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RESEARCH ARTICLE

Is landscape sustainability a useful concept in a changing world?

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Abstract The world is changing rapidly, challenging the sustainability of landscapes and the resources and ecosystem services they provide to people and to plants and animals. Changes in land use and climate will alter the structure and composition of landscapes, and landscape functions may also be disrupted if the changes drive systems past thresholds into novel, no-analog configurations. Although landscapes will persist in some form, it is unlikely that they will provide the same values to people or habitat for wildlife that are the focus of current sustainability efforts. Trade-offs among services to people or resources for wildlife will be inevitable. For the concept of sustainability to be relevant under these conditions, we must ask, "Sustainability of what, for whom?" Landscapes cannot be all things to all people (or organisms). Decisions about how to balance competing needs and goals and set priorities requires an understanding of landscape structure, function, and change—the foundation elements of landscape ecology.

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Introduction

A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.

This statement, penned decades ago by the American ecologist Leopold (1949, p. 262), captures the essence of sustainability. Those interested in agriculture, development, or other human endeavors can make the appropriate substitution for "biotic community"—the meaning remains the same.

Leopold offered this wisdom at a time when a belief in the balance of nature and related concepts—carrying capacity, equilibrium, stationarity, and the like—was much in vogue. This is no longer the case. The pace of environmental change is quickening, driven by a host of factors, some economic, some political, some social, and some cultural. Ultimately, they all relate to the intersections of the growth of human populations, aspirations of people in the developing world, globalization of economies, increasing speed and reach of communication, and the availability of technological innovations. The changes have prompted increasing concerns that humans may be pushing the limits of the earth and its resources.

These concerns are not new. They were the foundation of Thomas Malthus' *Essay on the Principle of Population* in 1798 and the cornerstone of Charles Darwin's theory of evolution by natural selection (Darwin 1859). They are the essence of Aldo Leopold's land ethic (1949). More recently, books such as *The Limits of the Earth* (Osborn 1953), *The Population Bomb* (Ehrlich 1968), *The Limits to Growth* (Meadows et al. 1972), *How Many People Can the Earth Support?* (Cohen 1995), or *Hot, Flat, and Crowded* (Friedman 2008) have explored these issues. The notion of planetary boundaries (Rockström et al. 2009) seeks to define a "safe operating space" for humanity, and in *Collapse*, Jared Diamond (2005) shows what can happen when societies go beyond the limits.

In this essay I offer a personal perspective on the intersection between landscape ecology and sustainability. How does the concept of sustainability apply to landscapes, and is the concept even relevant in a world undergoing rapid change?

Sustainability

Concerns about the future have prompted increased attention to the notion of sustainability. "Sustainability" has become the new focus of conservation, environmental management, agriculture, forestry, urban planning, development, business, and virtually any human activity that intersects the environment. The Ecological Society of America launched the Sustainable Biosphere Initiative in 1991 (Lubchenco et al. 1991). "Sustainability science" emerged as a new academic discipline in 2001 (Kates et al. 2001). There has been a proliferation of journals dealing with sustainability over the past decade, and a new section of the *Proceedings of the National Academy of Sciences* highlights work in this area. The topic of this special issue of *Landscape Ecology* is landscape sustainability. Sustainability is "in."

Most discussions of sustainability start with the definition of sustainable development offered by the Bundtland Commission in 1987: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987). How this definition is interpreted and how it influences policy depends on whether the emphasis is on *sustainable* (i.e. a capacity to maintain or continue) or *development* (i.e. enhancement and growth). Here I'll focus on the sustainability aspect; Termorshuizen and Opdam (2009) consider sustainable landscape development in some detail.

In either case, however, the emphasis in most discussions of sustainability is on the capacity of the environment to meet the needs of *people* over the long haul, particularly by providing valued ecosystem services (Millennium Ecosystem Assessment 2005). The underlying belief (or hope) is that the specified activities or services can be maintained to meet peoples' needs *despite* changes in the environment. The challenge is to figure out how to do this as the environment changes rapidly in ways that humans have not experienced before. Broader perspectives recognize that meeting these needs also entails sustaining species, ecological communities, and ecosystems—in short, the biosphere (Lubchenco et al. 1991)—whether or not they directly affect ecosystem services.

Landscape sustainability

How does "landscape sustainability" fit into this picture? Landscape sustainability can be viewed in two ways: (1) the degree to which the patterns and processes that characterize a landscape will persist indefinitely into the future (Cumming et al. 2012), and (2) how the features of landscapes affect the sustainability of things that matter to people (such as ecosystem services) or to organisms (such as habitat, food, or mates). The second perspective is strongly dependent on the first.

Landscapes can be characterized by their *structure, function*, and *change* (Hobbs 1994). Among the structural features of a landscape, differences in the quality of elements in a landscape ("patches") or in the surroundings of a landscape element (patch context) can have particular implications for sustainability (Wiens 2009; Lindenmayer and Cunningham 2012). For example, if landscape elements differ in the ecosystem services they provide (e.g. Nelson et al. 2009) or in habitat suitability (Wiens et al. 2002), sustainability measures might best be focused on maintaining those high-value elements in the landscape. Variations in patch context, however, suggest

that the sustainability of high-quality landscape elements may be contingent on the composition and configuration of the surrounding landscape. Consequently, managing the broader landscape mosaic is often necessary to sustain what is valued in a landscape. It is the particular heterogeneity of a landscape—the composition and arrangement of landscape elements—that can enhance the spatial resilience of a landscape (Pascual et al. 2001; Cumming 2011; Turner et al. 2012) and provide a diversity of values to a diversity of organisms, including people.

Landscape structure affects landscape functions; this is the basis of Turner's (1989) depiction of landscape ecology as the study of the influence of pattern on process. Elements in a landscape are delimited by boundaries of varying distinctiveness and permeability (Hansen and di Castri 1992). How water, nutrients, organisms, or other materials move through a landscape is therefore determined not only by the context of patches, but by their boundary characteristics as well (Reiners and Driese 2004). Boundary conditions influence whether the ecosystem services or resources that account for patch quality are retained in or lost from individual patches, or from the landscape as a whole. Whether or not the desired values of a landscape are sustained depends on what happens at patch and landscape boundaries.

How things move through a landscape is also determined by the structural and functional connectivity among patches (Bennett 1998). Connectivity is what binds elements of a landscape together and makes it something more than a mosaic on a map. It is what ensures that patches do not stand alone, and that the ebb and flow of individuals, materials, and nutrients across the landscape can continue. Connectivity is essential to the provisioning of most ecosystem services by a landscape. On the other hand, the heterogeneity of a landscape, reduced structural connectivity, and the impermeability of path boundaries may also limit the spread of disturbances that, if unchecked, might threaten the sustainability of valued services or resources.

What is sustainable in a changing world?

Hobbs' (1994) characterization of landscapes included *change*: landscapes are dynamic. We have entered the Anthropocene, in which human actions have become a dominant force affecting the Earth's ecosystems and landscapes (Crutzen and Stoermer 2000). The changes will only accelerate in response to the dual drivers of land-use change and climate change. The effects of land use on landscapes are well-known (Meyer and Turner 1994; Lambin and Geist 2006). The conversion of "natural" landscapes to human-dominated landscapes that is the signature of the Anthropocene leads to fragmentation of native vegetation and habitats, a breakage in connectivity, increased spatial homogeneity, and a substitution of agricultural and developed landscape elements for a broader diversity of patch types. The properties of landscapes that contribute to sustaining natural landscape functions are altered and degraded. Of course, these land-use changes are usually driven by the need to provide essential services (e.g. food, housing) to people, at the cost of the substantial energy and material subsidies required to sustain the services. As such land-use changes increase, the direct and indirect costs of maintaining these services will mount, threatening the sustainability of the altered landscapes.

While the effects of land use on landscapes are usually immediate and local, those of climate change are global and long-lasting. The effects of climate change on the structure of landscapes may be especially great. A variety of models suggests that many species may shift in local or geographic distribution as climate changes (e.g. Lawler et al. 2009; Wiens et al. 2009; Matthews et al. 2011), leading in some cases to assemblages that have not previously existed—so-called "no-analog" assemblages (Hobbs et al. 2009; Stralberg et al. 2009). Herbivores may face new arrays of predators, and plants may be grazed by novel suites of herbivores. These changes will alter the structure as well as the composition of landscapes. The quality of patches, their context, and the distribution and configuration of patches in a landscape mosaic all will change. Consequently, many of the ecosystem services provided by landscapes will occur in different places or in different forms or, in some cases, no longer be available (Shaw et al. 2011). The heterogeneity that helps to buffer landscapes from the spread of disturbances such as fire or beetle infestations may be altered. Sustaining the structural configuration of landscapes as we have come to know them, be they natural or managed landscapes, may not be possible.

Even though the details of landscape structure may change, hope remains that many of the functional

properties of landscapes can be sustained (e.g. Haines-Young 2000; Potschin and Haines-Young 2012). Some landscape functions may not depend on the specific composition or structural configuration of a landscape, but instead relate to general structural properties of a landscape that can be expressed in multiple ways. For example, the connectivity that allows individuals in a metapopulation to disperse or pollinators to foster the cross-fertilization of plants that enhances genetic diversity may be achieved by a variety of network configurations or corridor compositions. The productivity of a landscape may remain much the same even if some patch types are replaced by others of equivalent productivity. The capacity of a landscape to sequester carbon may not change if patches of one forest type are replaced by forest patches of a similar type.

Because landscape structure and function are linked and landscape functions are interwoven, however, there will inevitably be some point at which the capacity of a landscape to retain critical functions (its "resilience"; Cumming 2011; Cumming et al. 2012) is passed. Exceeding such thresholds or tipping points (Wiens 2010) may thrust the landscape into an alternative state where different patterns and processes dominate (Bestelmeyer 2006; Barnosky et al. 2012). The "new" landscape may be sustainable (at least over the short term), but in a different form. Unfortunately, it is the nature of thresholds that one usually doesn't know about them until they are passed. Although it may be possible in some cases to predict an approaching threshold by changes in the variance of system parameters (Wiens 1992; Carpenter and Brock 2006), it is difficult in most cases to anticipate when changes in landscape structure or function will push the system over the edge. The values to people and wildlife that were the goals of sustainability will be fundamentally altered.

I would be remiss if I did not mention scale. The structure, function, and change that characterize landscapes occur at multiple scales in space and time, but specific features and dynamics are expressed at particular scales. Any attempt to think about the sustainability of landscapes or the services or resources they provide must therefore focus on the appropriate scale(s) for what it is that is to be sustained. Mismatches between the scales of ecosystem services or resources in the natural world and the scales at which management or policy is applied to those services or resources are commonplace and can easily lead to ineffective management or policy, or to nasty surprises (Wiens et al. 2002; Cumming et al. 2012; Dramstad and Fjellstad 2012). National resource-management policies may be inappropriate at a local scale of application, and local practices may fail when uncritically extrapolated to regional or national scales. Termorshuizen and Opdam (2009, p. 1040) have gone so far as to suggest that the spatial scale of most information generated in landscape ecology studies is too broad to meet the requirements of policy assessment and collaborative landscape planning and "is not useful for deliberation." Although this is an arguable assertion, it is nonetheless clear that what is sustainable at one scale may not be at another. Scale matters.

Future directions

My title posed the question: Is landscape sustainability a useful concept in a changing world? If by "sustainability" we mean maintaining the structure and function of landscapes and the ecosystem services and resources they provide as they have been in the past, the answer is "no." Landscapes change. The landscapes of the past are no longer with us, and those of the present are destined to change dramatically, driven by the combined forces of land-use change and climate change. A conventional view of sustainability no longer seems relevant to landscapes.

Despite all the changes, however, landscapes will continue to exist. There will be patches, boundaries, connectivity, fragments, context—all the things that are the stuff of landscape ecology. To manage the landscapes of the future and to ensure that some of the critical values of landscapes persist will require stepping back to consider the general rather than the specific attributes of landscapes. As landscape ecology progresses from descriptive analyses of landscape structure to examine how landscape structure affects the functioning of landscapes—facilitating or impeding the spread of disturbances or the movements of nutrients or pollinators; sequestration of carbon; production of timber or wildlife resources; the amelioration of pulses of water movement that can produce floods; and so on—it will become increasingly relevant to discussions of sustainability. The role of landscape heterogeneity in buffering environmental variation, enhancing the resilience of ecosystems, and

forestalling transitions past thresholds to alternative states may be a key to resource and landscape sustainability, but it has been little explored (but see Walker and Salt 2012).

Ultimately, any discussions of sustainability—of landscapes or of anything else—must confront the question, Sustainability of what, for whom (National Research Council 1999; Kates et al. 2005)? To some people, it is the beauty of natural landscapes and the array of habitats they provide for plants and animals that should be managed and sustained. To others, it is the provisioning of essential products and services that should be sustained. Yet others seek to sustain an elusive balance between the value of landscapes to biodiversity and the needs of people. In the end, however, we must recognize that sustainability is a human-centered concept. It is about meeting the needs of people, now and in the future. Ecologists, conservationists, and environmentalists may wish to think about sustainability in terms of the environment or the natural world, but in practice this means maintaining a relationship between people and what the environment provides. People's values determine what should be sustainable.

Because values differ among different groups of people, however, conflicts and tradeoffs are inescapable. Managing landscapes to enhance populations of some species of interest or the provisioning of some ecosystem services will inevitably diminish the value of the landscape for other species or services. Priorities must be established. A jack-of-all-trades landscape is likely to be the master of none—an inadequate compromise among goals that will please no one.

Which attributes of landscapes and ecosystems are to be sustained and whether or how the tradeoffs among competing needs and goals can be balanced are societal, not scientific, decisions. Landscape ecology can provide the information and insights necessary to make intelligent and sustainable choices in a changing world. One must hope that Leopold's admonition, stated at the outset of this paper, is not forgotten.

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