gene sequencers through advanced computers and networking to global-observing satellites—coupled with keen scientific curiosity present an opportunity for unprecedented advances. Together, we can make ecological science a mainstay of sustainability.

While pursuing that goal, we need to ensure that our best efforts are made available to society along the way. The time of science remaining in its ivory tower is long gone. And, ecological science is at the center of so many of the major crises affecting the planet today—deforestation, biodiversity loss, land degradation, fisheries decline, coastal pollution, climate change. As scientists, we have a special responsibility not just to increase our understanding of these issues, but also to assess and predict, help evaluate, and, in turn, support decision makers and society at large in averting worst-case future scenarios and managing wisely. I encourage all ecologists to work actively with community groups, large and small, to build understanding, bring the scientific perspective to bear on decision making, and blend this perspective with a more civic perspective of other dimensions. The principles and guidelines for land use proposed by ESA provide a valuable framework to help all of us to carry out this responsibility.

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THE APPLICATION OF ECOLOGICAL PRINCIPLES TO URBAN AND URBANIZING LANDSCAPES

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Vitousek (1994) has identified land-cover changes by humans as a primary effect of humans on natural systems. With the projected global increase of urbanization, land-cover conversions for urban use will only increase. An ecological approach to land-use planning is not only necessary but essential to maintain the long-term sustainability of ecosystem benefits, services, and resources. In this article, we first examine the potential impacts of a new suburbanization pattern—the edge city—on natural and social systems. Second, we present an ecological framework for studying and managing urban and urbanizing landscapes based upon approaches and concepts adopted by the Baltimore and Phoenix long-term ecological research projects. Finally, we compare the five key ecological principles presented by Dale et al. (2000) to those proposed by Flores et al. (1998) for urban and urbanizing landscapes.

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New Suburbanization Pattern

The ecological effects of urbanization have been highlighted in Dale et al. (2000). We build upon their report by highlighting key ecological and social changes brought about by a new pattern of suburbanization—a multinucleated city called the "edge city" (Garreau 1991, Stern and Marsh 1997). Unlike the older core city, edge cities are characterized by isolated areas of residential, commercial centers and corporate/industrial campuses (Kaufman and Marsh 1997). As decentralization of employment increases, the amount of exurban and rural land accessible to these new workplaces and available for development increases exponentially, thus allowing further suburbanization of the exurban and rural landscape (Lucy and Phillips 1997). Similarly, with the expansion of available land for development, we would expect greater rates of farmland losses and forest fragmentation.

The ecological and social effects of the edge city may be greater than the previous patterns of suburbanization. For example, an edge city often develops in the upper portion of a drainage network (Kaufman and Marsh 1997). Small tributaries are covered over with infrastructure and are replaced by a first- and second-order network of roads and ditches (Marsh and Marsh 1995). Not only do remaining small streams suffer increased stormwater loading, pollution, stream scouring, and erosion but also communities downstream from edge cities experience more frequent and severe flooding (Marsh and Marsh 1995).

The social changes brought about by the edge city continue to drain population and economic resources not only from the city, but also from older suburbs (Lucy and Phillips 1997). Unlike the older central city, which may experience a revival of neighborhoods because of interesting architecture, connected neighborhoods, and the presence of government centers, universities, and cultural facilities, inner suburban revival is unlikely (Lucy and Phillips 1997). Inner suburbs generally lack nonprofit institutions and have non-aesthetic, inconvenient, and unwalkable community designs. The long-term sustainability of inner suburbs, and suburbs in general, that lack desirable context and connectivity, is questionable.

Ecological Framework

We suggest that two ecological approaches are needed to understand and manage the dynamics of urban and urbanizing ecosystems: the classical ecosystem approach and a patch-dynamic approach (Pickett et al. 1997). The ecosystem approach focuses on the magnitude and control of the fluxes of energy, matter, and species. The patch-dynamic approach focuses on the creation of the spatial heterogeneity within landscapes and how that heterogeneity influences the flow of energy, matter, species, and information across the landscape.

The urban and urbanizing landscape is a complex mosaic of human modification and built structure. Dale et al. (2000) have reviewed the direct effects of urbanization on ecosystem structure and function. Yet, because the urban environment creates novel combinations of stresses and disturbances (McDonnell et al. 1993), subtle and indirect effects from these combinations may have altered ecosystem processes. For example, air pollution in urban areas can affect leaf chemistry, which in turn can affect decomposition rates and nutrient availability once that litter enters the decomposer pathways. Furthermore, a new soil environment can be created in urban and urbanizing areas by combining modifications in nutrient dynamics with chronic N inputs (as well as other chemicals such as heavy metals) from the atmosphere and the effect of the urban heat island (Pouyat et al. 1995*a*, McDonnell et al. 1997). Indeed, research in the New York metropolitan area has shown that urban forest stands exhibited highly altered litter decomposition and nitrification rates, soil carbon pools, and fungal and faunal densities (Groffman et al. 1995, Pouyat et al. 1995*b*, Pouyat et al. 1996). These changes to the soil environment, while having significant effects on nutrient and carbon cycling, also can alter vegetation dynamics and, thus species composition in the long term.

To account for human influence on the urban landscape, the basic concept of the ecosystem must incorporate a human component. A human ecosystem model has been proposed as a framework to link human and natural components (Machlis et al. 1997, Pickett et al. 1997). The model recognizes five major rank hierarchies that operate in human societies: wealth, education, status, property, and power (Logan and Molotch 1987) and identifies important social components and processes that can be linked to ecosystem structure and processes (Grove and Burch 1997, Pickett et al. 1997). Our intent is not to provide a detailed review of this research but rather to illustrate that social structure and communities, like ecological structure and communities, can be characterized for a landscape. In so doing, the linkages between social and ecological structure and processes can be identified through comparative studies along urban continuums or gradients of urbanization (McDonnell et al. 1993). Likewise, these organizations can be expressed at different spatial scales and employed to interpret functionally the rich spatial heterogeneity of urban landscapes.

The second approach to studying urban landscapes is the spatially focused approach of patch dynamics (Wu and Loucks 1995, Pickett et al. 1997). The urban landscape is a mosaic of biological and physical patches within a matrix of infrastructure, social institutions, cycles, and order (see Machlis et al. 1997). Spatial heterogeneity within an urban landscape has both natural and human sources. Natural sources include the physical environment, biological agents, the disturbance regime, and stresses (Pickett and Rogers 1997). In the urban landscape, human sources of heterogeneity include the introduction of exotic species, modification of landforms and drainage networks, control or modification of natural disturbance agents, and the construction of massive and extensive infrastructure (Pickett et al. 1997).

One useful feature of patchiness is that it can be applied to various spatial scales (Wu and Loucks 1995, Wu 1999). For example, the urban continuum can be divided into different urban contexts: city, inner suburbs, suburbs, exurban, and hinterlands. Each of these contexts can be divided further into land-use types, neighborhoods, blocks, and so on. Likewise, vegetation in an urban landscape can be delineated by structural characteristics to form tree-covered patches, ruderal communities, and managed lawns (e.g., Zipperer et al. 1997). Each of these nested patch hierarchies is more than a convenient way to organize spatial heterogeneity. Patch hierarchies allow researchers to ask questions related to what factors influence the patterns and

TABLE 1. Definition of key ecological principles applicable to ecological research and land-use decisions in urban landscapes (adapted from Forman [1995], Flores et al. [1998], and Wu [1999]).

Principle	Definition
Content	the structural and functional attributes of a patch where "structure" is the physical arrangement of ecological, physical, and social components, and "function" refers to the way the components interact
Context	the patch's location relative to the rest of the landscape as well as the adjacent and nearby land units that are in direct contact or linked to a patch by active interactions
Connectivity	how spatially or functionally continuous a patch, corridor, network or matrix of concern is
Dynamics	how a patch or patch mosaic changes structurally and functionally through time
Heterogeneity	the spatial and temporal distribution of patches across a landscape. Heterogeneity creates the barriers or pathways to the flow of energy, matter, species, and information
Hierarchy	a system of discrete functional units that are linked but operate at two or more scales. Proper coupling of spatial and temporal hierarchies provides a key to simplifying and understanding the complexity of urban landscapes

processes observed at each nested scale and the functional relationships within and between scales (Pickett et al. 1997).

LAND-USE DECISIONS IN URBAN AND URBANIZING LANDSCAPES

Land-use decisions affect both ecological and social structure and processes. In urban and urbanizing landscapes, land-use planners must not only understand how the proposed land-use change may affect ecological components but also how social structure and processes are affected. Consequently, any principles used to guide land-use decisions in an urban landscape must account for the ecological, physical, and social components of the ecosystem.

Flores et al. (1998) presented five ecological principles to guide land-use decisions for the New York City metropolitan area. Although these ecological principles primarily were used to account for the ecological and physical components of the ecosystem, they also are appropriate to define the social component. To these principles we have added connectivity (Table 1). While our six principles are not at odds with Dale et al. (2000), they call for the integration of the ecosystem-gradient and patch-dynamic approaches. In our view, our proposed principles highlight the salient characteristics of urban and urbanizing landscapes and their interactions with humans, and thus are better suited for studying human-dominated systems.

The key ecological principles—time, species, place, disturbance, and landscape—used by the ESA Committee on Land Use focused on minimizing the ecological impacts of land-use decisions on the landscape. Our perspective is one of humans as components of the landscape and understanding the interrelationships between ecological patterns and processes and social patterns and processes.

Although the two sets of guiding principles are similar, they connote different information and approaches for making decisions. For example, Dale et al. (2000) use the terms "species" and "place" to define the composition and interactions among populations of a site. In urban landscapes, however, only one species, *Homo sapiens,* dominates. The proposed human-ecosystem model, therefore, identifies the social structure and the interactions that may occur on a site or within a patch. Accordingly, we use the term "content" to encompass not only the biophysical composition but also the social composition and interactions within a patch. Similarly, much like Dale et al.'s use of the term "landscape", we use "context" to describe the ecological, physical, and social interactions among patches and to define spatial heterogeneity. From an anthropocentric perspective, a landscape often represents a relatively large area of tens to hundreds of square kilometers (Forman 1995), whereas context can be viewed from different scales. A city block, for example, may be the context to examine the movement of small mammals among different land covers, while a neighborhood may serve as the context to examine the effect of human population shifts from urban to rural landscape on ecological structure.

One particular difference between the two sets of principles is our apparent omission of disturbance. Actually, both disturbance and temporal changes are encapsulated within dynamics and heterogeneity. In particular, the patch-dynamics approach emphasizes the spatial and temporal interactions between disturbance and spatial heterogeneity. Our omission of disturbance as a key ecological principle does not diminish its importance, but rather we acknowledge disturbance as one component of the many different types of causal agents causing structural and resource changes within an urban landscape.

Our list also includes connectivity and heterogeneity. These features are elements of the landscape principles of Dale et al. (2000); however, we emphasize connectivity and heterogeneity because of their importance within the urban landscape. Urban landscapes are highly heterogeneous at multiple scales and not just the at the anthropocentric-landscape scale. Maintaining this heterogeneity may be critical for the movement of energy, matter, species, and information within different social contexts. We have taken a patch-dynamic approach to determine how this heterogeneity influences the ecological and social processes within and between scales.

Throughout the landscape-architecture literature and more recently the ecological literature the importance of connectivity is evident. In the urban landscape connectivity may be linked to the long-term sustainability of communities (Girling and Helphand 1997). The demise of older suburbs and the revitalization of core-city neighborhoods have been linked to connectivity (Lucy and Phillips 1997). Likewise, the connectivity of greenspaces within a neighborhood to adjacent and regional greenspaces may be critical to maintaining metapopulations for a variety of species, especially in a highly fragmented urban landscape.

Regardless of which set of guiding principles is used, ecological principles are essential to making land-use decisions along any urban to rural continuum. Only through the incorporation of ecological principles into the decision-making process can ecosystem benefits, services, and resources be maintained for future generations.

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