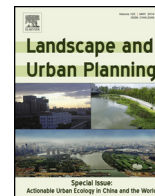




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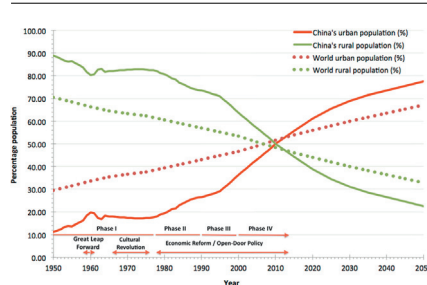
Urban ecology in China: Historical developments and future directions

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HIGHLIGHTS

- China's urban population rose from 18% in 1978 to about 50% in 2010.
- Urban ecology in China started in the early 1980s.
- China's urban ecology has focused on environmental pollution and eco-cities.
- Holistic and systems thinking has been important in China's urban ecology.
- Urban ecology in China is developing rapidly, embracing diverse ideas and methods.

GRAPHICAL ABSTRACT



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ABSTRACT

China has the largest population and the longest urban development history in the world, with primitive cities first occurring along the Yellow River in northern China more than 4000 years ago. After a long period of stagnation during recent centuries, urbanization has revived again in China since the economic reform in 1978. Strongly influenced by national land use policy and the history of urbanization after 1949, China's urban ecology has gone through three development periods: the emergent period (1983–1989), the early growth period (1990–1999), and the rapid development period (2000–present). In this paper, we first provide a historical review of urbanization and urban ecology in China; based on this retrospective analysis, we further identify the main characteristics of, and missing links in, China's urban ecological research; and finally we suggest future research directions. The amount and scope of research in urban ecology and environment conducted in China since the 1980s are impressive. Not only did Chinese scholars import Western ideas to develop urban ecological science, but also they have promoted a holistic, use-inspired, transdisciplinary philosophy for studying and managing urban systems – which has unique Chinese characteristics. After more than 5000 years of being predominantly agrarian, China is now urban, and will become only more urban in the future. This continued fast urbanization makes China a living laboratory for studying urbanization, and China's urban ecology seems poised to make strides in the coming decades.

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1. Introduction

One of the most salient features that characterize human civilization during the past millennium is accelerating urbanization. According to the United Nations (<http://esa.un.org/unpd/wup/>), more than half of the world's population now lives in urban areas, and almost all future global population growth will take place in urban areas. The world's population will continue to urbanize even after it stops growing around 2050, and we have entered “the century of the city” (Anonymous, 2010). Urbanization seems both a driver for, and a consequence of, socioeconomic development, cultural transformation, and technological invention. Higher levels of urbanization often correspond to higher levels of economic and social development at the national and regional scales, but urbanites usually have substantially greater and more diverse demands for resource consumption than agrarians, thus adversely affecting ecosystems and landscapes at the local and regional scales. As such, the ecological footprint of contemporary cities – the land (and water) area needed to support an urban population for resource consumption and waste disposal – is often tens to hundreds of times larger than their physical size (Luck, Jenerette, Wu, & Grimm, 2001; Rees & Wackernagel, 1996). Although cities often are engines of economic growth and centers of culture and innovation, they are also frequently the hubs of increasing environmental pollution, infectious diseases, and social inequity (Redman & Jones, 2005; Wu, 2008a, 2010).

As an increasing majority of humans will reside in cities, improving human well-being while preserving the environment within and beyond urban areas is a great challenge. This is especially true for developing countries because their cities are faced with more severe environmental and socioeconomic problems and because their small- and medium-sized cities will be home to most of the future urban growth (Redman & Jones, 2005; Wu, 2008a). To meet this challenge, we have to better understand the ecology and sustainability of cities. As noted elsewhere (e.g., McDonnell, 2011; Wu, 2014, this volume), the terms – urban ecology and urban sustainability – have various connotations. Here, we adopt the definitions in Wu (2014): Urban ecology is “the study of spatiotemporal patterns, environmental impacts, and sustainability of urbanization with emphasis on biodiversity, ecosystem processes, and ecosystem services,” and “urban sustainability is . . . an adaptive process of facilitating and maintaining a virtuous cycle between ecosystem services and human well-being through concerted ecological, economic, and social actions in response to changes within and beyond the urban landscape.” As illustrated in Fig. 1, ecosystem services, as benefits that people derive from biodiversity and ecosystem functions, provide a key nexus that links urban ecology and sustainability. Urban ecology clearly has an “ecological” focus while considering a number of socioeconomic and planning processes that influence or interact with the “ecology in cities” and “ecology of cities” (Grimm, Grove, Pickett, & Redman, 2000; Pickett et al., 2001; Wu, 2008a, 2014). On the other hand, the central issue in urban sustainability is human well-being, which depends on ecosystem services, and thus “sustainability of cities” requires maintaining and improving both ecosystem services and human well-being for the long-term. Urban ecology and urban sustainability (science) inevitably overlap with each other, but differences can be seen in cross-disciplinarity, main research foci, and major participating disciplines.

China, as a developing country and a major emerging economy of the world, has been urbanizing at a record speed with rapid economic development during the past three decades. The myriad environmental problems induced by urbanization in China are similar to those encountered in many developing countries today and in many developed countries during their intensive industrialization several decades ago. As one of the fastest urbanizing

nations and with more than one fifth of the world's population, China has a critically important role to play in promoting urban sustainability. Indeed, the Chinese government has placed an increasing emphasis on urban development in the past several decades, attempting to guide the trajectory of urbanization through a number of institutional changes and reforms (Huang, 2006; Wang, 2013a). Furthermore, Chinese scholars have much to share with the rest of the world as their unique experience in urban ecological research dates back to the early 1980s – well before urban ecology became mainstream in North America and other parts of the world. It is thus timely to review some of the key characteristics in China's urban development and urban ecological research.

Specifically, this paper has three distinct yet interrelated objectives. First, we briefly review urban development in China, identifying major characteristics in urban landscape dynamics during the past few decades. As urban ecological studies often focus on the interactions among biodiversity, ecological processes, and landscape pattern, all of which are influenced by urban planning and myriad sociopolitical factors, their theoretical frameworks, dominant methodologies, and emphasized applications are influenced by culture. Thus, our second objective is to review the historical development of China's urban ecology as it has been shaped by its own history of urbanization. Based on this retrospective analysis, our third objective is to identify main characteristics of urban ecology in China and missing links in its development, with suggested future directions.

2. Urban development in China

China has the longest history of urbanization in the world, with nine development periods (Wu, 1988; Xu, Zhou, & Ning, 2009). Reviewing the urban history of China in detail is beyond the scope of this paper, and such publications exist (e.g., Huang, 2006; Lu, Yao, Li, Liu, & Gao, 2007; Wu, 1988; Xu et al., 2009). In this section, we provide a succinct overview of China's urban development to facilitate our discussion and understanding of China's urban ecology. Here we use the term “urbanization” to refer to the development and expansion of cities and regard cities broadly as areas with high concentrations of people and human-made structures.

2.1. China's urbanization before 1949: Five development periods

Archeological evidence indicates that the earliest Chinese cities occurred along the lower and middle reaches of the Yellow River more than 4000 years ago (the Xia Dynasty – the Shang Dynasty in Chinese history) (Xu et al., 2009). According to Xu et al. (2009), the long history of urbanization in China before 1949 can be divided into five periods: (1) emergence and nascent development of cities between the Shang Dynasty and the Spring and Autumn Period (2000 BC–770 BC), (2) urban development of the early feudal society between the Spring and Autumn Period and Han Dynasty (770 BC–206 BC), (3) urban development of the mid-term feudal society between Han Dynasty and Yuan Dynasty (206 BC–1279 AD), (4) urban development of the late feudal society between Yuan Dynasty and the First Opium War (1279–1840), and (5) urban development of the early modern era between the Opium War and the founding of the People's Republic of China (1840–1949).

During the first two periods of urban development in China (about 2000 BC–206 BC), cities were mainly political and military centers with few other functions, and they began to assume major economic functions during the third urban development period (206 BC–1279 AD) (Wu, 1988; Xu et al., 2009). The total number of cities in China was 800–900 in Qin Dynasty (221–207 BC) when China was unified, and reached 1500 by the end of Western Han Dynasty at the beginning of the first century A.D. (Wu, 1988). In the

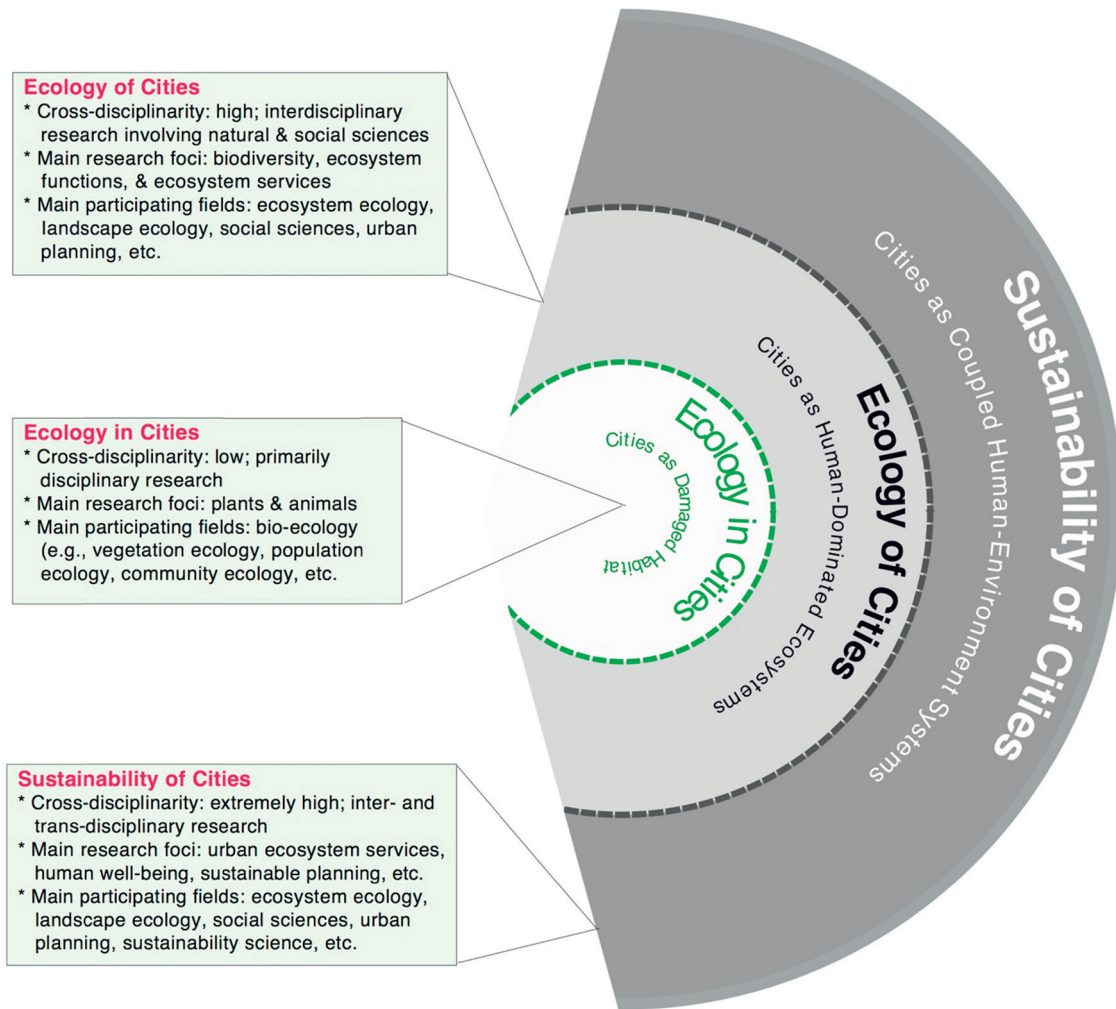


Fig. 1. Illustration of the relationship among “ecology in cities,” “ecology of cities,” and “sustainability of cities.” Urban ecology focuses mainly on ecology *in* and *of* cities, and overlaps with urban sustainability science mainly through ecosystem services that link biodiversity and ecosystem processes with human well-being in spatially patchy landscapes. The spatiotemporal patterns of both the urban landscape and ecosystem services within are affected not only by urban green-scape and blue-space (water), but also by a suite of socioeconomic, institutional, and planning and management processes.

beginning of the 19th century, Beijing was the only city in the world with a population of over 1 million, followed by London which had 959 thousand residents (Xu et al., 2009). However, after the Opium War (1840–1842), China’s urban development suffered for a long period of time, due mainly to foreign invasions and civil wars. In 1850, London’s population (2.3 million) far exceeded that of Beijing (1.65 million), and from 1843 to 1949 China’s urbanization level (i.e., percent of the total population that is urban) increased by merely 5.5% while the world’s urbanization level by 22.8% (Xu et al., 2009). So, China’s urban development started earlier, but fell behind after the industrial revolution.

2.2. China’s urbanization after 1949: Four development periods

Numerous recent studies by both Chinese and international researchers have focused on the spatiotemporal patterns, drivers, and socioeconomic and environmental consequences of China’s urbanization in the past several decades (Chen & Bao, 1994; Gaubatz, 1999; Huang, 2006; Liu, Zhan, & Deng, 2005; Lu et al., 2007; Wu, 1988). Most of these recognize striking differences in urbanization rates before and after the beginning of China’s economic reform in 1978. China’s total population increased from 0.54 billion in 1949 to 13.4 billion in 2010, significantly contributing to the growth of the world’s population. However, its annual growth

rate was generally lower than that of the world, except for the late 1960s and early 1970s. During the same period, China’s urban population increased from 58 million in 1949 to about 670 million in 2010. The number of Chinese cities with more than 1 million people increased to 12 in 1955 and 197 in 2010 at an accelerating rate.

In 1949, China’s urbanization level was about 10% whereas the global urbanization level was about 29%. For the following 61 years, the urbanization level of China was always below that of the world, but the gap quickly became narrower with China’s urbanization level increasing to 50% in 2010 while the world’s population arrived at the 50% mark in 2007 (Fig. 2). By 2050, the urbanization level of China is projected to be 77.5% when 67.2% of the world’s population will be urban. China’s sustained rapid urbanization during the past few decades was driven mainly by changes in land use and urban development policies, demographic transitions (agrarians to non-agricultural populations), and enormous economic growth (Chen & Bao, 1994; Liu et al., 2005; Wu, 1988; Ye, Xu, & Yi, 2006). The increase in China’s GDP and its urbanization rate is highly correlated, and the increase rate of GDP grew even faster than urbanization since 1990.

In an insightful analysis, Ye et al. (2006) identified four phases (or waves) of contemporary urbanization in China since 1949 (Fig. 2). Phase I (1949–1977) was characterized by industrialization-oriented urbanization at a controlled speed,

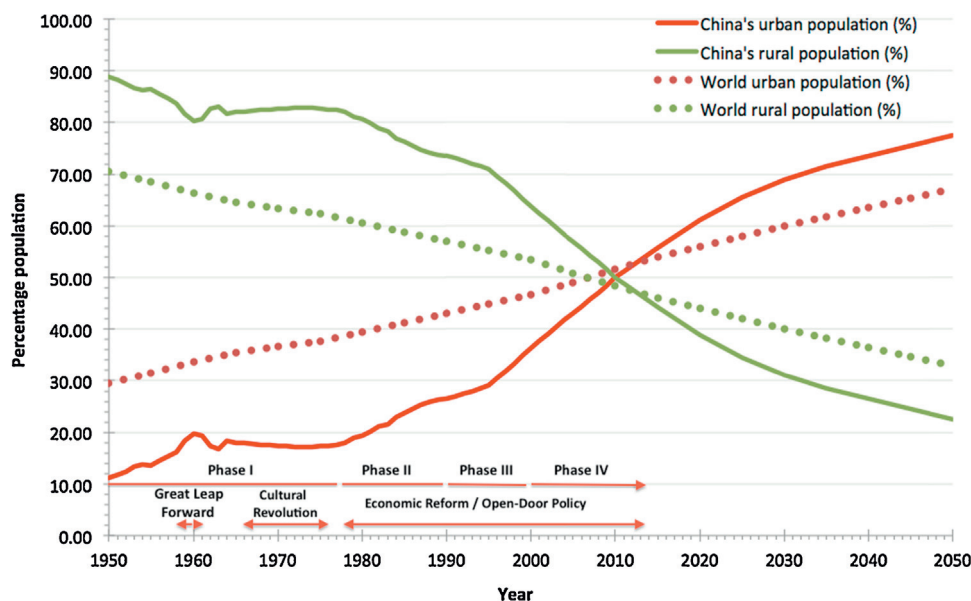


Fig. 2. Temporal dynamics of the urbanization levels (% urban population) for China and the world (data for China between 1950 and 2010 compiled from the 2012 and previous versions of China Population and Employment Statistics Yearbook published by the National Bureau of Statistics of China, <http://www.stats.gov.cn/>, and the rest of the data all from <http://esa.un.org/unpd/wup/>). The percent rural populations for China and the world are also plotted here for comparison. Some major sociopolitical events in the recent Chinese history are noted to indicate key drivers of urbanization.

during which the urbanization level was low (<20%), urban policies were dictated by traditional socialist economic development dogmas, and urban development geared toward heavy (or large-scale) industry, ignoring urban infrastructure and services industries. Consequently, most Chinese cities were transformed into, or constructed as, “production centers” or “industrial bases” (Ye et al., 2006). This combination of slow urban development and rapid building of industrial base has been referred to as “under-urbanization,” which contrasts with “over-urbanization” that is often observed in most other developing countries (Huang, 2006). During this period, several major political movements, especially the Great Leap Forward (1958–1961) and the Cultural Revolution (1966–1976), severely disrupted the course of urbanization (Fig. 2). The urbanization level abruptly increased during the Great Leap due to tens of millions of peasants pouring into industrial plants in cities (spurious urbanization or over-urbanization; Ye et al., 2006), but dropped during the Cultural Revolution when tens of millions of young people were sent to the countryside (Fig. 2).

Phase II (1978–1989) covers the first 12 years of China’s current economic reform era, during which China was transitioning from a command economy to a socialist market economy. This period was characterized by fast urbanization with faster industrialization. The thrust of China’s urban development policies in this period was to highly promote small cities, properly develop medium-sized cities, and control the expansion of metropolises (Fang, 2009). China’s open-door policy was able to attract foreign investment to become a major driver of rapid economic development that fueled urbanization. Consequently, China’s urbanization level increased by 8.5% (Fig. 2), with much of the urbanization taking place in the east coast region (Chen & Bao, 1994; Wu, 1988; Ye et al., 2006). A main feature of urbanization during this period was the phenomenon of rural industrialization—rural areas turning into towns and cities with manufacturing plants and peasants becoming urban residents without migration. As a result, urbanization seriously fell behind industrialization (Ye et al., 2006).

Phase III (1990–1999) was characterized by rapid urbanization with urban landscape reconfiguration. During this period, China’s urban policy remained focusing on developing small and medium cities (Fang, 2009). Urban growth and urban land expansion

continued, and the urbanization level increased by 10% (Fig. 2). Further economic reform and land use policy changes further promoted rapid urban expansion and reconfiguration of cities with renovation of old city districts and construction of new urban areas, including new cities, high-tech parks, industrial development parks, and central business districts (Ye et al., 2006). These changes lead to disordered urban sprawl, loss of agricultural land, and severe environmental degradation (Huang, 2006; Liu et al., 2005; Lu et al., 2007; Ye et al., 2006). They also propelled Chinese cities to change from work unit-oriented, production-dominated cities to multi-functional modern cities, and consequently urban residents were freed from the strict constraints of administrative regulations associated with work units (Huang, 2006; Ye et al., 2006).

Phase IV (2000–present) is characterized by Chinese government’s increasing emphasis on high-quality and healthy urbanization. After 22 years of rapid urbanization from 1978 to 2000, China’s urban infrastructure and services industries lagged behind its economic and social development, and this problem became quite apparent in the early 2000s (Ye et al., 2006). To overcome this problem, China’s urban development policies explicitly demand coordinated development of urban agglomerations, large, medium, and small cities, and towns, while promoting “high-quality” and “healthy” urbanization, improving land use efficiency, and optimizing the landscape pattern for sustainability (Fang, 2009). Since 2000, the Chinese government has placed increasing emphasis on developing tertiary (services) industries, particularly producer services industries (Ye et al., 2006), which include “advertising, computer and data processing services, personnel supply services, management and business consulting services, protective and detective services, services to dwellings and other buildings, legal services, accounting and auditing services, and engineering and architectural services” (Tschetter, 1987). As the urban growth rate continues to pick up speed in terms of both urban population and land area, several major city clusters – urban agglomerations or megalopolises – have emerged. These include the three major ones – the Pearl River Delta Urban Agglomeration, the Yangtze River Delta Urban Agglomeration, and the Beijing-Tianjin-Tangshan Urban Agglomeration, as well as a dozen regional-level megalopolises such as the Shandong Peninsula Urban Agglomeration, the

Shenyang-Dalian Urban Agglomeration, and the Hohhot-Baotou-Ordos-Yulin Urban Agglomeration (Fang, Song, Zhang, & Li, 2005; Ye et al., 2006).

2.3. Some key features of recent urbanization in China

China's rapid urbanization since the economic reform in 1978 has been driven by the exponential growth of national GDP. Reviewing urbanization around the world, Redman and Jones (2005) identified four basic processes underlying urban growth: (1) rural to urban migration, (2) natural increase, (3) cross-border immigration, and (4) reclassification of land from rural to urban categories. Two of the four processes – rural to urban migration and land reclassification – definitely have played an important role in China's fast urbanization during its current reform era. However, the specific driving processes and mechanisms of China's urbanization differ substantially from those in the Western countries in several ways (Fang, 2009; Huang, 2006; Liu et al., 2005; Lu et al., 2007; Ye et al., 2006). Gaubatz (1999) indicated that "The physical transformation of Chinese urban form is both a consequence of social and economic changes such as the restructuring of employment and investment patterns and a contributor to changes such as the growing need for transport and housing alternatives." The major determinants of the landscape patterns of China's urbanization include the top-down administrative hierarchy, national policies on land use and population mobility, and the "socialistic market economy." Thus, several salient and unique features of China's recent urbanization, summarized below, all have had appreciable imprints on urban ecological studies in China.

First, the speed and scale of urbanization of China's recent urbanization waves were truly colossal – unprecedented in the history of the world (Figs. 1 and 2). As a result, landscapes across the country have been extremely dynamic during the economic reform era. This is especially true for the eastern coastal regions during the past three decades and almost everywhere else since the mid-1990s. Second, the breakneck rates of urbanization were often accompanied with hasty and ecologically unsound pre-development planning and design at local and regional scales, resulting in severe environment pollution, seriously damaged ecosystems, and highly fragmented landscapes. Third, urban expansion was extremely uneven in space and time: the rate of urbanization increased, especially since the early 1990s; small- and medium-sized cities grew faster than large ones; and cities coalesced to form megalopolises or urban clusters across broad regions.

Fourth, a unique and wide-spread landscape pattern created by rapid urbanization in China is "desakota" (from Indonesian word *desa* meaning "village" and *kota* meaning "city"), referring to the amalgamation of cities and surrounding agricultural areas (McGee, 1991). "The essential feature of these desakota zones is that the landscape appears essentially rural and almost all the land is still under cultivation yet a large proportion of household income is derived from non-agricultural sources because the local economy has expanded to include cottage industry, industrial estate, and suburban development" (Cohen, 2006). These desakota landscapes are complex social-economic-ecological systems, which usually have dense populations, fast growing non-agricultural activities, high labor mobility and occupational fluidity, and interdigitated land use mosaics (Xie, Yu, Bai, & Xing, 2006). Similar to desakota, "urban villages" (villages within cities) also have appeared as a result of rapid urbanization, which are characterized by little or weak institutional regulation, mixed rural and urban cultures and social norms, and high concentrations of migrant workers (Liu et al., 2005; Liu, He, Wu, & Webster, 2010; Song & Zenou, 2012). Fifth, urban agglomeration through coalescence of existing and expanding cities has become a salient feature of China's urbanization in

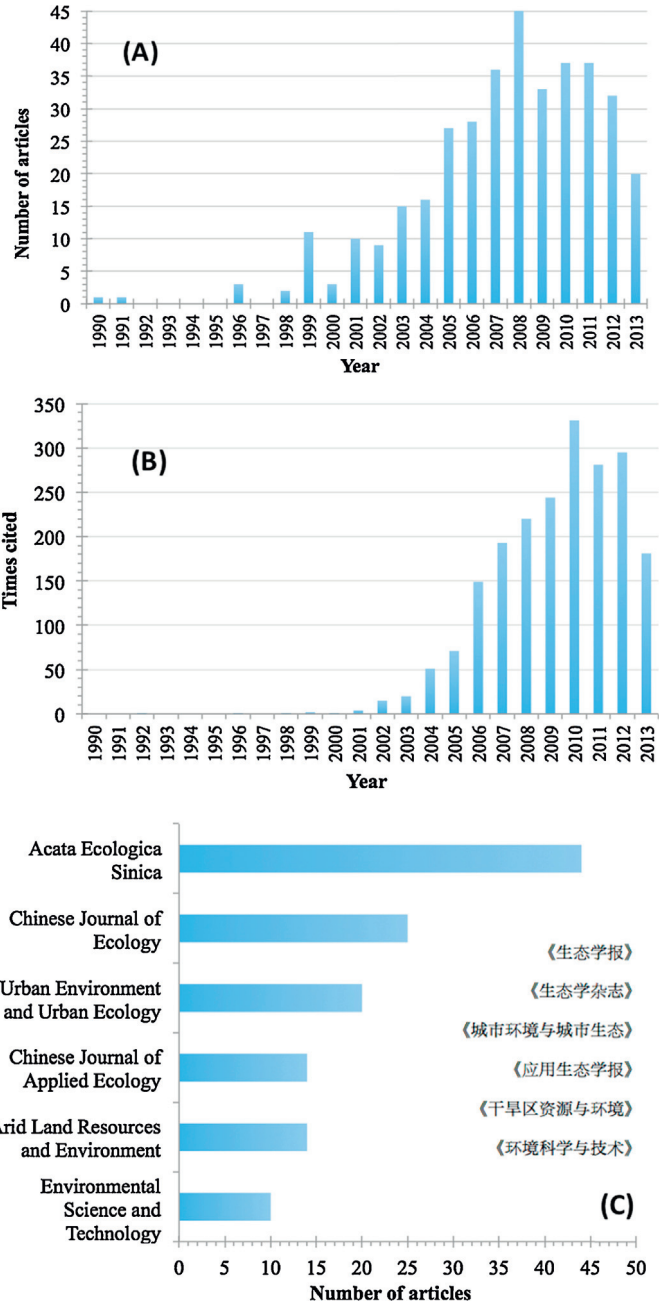


Fig. 3. The rise of China's urban ecology as indicated by publications in Chinese journals between January 1990 and August 2013 (data for 2013 were incomplete at the time of analysis). (A) the number of journal articles (366 in total); (B) the number of citations in a given year to all previously published Chinese journal articles on urban ecology (2061 citations in total); and (C) Chinese journals that published 10 or more articles on urban ecology between 1990 and 2013. Data were obtained by searching article titles in the Chinese Science Citation Database (CSCD; <http://sciencechina.cn/>; accessed September 15, 2013), with the following Chinese phrases as keywords: "城市生态" (urban ecology, urban ecological), "城市绿地" (urban green space), "城市生物多样性" (urban biodiversity), and "城市植物多样性" (urban plant biodiversity).

the past decade. This has led to the loss of agricultural land and habitat for biodiversity at an unprecedented rate in China's history. The ecological and environmental consequences of these rapidly advancing urban agglomerations are yet to be understood.

3. Development of urban ecology in China

Urban ecology, as a field of research, emerged around 1925, due largely to the work of the Chicago school of human ecology

or sociology (Wu, 2014). China has the longest history of urban development, but its history of urban ecology is rather short. Nevertheless, China's urban ecology has developed as dramatically as its economic growth during the past few decades. Different development periods may be distinguished, in which dominant ideas and approaches can be identified. In this section, we examine the historical roots and some major events in the development of urban ecology in China.

3.1. Identifying different development periods of China's urban ecology

Several Chinese authors have attempted to divide the development of China's urban ecology into periods, based entirely on subjective criteria. The most sensible among these efforts is the one given by Song and Gao (2008), who identified three developmental phases: (1) "starting phase" (1982–1990), (2) "growth phase" (1991–2000); and "development phase" (2001–present). We conducted a literature search to explore if this periodization would be supported by scientific publication records. We intentionally focused our search on urban ecological research that had a major "bio-ecological" component, which is generally consistent with the ecology in city and the ecology of city perspectives. The literature search consisted of three components: (1) searching Chinese scientific journals for articles on urban ecology; (2) searching 20 of the world's top ecology journals (all in English) for articles on urban ecology by Chinese authors; and (3) compiling a list of most if not all of the Chinese books on urban ecology.

To conduct the first part of the search, we chose to use the Chinese Science Citation Database (CSCD) which was established in 1989 as the first database for scientific literature citation in China. CSCD covers about 1200 top scholarly publications from China, with nearly 2 million records, and has been incorporated into Web of Science since 2007 (http://sciencechina.cn/index_more5.jsp; <http://thomsonreuters.com/chinese-science-citation-database/>). However, this database does not include records prior to 1990. From a much more inclusive Chinese information resource database, the China Knowledge Resource Integrated Database (<http://www.cnki.net>), we know that many articles on urban ecological and environmental issues were published in all sorts of journals, magazines and newspapers before 1990. A close examination, however, revealed that few of those publications had adequate scientific relevance or rigor for further consideration (three selected ones will be discussed later). So, it seems clear that Chinese publications on urban ecology as a science were small in number and influence, and essentially absent from any major professional journals before 1990.

Based on CSCD, we found a small number of articles on urban ecology in Chinese scientific journals between 1990 and 2000 (Fig. 3A), and the number of citations to these publications was close to nil (Fig. 3B), indicating a minimal influence in academia. Since 2001, the number of Chinese journal articles on urban ecology, as well as citations to them, has increased rapidly (Fig. 3A and B). Most of the papers have been published in three major Chinese ecology journals (Fig. 3C): *Acta Ecologica Sinica*, *Chinese Journal of Ecology*, and *Chinese Journal of Applied Ecology*, all of which are under the auspices of the Ecological Society of China. Also, a literature search for publications by Chinese authors in 20 well-respected ecology journals revealed a similar trend: urban ecological studies by Chinese researchers did not begin to appear in the world's premier ecology journals until 2000, and the journal, *Landscape Ecology*, is by far the major outlet for these publications (Fig. 4). In addition, we found more than 20 Chinese books that are relevant to urban ecology since 1988 (Table 1). Chinese books on urban ecology proliferated between 1990 and 2000, and the trend has continued since then. Most of these books are similar in terms of the scope

and contents. Those published before 2000 are commonly agglomerations of materials on urban issues from different disciplines (e.g., ecology, geography, meteorology/climatology, hydrology, and social sciences), mainly introducing foreign ideas and case studies to China. A few of them represent idiosyncratic perspectives that were shaped by China's urban development needs. Since 2000, a more balanced and comprehensive approach that emphasizes the ecology in and of cities is reflected in some of the books (e.g., Song, You, & Wang, 2000; Wang, 2011; Yang & Wu, 2000).

The results of our literature analysis generally support the three-phase characterization of the history of China's urban ecology by Song and Gao (2008). With slight modifications, we rename the three phases as: (1) the emergent period (1983–1989), (2) the early growth period (1990–1999), and (3) the rapid development period (2000–present). It is interesting, but not surprising, to notice that the three periods for urban ecology coincide nicely with the last three urbanization phases of China since 1949 that we discussed earlier: Phase II (1978–1989), Phase III (1990–1999), and Phase IV (2000–present). In the following, we discuss the development of China's urban ecology according to these three periods.

3.2. The emergent period (1983–1989)

Urban ecology and urban geography in China began to develop about the same time, both influenced heavily by China's urban development needs. Before 1949, there was essentially no urban geography or urban ecology in China. In the 1950–1960s, China divided geography into physical and economic geography based on the then Soviet Union's system, and only a small number of economic geographers conducted sporadic studies in cities (Xu et al., 2009). During the Cultural Revolution (1966–1976), almost all sciences in China stagnated (except those directly serving military and defense purposes). China's urban geography began to take off in the late 1970s as the government recognized that urban planning and design was important for socioeconomic development (Xu et al., 2009). By the late 1980s and the early 1990s, urban geography in China flourished, evidenced by the proliferation of books and journal articles in both Chinese and English, as well as the establishment of the Urban Geography Committee within the Geographic Society of China (Fang, 2009; Gu & Xu, 1999; Xu et al., 2009).

Today, China's urban geography is well-established, and covers a wide range of research topics such as: the city–region relationship, urban planning research (the functionality, size, and land use evaluation of cities), urbanization processes (drivers and mechanisms, rural urbanization, and city–town complexes), urban development policies, urban spatial pattern (e.g., urban morphology, landscape pattern, spatial optimization, and city clusters), and urban sustainable development (e.g., ecopolis or eco-city, ecological urban planning, and urban sustainability indicators) (Fang, 2009; Gu & Xu, 1999; Shi, 1997; Shi, Li, Zhang, & Xu, 2004). All these topics are also frequently considered part of urban ecology, particularly in urban landscape ecology (Berling-Wolff & Wu, 2004; Jenerette & Wu, 2001; Luck & Wu, 2002; McDonnell & Hahs, 2008; Wu, 2013a, 2014; Wu et al., 2011; Wu, He, Huang, & Yu, 2013).

Urban ecology arrived somewhat later than urban geography in China. The very first university major in ecology (plant ecology) in China was established at Inner Mongolia University in 1977 after the Cultural Revolution. As in other countries, early ecological studies in China also focused on natural ecosystems, particularly subtropical forests in the south, the coniferous forests in the northeast, grasslands in the north, and deserts in the northwest. In the late 1970s, China's ecology was rapidly developing, but still in its nascent stage. In parallel to urban geography, China's urban ecology began to emerge in the early 1980s (Chen, 1989, 1990; Song, 1983; Song & Gao, 2008; Wang, 2000). Probably the first Chinese publication explicitly discussing "urban ecology" was

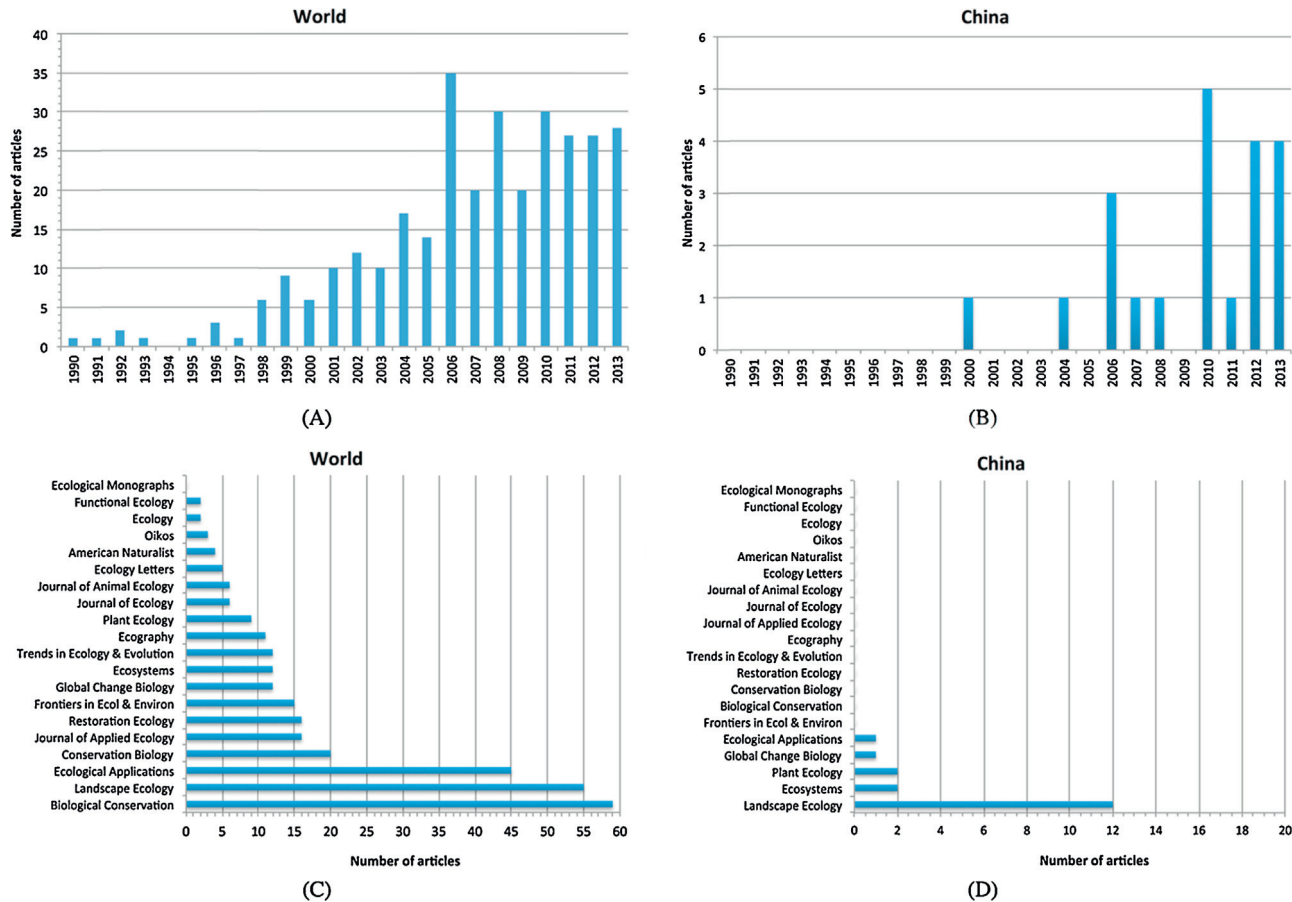


Fig. 4. Articles on urban ecology published in 20 selected ecology journals: (A) the total number of articles by all authors; (B) the total number of articles by Chinese authors only; (C) the number of articles published by journal for all authors; and (D) the number of articles published by journal for Chinese authors only. Data were obtained by searching article titles between January 1990 and December 2013 in the Web of Science database with the following search words: *urban*, *urbanizing*, *urbanized* and *urbanization* (accessed December 28, 2013).

a translated book section by Xue (1980), published in a Chinese popular science journal sponsored by the Shanghai Institute for Science of Science (World Science, <http://www.worldscience.cn>). The article discussed four classic urban forms frequently found in sociology textbooks: the star-shaped model, the concentric zone model, the sector model, and the multiple nuclei model. Two years later, in a paper entitled “Some advances in the study of urban ecology,” Dong (1982) briefly introduced some urban studies from Europe, USA, and Japan, characterizing urban ecology as a new field of study with two major approaches: “geo-ecological” and “social–economic–ecological.” As a review paper published in the inaugural issue of *Chinese Journal of Ecology*, it surprisingly did not have any references.

The most important Chinese publication on urban ecology before 1990 was probably the comprehensive review by Song (1983), a leading plant ecologist and the best-informed pioneer in urban ecology in China. Based heavily on the European literature on urban ecology and his experience in Germany between 1980 and 1982, Song (1983) described urban ecology as an emerging field with 7 research areas: (1) the processes of urbanization (e.g., population growth and distribution, land use, industrialization), (2) the environmental impacts of urbanization (e.g., urban climate, air pollution, water pollution, noise, nuclear radiation), (3) the effects of urbanization on biological organisms (e.g., urban vegetation, plant phenology, plants as indicators for air pollution, behavioral and eco-physiological responses of animals), (4) the effects of urbanization on human well-being (e.g., physiological and psychological health, behavioral responses, crime rates), (5) the function and

mechanisms of urban ecosystems (e.g., energy flow, biogeochemical cycles, urban metabolism), (6) the relationship of an urban ecosystem to other urban and rural ecosystems (e.g., considering a city in a regional and global context in terms of flows of energy, material, and information), and (7) monitoring and evaluation. The scope of urban ecology described by Song (1983) seems to coincide with the conceptualizations of urban ecology as ecology both “in” and “of” cities (Fig. 1). In comparison, during the early 1980s urban ecology in the United States was still predominantly urban sociology or urban human ecology, with little emphasis on urban biodiversity and biogeochemistry (Wu, 2014).

Another important Chinese publication before 1990 that has had persistent influence on China’s urban ecology was Ma and Wang (1984) who articulated that human-dominated ecosystems (e.g., cities and agricultural areas) should be studied and managed as social–economic–natural complex ecosystems (SENCE). This conceptualization of ecosystems was motivated by solving ecological and environmental problems in China, and can be viewed as an innovative extension of the holistic ecosystem ecology of Odum (1953) and the systems ecology of Odum (1983). The theoretical and operational principles of SENCE have been further developed by Ma’s students (Wang, 1988, 2013b; Wang, Li, Hu, & Li, 2011; Zhao, 1995). The SENCE approach has encouraged a number of comprehensive, use-inspired urban ecological studies in China, and remains influential to the development of the field in China.

In general, early Chinese studies on urban ecology were mostly associated with applied projects that aimed to solve specific environmental problems in major Chinese cities, including Beijing,

Table 1
List of Chinese books of urban ecology published before the end of 2013.

	Year	Book	Notes
(1)	1988	Wang, Ru-Song. <i>High efficiency and harmony – Methods for urban eco-regulation</i> . Hunan Education Press, Changsha	City as a social–economic–ecological complex system; ecological urban planning; urban ecosystem management and risk analysis; sustainable cities and towns
(2)	1989	Zhou, Ji-Lun. <i>Urban–rural ecological–economic systems</i> . China Environmental Science Press, Beijing	Cities and surrounding rural areas as coupled ecological–economic systems; harmonizing the relationship between urban and rural areas; regional planning
(3)	1992	Yu, Zhi-Xi. <i>Urban ecology</i> . Beijing: China Forestry Press	The first Chinese book in urban ecology to cover biophysical, socioeconomic, and planning aspects, including topics on climate, pollution, disasters, landscape pattern, environmental assessment, and planning
(4)	1993	Dong, Ya-Wen. <i>Urban landscape ecology</i> . Beijing: China Commercial Press	A landscape ecology approach to urban studies; urban pollution; urban vegetation and fauna, soils, and hydrology; urban and landscape planning
(5)	1995	Leng, Ping-Sheng. <i>Urban plant ecology</i> . Beijing: China Construction Industry Press	Plant growth in relation to urban air, water, and soil; urban plant communities; urban forestry; regulating services of plants in cities
(6)	1996	Yang, Shi-Hong. <i>Urban eco-environmental science</i> (2nd ed., 2003). Beijing: Science Press	Focusing on the relationship between humans and their environment in urban settings; urban biodiversity and urban green space; urban climate, soils, and pollution; urban planning; urban sustainability; eco-cities
(7)	1997	Kang, Mu-Yi. <i>Urban ecology and urban environment</i> . Beijing: China Metrology Press	Cities as ecological, economic, and social systems; urban environment; urban socioeconomic systems; urban green space; urban planning; urban regional assessment
(8)	1998	Shen, Qing-Ji. <i>Urban ecology and urban environment</i> . Tongji University Press, Shanghai	Covering basic concepts of population, community, and ecosystem ecology as well as issues of urban environmental studies
(9)	2000	Song, Yong-Chang, Wen-Hui You, and Xiang-Rong Wang. <i>Urban ecology</i> . East China University Press, Shanghai	Covering structure and function of urban ecosystems, ecosystem management, urban planning, and ecological assessment
(10)	2000	Wang, Ru-Song, Qi-Xing Zhou and Dan Hu. <i>Methods for urban eco-regulation</i> . Beijing: China Meteorology Press	City as a social–economic–ecological complex system; sustainable cities; sustainable urban planning and management; risk management
(11)	2000	Yang, Xiao-Bo and Qing-Shu Wu. <i>Urban ecology</i> (2nd ed., 2006). Beijing: Science Press	Ecosystem ecology; urban demography; urban environment; urban landscape, and urban sustainable development
(12)	2002	Dai Tian-Xing. <i>Urban environmental ecology</i> . Beijing: China Building Materials Press	Urban environment; urban population; urban pollution and control; urban disasters and prevention; urban green space; urban planning; urban environmental quality assessment
(13)	2004	Wang, Ru-Song (Ed.). <i>Ecosystem services for urban living and development</i> . Beijing: China Meteorology Press	Urban ecosystem services; urban green space; urban landscape–ecosystem services; urban planning; case studies
(14)	2005	Zhao, Yun-Lin and Dong-Sheng Zou. <i>Urban ecology</i> . Beijing: Science Press	Urban ecosystem structure and dynamics; urban planning and design; human–environment relationship
(15)	2006	Li, Jianlong. <i>Modern urban ecology and environmental science</i> . Beijing: Higher Education Press	Urban ecosystem structure and function; ecological planning; environmental problems and protection; urban green tourism and economic development; assessment
(16)	2008	Zou, Dong-Sheng and Yong-Lin Zhao (Eds.). <i>Urban ecology</i> . Beijing: China Agriculture Press	Urban ecosystem structure and function; urban planning; urban ecosystem management
(17)	2008	Gong, Jian-Zhou and Bei-Cheng Xia. <i>Urban landscape ecology and ecological security: Guangzhou as an example</i> . Science Press, Beijing	Urban land use and land cover; soil erosion; multi-scale landscape analysis; Guangzhou
(18)	2010	Liu, Yue-Qiu and Ke-Feng Liu. <i>Urban ecology</i> . Beijing: China Meteorology Press	Urban ecosystem structure and function; urban biodiversity; urban environment; urban landscape ecology; planning and assessment
(19)	2011	Wang, Xiang-Rong. <i>Urban ecology</i> . Shanghai: Fudan University Press	Urban ecosystem structure and function; urban demography; urban forestry; hydrology; planning; sustainability; assessment
(20)	2013	Wen, Guo-Sheng. <i>Urban ecology</i> . Beijing: China Forestry Press	Applications of population, community, and ecosystem ecology; urban landscape ecology; urban planning; ecological assessment

Tianjin, Shenyang, Shanghai, Guangzhou, and Nanjing (Chen, 1989, 1990). In these early years, China's urban ecology focused on issues of pollution, land use pattern, city planning, and urban land management, which overlapped greatly with urban geography in topic. In contrast, little research was carried out on urban vegetation, biodiversity, soil, hydrology, and climatology (Chen, 1989, 1990), although Song's (1983) review explicitly discussed these topics. Herbert Sukopp's visit to China in 1988 presumably promoted the adoption of the "ecology in city" approach in China. Several major events took place between 1983 and 1990 which may be considered as the milestones during the initial development of China's urban ecology (Table 2).

3.3. The early growth period (1990–1999)

When China's landscapes – especially the eastern regions – became conspicuously dynamic in structure and function as a consequence of rapid land use change, governmental funding to investigate urban ecology increased, and more and more Chinese

researchers began to shift their interest to cities. Chinese books (Table 1) and articles in environmental science (not mainstream ecology) journals proliferated. Although urban ecology in China developed quickly during this period, the main scientific output was in Chinese, and scholarly communication was predominantly among Chinese scholars themselves. Publications on the subject by Chinese authors were hardly detectable in the world's reputable ecology journals (Fig. 4).

During this early period, urban ecological studies in China focused mainly on urban environmental problems, eco-cities, and urban sustainable development. A number of studies dealt with urban green space, urban pollution problems, clean production technologies, environmental and ecological risk assessments, and ecological urban planning for newly developed areas (Chen, 1990; Kang, 1997; Shen, 1998; Song & Gao, 2008; Song, Qi, You, Wang, & Zhu, 1999; Song et al., 2000; Yang, 1996; Yu, 1992). Also, a landscape ecology approach, along with remote sensing and geographic information systems (GIS), became increasingly recognized in urban studies (Dong, 1993; Li & Xiao, 1995).

Table 2
Milestones in the early development of urban ecology in China (information primarily from Chen (1989, 1990); Song, You, and Wang (2000)).

Time	Event	Notes
1983	Song, Y.-C. (1983). A brief introduction to urban ecology. <i>Studies of Environmental Science</i> , 10, 1–13	The first comprehensive introduction to urban ecology in the Chinese literature
1984	Ma, S.-J., & Wang, R.-S. (1984). The social–economic–natural complex ecosystem. <i>Acta Ecologica Sinica</i> , 4, 1–8	The earliest sustainability framework in China for studying and managing human–dominated ecosystems
1984	Ecological Society of China (ESC) organized the First National Symposium on Urban Ecology, and established its Urban Ecology Specialty Committee (UESC) in Shanghai	Urban ecology recognized by ESC; 55 symposium participants; Jilun ZHOU was elected Chair of UESC
1986	The Second National Symposium on Urban Ecology held in Tianjin	84 symposium participants; presentations on theory and applications of urban ecology
1987	Symposium on urban development in Yangtze River Watershed in Anhui Province	60 symposium participants; emphasizing regional-scale urban ecological studies
1987	International Symposium on Urban and Peri-urban Ecosystems Research and Applications in Planning and Development held in Beijing, organized by ESC-UESC, in collaboration with China National Committee of Man and Biosphere Program (MAB), China's National Environment Protection Agency, and Beijing Institute of Environmental Protection	80 participants, including 20 foreigners from 13 countries; the first international conference on urban ecology held in China
1988	Chinese Journal, "Urban Environment and Urban Ecology," founded by Tianjin Society of Environmental Sciences, Tianjin Academy of Environmental Protection, and the Ecological Society of China	The first journal in China which focuses on urban ecosystems
1988	The noted urban ecologist, Herbert Sukopp, visited Tianjin, China, sponsored by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences	Promoted urban ecology, particularly urban vegetation research
1989	Chen, C.-D. (1989). Urban ecology in China. <i>Journal of Applied Ecology</i> , 26, 875–877.	The first review of China's urban ecology in English

3.4. Rapid development period (2000–present)

This period corresponds to the fourth phase of China's modern urbanization since 1949, which is characterized by the central government's increasing emphasis on high-quality and healthy urban development. Since 2000, China's urban ecology not only has continued its rapid growth but also has rapidly increased its international visibility. While the Chinese literature continues to grow (Fig. 3; Table 1), publications by Chinese authors have begun to take the world stage, and the scholarly exchange on urban ecology has become increasingly international for Chinese scientists. For example, the International Symposium on Urban Forestry and Eco-Cities was held in Shanghai in 2002, with invited international speakers from Canada, Germany, Italy, Japan, Korea, Malaysia, Singapore, UK, and USA (Carreiro, Song, & Wu, 2008). Since 2002, international conferences on urban ecology have become increasingly more frequent. In addition to publishing hundreds of papers on urban environmental science and planning in international journals each year, Chinese authors have increased steadily their contributions to mainstream ecology journals during the past decade (Fig. 4).

The rapid development of urban ecology in China during this period has been propelled and shaped by several factors, including accelerating urbanization in China, significantly increased governmental funding for urban research, and the state-of-the-science of modern urban ecology (Grimm et al., 2000, 2008; Pickett et al., 2011; Wu, 2008a, 2014). Chinese scientists have been conducting cutting-edge research in several areas of urban ecology and urban sustainability. These include the spatiotemporal patterns and driving processes of urbanization (Li, Li, & Wu, 2013; Li, Li, Zhu, Song, & Wu, 2013; Liu et al., 2005, 2010a; Zhu, Xu, Jiang, Li, & Fan, 2006), urban growth modeling (He, Okada, Zhang, Shi, & Zhang, 2006; He, Tian, Shi, & Hu, 2011; Liu, Lao, Li, Liu, & Chen, 2012; Xie et al., 2006), urban heat islands (Li et al., 2011; Li, Zhou, Ouyang, Xu, & Zheng, 2012; Zhou, Qian, Li, Li, & Han, 2014), environmental impacts of urbanization (Shao, Tang, Zhang, & Li, 2006; Yu, Shao, Shi, Pan, & Zhu, 2009; Zhu, 2012; Zhu, Ioannidis, Li, Jones, & Martin, 2011), urban ecosystem services (Jim, 2013; Jim & Chen, 2009; Wang, 2004), sustainable cities or eco-cities (Jim, 2013; Wang et al.,

2011; Wang & Ye, 2004; Zhao, Song, Shi, & Tang, 2011), and urban sustainability assessment (Song & Gao, 2008; Song et al., 1999; Zhao, 2013; Zhao et al., 2011; Zhao, 2011). Chinese urban ecological studies have been making strides, particularly, in urban pollution ecology, urban landscape ecology, sustainable cities or eco-cities. Also, urban ecology and urban planning in China have become increasingly interactive in research and practice during the past decade after many years of operating on parallel tracks (Chen & Wu, 2009; Wang, 2011; Yu, Li, & Li, 2008).

The recent burst of urban ecological research has been boosted by heightened recognition of urbanization-induced environmental problems, substantially increased governmental funding, and consequently the formation of major research institutions that focus on urban ecological and environmental issues. For example, the Chinese Academy of Sciences established the Institute of Urban Environment in Xiamen in 2006 which has hundreds of researchers and graduate students who conduct a wide range of ecological and environmental studies of cities and urban regions (<http://english.iue.cas.cn>). In addition, large urban ecology research groups are found in a dozen Chinese research universities (e.g., Peking University, Beijing Normal University, East China Normal University, and Sun Yat-sen University) and the other institutes of the Chinese Academy of Sciences (e.g., the Institute of Geographic Sciences and Natural Resources Research and the Institute of Applied Ecology, and the State Key Lab of Urban and Regional Ecology).

4. Characteristics of urban ecology in China

Based on the review of its historical development presented above, urban ecology as the study of spatiotemporal patterns and ecological and environmental impacts of urbanization began to take root in China in the 1980s, earlier than the United States but later than some European countries where the bio-ecological approach to studying cities originated. The developments of China's urban ecology in the 1980s and the 1990s were influenced appreciably by urban ecological studies carried out in Europe. From the late 1990s and early 2000s, as the field of urban ecology became

part of mainstream ecology around the world, China's urban ecology diversified in its perspectives with increasing influences from the "new" urban ecology being rapidly developed in the United States (Collins et al., 2000). Given this somewhat complicated history, what are the salient characteristics of China's urban ecology in terms of theory, methods, and key research topics?

First, there are two schools of thought that have dominated the urban ecological studies in China since its inception. These are the bio-ecological and environmental school, which focuses on bio-ecology and environmental quality in cities, and the SENCE school emphasizing the regulatory mechanisms of social-economic-ecological systems. The former roughly corresponds to the ecology in cities perspective, whereas the latter to the ecology and sustainability of cities perspectives (Fig. 1) (Wu, 2014). As Song et al. (2000) stated, however, not only are the two schools conceptually legitimate and practically useful in their own right, but also they both are complementary with each other.

Second, China's urban ecology has always had a practical orientation, emphasizing on practical and domestic issues such as urban air and water pollution as well as eco-city or sustainable city development (Song & Gao, 2008; Wang, 2000). Much research in these applied areas has been published in Chinese, especially before 1990. While Chinese scholars' contributions to international journals have increased dramatically since the 1990s, this practical emphasis is still apparent in most Chinese urban ecological studies. For instance, Wang (2000) asserted that there have been, and remain to be, three frontier fields in urban ecology in China – industrial ecology, built-environment ecology, and life-support system ecology – all of which demand for continued attention from both the academic and professional communities.

Third, a landscape ecology approach has become increasingly dominant in many urban ecological studies in China since the early 1990s. The rate and magnitude of landscape change induced by the rapid and massive urbanization have made a landscape ecology approach both attractive and effective. This is evident in recent publications by Chinese scholars, in both Chinese and English journals, in which landscape metrics and simulation models have been employed extensively in investigating spatiotemporal patterns and socioeconomic drivers of urbanization. Through the adoption of landscape ecology approach, a related and much celebrated development is the formation of an emerging community of ecologists and geographers – many authors or co-authors of the above-mentioned scholarship are urban geographers by training. Indeed, a landscape- or region-based approach that integrates geospatial patterns, ecological and socioeconomic processes, and ecosystem services will not only serve as a foundation to unite scholars and practitioners of different kinds, but also provide a common ground to cultivate actionable knowledge for sustainable urban solutions.

Fourth, the study areas of many urban ecological investigations in China include not only the cities themselves but also the rural areas enclosed in the administrative boundaries. Chinese cities are of several classes, including provincial capital cities, prefectural-level cities, and county-level cities, forming a diversity of urban spatial hierarchies (Li et al., 2013a). This particular phenomenon is unique to China, as discussed earlier in this paper, because of its characteristics in urban management and governance (here governance refers to all processes of governing that may or may not involve a government). As a result, the spatial domain, key components, and internal processes of an "urban system" for urban ecological research in China have often differed from those in North America and Europe.

5. Missing links and future directions

What are the areas of urban ecology in China that need to be emphasized in future research? How can China's urban ecology

be further advanced? There are important missing links in China's urban ecology that, with rare exceptions, have yet to be taken note by the community of scholars and practitioners. Here we elaborate on several of them, and explore possible ways for improvement.

First of all, China's urban ecology has historically lacked an emphasis on the comprehensive study of biodiversity and ecosystem processes in cities. The majority of researchers working on urban ecological problems are geographers and environmental scientists who are skilled in remote sensing, GIS, and related technical areas, but lacking training in fundamentals of ecology. Most of their studies have been focused on either urban pollution problems or urban "systems" problems with "holistic" approaches that deemphasize the role of biological organisms and fundamental ecological processes in cities. Chang-Du Chen, a leading urban ecologist in China, repeatedly pointed out this problem and urged strengthening "bio-ecology" in urban ecology (Chen, 1989, 1990; Chen & Bao, 1994). Unfortunately, the problem remains today.

Second, long-term urban ecological studies, including monitoring programs, are needed. The Chinese Ecosystem Research Network (CERN; <http://www.cern.ac.cn/>) was established in 1988 by the Chinese Academy of Sciences, which integrates former diverse and independent field experimental and monitoring sites. CERN is, to a large extent, the Chinese version of the Long-Term Ecological Research network (LTER) in the United States. Among its 42 sites, only one revolves on urban ecology (in Beijing). Despite several new initiatives have been proposed, including the Shanghai-Yangtze River Delta Urban Agglomeration (SHYRDU) research project (<http://www.giurs.com/>), more long-term urban ecological programs are needed for both research and student training in China.

Third, neither the value of basic research nor the importance of theoretical development in advancing the state-of-the-science of urban ecology has received due appreciation. Consequently, there is a lack of tested conceptual frameworks systematically developed for urban ecological research in Chinese cities. As a result, many studies are either overly reductionist, dealing with one or a few aspects of urban ecology without considering the whole urban ecosystem and landscape, or too meager, overemphasizing the wholeness of the urban system at the expense of mechanistic details. To close this gap, several emerging conceptual frameworks should be helpful, including urban landscape ecology (Turner, Lambin, & Reenberg, 2007; Wu, 2008b; Wu et al., 2013; Zipperer, Wu, Pouyat, & Pickett, 2000), urban and land sustainability (Turner, Janetos, Verburg, & Murray, 2013; Wu, 2010, 2013b), and urban resilience (Pickett, Cadenasso, & McGrath, 2013; Wu & Wu, 2013).

Fourth, until recently, urban planning and urban ecology in China have interacted little, and thus most use-inspired or problem-oriented studies lack either ecological science or design practicality. The dual phenomenon of "developing cities without planning" and "planning cities without ecology" reflects the poor communication and collaborations between the two camps, resulting in numerous ecologically ill-designed cities and towns around China in the past three decades. Sustainable urban planning is more than ecological planning, but nothing will be sustained if the environment is destroyed. The rapid urbanization in China provides great opportunities for both urban design and urban ecology, and the mounding environmental problems around the country certainly have motivated ecologists, planners, and other urban scholars and practitioners to work synergistically more often than ever.

Fifth, although China's urban geography has a tradition of studying the city in its regional context, urban ecology in China so far has mostly dealt with individual cities or relatively small urban areas. Recently, there have been a number of large-scale government-sponsored projects on evaluating the ecological and environmental conditions of rapidly urbanizing regions and major

urban agglomerations. However, hierarchically designed, multi-scale studies are needed to link local cities to urban regions and the overall land architecture of the entire nation (here “land architecture” refers to the composition and configuration of land use and land cover on a range of spatial scales). This is especially important considering that urban clusters or agglomerations will provide the main framework for the future urban development of China (Fang, 2009). Such an urban-regional approach permits research on many critically important topics that leads to the discovery of novel, deep and elegant understanding of urban ecosystems. These topical areas include, but are not limited to, landscape sustainability science (Wu, 2013b), land systems architecture (Turner et al., 2013), the relationship of urbanization to climate change and human health (Gong et al., 2012; Li, Liu, Gibson, & Zhu, 2012; Li, Wang, Zhang, Xiao, & Dixon, 2012; Zhu, 2012; Zhu et al., 2011), the relationship between urban ecosystem services and human well-being (Grimm et al., 2013; Jenerette, Harlan, Stefanov, & Martin, 2011; Jones et al., 2013; Potschin & Haines-Young, 2013; Wu, 2013b), and balancing environmental health, human welfare, and social equity in urban areas (Xiang, Stuber, & Meng, 2011). To seize the opportunity for developing a transdisciplinary science of urban regions and meanwhile to meet the national needs, Chinese urban ecologists, geographers, and designers must increase their collaborations and “scale up” their research.

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