Ecological Indicators 84 (2018) 183–193

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Projecting the impacts of urban expansion on simultaneous losses of ecosystem services: A case study in Beijing, China

Wenxuan Xie[a,c,1], Qingxu Huang[a,b,1], Chunyang He[a,b,*], Xue Zhao[a,c]

[a] Center for Human-Environment System Sustainability (CHESS), State Key Laboratory of Earth Surface Processes and Resource Ecology (ESPRE), Beijing Normal University, Beijing 100875, China
[b] School of Natural Resources, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China
[c] Academy of Disaster Reduction and Emergency Management, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China

ARTICLE INFO

Keywords:
Urban expansion
Ecosystem services (ESs)
Simultaneous losses
Beijing
Tradeoff and synergy

ABSTRACT

Assessing the impacts of urban expansion on ecosystem services (ESs) is fundamental to understanding urban sustainability. However, little is known about the intensity of simultaneous losses of ESs over time caused by urban expansion. Taking Beijing as an example, this study sought to simulate the historical and potential impacts of urban expansion on the simultaneous losses of main ESs. We projected the impacts of urban expansion on the simultaneous losses of main ESs from 1990 to 2013 and simulated the potential impacts from 2013 to 2040 by combining ES mapping models, an urban expansion model and statistical methods. The results show that food production, water conservation, habitat quality, carbon storage, and air quality regulation in Beijing from 2013 to 2040 will decrease by 20.70%, 8.69%, 6.45%, 5.76%, and 3.92%, respectively. Meanwhile, the simultaneous losses of water conservation, habitat quality, carbon storage, and air quality regulation will be aggravated. Increases in the replacement of forest land by urban land will be the main cause for the aggravation of simultaneous losses of ESs. From 2013 to 2040, 11.08% of expanded urban land will replace forest land, which is much higher than the 3.24% change from 1990 to 2013. Thus, more attention should be paid to protecting forest land and cropland with high ES values in rapidly urbanized regions.

1. Introduction

Ecosystem services (ESs) are the benefits people obtain from ecosystems and have been considered as crucial bridges between the environment and society (MA, 2005; Wu, 2013; Dominati et al., 2010). Urban expansion is a land-use change process that transforms non-urban land to urban land (He et al., 2016). Urban expansion alters the natural cover on land surfaces and promotes the conversion of natural and semi-natural land, such as forest land and cropland that can simultaneously provide ESs, into urban impervious surfaces. In addition, urban expansion affects ecosystem processes by changing biogeochemical circulation patterns (Grimm et al., 2008; Zhang et al., 2009; Kaye et al., 2006), which leads to simultaneous losses of ESs (Foley et al., 2005; Lawler et al., 2014; Delphin et al., 2016; Eigenbrod et al., 2011). Previous studies at different scales around the world have shown that urban expansion usually results in simultaneous losses of regulating, provisioning, and supporting services (Foley et al., 2005; Blumstein and Thompson, 2015; Anaya-Romero et al., 2016). This phenomenon is crucial for future urban planning because, on the one hand, urban expansion is characterized by irreversible and long-term legacy effects. On the other hand, growing human populations that accompany urban expansion also demand greater levels of ESs (Foley et al., 2005; Nelson et al., 2010; Li et al., 2014). Therefore, projecting the impacts of urban expansion on the simultaneous losses of ESs in the future is scientifically significant for promoting regional sustainable development and is of crucial practical significance for future urban development planning.

Currently, researchers have explored the decreases of ESs caused by urban expansion on different scales. For instance, at the global scale, Nelson et al. (2010) projected the impacts of urban expansion on ES losses, and found that the urban expansion could lead to declines in available habitats for species and biomass carbon storage (CS). At the national scale, Eigenbrod et al. (2011) examined the dynamics of ESs under the influence of urban expansion in Britain from 2006 to 2031 and found that CS and agricultural production are likely to decrease significantly. At the regional scale, Delphin et al. (2016) simulated the impacts of future urban expansion on forest-related ESs in the rural Lower Suwannee River and urbanized Pensacola Bay watersheds in

* Corresponding author at: State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, 19 Xinjiekouwai Street, Beijing 100875, China.
E-mail addresses: xiewx1213@163.com (W. Xie), qxhuang@bnu.edu.cn (Q. Huang), hcy@bnu.edu.cn (C. He), zhaoxue93@126.com (X. Zhao).
[1] Co-first author of this work.

http://dx.doi.org/10.1016/j.ecolind.2017.08.055
Received 23 December 2016; Received in revised form 19 August 2017; Accepted 23 August 2017
Available online 25 September 2017
1470-160X/

Florida, USA. The results show that both the amount of CS and timber volume could exhibit different degrees of reduction. Existing studies have found that urban expansion has and will continue to result in the decreases of ESs. However, little is known about the intensity of simultaneous losses of ESs over time caused by urban expansion.

Combining ES mapping models, an urban expansion model, and statistical methods provides a feasible approach to revealing the dynamic impacts of future urban expansion on simultaneous losses of ESs. First, ES mapping models can be used to measure the delivery of regional ESs. For example, scholars have used the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) model and other models to map ESs, such as habitat quality (HQ) (Blumstein and Thompson, 2015), water yield (Leh et al., 2013), CS (He et al., 2016), air quality regulation (AQR) (Landuyt et al., 2016), water conservation (WC) (Yang et al., 2015), and soil conservation (Li et al., 2014), based on land use/land cover (LULC) data. Second, urban expansion models, such as SLEUTH (Slope, Land use, Exclusion, Urban extent, Transportation, and Hill shade) (Clarke et al., 1997), CLUE-S (the Conversion of Land Use and its Effects at Small regional extent) (Verburg et al., 2002), and LUSD-urban (Land Use Scenario Dynamics-urban) (He et al., 2006), can accurately simulate urban expansion on different scales. The LUSD-urban model can represent the micro-scale evolutionary factors and macro-scale resource constraints of urban expansion by integrating cellular automata and system dynamics models. Recently, the LUSD-urban model has undergone several rounds of modification, and its simulation accuracy has been improved, with an average Kappa index of 0.75 (He et al., 2006, 2008, 2013, 2015). Third, statistical methods, such as correlation analysis (Raudsepp-Hearne et al., 2010), regression analysis (Jia et al., 2014), and root mean square deviation (Lu et al., 2014), have been adopted to analyze the associations between ESs. Among these methods, the correlation analysis is the most commonly used because of its simplicity. For example, using this method, Delphin et al. (2016), Verkerk et al. (2014), and Bai et al. (2011) studied the tradeoffs and synergies between ESs in two watersheds in Florida, across 26 European countries, and over the Baiyangdian watershed in China, respectively.

Against this background, we used Beijing as the study area and projected the impacts of urban expansion on the simultaneous losses of main ESs by combining ES mapping models, an urban expansion model, and statistical methods. Our objective was to project the historical and potential impacts of urban expansion on simultaneous losses of main ESs in the rapidly urbanized Beijing, China. The results will also provide a theoretical basis for ensuring sustainable urban development and practical recommendations for forming urban development plans.

2. Study area and data

2.1. Study area

Beijing, the capital of China, is located in the northern part of the North China Plain (Fig. 1) and has a total land area of 16808 km^2 (He et al., 2016). Beijing is adjacent to Tianjin city and Hebei province. It contains 16 districts (including Dongcheng, Xicheng, Chaoyang, Fengtai, Shijingshan, Haidian, Shunyi, Tongzhou, Daxing, Fangshan, Mentougou, Changping, Pinggu, Miyun, Huairou, and Yanqing) and 295 townships/streets (streets in Dongcheng and Xicheng districts are not included). The elevation of this region declines from the northwest to the southeast (He et al., 2016). Beijing is in the temperate zone and has a semi-humid, continental, monsoon climate (He et al., 2011). The climate is hot and rainy in summer and cold and dry in winter (He et al., 2016). From 1990 to 2013, the average temperature and precipitation in winter was −2.38 °C and 9.64 mm, in summer was 25.48 °C and 392.63 mm.

Since the 1980s, Beijing has experienced rapid and large-scale urban expansion, along with rapid economic development and substantial population growth (Wu et al., 2006; Li et al., 2013a). The urban land

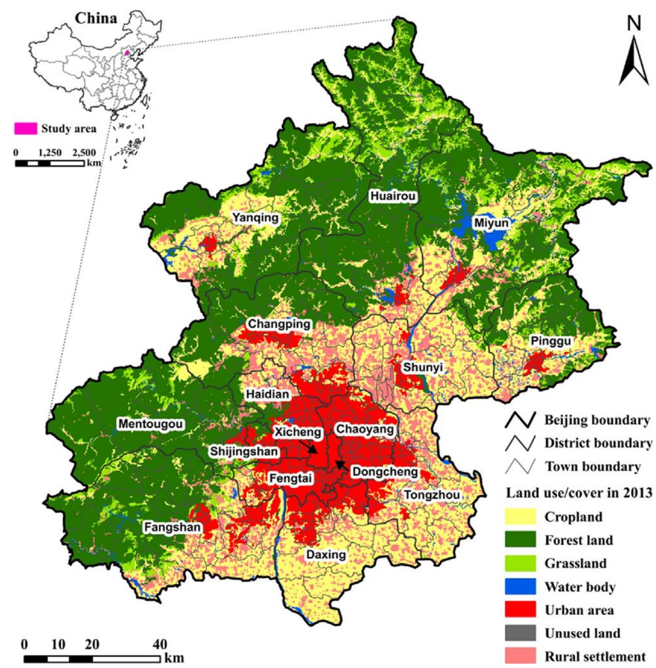

Fig. 1. Study area.

area, which is dominated by built environment within the administrative city boundary (Liu et al., 2014), in Beijing has increased by 4.5 times, from 2701 km^2 to 12187 km^2, from 1981 to 2013 (NBSC, 1982, 2014). Meanwhile, the proportion of the urban population increased from 58.0% to 86.3% of the total population in Beijing, and the gross domestic product increased from 13.92 billion Yuan to 195.06 billion Yuan (BMBS, 2014). Recently, many researchers have paid attention to the impacts of urban expansion on main ESs in Beijing. For instance, urban expansion has already had negative influences on the deliveries of food production (FP), carbon sequestration, soil conservation, water purification, and water yield in Beijing (Li et al., 2014; Gao et al., 2014; Yan et al., 2009; He et al., 2016; Jiang et al., 2008; Li et al., 2013b). It is expected that urban expansion in Beijing will continue in the future, which will inevitably affect ESs (GBC, 2005). However, research focused on projecting the impacts of urban expansion on ESs and the intensity of simultaneous losses of main ESs over time is rare.

2.2. Data

In this study, we used LULC, meteorological, socioeconomic, and geographic ancillary data. LULC data for 1990, 2000, and 2013 were obtained from the Earth System Science Data Sharing Infrastructure of the Chinese Academy of Science (http://www.geodata.cn/). This dataset was based on Landsat TM images and acquired via human-computer interactive extraction of remote sensing information. The spatial resolution is 30 m, and the overall accuracy is above 90%. This dataset includes six LULC classes (i.e., cropland, forest land, grassland, water body, urban land, and unused land) (Liu et al., 2003, 2010, 2014). The meteorological data were obtained from the Chinese meteorological data network (http://data.cma.cn/). Precipitation data from 1990 to 2013 was obtained from 24 meteorological stations in Beijing and within 200 km around Beijing. Meteorological data were interpolated using the inverse distance weighted method (Boreux et al., 2013). Socioeconomic data were collected from the Beijing Statistical Yearbook from 1981 to 2013, including Beijing's annual urban population. SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model) data, which have a resolution of 90 m, were obtained from the National Science Data Sharing Platform. Other GIS ancillary data, including administrative boundaries, city center, highways, and rivers were