

# Chapter 3

## Urban Landscape Ecology: Past, Present, and Future

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**Abstract** Cities are home to more than half of the world population. Cities have been the centers of economic and social developments, as well as sources of many major environmental problems. Cities are created and maintained by the most intense form of human-nature interactions. Cities are spatially extended, complex adaptive systems—which we call landscapes. The future of humanity will increasingly rely on cities, and the future of landscape ecology will inevitably be more urban. To meet the grand challenge of our time—sustainability—cities must be made sustainable and, to this end, landscape ecology has much to offer. In this chapter, we discuss the intellectual roots and recent development of urban landscape ecology and propose a framework for helping move it forward. This framework integrates perspectives and approaches from landscape ecology, urban ecology, sustainability science, and resilience theory.

**Keywords** Urban landscape ecology · Urban ecology · Urbanization · Urban ecosystem services · Urban sustainability · Research framework

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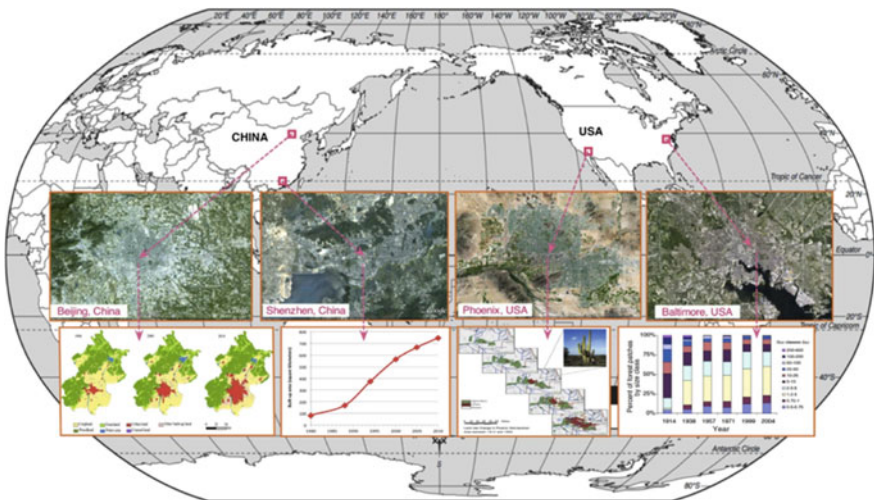
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### 3.1 Introduction

Urbanization has been a dominant driving force for global environmental changes and socioeconomic transformations across the world since the Industrial Revolution between 1750 and 1850 (Grimm et al. 2008; Wu 2008a, 2010b). This is especially true during the past several decades, with the rapid development of new cities and expansion of old ones in both developed and developing countries. For example, Beijing, one of the oldest cities in the world, and Shenzhen, one of the fastest growing young cities in China, both experienced rapid urban expansion during the past several decades (He et al. 2006, 2008, 2011; Yu et al. 2009); Phoenix—home to the Central Arizona-Phoenix Long-Term Ecological Research Project (CAPLTER)—is a relatively young, but the fastest growing, city in the US (Wu et al. 2011a, b; Grimm et al. 2012); Baltimore—home to the Baltimore Long-Term Ecological Research Project (Baltimore LTER)—is an old port city which also has gone through a profound landscape transformation since 1914 (Zhou et al. 2011) (Fig. 3.1).

As of 2008, more than 50 % of global human population live in urban areas, and the number of urban residents is currently increasing by 1 million every week (Anonymous 2010). According to the projections by the United Nations, 80 % of the global population will be urban by 2050. Even after the world population stabilizes around 2050, the urban population will continue to grow, and almost all future



**Fig. 3.1** Examples of urbanization at the landscape scale—four of the best studied cities in China and the United States: Beijing, China ( $39^{\circ}55' \text{ N}$ ,  $116^{\circ}23' \text{ E}$ ), Shenzhen, Guangdong Province, China ( $22^{\circ}39' \text{ N}$ ,  $114^{\circ}13' \text{ E}$ ), Phoenix, Arizona, USA ( $33^{\circ}27' \text{ N}$ ,  $112^{\circ}04' \text{ W}$ ), and Baltimore, Maryland, USA ( $39^{\circ}17' \text{ N}$ ,  $76^{\circ}37' \text{ W}$ ). The background map was obtained from <http://eduplace.com/> and the *inset* images of the four cities were from Google Earth (<http://www.google.com/earth/index.html>). The *insets* showing urbanization patterns for the four cities are from several published sources (He et al. 2006, 2008, 2011; Yu et al. 2009; Wu et al. 2011a, b; Zhou et al. 2011; Grimm et al. 2012)

population increases will take place in urban areas (mostly in developing countries of Asia and Africa). It is certain, therefore, that our future will be increasingly urban.

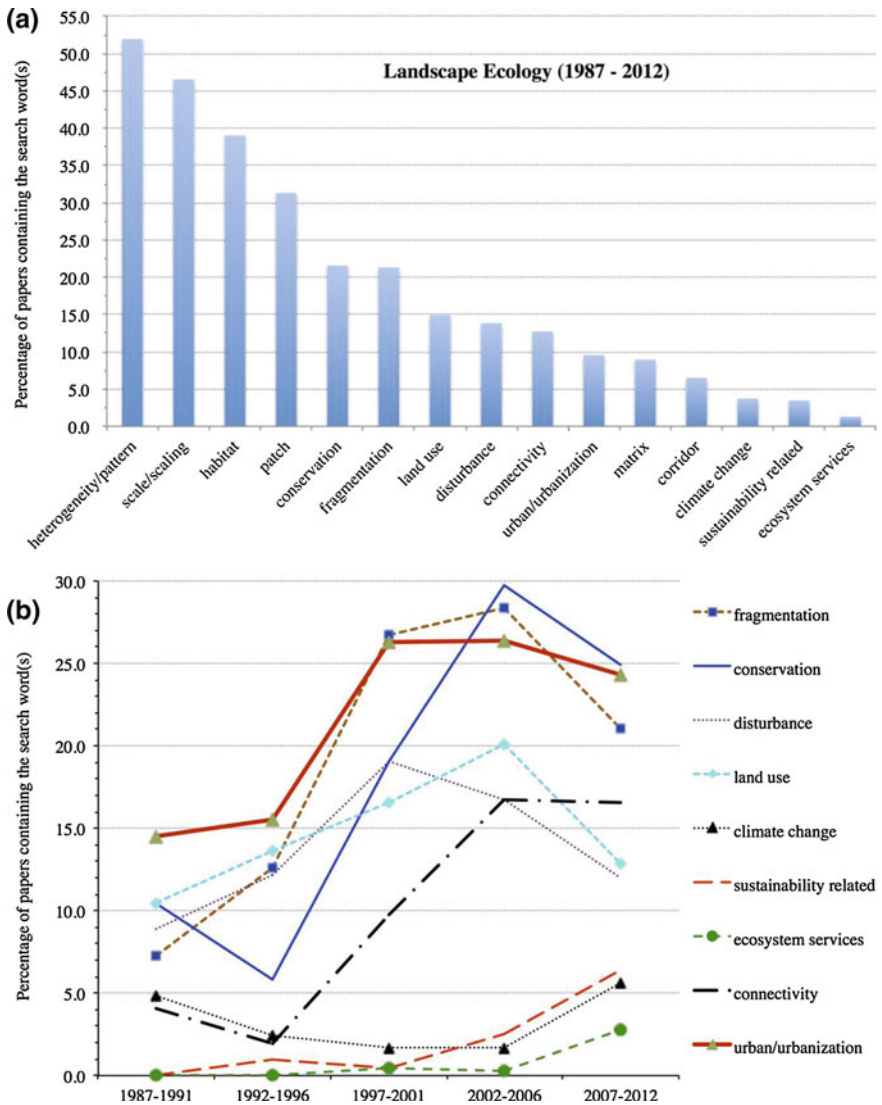
Urbanization has been both a boon and a bane (Wu 2008a, 2010b). Cities have been the engines of economic growth and centers of innovation and sociocultural development. Cities usually have higher use efficiencies of energy and materials, as well as better access to education, jobs, health care, and social services than rural areas. In addition, by concentrating human populations, urbanization should be able to, at least in principle, save land for other species or nature conservation. However, cities are also places of severe environmental problems, growing socioeconomic inequality, and political and social instabilities. Although the physically urbanized land covers merely about 3 % of the earth's land surface, the "ecological footprints" of cities are disproportionately large—often hundreds of times their physical sizes (Luck et al. 2001; Jenerette and Potere 2010). Urban areas account for about 78 % of carbon emissions, 60 % of residential water use, and 76 % of the wood used for industrial purposes (Grimm et al. 2008; Wu 2008a, 2010b). As a result, urbanization has profoundly affected biodiversity, ecosystem processes, ecosystem services, climate, and environmental quality on scales ranging from the local city to the entire globe.

Until quite recently, however, ecologists have focused primarily on "natural" ecosystems, and treated cities largely as "trashed ecosystems" unworthy of study (Collins et al. 2000). This does not mean that urban ecology is really "new." In fact, the field known as "urban ecology" had already existed before the terms "ecosystem" and "landscape ecology" were coined. Nevertheless, it is during the past two decades that urban ecology has developed into a highly interdisciplinary field of study, increasingly embraced by ecologists, geographers, and social scientists. These recent and unprecedented developments in urban ecology have had much to do with the rise of landscape ecology in general and urban landscape studies in particular, resulting in a dynamic and exciting research field—urban landscape ecology. Today, studies that focus on the spatiotemporal patterns, biophysical and socioeconomic drivers, and ecological and environmental impacts of urbanization are mushrooming around the world (e.g., Fig. 3.1).

The main goal of this chapter is to provide a perspective on the scope, objectives, and recent developments of urban landscape ecology. This is not intended to be a comprehensive review of the literature on urban ecology. Rather, it is a perspective on the past, present, and future of urban landscape ecology based on our research experiences with cities in China and USA (Fig. 3.1).

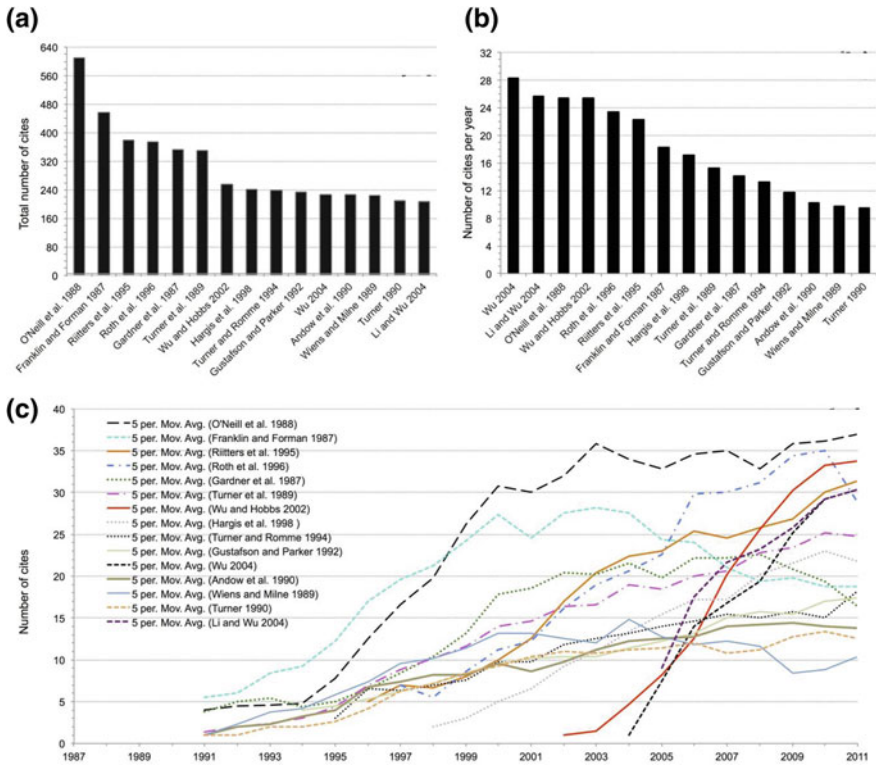
## 3.2 Landscape Ecology and the Rising Urban Theme

Apparently, urban landscape ecology is part of landscape ecology, and thus it makes sense to discuss the former within the context of the latter. Landscape ecology is the science of studying and improving the relationship between spatial pattern and ecological (and socioeconomic) processes on multiple scales (Wu and



**Fig. 3.2** Percentage of published papers in the journal *Landscape Ecology* between 1987 and 2012 which contain important landscape ecological terms in their titles, keywords, and abstracts: **a** ranking according to the relative frequency of occurrence, and **b** changes in relative frequency of occurrence over time (calculated by dividing the 1987–2012 period into 5 segments)

Hobbs 2007). Although landscape ecology has long considered humans and their activities as part of the landscape, its most salient feature that distinguishes itself from other ecological fields (e.g., population, community, and ecosystem ecology) is its explicit emphasis on spatial heterogeneity or pattern (Wu 2013a). This emphasis on heterogeneity should not be interpreted as stressing “structure” only



**Fig. 3.3** The top 15 most-cited papers published in *Landscape Ecology* (data from the ISI web of science, <http://apps.webofknowledge.com/>; accessed on December 5, 2012): **a** ranking by the total number of citations, **b** ranking by the number of citations per year, and **c** temporal changes in the number of citations (5-year moving average values used here to smooth out annual fluctuations)

or deemphasizing “function.” A background assumption in landscape ecology is that landscape structural patterns are related to ecological processes and ecosystem functions. In other words, the ultimate goal of analyzing spatial patterns is to get to the underlying processes or functions—pattern analysis is a “means” not an “end.” Also, both landscape structural and functional attributes have “spatial patterns” which are important for ecological understanding and management.

A review of all the publications in the field’s flagship journal—*Landscape Ecology*—since its establishment in 1987 confirms that landscape ecology is a spatially explicit interdisciplinary science (Figs. 3.2 and 3.3). First, the most commonly used terms in landscape ecology are those that are directly related to spatial heterogeneity or spatial pattern, including heterogeneity, pattern, fragmentation, disturbance, and connectivity (Fig. 3.2a). The frequent use of words like habitat, conservation, fragmentation, and connectivity reflects the predominance of biodiversity conservation, as a research topic, in landscape ecological studies. Another trend in the frequency of word occurrence is that urbanization,

**Table 3.1** The top 15 most cited papers that were published in landscape ecology based on data from web of science (accessed on December 5, 2012)

Order	Author (year)	Article title	Vol (issue)	Total cites	Cites/year
1	O'Neill et al. (1988)	Indices of landscape pattern	1(3)	609	25.4
2	Franklin and Forman (1987)	Creating landscape patterns by forest cutting: ecological consequences and principles	1(1)	456	18.2
3	Riitters et al. (1995)	A factor-analysis of landscape pattern and structure metrics	10(1)	378	22.2
4	Roth et al. (1996)	Landscape influences on stream biotic integrity assessed at multiple spatial scales	11(3)	374	23.4
5	Gardner et al. (1987)	Neutral models for the analysis of broad-scale landscape pattern	1(1)	352	14.1
6	Turner et al. (1989)	Effects of changing spatial scale on the analysis of landscape pattern	3(3–4)	349	15.2
7	Wu and Hobbs (2002)	Key issues and research priorities in landscape ecology: an idiosyncratic synthesis	17(4)	254	25.4
8	Hargis et al. (1998)	The behavior of landscape metrics commonly used in the study of habitat fragmentation	13(3)	240	17.1
9	Turner and Romme (1994)	Landscape dynamics in crown fire ecosystems	9(1)	237	13.2
10	Gustafson and Parker (1992)	Relationships between landcover proportion and indexes of landscape spatial pattern	7(2)	233	11.7
11	Wu (2004)	Effects of changing scale on landscape pattern analysis: scaling relations	19(2)	226	28.3
12	Andow et al. (1990)	Spread of invading organisms	4(2–3)	225	10.2
13	Wiens and Milne (1989)	Scaling of 'landscapes' in landscape ecology, or, landscape ecology from a beetle's perspective	3(2)	223	9.7
14	Turner (1990)	Spatial and temporal analysis of landscape patterns	4(1)	208	9.5
15	Li and Wu (2004)	Use and misuse of landscape indices	19(4)	205	25.6

climate change, ecosystems services, and sustainability have become increasingly dominant in landscape ecology during the past two decades (Fig. 3.2b). In addition, the top 15 most-cited papers published in *Landscape Ecology* since 1987 have been overwhelmingly dominated by topics of spatial pattern analysis and scale-related issues (Table 3.1; Fig. 3.3a, b). Again, this is indicative of the field's paramount emphasis on spatial heterogeneity and scale.

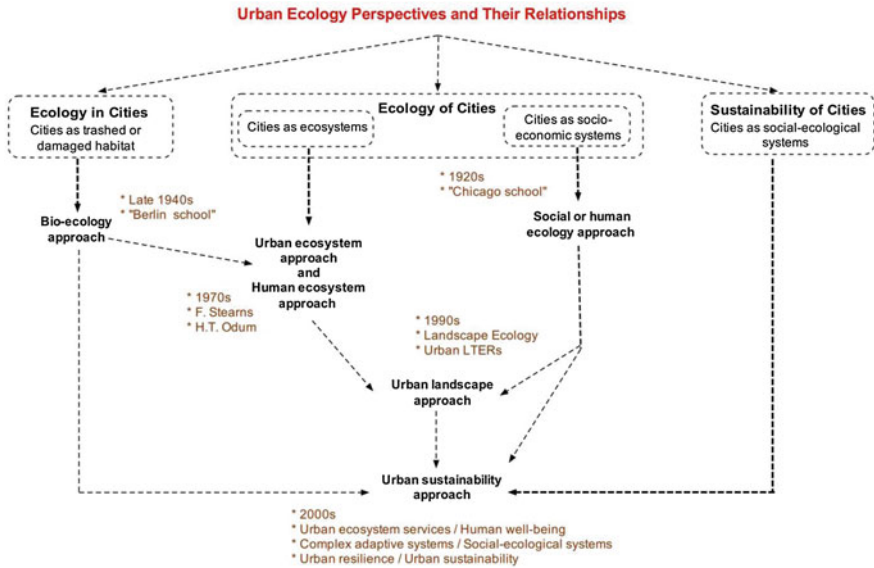
Particularly relevant to this chapter is that the number of publications on urbanization or urban landscapes in the journal has increased rapidly during the past two decades. This is not surprising because of several reasons. First, urban

landscapes exhibit the most conspicuously heterogeneous patterns among all landscapes, and thus are ideal objects for applying and testing landscape metrics and spatial statistical methods. From a more dynamic perspective, urbanization is fundamentally a spatial process, and its understanding relies on spatially explicit methods that characterize landscape ecological studies. Second, urbanization and its ecological impacts have gained unprecedented impetus in research during the past 20 years as we have entered a new urbanization era. The urban landscape (the city and its surrounding areas or a metropolitan region) has emerged as a primary scale for urban studies. In fact, one may argue that a landscape approach is not only appropriate in theory but also imperative in practice for urban ecology and urban sustainability. Given the increasingly urban nature of our landscapes and the increasingly urban future of humanity, urban sustainability is becoming “an inevitable goal of landscape research” (Wu 2010b).

### 3.3 From Urban Ecology to Urban Landscape Ecology

To discuss the present and future of urban landscape ecology, it is helpful to recall important milestones in the history of urban ecology. This is because urban landscape ecology may be viewed as a product of the integration between landscape ecology and urban ecology. Several recent reviews on the history of urban ecology can be found elsewhere (Pickett et al. 2001, 2011; Wu 2008a, b, 2013b; McDonnell 2011). To illustrate how urban landscape ecology is related to urban ecology, here we provide a synopsis of the evolution of different perspectives and approaches in urban ecological research since its early years (Fig. 3.4).

The earliest version of “urban ecology” was developed in the 1920s, as part of human ecology, by the Chicago school of sociology, championed by Robert E. Park and Ernest W. Burgess (Park et al. 1925). In other words, urban ecology was born in a “social science family,” as a sociological approach that uses ecological concepts (e.g., competition, ecological niches, and succession) and natural selection theory as organic analogies to study the social life and societal structures in the city. The key idea of this urban ecology approach is that competition for land and resources in an urban area leads to the continuous structuring of the city space into ecological niches (e.g., zones) through “invasion-succession” cycles (to put it blatantly, the poor and immigrants come in and the rich and “original” move out). Spatial and social differentiations occur consequently, and different social groups occupy different zones (or niches). This idea is epitomized in the concentric zone theory (Park et al. 1925). The Chicago school urban ecology was quite influential for a few decades, but largely disregarded by the 1950s as criticisms mounted of its neglecting the roles cultural and social factors (e.g., race and ethnicity) as well as planning and industrialization. This sociological tradition of urban ecology is still alive today as one may often find a chapter or a section on urban ecology in most sociology textbooks (but rarely in classic ecology texts). In fact, one may argue that understanding the relationship between spatial and social structures in the city



**Fig. 3.4** Different perspectives in urban ecology and the rising prominence of the urban landscape ecology approach to the studies of cities and human-dominant areas (modified from Wu 2008a, b, 2013a, b)

is a key component in urban landscape ecology, particularly when urban sustainability is considered as its ultimate goal (Fig. 3.4).

In the late 1940s, European ecologists, most noticeably the “Berlin school,” began to study remnant plant and animal species in cities—a bio-ecological approach or the “ecology in cities” approach (Grimm et al. 2000; Pickett et al. 2001; Wu 2008a). Excellent reviews of these studies are found in Sukopp (1990, 2002). In the 1970s forest ecologists (e.g., Forest Stearns) and ecosystem ecologists (e.g., the Odum brothers) advocated ecosystem-based approaches to studying the structure and function of cities (Stearns and Montag 1974; Odum 1983). H. T. Odum’s emergy-based urban approach is still being used by some (Huang and Chen 2009; Lee et al. 2013). Not until the early 1990s did urban ecology start to move into the mainstream of ecology. A seminal paper during this time period was McDonnell and Pickett (1990) that introduced the well-established gradient analysis method in plant community ecology and vegetation science to the study of urban ecosystems—the urban–rural gradient approach.

During the 1980s, landscape ecology was developing swiftly in North America and beyond, and many of the landscape studies dealt with land use and land cover change including urbanization. With the rapidly increasing availability of remote sensing data, GIS, and spatial pattern analysis methods (e.g., landscape metrics), the number of studies on the spatiotemporal patterns and socioeconomic drivers of urbanization began to soar (many such “patterns and drivers studies” continue to be done by physical geographers, remote sensing scientists, and the like). The



launching of the two Long-Term Ecological Research projects on urban ecology (Urban LTERs) by the US National Science Foundation in 1997 played an instrumental role in promoting the integration between human ecosystem-based functional approaches and pattern-oriented landscape approaches (Pickett et al. 1997; Grimm et al. 2000; Jenerette and Wu 2001; Luck et al. 2001; Luck and Wu 2002; Wu and David 2002; Wu et al. 2003; Jenerette et al. 2006; Buyantuyev and Wu 2009, 2012). An urban landscape ecology that couples spatiotemporal patterns with ecological processes began to take form in the early 2000s.

Since the publication of the Millennium Ecosystem Assessment in 2005, ecosystem services (and their relationship with human well-being) have increasingly become mainstream in ecology. This trend has been accompanied by the rapid development of sustainability science that focuses on the dynamic relationship between society and nature (Kates et al. 2001; Wu 2006). Consequently, a nascent but robust research direction in urban landscape ecology now is focused on urban sustainability (Fig. 3.4). This emerging urban sustainability approach integrates the various urban ecology perspectives, and its scientific core develops around the structure, function, and services of the urban landscape, frequently invoking hierarchy theory, complex adaptive systems theory, and resilience theory (Wu and David 2002; Alberti 2008; Wu 2010b; Ahern 2013; Wu and Wu 2013).

### 3.4 A Framework for Urban Landscape Ecology

So, how should urban landscape ecology be defined? Simply put, urban landscape ecology is landscape ecology of urban areas. More specifically, it is the science of studying and improving the relationship between urban landscape pattern and ecological processes for achieving urban sustainability. While urban sustainability may be defined in a number of ways, here we define it as an adaptive process of maintaining and improving ecosystem services and human well-being in the urban landscape (Wu 2010a, 2013b). As such, urban landscape ecology consists of three interactive major components: quantifying the spatiotemporal patterns and understanding the drivers and mechanisms of urbanization (“patterns/drivers studies”), assessing the ecological and environmental impacts of urbanization (“impacts studies”), and understanding and improving urban sustainability (Figs. 3.5 and 3.6).

The first component is to characterize the spatiotemporal patterns and driving processes of the urban landscape. This involves mapping and quantifying urban morphological attributes and landscape patterns over time, identifying key socioeconomic and environmental drivers, and understanding urban pattern-process relationships on multiple scales ranging from the parcel to the metropolitan region. Both landscape ecologists and geographers have done a great deal in this front (Jenerette and Wu 2001; Luck and Wu 2002; Batty 2005; Schneider and Woodcock 2008; Wu et al. 2011a, b). Recent years have seen a rapid increase in the number of this sort of studies. For these studies to be really relevant to societal

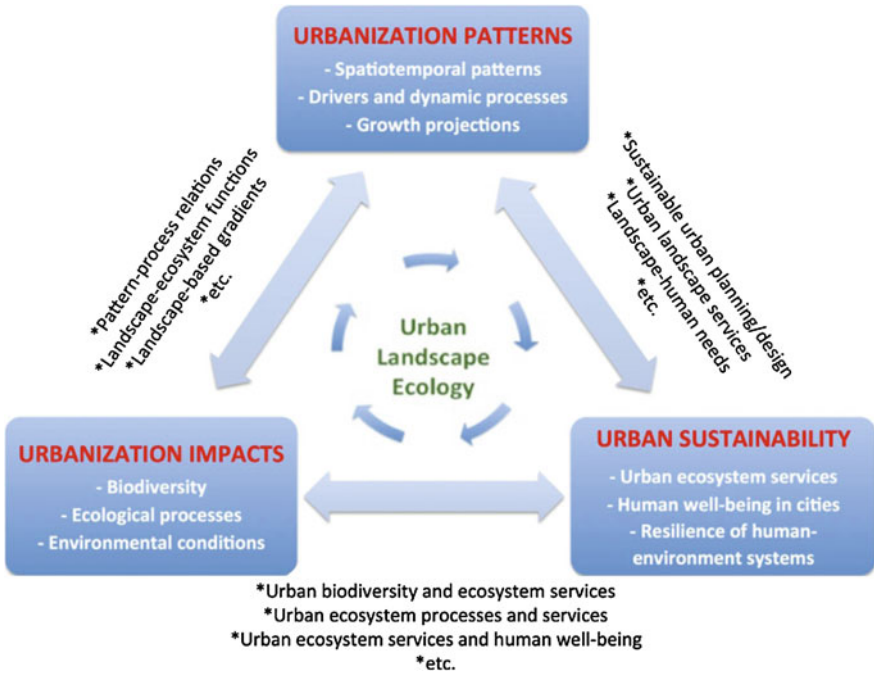


Fig. 3.5 The scope of urban landscape ecology: three key components and their relationship

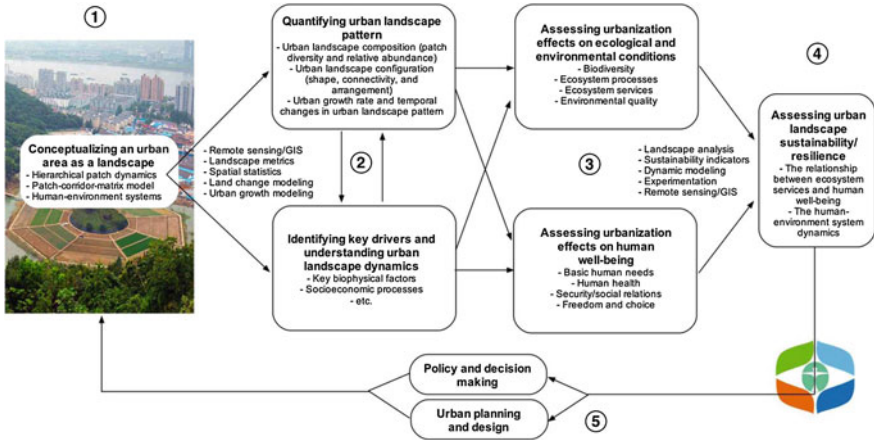
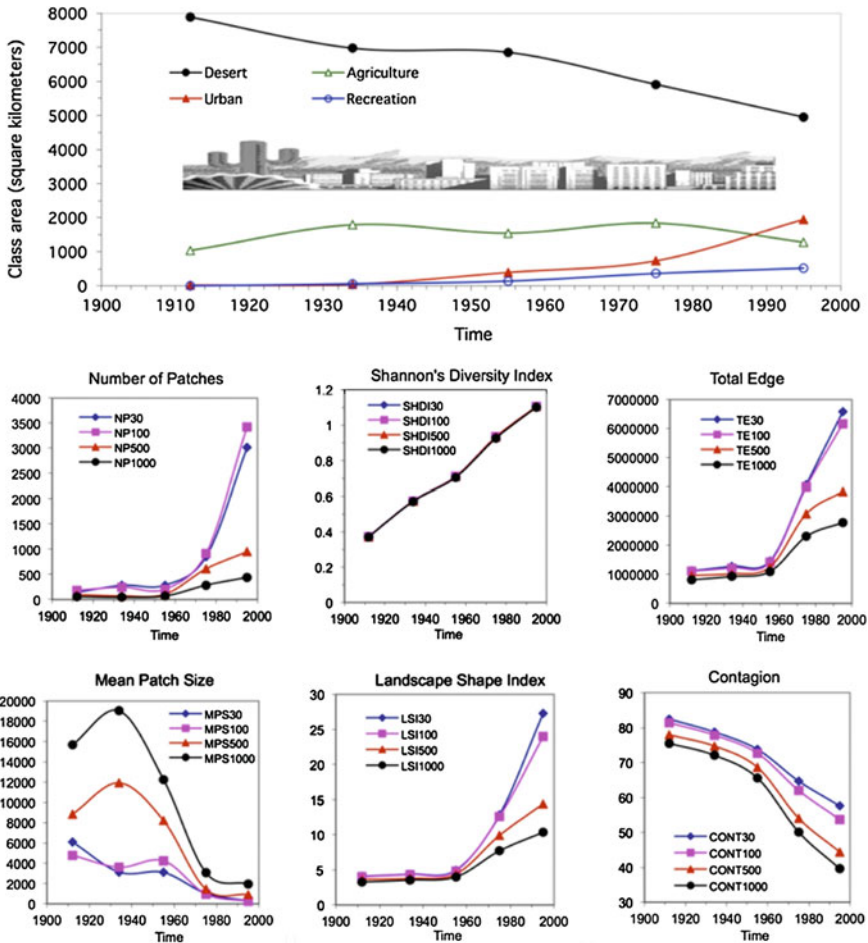


Fig. 3.6 A framework for urban landscape ecology that integrates “patterns/drivers studies” with “impacts studies,” and promotes urban sustainability as its ultimate goal

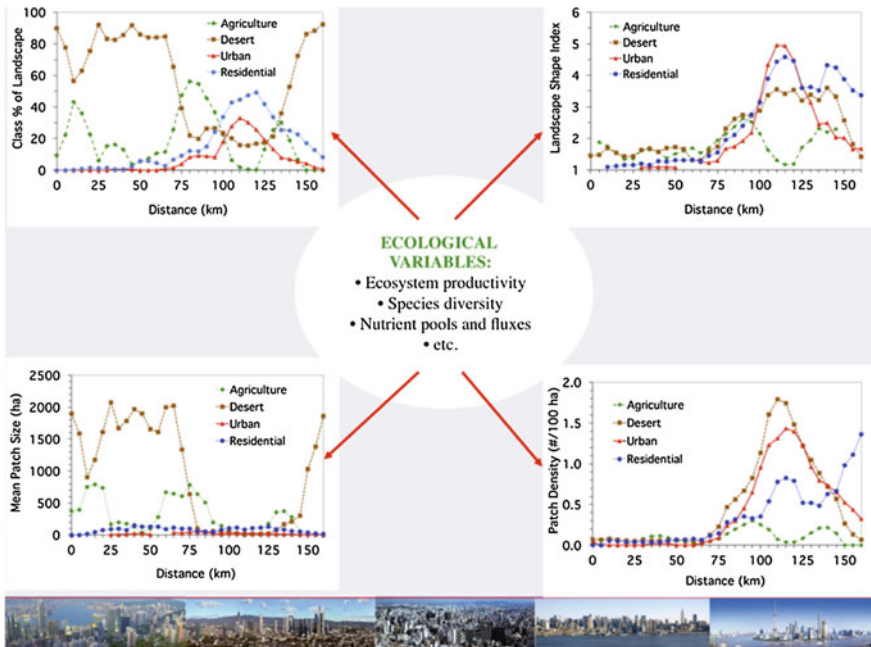
needs and policy making, they must be integrated with the other two components. An example demonstrating two major methods on these topics—landscape pattern metrics and landscape gradient analysis—is illustrated in Figs. 3.7 and 3.8, based



**Fig. 3.7** Quantification of the spatiotemporal patterns of urbanization in the Phoenix metropolitan region, Arizona, USA, using landscape pattern metrics (modified from Wu 2004; Wu et al. 2011a, b). A large number of landscape metrics have been used to characterize urbanization patterns, and seven of them are shown here

on the Central Arizona-Phoenix Long-Term Ecological Research project (CAPLTER). Among many other studies using these methods are those at Baltimore, Beijing, and Shenzhen (Fig. 3.1).

The second component is focused on “impacts studies” that investigate how urbanization affects biodiversity, population and community processes, ecosystem functions, and ecosystem services. Most studies on cities that have been carried out by bio-ecologists and environmental scientists belong to this category, and several recent books have reviewed these studies (Carreiro et al. 2008; McDonnell et al. 2009; Niemela 2011). It is well documented that urbanization may decrease native species richness but increase the number of exotic species; increase landscape-level



**Fig. 3.8** Landscape pattern gradient analysis as used in the quantification of the spatial pattern of the Phoenix metropolitan region, USA (modified from Luck and Wu 2002)

ecosystem primary production due to irrigation but reduce environmental quality; and alter soil properties and biogeochemical and hydrological cycles (Pickett et al. 2001, 2011; Wu 2013b). Also, urban heat islands—pronounced increases in air and surface temperatures (especially nighttime) over non-vegetated impervious surfaces due to enhanced longwave radiation—and their effects on air quality and human health have long been studied (Oke 1982; Jenerette et al. 2007; Buyantuyev and Wu 2010; Jenerette et al. 2011; Li et al. 2011). While understanding the various effects of urbanization is important and necessary, the “impacts studies” need to address how these effects can be eliminated, mitigated, or adapted through urban design and planning actions. This requires the integration among the three components (Fig. 3.5).

The third component of urban landscape ecology focuses on the sustainability of urban areas—urban sustainability. Rigorous research in urban sustainability is still nascent, and a cohesive framework is yet to be developed. However, several core research questions are emerging, including the kinds, amounts, and spatial interactions of urban ecosystem services, human well-being (measured as the degrees of satisfying the basic, psychological, and spiritual needs of humans as influenced by landscape structural and functional attributes), and the resilience of coupled human-environment systems in the urban landscape (Wu 2010b, 2013b). To address these questions, it is imperative to integrate the three components (Fig. 3.5). These new developments in urban landscape sustainability differ from

previous studies focused on urban sustainability indicators in terms of both key research questions and methodologies. For example, the urban landscape ecology approach to urban sustainability increasingly emphasizes ecosystem services and their relationship with human well-being, with spatially explicit methods that consider both ecosystem properties and landscape structural attributes (Ahern 2013; Wu 2013b). From a broader perspective, this surge of interest in urban sustainability by landscape ecology is part of the recent movement towards a “landscape sustainability science” (Wu 2006, 2012, 2013a; Musacchio 2009, 2011).

Complementary to the three-component framework is a more detailed 5-step strategy that outlines the major steps for urban landscape ecological studies (Fig. 3.6). To follow this strategy, the first step is to conceptualize an urban area as a spatially heterogeneous human-environment system (i.e., a landscape). This can be done based on, for example, the patch-corridor-matrix model (Forman 1995) or the hierarchical patch dynamics paradigm (Wu and Loucks 1995; Wu and David 2002). Then, in the second step the spatiotemporal patterns, including the kinds, amounts, diversity, connectivity, and spatial configuration of the urban landscape and their temporal changes, can be quantified, and key biophysical and socio-economic drivers identified. These patterns-and-drivers studies can be, and have frequently been, done with a combination of methods—remote sensing, GIS, landscape metrics, spatial statistics, simulation modeling, and, to a much lesser extent, experiments (mainly longitudinal). The third step is to link the spatiotemporal patterns of urbanization to ecological and environmental variables of interest so that the impacts of urbanization can be assessed. The impacts studies need to go beyond environmental quality, biodiversity, and ecosystem functions and services to include variables that are directly related to human well-being (e.g., those of human survival, security, and psychological needs). These impacts studies can be done using a number of statistical and modeling methods, including those in step one. The fourth step is to assess the sustainability and resilience of both ecosystem services and human well-being in the urban landscape. The tradeoffs and synergies among ecosystem services and between ecosystem services and human well-being in the urban landscape need to be understood, and scenarios for sustaining natural capital and flows as well as human well-being need to be sought. These scenarios have to be investigated in concert with landscape planning and design because they involve intentional alterations of landscape composition and configuration. In addition to the methods mentioned above, sustainability indicators may play an important role in accomplishing these goals.

### 3.5 Concluding Remarks

The world has become increasingly urban, and the ecology of landscapes needs to reflect this reality in its science. Indeed, this has been happening in the past few decades, and studies of urban areas now are prominent in landscape ecology.

A research area that can be called urban landscape ecology is identifiable, which is part of landscape ecology and also related to urban ecology (as well as urban geography and urban sociology). The existing studies on this topic, however, do not yet form a cohesive framework or have a unified goal. In this chapter, we have reviewed the intellectual roots of urban landscape ecology, and proposed a framework to help move the field forward.

Landscapes and regions represent arguably the most operational scales for sustainability research and practice (Forman 1990, 2008; Wu 2006). To meet the challenge of urban sustainability, cities need to be studied as spatially extended, complex adaptive systems with interdisciplinary approaches integrating ecological, economic, social, and design/planning sciences (Wu 2013b). This seems to be the main theme of urban landscape ecology or the future direction it is moving towards. Landscape ecology needs to be more “urban;” urban ecology needs to be more landscape-realistic; both need to focus more on sustainability.

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