongly influenced by ecological networks, spatial patterns in ecosystems and in societies in shared landscapes are strongly interdependent. Landscape ecology concepts and approaches, together with the necessary spatially explicit data sets, thus have a strong potential for both contributing to and learning from the further development of theories about resilience and sustainability. Spatial resilience offers a potentially powerful conceptual bridge between landscape ecology and other disciplines within the broader contexts of social–ecological resilience, vulnerability, robustness, and sustainability (see, for example, Turner et al. 2003, 2007; Anderies et al. 2004; Walker and Salt 2006; Levin and Lubchenco 2008). Spatial variation is fundamental to sustainability; and landscape ecologists, by virtue of their training in the spatial analysis of pattern–process interactions, are uniquely positioned to develop and advance new methods and conceptual tools in this context. I for one am greatly looking forward to seeing where and how this field progresses over the next decade.

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