Making the Case for Landscape Ecology

An Effective Approach to Urban Sustainability

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ABSTRACT Urban sustainability is one of the most pressing and challenging tasks facing humanity today because cities are the primary sources of major environmental problems, the centers of economic and social developments, and home to more than half of the world population. While the ecological, economic, and social dimensions of sustainability are equally important in principle, the ecology of cities is arguably least studied. But this situation has been changing rapidly in recent years. In this paper, the author compares and contrasts different perspectives in urban ecology and examines their relevance to urban sustainability. While all perspectives are useful in some ways, the author argues, a landscape ecology perspective that integrates elements of sustainability science seems most comprehensive and effective. This integrative perspective views humans as powerful "ecosystem engineers" or agents that are critically important for developing urban sustainability. It focuses on the human landscape scale that is large enough to include key ecological and socioeconomic processes and small enough to allow for detailed mechanistic studies. The landscape ecology approach also emphasizes the interrelationship between urban landscape patterns and ecological/socioeconomic processes on different scales, and encourages place-based research that integrates ecology with planning, design, and other social sciences.

KEYWORDS Urban ecology, landscape ecology, urban sustainability, landscape planning and design

We are at a historic turning point in human civilization as *Homo sapiens* is transforming from a predominantly agrarian to a mostly urban species (Figure 1). The global human population has grown exponentially since the Industrial Revolution in the late 1700s, rising from 1 billion around 1800 to 2 billion in 1927, 4 billion in 1974, and 8 billion by 2025 (United Nations 2004a). The world urban population has increased much faster than the rural population, rising from 14 percent in 1900 to 29.1 percent in 1950, 47 percent in 2005, and about 61 percent by 2030. The rural population has essentially stopped growing, and all future population growth is expected to occur in urban areas, most of which will take place in developing countries.[1] While the global population is likely to stabilize around 9.1 billion by 2100 (United Nations 2004b), urbanization will continue even after 2100 because of continuing rural-to-urban migrations. Therefore, urban areas will increasingly become the primary habitat for humans although their consumption of resources reaches into diverse ecosystems near and far.

This increasingly urban nature of humanity has a number of profound environmental, economic, and social implications for the world's future. Although urbanized areas cover about 2 percent of the earth's land surface, they account for 78 percent of carbon emissions, 60 percent of residential water use, and 76 percent of the wood used for industrial purposes (Brown 2001). The environmental impacts of urbanization are exceptionally intense locally and go far beyond the city limits to have regional and global consequences. The "ecological footprints" of a city for different resources can be hundreds of times as large as its physical size.[2] Here I briefly discuss several environmental effects of urbanization to lay the groundwork for later exploration on urban sustainability.

First, urbanization can significantly influence local and regional climate by altering land cover patterns and consequently surface radiation regimes and energy balance. The best-documented example of anthropogenic climate modifications is the urban heat island (UHI) phenomenon, that is, cities tend to have higher air and surface temperatures than their rural surroundings (Voogt 2002; Arnfield 2003).[3] For example, in metropolitan Phoenix, Arizona, urbanization increased the mean daily temperature by 3.1˚C (or 5.58˚F) and nighttime minimum temperature by 5˚C (or 9.0˚F) over a period of 50 years, resulting in the doubling of "misery hours per day" for humans and a significant increase in energy consumption for cooling, and heat stress on biological organisms (Baker et al. 2002). Second, urbanization significantly affects water resources due to increased per capita use of fresh water and contamination of water sources by sewage and wastes in cities. Also, altered land cover patterns and increased impervious surfaces can significantly change the flow paths of surface water and hydrologic cycling of the urban landscape. Third, cities are the major producers of greenhouse gases and air pollutants that cause health problems for humans and the environment.[4] Fourth, urbanization is the most

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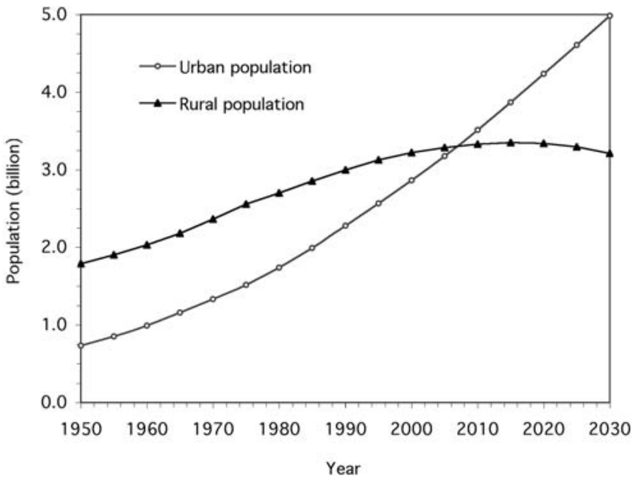

Figure 1. The dynamics of world urban and rural populations between 1950 and 2030 (United Nations 2004a). The projection of future population growth shown here was based on the medium variant scenario (i.e., assuming that fertility will decline from 2.6 children per woman today to slightly over 2 children per woman in 2050).

drastic form of land-use change that affects biodiversity and ecosystem services intensively and extensively. Urbanization results in the loss and fragmentation of natural habitats as well as the introduction of exotic species (Hope et al. 2003; Martin, Peterson, and Stabler 2003). Numerous studies have shown that urbanization has profound effects on biodiversity, net primary productivity, watershed discharge characteristics, and biogeochemical cycles (Pickett et al. 2001; Whitford, Ennos, and Handler 2001; Gregg, Jones, and Dawson 2003).

The myriad environmental problems caused by urbanization indicate that most if not all our cities are not sustainable (McGranahan and Satterthwaite 2003).[5] If global urbanization continues the way it has, these problems will likely accelerate explosively as humans become progressively more urban. To gain a glimpse of this possible future, just think of the differences in life supporting needs, aspirations, and ecological footprints between a farmer in India and an urbanite in New York, and then magnify them by several billion times. Undoubtedly, the performance of cities will increasingly determine human and environmental health as well as regional and global sustainability. As Kofi Annan (2002), the former secretary-general of the United Nations, stated: "The future of humanity lies in cities."

How can we develop more sustainable cities? Given the various environmental problems associated with cities, ecology ought to have much to offer. However, has this been the case? How can we make ecological approaches more relevant and effective for urban sustainability? In this paper, I address these questions by first reviewing different perspectives in urban ecology, and then proposing a transdisciplinary framework for studying and developing sustainable landscapes.

Different Perspectives in Urban Ecology

A major goal of urban ecology is to understand the relationship between the spatio-temporal patterns of urbanization and ecological processes. Cities may differ drastically in their architectural appearance and environmental settings, but one commonality is that the diversity and spatial arrangement of their landscape elements undoubtedly affect and are affected by physical, ecological, and socioeconomic processes within and beyond their boundaries. Ecologists have long studied the effects of the spatial pattern of urbanization on ecological processes (Stearns and Montag 1974; Sukopp 1990, 1998; Loucks 1994; Breuste, Feldmann, and Uhlmann 1998). Recognizing that any classification is biased by the classifier, be it an educated human or a programmed computer, I distinguish five urban ecological perspectives based on their research focus and methodology (Figure 2).

These perspectives seem to have stemmed from three traditions: ecology in cities (EIC), ecology of cities as socioeconomic structures (EOC-S), and ecology of cities as ecosystems (EOC-E). From the EIC tradition, a bioecology approach has evolved with a focus on how urbanization affects the distribution and dynamics of plants and animals in cities, and much of this research is related to urban biogeography. For example, botanists have documented the diversity and distribution of plants in cities for several decades (see Sukopp 1990; Sukopp 1998). To some extent, this EIC perspective has influenced ecology-based concepts in design and planning of cities. Second, the socioecology perspective has followed the EOC-S tradition that views cities as socioeconomic structures and applies ecological concepts

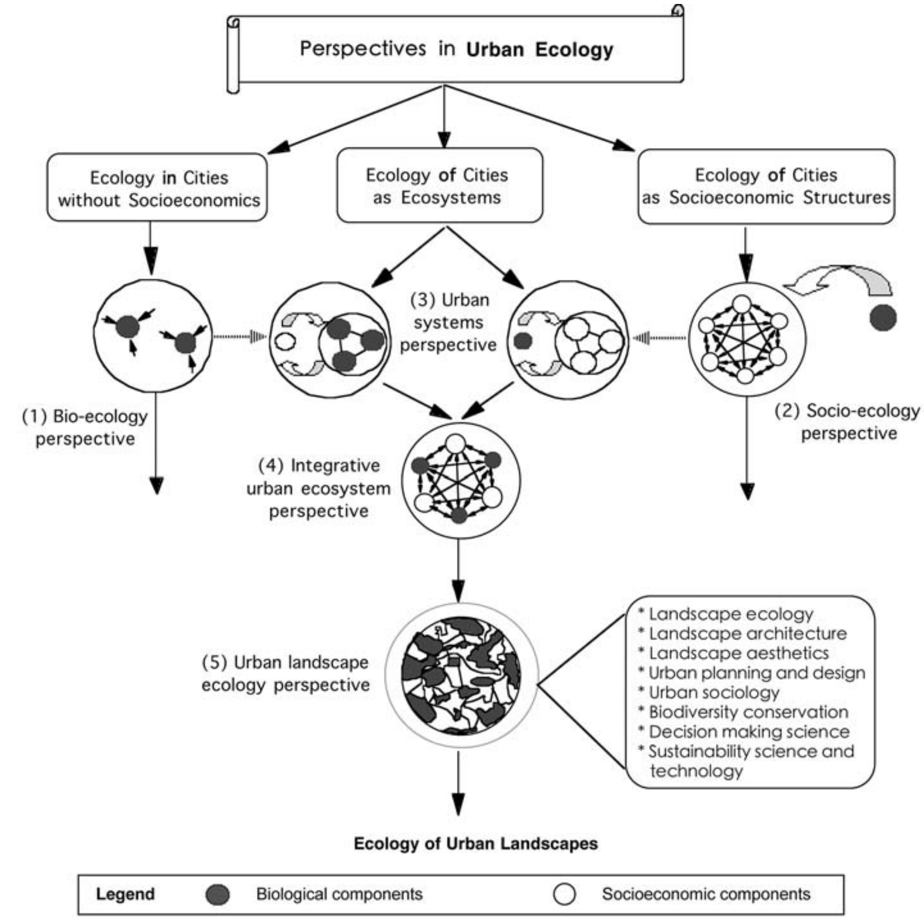

Figure 2. An illustration of the evolution of urban ecological perspectives.

and principles such as competition, succession, invasion, and niche theory to understand them. This perspective is epitomized by the Chicago school of urban ecology that defined the field as the study of the relationship between people and their urban environment (Thio 1989). This is essentially "the" urban ecology typically seen in sociology textbooks, whose influences can be found in socially based concepts about cities in design and planning.

The other three perspectives have evolved out of the EOC-E tradition that considers the city as an ecosystem with both socioeconomic and biological components (Figure 2). The urban systems perspective is exemplified by studies that focus mostly on socioeconomic processes with bioecological components considered, but only as a factor (for example, Forrester 1969), and those that examine the functioning and dynamics of urban areas as disturbed ecosystems with a predominant emphasis on bioecological components. A more balanced emphasis on both bioecology and socioeconomics is found in the integrative urban ecosystem approach, which is exemplified by the "Total Human Ecosystem" model of Naveh and Lieberman (1984), or "holistic landscape ecology" (Naveh 2000). This approach emphasizes the process interactions, feedbacks, control mechanisms, and totality of coupled human-environment systems. Since the 1990s, a landscape ecological perspective to urban studies has emerged as ideas of heterogeneity, scale, and patch dynamics have pervasive influences in ecology and environmental sciences (Wu and Loucks 1995; Pickett et al. 1997; Zipperer et al. 2000; Luck and Wu 2002; Blaschke 2006). This urban landscape ecology perspective views cities as spatially heterogeneous landscapes that are composed of multiple interacting patches within and beyond the city limits (Pickett et al. 1997; Zipperer et al. 2000).

So, are these urban ecological perspectives adequate for urban sustainability research and practice? The simple answer is no. While all of them are useful in certain ways, some are more relevant than others. The five perspectives seem to have distinctive characteristics in their research focus and methodology (Figure 3). The bioecology perspective views cities as severely disturbed ecosystems and humans as disturbance agents,

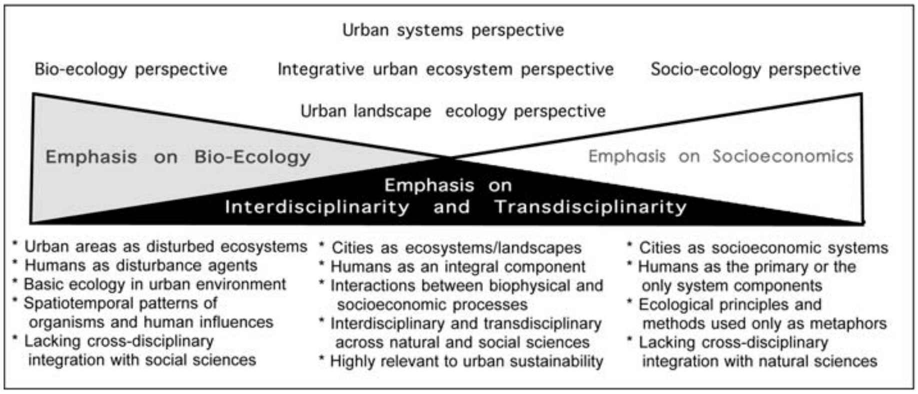

Figure 3. Different perspectives in urban ecology and their major characteristics in terms of assumptions, research emphases, and methodology.

adopts a biology-centered, basic science approach, and offers little interdisciplinarity between natural and social sciences. The socioecology approach, on the other hand, views cities as socioeconomic systems designed for human welfare, and tends to deemphasize the importance of biodiversity and ecosystem services, thus again discouraging cross-disciplinary interactions between natural and social sciences. The urban systems perspective and the integrative urban ecosystem perspective are centered on the principles and methodology of the systems approach, consider humans as integral components of the urban systems, and encourage interdisciplinary and problem-solving research. Although the systems approach has proven to be quite powerful in studying feedbacks and process interactions, its ability to deal with spatial heterogeneity of ecological and socioeconomic patterns, which is essential in urban studies, is limited. The urban landscape ecology perspective is the most inclusive approach in which all previous approaches can be integrated together as complementary elements. In the next section, I attempt to explore why this is so and how this perspective may help us to study and develop urban sustainability.

A Landscape Ecology Approach to Urban Sustainability

Landscape ecology is the science and art of studying and influencing the relationship between spatial pattern and ecological processes on multiple scales (Wu and Hobbs 2007). The "science" of landscape ecology focuses on the theoretical basis for understanding the formation, dynamics, and effects of spatial heterogeneity, whereas the "art" of landscape ecology reflects the humanistic and holistic perspectives necessary for integrating ecology, design and planning, socioeconomics, and management practices. Landscape ecology promotes interdisciplinary and transdisciplinary approaches,[6] and landscape optimization and sustainability are among the top research priorities in the field (Wu and Hobbs 2002, 2007; Ahern 2005). The function and sustainability of cities influence and are influenced by urban morphology and spatial processes of socioeconomic activities. These networks of activities associated with cities are geographically distributed in space and operate on multiple scales ranging from local neighborhoods to the region and beyond. Thus, the spatially explicit, pattern-process approach developed in landscape ecology seems quite appropriate for urban systems.

Landscape ecology can significantly contribute to and gain from sustainability science, a rapidly emerging transdisciplinary field that provides the scientific basis for sustainable development (National Research Council 1999; Kates et al. 2001; Parris and Kates 2003). Sustainability science focuses on the dynamic interactions between nature and society, and addresses issues of self-organizing complexity, vulnerability and resilience, inertia, thresholds, complex responses to multiple interacting stresses, adaptive management, and social learning (National Research Council 1999; Kates et al. 2001; Clark and Dickson 2003). Thus, it is committed to place-based and solution-driven research that integrates environmental, economic, and social dimensions encompassing local, regional, and global scales. In light of sustainability science, urban sustainability may be considered as the dynamic capacity of an urban area for adequately meeting the needs of its present and future populations through ecologically, economically, and socially sound planning, design, and management activities.

Landscape ecology is essential for sustainability research and practice for several reasons. First, the human landscape (for example, a watershed or metropolitan area) represents the most operational scale for

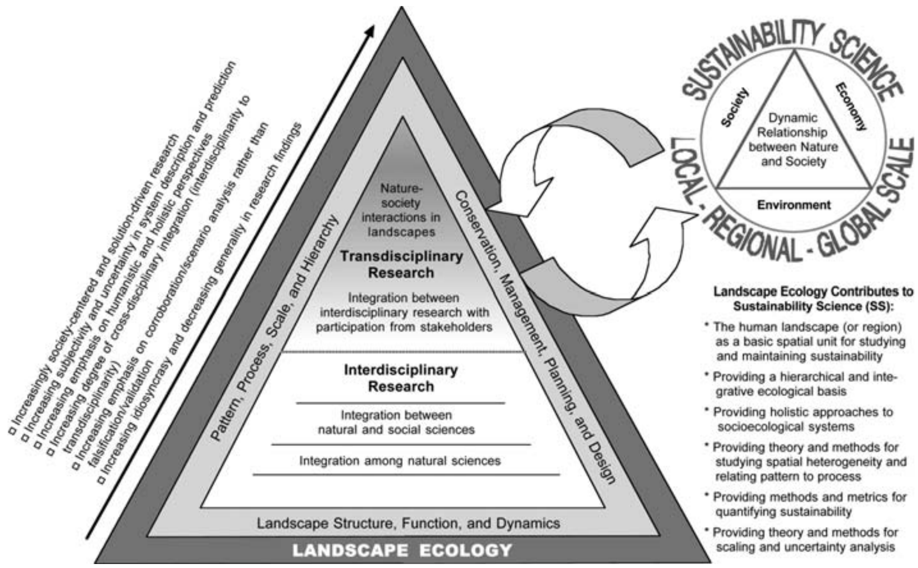

Figure 4. The scope of landscape ecology and its relationship to sustainability science.

studying and maintaining sustainability because it represents the smallest scale below which nature-society interactions cannot be adequately addressed (Forman 1990). For example, to tackle the problem of urban sustainability, focusing on individual cities without adequate consideration of their surrounding landscapes is not sufficient because important neighborhood interactions and top-down constraints would be missed. On the other hand, studying the sustainability of a particular city by focusing on the global urban system is unlikely to produce practical outcome because of the lack of details. Also, Gobster et al. (2007) has recently argued that, although environmental problems and human experiences may take place on a range of scales, the scale of landscape surroundings represents the human "perceptible realm." While perception is not always reality, it certainly helps actions in reality. Thus, the metropolitan landscape arguably is the most effective focal level of study for urban sustainability, which provides a common ground that facilitates interactions and integration among biophysical, socioeconomic, and planning and design disciplines (Figure 4).

Second, landscape ecology provides a hierarchical and integrative ecological basis for dealing with issues of biodiversity and ecosystem functioning at multiple scales. For example, the principles and insights of ecological hierarchy theory (O'Neill et al. 1986; Wu 1999) can clarify our understanding of urban hierarchies and ecological footprints. Third, landscape ecology has already developed a number of interdisciplinary and transdisciplinary approaches to studying nature-society interactions (e.g., Opdam, Steingröver, and van Rooij 2006; Pedroli and Pinto-Correia 2006; Potschin and Haines-Young 2006). Fourth, landscape ecology offers theories and methods for studying the relationships between spatial patterning and biophysical and socioeconomic processes. These relationships will not only help us better understand the interactions between urban form and function, but also can guide design and planning practices (e.g., in terms of alleviating urban heat islands or increasing urban biodiversity). Fifth, landscape ecology provides a suite of methods and metrics that are helpful for developing sustainability indicators (e.g., Blaschke 2006). Finally, landscape ecology provides both theoretical and methodological tools for dealing with scaling and uncertainty issues that are fundamental to nature-society interactions (Wu et al. 2006), particularly in urban landscapes where human-induced contingencies abound.

Urban sustainability certainly has much to do with landscape planning and design. Recent developments in urban planning and design also seem to support an urban landscape ecological perspective. Platt (1994) provided a lucid discussion of how the concepts of open space in North American cities have evolved in relation to urban design and planning. The "Picturesque Rurality" favored "the establishment of large, lavishly planted urban parks," but "put less emphasis on functional utility than on aesthetic effect through landscape design and horticulture." The "City Beautiful" monumentalism "emphasized large, geometric plazas embellished with fountains, statuary, and formal landscaping," while the "Garden City" notion advocated open spaces of different forms (for example, practical community parks and individual garden plots) as major elements of the city and throughout the core of the city (Platt 1994). Although the City Beautiful and Garden City were among the most influential paradigms in urban design and planning, modern urban design and planning principles have moved beyond an initial focus on city form and human interests (Steiner 2000; Ahern 2005). Efforts by urban planners, designers, and architects to combine urban morphology with ecological functioning and efforts by ecologists to integrate the "ecology in cities" with socioeconomic patterns and processes have brought both sides much closer to a common perspective—a landscape ecological perspective of cities (Musacchio and Wu 2004). Yet, explicitly integrating landscape ecology principles with architecture and planning for achieving urban sustainability is still in the early stages, and many challenges and opportunities are expected (Ahern 2005).

Urban sustainability needs a spatially explicit, multi-scaled, and cross-disciplinary framework so that environmental, economic, and social components are integrated. Landscape ecology provides such a framework with theories and methodologies that facilitate interfaces with natural and social sciences, particularly, on the scale of metropolitan landscapes. Urban sustainability is intrinsically related to landscape sustainability. Indeed, it is hard to imagine how anyone can develop a sustainable city without considering the bigger landscape and global contexts as indicated by its ecological footprint. A sustainable world is most likely composed of sustainable regions and landscapes, which in turn consist of sustainable cities designed not only with sustainable materials but also spatial patterns promoting environmental, economic, and social functioning. These spatial patterns of urbanization from the local city to the entire globe are all important for achieving sustainability because of the hierarchical linkages and influences between the levels of organization. However, as cities are engines of economic growth and centers of diversity and change (Hinrichsen, Salem, and Blackburn 2002), regional and global sustainability may increasingly hinge on urban sustainability. The performance of major cities is thus a barometer of the region or nation in which they reside. Therefore, our challenge is not to stop urbanization, but rather to speed up the process of designing and planning better cities.

Discussion

Cities epitomize the creativity, imagination, and mighty power of humanity. Cities are magnificent because of spectacular architecture; cities are inspirational because fascinating stories of human history abound. Cities are attractive because resources, opportunities, and comfort coincide, and yet cities can be ugly and dreadful because poverty, pollution, and destruction of nature often reach the extreme. However, influenced by the natural history tradition, ecologists have long ignored cities as legitimate study areas until recently (Collins et al. 2000). As a result, ecologists know more about the habitat of penguins in the Antarctic than the ecology of cities in which they reside; they know more about the ozone hole in the stratosphere than the urban heat island in their neighborhoods. Most existing ecological studies in urban areas have focused primarily on the negative impacts of human activities on biodiversity and ecosystem processes. There even seems to have been a perception that ecologists are professionally at odds with developers, architects, engineers, and the like because almost everything that humans do to nature was traditionally viewed as ecologically negative. Thus, ecology has been viewed historically as a "subversive science" by many (Kingsland 2005). The reality is that scientists, engineers, and artists of all kinds must work together in order to achieve urban sustainability. This need necessarily begets a shift in research emphasis from "ecology in cities" to "ecology of cities" and to "sustainability of cities" through interdisciplinary and transdisciplinary collaborations. It is encouraging that the current research activities in urban ecology seem to move toward this direction (Breuste, Feldmann, and Uhlmann 1998; Zipperer et al. 2000; Pickett et al. 2001; Musacchio and Wu 2004).

Urbanization should not be viewed merely as a cause for environmental problems, but also as an inevitable path to regional and global sustainability. Cities have lower per capita costs of providing clean water, sanitation, electricity, waste collection, and telecommunications, while offering better access to education, jobs, health care, and social services. At the present, urban areas are home to more than 50 percent of the world population, while accounting for less than 2 percent of the earth's land surface. To achieve regional and global sustainability, we need to restrain the sprawl of human habitations and minimize the ecological footprints of cities and individuals within them. This encourages urbanization upwards (instead of outwards). In this regard, the idea of contact cities, or "arcology" (architecture + ecology), proposed by the renowned architect Paolo Soleri, may indeed be relevant to urban sustainability, and needs to be practiced beyond Arcosanti, a small experimental town 70 miles north of Phoenix, Arizona (see http://www.arcology.com/). Although intensified urbanization does not necessarily reduce human impacts on the environment, this actually is happening in many developed countries when more land is set aside for natural recovery (Bisborrow 2006).

Urban sustainability requires the active participation of humans. In this regard, it may be helpful to view humans as the most mighty ecosystem engineers for creating sustainable landscapes rather than just disturbance agents as in traditional ecology. In the natural world, most species adapt to their environment, but some, known as "ecosystem engineers," actively create and maintain their own habitats (Jones, Lawton, and Shachak 1994). Beavers are a prototypical ecosystem engineering species who build dams with tree branches to create a suitable habitat for themselves. As a consequence, the hydrology, vegetation, and function of the whole landscape are altered significantly. However, even if beavers change a natural landscape from one state to another, their influences are usually confined within the local landscape. In the process of building cities, on the other hand, humans directly eradicate parts or the whole of ecosystems, replace organisms with concrete and bricks, and substitute biological complexity with artificial regularity. The scale of human influences on the environment through urbanization can be of global reach. Beavers cannot possibly destroy the earth ecosystem no matter how diligently they work; but humans can if their greed for consumption is not tamed. The rapid urbanization around the globe will not only change the face of the earth ecosystem, but also profoundly influence the future of humanity.

Urban systems are spatially extended complex systems that often exhibit critical thresholds and surprises (Wu and David 2002; Alberti and Marzluff). Alan Kay, a pioneer of object-oriented programming and personal computing, once said: "The best way to predict the future is to invent it." Developing sustainable cities, however, may be more difficult than inventing anything humans have ever created. This requires a paradigm shift in the study of cities and an unprecedented level of transdisciplinarity. The integration between landscape ecology and sustainability science seems to provide an effective approach to achieving the goal of urban sustainability.

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NOTES

1. In 2005, the percentage of urban population was 37 percent for China and 28 percent for India, as compared to 79 percent for Canada and the United States, 89 percent for the United Kingdom, and 91 percent for Australia (Population Reference Bureau 2005). However, this urbanization gap between developed and developing regions has been narrowing steadily since 1975. By 2030, the urban population will reach 57.1 percent in developing regions and 81.7 percent for developed regions (United Nations 2004a).
2. Ecological footprint is measured as the land area necessary for sustaining the current levels of resource consumption

and waste discharge by a population (Wackernagel and Rees 1996). Cities often have huge ecological footprints because of their colossal demands for water, food, and energy as well as their enormous output of wastes and pollutants. For example, Luck et al. (2001) calculated that among the 20 major metropolitan regions of the continental US, Phoenix—a desert city in the southwest—had the largest ecological footprint for water (4.3 times the size of the metro area), food (116.1 times the metro area), and carbon assimilation (244.6 times the metro area).

3. UHI is attributable primarily to the replacement of vegetation by impervious surfaces that reduce or eliminate evapotranspiration by plants and soil. In this case, much of the solar radiation energy used for evapotranspiration in natural landscapes becomes available for heating the air and surfaces in cities. Also, thermal radiation from the heated urban surfaces, often reflected many times by artificial walls before escaping into space, further increases the air temperature in cities, especially during nighttime.
4. Air pollutants from urban centers are emitted primarily from transportation and industrial sources, including sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), suspended particulate matter (SPM), and greenhouse gases. Most serious air pollution problems (for example, photochemical smog, acid rain, and tropospheric ozone) occur in urban areas.
5. Sustainability is commonly defined as the ability to meet fundamental human needs today while conserving the life-support systems of the earth for future generations (National Research Council 1999, Kates et al. 2001). The three pillars of sustainability are environmental, economic, and social sustainability.
6. The terms *interdisciplinarity* and *transdisciplinarity* have different connotations in the literature. Here I adopt the usage by Tress, Tress, and Fry (2005): interdisciplinary research involves multiple disciplines that interact closely to achieve a common goal based on a concerted framework, whereas transdisciplinary research has both close cross-disciplinary interactions and participation from nonacademic stakeholders and governmental agencies guided by a common goal.

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