Urban Forestry & Urban Greening 13 (2014) 19–27

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

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

The temporal trend of urban green coverage in major Chinese cities between 1990 and 2010

Jun Yang[a,*], Conghong Huang[b], Zhiyong Zhang[b], Le Wang[c]

[a] Ministry of Education Key Laboratory for Earth System Modeling, Center for Earth System Science, Tsinghua University, Beijing 100084, China
[b] College of Forestry, Beijing Forestry University, Beijing 100083, China
[c] Department of Geography, The State University of New York at Buffalo, Buffalo, NY 14261, USA

ARTICLE INFO

Keywords:
Driving forces
Remote sensing
Turn-over
Urbanization
Urban expansion

ABSTRACT

Information on changes in urban green spaces and the causes of these changes is important for urban planning. In this study the trends of urban green coverage (UGC) between 1990 and 2010 in 30 major Chinese cities were studied using classified Landsat satellite images. Associations between the trends and natural and socio-economic variables were analyzed using the maximum information-based non-parametric exploration method. The results showed that, overall, the studied cities have become greener over the past two decades. Greening in old city districts and expanded built-up areas (BUAs) led to the increase of urban green coverage at a mean annual rate of 1.51%. However rapid urbanization also caused a dramatic turn-over in vegetation covers. On a regional scale, around 46.89% of original vegetation cover was converted to other land cover types. The trends of UGC cannot be attributed to any one of natural or socio-economic variables alone. The combined influences of economic growth, climate change, and urban greening policies are the most likely causes behind the detected trend. One lesson from this study is that the preservation of existing vegetation cover must be a priority in urban greening programs.

Introduction

Urbanization has brought the convenience of city life to many people but has also subjected them to changing environments. Urban environmental problems such as air pollution, noise, and urban heat islands pose serious risks to urban residents' health (Douglas, 2012). Urban greening is often proposed as an effective way to mitigate these problems. Extensive studies have shown that urban green spaces can generate multiple environmental benefits, including cleaning the air, lowering noise levels, reducing urban heat island intensity, and improving storm water runoff quality (McPherson and Simpson, 2002; Buccolieri et al., 2009; Samara and Tsitsoni, 2011). Urban green spaces can also provide significant psychological and socio-economic benefits to their residents such as relieving stress and increasing property value (Fuller et al., 2007; Donovan and Butry, 2010). With the increased concern on climate changes, urban greening has gained new importance by serving as a low-cost approach for cities to mitigate and adapt to these changes (Gill et al., 2007). Cities around the world are increasingly adopting urban greening as an environmental management strategy.

Despite the proven benefits of urban green spaces, both North America and Europe reported widespread losses of urban green spaces. In England, nine out of 13 studied cities have shown a decline of urban green spaces between 2000 and 2008 leading the authors to conclude that urban centers across England have become less green (Dallimer et al., 2011). A survey of 24 cities across Europe reported a net loss of urban green spaces in 10 cities in last ten years (Baycan-Levent et al., 2009). A larger sample of 202 European cities showed improvement in the annual percentage change of urban green spaces from −0.2% in 1990–2000 to 0.54% in 2000–2006. However, a consistent declining trend of urban green spaces has been identified in most Eastern European cities (Kabisch and Haase, 2013). A recent analysis of 20 major cities in the United States found 17 with a statistically significant decline in tree covers between 2003 and 2009 (Nowak and Greenfield, 2012). Unlike the declining trend in UGC in other regions, Chinese cities reported a consistent increasing trend over the past two decades, from 17.0% in 1989 to 37.3% in 2009 (Zhao et al., 2013). This contrast has generated interest in the reliability of the reported trend and its causative factors.

It is known that the relative abundance and dynamics of urban green spaces in cities are affected by both natural and socio-economic factors (Rowntree, 1986; Dwyer et al., 2000). Natural factors, mainly climate, topography and pre-settlement vegetation cover, determine the potential vegetation types. For example cities

* Corresponding author at: Tsinghua University, Weiqing Building 706, Haidian District, Beijing 100084, China. Tel.: +86 10 62786859; fax: +86 10 62797284.
E-mail address: larix001@gmail.com (J. Yang).

1618-8667/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ufug.2013.10.002

built in forest zones normally have more tree cover than cities in grassland and desert zones (Nowak et al., 1996). The effects of natural factors can be direct or indirect depending on the time scale. Direct natural factors (e.g., extreme weather events, fire, and epidemics) have an immediate impact on urban green spaces (Duryea et al., 2007). Indirect natural factors (e.g., climate and geographical changes) have long term impacts on the structure and composition of urban green spaces (Dwyer et al., 2000). Socio-economic factors (e.g., urban morphology, developmental history, population densities, income and education, management, and policies) affect the planning, construction and maintenance of urban green spaces in direct or indirect ways (Rowntree, 1986; Dwyer et al., 2000; Hill et al., 2010; Kendal et al., 2012). Factors such as daily management activities shape the progress of urban green spaces directly (Hitchmough, 1994). Economic policies and technology have indirect influences by affecting the resources supporting the urban green spaces (Young, 2011). The combined effect of these factors and their interactions cause the spatial and temporal changes of urban green spaces (Dwyer et al., 2000).

There have been few studies conducted at the national level on China's urban greening trend and its causative factors. In a study based on remotely sensed Normalized Difference Vegetation Index (NDVI) data from 117 cities, Sun et al. (2011) found a decreasing trend of urban vegetation cover between 1982 and 2006. They concluded that urban development was the cause of this trend. For example, the Pearl River Delta in southern China experienced a rapid decline of urban vegetation cover when it went through a period of fast urbanization and economic development (Sun et al., 2011). The study's conclusion contradicted a recent study based on data released by the Chinese government showing that the average UGC of 286 Chinese cities increased steadily between 1989 and 2009 with the per capita gross domestic product (PCGDP) having the highest contribution to the observed trend (Zhao et al., 2013). A quick look at both studies revealed limitations in their methods. Sun et al.'s study used NDVI data which do not capture many small changes in green spaces. Remotely sensed NDVI data have a ground resolution of 8 km, too coarse for studying urban features that normally have scale lengths ranging between 10 m and 70 m (Small, 2003). Zhao et al.'s study used statistics compiled by government agencies. This data is known to be inaccurate due to poor reporting practices and biased surveying procedures (Lin, 1996; Liu and Yang, 2009).

Therefore, there continue to be significant questions about the trend in urban greening in Chinese cities. The main goal of this study is to address these questions with independently generated data and new analytical methods. Specifically, the study has three objectives: (1) to detect the greening trend in major Chinese cities; (2) to find out where greening has occurred; and (3) to identify the driving forces behind the identified trend. The results of this study will increase the understanding of urban greening trends in China. Many emerging and developing countries are currently experiencing rapid urbanization processes similar to China's. This study will provide information regarding the possibilities and challenges of using urban greening to improve urban environments in these countries.

Study sites and methods

Study sites

This study used 26 prefecture-level cities and four municipalities directly under the jurisdiction of China's central government as study sites. A prefecture-level city is an administration unit which is below the province level and above the county level. Municipalities directly under the jurisdiction of the central government are at the same administrative level as provinces. The 30 studied cities accounted for 37% of the BUAs of all 287 cities at and above the prefecture-level in China in 2010 (National Bureau of Statistics of China, 1990–2010). UGC – defined as the percentage of built-up areas covered by vegetation here (Ministry of Housing and Urban-Rural Development of China, 1993), ranged from 26.39% to 55.1% in these cities. The socio-economic levels of the cities varied. Guiyang and Haikou were less-developed cities while Beijing, Shanghai, and Guangzhou were highly-developed cities.

Analysis of remote sensing images

Landsat TM5 and ETM+ SLC-on images with a processing level at Level 1T of the 30 cities in 1990, 2000, and 2010 were obtained from the Earth Resources Observation and Science Center (EROS), United States Geological Survey (USGS). Only images taken during the growing season (May to October) and with an overall cloud cover of less than 10% were used. A total of 93 Landsat images were selected out and acquired from the EROS/USGS. Because EROS/USGS already conducted geometric corrections on Level 1T products, no further geometric corrections were conducted in this study. The Atmospheric Correction and Haze Reduction module in ERDAS Imagine 2011 software was used to apply atmospheric corrections on the images. After atmospheric correction, the 1990 and 2000 images were co-registered to the 2010 images and the root mean square errors of registration was controlled to less than one pixel. For cities that were covered by two images, the mosaic procedure in the ERDAS software was used to merge the two scenes.

After preprocessing, the BUAs of each city at different times were then manually delineated out from the Landsat images by using ArcGIS 10.0 software. This study used the Chinese national standard to determine if an area was BUA (Ministry of Housing and Urban-Rural Development of China, 1998). China's standard defines BUA as large connected urban lands in city districts and those areas in suburbs that have basic infrastructures and intensive linkages with city districts. Wang et al.'s (2012) method for delineating BUAs from Landsat images was used. The delineated BUAs were clipped out from the Landsat images for further classification.

The Supported Vector Machine (SVM) method was used to classify the BUAs into five land cover types: impervious cover, tree/shrub cover, herbaceous plant cover, bare land cover, and water surfaces. The classification was implemented by using the Image SVM module developed by Geomatics Laboratory of Humboldt-Universität zu Berlin, which works as an extension for ENVI 4.7 software (Van der Linden et al., 2009). All bands, except band 6 of the Landsat images, were used in the classification process. A modified Normalized Difference Water Index was produced for each image and used in classification with other bands to distinguish between shadows and water surfaces (Xu, 2006). After classification, the accuracy assessment module of ERDAS software was used to assess the accuracy of the classification. A stratified random sampling approach was adopted to extract 300 pixels from each classified image with no less than 20 pixels selected for each class. These pixels were compared to the visual interpretations of pixels from the original images and the results were summarized into accuracy reports.

Data analysis

The mean annual percentage changes of UGC and BUAs in each city were summarized from the classification results during three time periods: 1990–2000, 2000–2010, and 1990–2010. In addition, an area-weighted method was used to remove the influence of city size on the averaged values of the 30 cities (Kabisch and Haase, 2013). The ratio of the BUAs of a specific city to the total BUAs of the 30 cities was used as the weight for that city. Student's *t* tests were