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Research Paper

# Urban ecology and sustainability: The state-of-the-science and future directions

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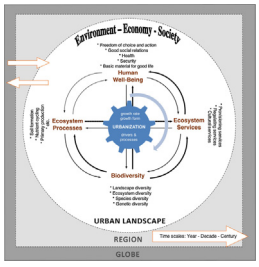
## HIGHLIGHTS

- Urban ecology has a history of more than 90 years, with diverse perspectives.
- Urban ecology has become a mainstream ecological field during the past two decades.
- Recent research focuses on urbanization patterns and environmental impacts.
- The most salient thrust of current research is urban sustainability.
- A key topic is urban ecosystem services in relation to human well-being.

## GRAPHICAL ABSTRACT

A conceptual diagram illustrating the relationships among biodiversity, ecosystem processes (or ecosystem functions), ecosystem services, and human well-being in an urban landscape. All the components and their relationships are influenced profoundly by the speed and spatiotemporal pattern of urbanization that is driven primarily by socioeconomic processes. Thus, understanding and improving the ecology and sustainability of urban landscapes and regions should not only consider how urbanization affects these key components but also how their relationships change in time. Human well-being is the primary focus for urban sustainability projects, whereas urban ecological studies often focus on biodiversity, ecological processes, and ecosystem services. In either case, the connections among the key components and their linkages across spatial (landscape–region–globe) and temporal (year–decade–century) scales should be taken into account.

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## ABSTRACT

Ecosystems and landscapes around the world have become increasingly domesticated through urbanization. Cities have been the engines of socioeconomic development but also the centers of major environmental problems since the industrial revolution. Numerous studies have shown that our urban ecosystems and landscapes are on an unsustainable trajectory. Global sustainability depends critically on cities, and urban ecology can – and needs to – play a key role in the transition toward sustainability. In this paper, I review different definitions and perspectives of urban ecology, discuss major advances and key issues, and propose a framework to help move the field forward. After almost 90 years of development, urban ecology has evolved into a truly transdisciplinary enterprise that integrates ecological, geographical, planning, and social sciences. The most salient thrust of current research activities in the field is the emerging urban sustainability paradigm which focuses on urban ecosystem services and their relations to human well-being. While urbanization is complex in many ways, we do know a lot about its patterns, processes, and effects. More specifically, we know a great deal about urban growth patterns in space and

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time, the underlying drivers and mechanisms, and myriad effects of urbanization on biodiversity, ecological processes, and ecosystem services. Compared to their ancient counterparts, contemporary cities tend to be bigger in physical size and ecological footprint, faster in growth rate in terms of both population and urbanized land, and more irregular in landscape composition and configuration. As coevolving human-environment systems, cities are spatially heterogeneous, complex adaptive systems. As such, the dynamic trajectory of cities can never be fully predicted or controlled, but can and should be influenced or guided in more desirable directions through planning and design activities that are based on urban ecological knowledge and sustainability principles.



## 1. Introduction

The world has urbanized at an accelerating rate during the past century, and humans have become a predominantly urban species in that more than 50% of the global population now live in urban areas (Wu, 2008). This global demographic transition has enormous environmental, economic, and social consequences that are yet to be fully understood. At the global scale, the general level of human well-being, as measured by Human Development Index (consisting of three components: life expectancy, GDP per capita, and education), has been steadily rising in spite of (not because of) the widely acknowledged declining trend in ecosystem services during the past several decades (Millennium Ecosystem Assessment, 2005; Raudsepp-Hearne et al., 2010). Multiple possible explanations for this so-called "environmentalist's paradox" have been offered – the prepotency of provisioning services to other ecosystem services, time lags in the relationship between ecosystem services and human well-being, and separation of humans from nature due to technology and social innovation (Raudsepp-Hearne et al., 2010). A better understanding of this seemingly paradoxical global-scale relation, however, requires scrutiny with more detailed data at local and regional scales. In particular, the roles of urbanization in the rise of human well-being and the fall of ecosystem services should be explicitly considered.

Although the urbanized land area dominated by the built environment – "all non-vegetative, human-constructed elements, such as buildings, roads, runways, etc." – occupies a surprisingly small percentage (<1%) of the earth's terrestrial surface (Schneider, Friedl, & Potere, 2010), the effects of urbanization are profound and pervasive from the local to the global scale. Cities now account for about 60% of all residential water use, 75% of energy use, 80% of the wood used for industrial purposes, and 80% of human greenhouse gas emissions (Grimm et al., 2008; Newman, Beatley, & Boyer, 2009). During the past 50 years, global urbanization has not only accelerated its pace in terms of urban population and the built environment, but also taken new developmental forms. These changes have contributed greatly to the domestication of ecosystems, landscapes, and even the biosphere, thus accelerating the arrival of the Anthropocene epoch.

"The future of humanity lies in cities. . . . Weak cities will almost certainly act as a brake on national development. Strong cities can be a key factor enabling a country to thrive in the global economy" (Annan, 2002). If our cities continue to grow and spread the way they have since the industrial revolution, there is little doubt that human civilization is destined to disaster. On the other hand, as engines of socioeconomic development and centers of cultural transformation and techonological innovation, cities can, and will have to, play a critical role in achieving sustainability at the regional and global scale (Wu, 2008, 2010a). Sustainability refers to sustainable development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987), or "meeting fundamental human needs while preserving the life-support systems of planet Earth" (Kates et al., 2001). To help achieve a sustainable urban future, we must understand how urban systems work and how they ought to work. Evidently, urban ecology is essential for developing such an understanding (Loucks, 1994; Wu, 2008, 2010a).

In this paper, I provide an overview of major advances and discuss future directions in urban ecology. Reviewing the history and progress of a burgeoning field like urban ecology is daunting as many aspects of the field are rapidly evolving with ambiguous relationships among them. Nonetheless, several recent attempts have been made, including a number of books in the past few years (Alberti, 2008; Douglas, Goode, Houck, & Wang, 2011; McDonnell, Hahs, & Breuste, 2009; Niemela, 2011; Weiland & Richter, 2011). This paper is neither a summary of these recent works nor a review of everything in urban ecology. Rather, it provides an overview of the state-of-the-science of urban ecology from a landscape perspective, in which urban areas are viewed as spatially heterogeneous human-environment systems – i.e., urban landscapes (Wu, 2008).

## 2. Evolving definitions and perspectives of urban ecology

### 2.1. What is urban?

There are diverse definitions of what is "urban." Consequently, a unified definition of urban ecology is nowhere to be found. Different definitions emphasize different aspects of urban systems, and each has advantages and disadvantages, depending on the situation in which it is used. Searching for a universally accepted definition for urban or urban ecology may be neither productive nor necessary. Nevertheless, it is necessary to know how these terms are usually defined (i.e., the meanings of their most common usage) in order to facilitate communication and avoid confusion.

While an urban area (i.e., a town, city, or metropolis) has been defined variously by governmental agencies and individual researchers, most of these definitions are based on one or more of three primary factors: total population size, population density, and impervious surface area or built structures. In general, urban areas share several common characteristics: high population density, abundant built structures, extensive impervious surfaces, altered climatic and hydrological conditions, air pollution, and modified ecosystem function and services (Grimm et al., 2008; McIntyre, 2011; Pickett et al., 2001). However, it is neither feasible nor essential to encapsulate all key components and characteristics of urban areas into one definition. In most cases, high human population density and extensive impervious surface area are two salient factors that sufficiently define what is urban. Essentially all major ecological and environmental characteristics of urban systems can be related to these two factors either directly or indirectly.

### 2.2. Urban ecology as human ecology and sociology

Urban ecology was originally developed as part of human ecology in the 1920s by a small but influential group of sociologists at University of Chicago (the Chicago school of sociology or human ecology). The key players of the Chicago school included Robert

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