Ecological Complexity 8 (2011) 1–8

Contents lists available at ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom

Quantifying spatiotemporal patterns of urbanization: The case of the two fastest growing metropolitan regions in the United States

Jianguo Wu [a,b,c,*], G. Darrel Jenerette [d], Alexander Buyantuyev [a,c], Charles L. Redman [b]

[a] School of Life Sciences, Arizona State University, Tempe, AZ 85287, USA
[b] School of Sustainability, Arizona State University, Tempe, AZ 85287, USA
[c] Sino-US Center for Conservation, Energy, and Sustainability Science (SUCCESS), Inner Mongolia University, Hohhot, China
[d] Department of Botany and Plant Sciences, University of California, Riverside, CA 92521, USA

ARTICLE INFO

Article history:
Received 3 March 2010
Received in revised form 10 March 2010
Accepted 10 March 2010
Available online 9 April 2010

Keywords:
Spatiotemporal patterns of urbanization
Land use change
Landscape metrics
Spatial pattern analysis
Scale
Phoenix
Las Vegas

ABSTRACT

Urbanization is the most drastic form of land use change affecting biodiversity and ecosystem functioning and services far beyond the limits of cities. To understand the process of urbanization itself as well as its ecological consequences, it is important to quantify the spatiotemporal patterns of urbanization. Based on historical land use data, we characterize the temporal patterns of Phoenix and Las Vegas – the two fastest growing metropolitan regions in the United States – using landscape pattern metrics at multiple spatial resolutions. Our results showed that the two urban landscapes exhibited strikingly similar temporal patterns of urbanization. During the past several decades, urbanization in the two desert cities resulted in an increasingly faster increase in the patch density, edge density, and structural complexity at both levels of urban land use and the entire landscape. That is, as urbanization continued to unfold, both landscapes became increasingly more diverse in land use, more fragmented in structure, and more complex in shape. The high degree of similarity between the two metropolitan regions may be attributable to their resemblance in the natural environment, the form of population growth, and the stage of urban development. While our results corroborated some theoretical predictions in the literature, they also showed spatiotemporal signatures of urbanization that were different from other cities. Resolving these differences can certainly further our understanding of urban dynamics. Finally, this study suggests that a small set of landscape metrics is able to capture the main spatiotemporal signatures of urbanization, and that the general patterns of urbanization do not seem to be significantly affected by changing grain sizes of land use maps when the spatial extent is fixed. This landscape pattern analysis approach is not only effective for quantifying urbanization patterns, but also for evaluating spatial urban models and investigating ecological effects of urbanization.

1. Introduction

Since the industrial revolution in the late 18th century, the world population has increased exponentially at an astonishing rate. The human population was only 5 million when primitive agriculture occurred more than 10,000 years ago, and crossed the first billion mark in 1830 (http://www.census.gov/ipc/www/idb/worldpopinfo.php). It reached 2 billion in 1930, 3 billion in 1960, 4 billion in 1975, 5 billion in 1987, and 6 billion in 1999, and now is approaching 7 billion (over 6.807 billion as of March 2010). In other words, it took more than 10,000 years for the world population to increase from 5 million to 1 billion, but only 100 years later did it reach 2 billion. Since then, the time for adding 1 billion people on the planet earth has been reduced to 30 years (from 2 to 3 billion), 15 years (from 3 to 4 billion), and 12 years (from 4 to 5 and from 5 to 6 billion). Importantly, the world urban population has increased much faster than the rural population, rising from 14% in 1900 to 29.1% in 1950, 47% in 2005, and will be about 61% by 2030. Furthermore, future population growth will occur primarily in urban areas. Now we are witnessing a historic turning point in human history as *Homo sapiens* transforms from a predominantly agrarian to a mostly urban species (Wu, 2008).

The United Nations (2004) projected that while the world population will most likely stabilize around 9.1 billion by 2100, the urban population will continue to increase. The increasing urban nature of humanity has a number of profound environmental and socioeconomic implications for the world's future (Grimm et al., 2000, 2008; McGranahan and Satterthwaite, 2003; Wu, 2008). Urbanization has affected biodiversity, ecosystem functioning and services, and these impacts go far beyond the city limits. Although urbanized areas cover only about 3% of the earth's land surface,

* Corresponding author at: School of Life Sciences, Arizona State University, 427 E. Tyler Mall, Tempe, AZ 85287, USA. Tel.: +1 480 965 1063; fax: +1 480 965 6899.
E-mail address: Jingle.Wu@asu.edu (J. Wu).

1476-945X/$ – see front matter
doi:10.1016/j.ecocom.2010.03.002

they account for more than 78% of carbon emissions, 60% of residential water use, and 76% of the wood used for industrial purposes (Brown, 2001). Cities in developed countries have historically contributed much more to the alteration of the atmospheric composition than those in developing countries. For example, the per person carbon dioxide emissions from Canberra, Chicago, Los Angeles and the like were 6–9 times the world's average, and the per capita emissions in the United States were 200–500 times those in developing nations in 1996 (McGranahan and Satterthwaite, 2003). In 1986, the developed countries used 100 times more chlorofluorocarbons and halons (chemicals responsible for the stratospheric ozone depletion) than the developing nations (McGranahan and Satterthwaite, 2003).

On the other hand, cities are the centers of scientific and technological innovations, economic development, and decision-making, and represent arguably the most important habitats for humans (Wu, 2008). Yet, cities are among the least understood ecosystems of all despite the fact that the study of "ecology in cities" may trace back several decades (Collins et al., 2000; Grimm et al., 2000; Wu, 2008). Urban ecological systems provide unique and important opportunities for studying the effects of human activities on ecosystem processes because urbanization exposes the entire ecosystem to severely altered climate and other environmental conditions, which allows for comparison with surrounding natural environment (McDonnell and Pickett, 1990; Zipperer et al., 2000; Carreiro and Tripler, 2005; Gagne and Fahrig, 2007; Roy et al., 2007). In addition, urban areas capture a wide variety of land use activities in a spatially heterogeneous mosaic of patches (e.g., various urban, residential, and agricultural cover types), providing a challenging yet necessary place to study the relationship between landscape pattern and ecosystem processes (Zipperer et al., 2000; Wu and David, 2002; Wu, 2008).

An important first step to understanding the effects of urbanization on ecological processes is to quantify the spatial and temporal patterns of urbanization itself. In the past few decades, with the rapid development of landscape ecology, geographic information science, and related fields, a number of quantitative methods have emerged for quantifying the spatial pattern and its dynamics of urban landscapes (Wu et al., 2000; Jenerette and Wu, 2001; Luck and Wu, 2002; Alberti, 2005). In particular, landscape pattern metrics have been increasingly used to quantify the spatial gradients of an urban area along a transect, to compare different urban landscapes, and to describe the temporal dynamics of the same urban landscapes (Wu et al., 2000; Jenerette and Wu, 2001; Luck and Wu, 2002; Berling-Wolff and Wu, 2004; Wu, 2004; Seto and Fragkias, 2005; Zhu et al., 2006; Weng, 2007). The main purpose of this study was to quantify the historical land use change of the two fastest growing cities in the United States – Phoenix and Las Vegas, using a selected set of landscape metrics. Specifically, we compare the spatial and temporal patterns of urbanization in the Phoenix (1912–1995) and Las Vegas (1907–1995) metropolitan regions, test some of the theories and hypotheses on urbanization patterns, and conclude the paper with a discussion on several key issues of urban ecological research.

2. Study areas

Our study areas are Phoenix of the state of Arizona and Las Vegas of the state of Nevada, the two fastest growing metropolitan regions in the United States (Fig. 1). Phoenix is located in the southwestern USA, and is home to the Central Arizona-Phoenix Long-term Ecological Research (CAP-LTER) project on urban ecology (Grimm and Redman, 2004). Situated in the northern part of the Sonoran desert, this region is characterized by a hot and dry climate. The average summer temperature is 30.8 °C, the average winter temperature is 11.3 °C, and the annual precipitation is about 180 mm. Native vegetation is characterized by desert scrub communities dominated by creosote bush (*Larrea tridentata*), mesquite (*Prosopis glandulosa*), and several other shrub species, including the magnificent cactus, saguaro (*Carnegiea gigantea*) – a widely recognized symbol of the Sonoran desert landscape.

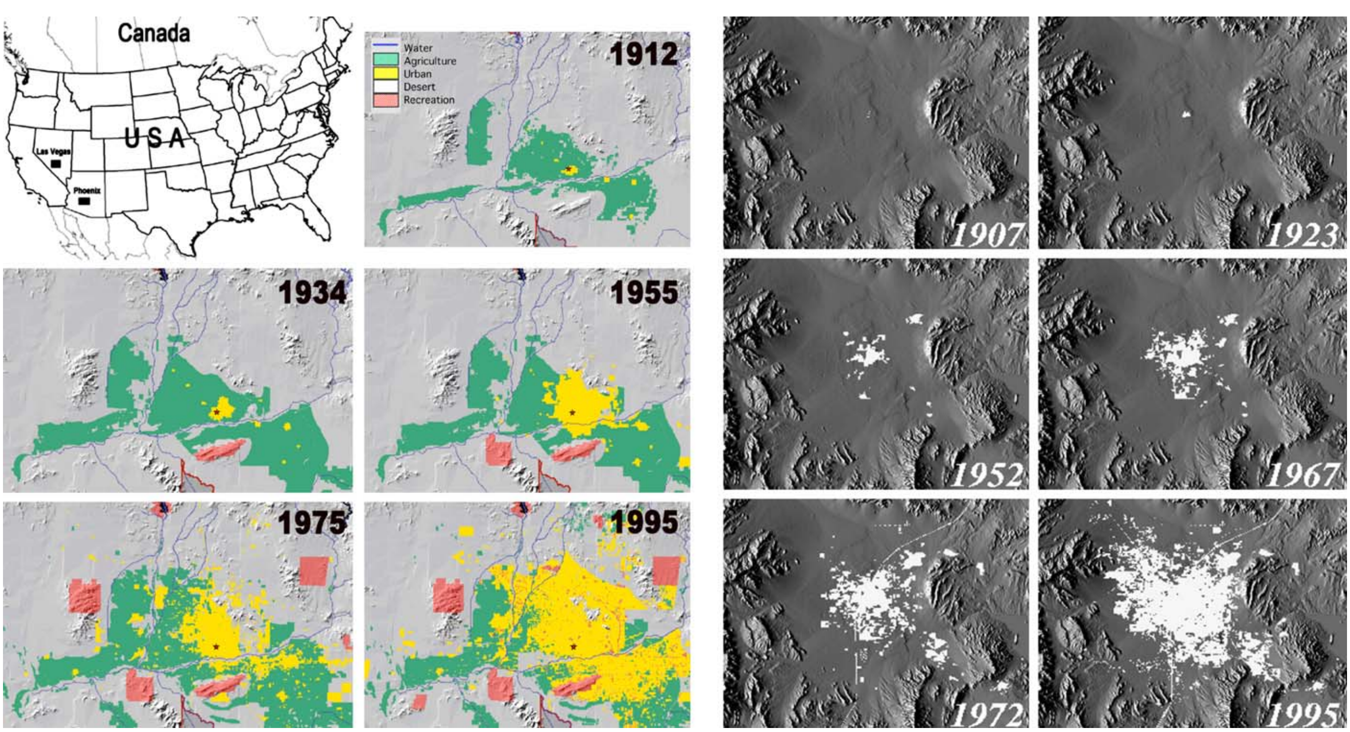

Fig. 1. Historical land use change in the Phoenix (a) and Las Vegas (b) metropolitan regions of USA (data for Phoenix from Knowles-Yanez et al., 1999; and data for Las Vegas from Acevedo et al., 2003).