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Spatio-temporal assessment of urbanization impacts on ecosystem services: Case study of Nanjing City, China

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ABSTRACT

Rapid urbanization is a global phenomenon that has altered many ecosystems, causing a decline in many ecosystem services, generating ecological risks such as water shortages, air pollution, and soil pollution. Here, we present a conceptual framework quantifying how urbanization influences the ecosystem services in a typical city (Nanjing) of China. Between 2000 and 2010, we separated the city into three urbanization categories (developing urban, developed urban, and rural areas) and quantified the status of six critical ecosystem services (food supply, carbon sequestration, soil water storage, air pollution removal, habitat suitability, and recreation potential). Our results show that urbanization significantly impacted all ecosystem services, with detected changes in ecosystem services being spatially heterogeneous due to urban expansion and population mobility. Developed areas contained greater amounts of green infrastructure, which improved carbon storage and reduced air pollution. In contrast, the rapid expansion of urban and industrial land in developing urban areas led to lower food supply, carbon sequestration, soil water storage, and habitat suitability. The expansion of rural residential areas led to lower soil water storage, carbon sequestration, and food supply, while greater amounts of abandoned cropland resulted in increased carbon sequestration, but decreased food supply in rural areas. Analysis of the interactions between pairs of ecosystem services identified urbanization development problems, including abandoned cropland and the expansion of rural residential land. Lastly, we proposed four key urban planning measures to mitigate the loss of ecosystem services during rapid urbanization. Acquiring quantitative knowledge about how rapid urbanization drives changes to ecosystem changes may help guide sustainable urban planning with respect to ecosystem service use, urban development, and human welfare benefits.

1. Introduction

Ecosystem services are benefits that people receive from the environment; specifically, provisioning (e.g., water and food), regulating (e.g., climate and disease control), supporting (e.g., nutrient cycles), and cultural services (e.g., recreational). However, humans are increasingly modifying natural ecosystems. Globally, 15 out of 24 ecosystems are in a state of decline, with nearly two thirds of the ecosystems that provide important products having already been destroyed by humans (MEA, 2003,2005). Human activities are undoubtedly degrading ecosystem functions, which might irreversibly change the environment on which we depend for survival.

The way in which urbanization is influencing ecosystems is of worldwide concern. The ecological risks (e.g., potential water crises, air pollution) generated by urbanization are major contributors of global change (Rees and Wackernagel, 2008). Urban populations are increasing rapidly, and are projected to reach nearly 60% of the human population by 2030 (Alberti, 2005), with urban areas growing twice as fast as urban populations (Elmqvist et al., 2013). Urbanization has changed the interactions among the atmosphere, hydrosphere, and biosphere; consequently, altering many ecosystem services, resulting in their broad decline. Assessments of ecosystem services provide quantitative information to initiate sustainable ecosystem management, by facilitating financial incentives for the responsible management of land and habitat (Robinson et al., 2013). Such assessments help identify which services are declining because of urbanization. Many studies have examined

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how urban–rural spatial gradients influence ecosystem services (Larondelle and Haase, 2013; Radford and James, 2013); however, few studies have examined the changing influence of urbanization on ecosystem services over time (i.e., spatio-temporal studies).

China is the largest developing country and the most populated country in the world; yet, few studies have examined how urbanization drives changes to ecosystem services in this country. Since the early 1980s, China has undergone rapid urbanization due to changing demographics and shifting land use (Tian and Qiao, 2014), with unprecedented urbanization rates occurring between 2000 and 2010. During this 10-year period, the urbanization rate in China increased from 36% to 47.5% (NBSC, 2011). In some of the more developed areas of eastern China, the urbanization rate was much higher by 2010: 89% in Shanghai (SBS, 2011). This urbanization process is associated with immigration from rural to urban areas, and is accompanied by unprecedented rates of forest clearance and conversion of cropland to urban land (Tian and Qiao, 2014; Tian et al., 2007). Many initiatives have been developed to maintain a balance between environmental sustainability and continuing urbanization. Such initiatives aim to protect cultivated land and natural landscapes, promote energy efficiency (Wang et al., 2012a; Wang et al., 2014), and reduce air pollution and greenhouse gas emissions (Wang and Yang, 2015; Wang et al., 2012b). However, to minimize the decline in ecosystem services in China, we must acquire quantitative knowledge about how urbanization processes influence ecosystem services.

Here, we aimed to: (i) propose a conceptual framework for the impacts of urbanization on ecosystem services in China; (ii) clarify typical urbanization impacts on specific ecosystem services using spatially explicit models; (iii) detect urbanization problems by the interactions between pairs of ecosystem services; and (iv) provide some suggestions for urban planning. Our results are expected to provide quantitative information towards minimizing the loss of ecosystem services with rapid urbanization, and enhancing sustainable urban planning in Nanjing City (our study area) and other cities with similar infrastructure throughout China.

2. Conceptual framework of the impacts of urbanization on ecosystem services in China

Since the early 1980s, the main features of urbanization have been urban land expansion and population shifts from rural to urban areas (Siciliano, 2012; Tian and Qiao, 2014). Undoubtedly, these features have changed the extent of the services that the ecosystems provided (Lin et al., 2013; Wu et al., 2013). We assumed that the spatially heterogeneous impacts of urbanization on ecosystem services are due to urban expansion and population mobility. The change in ecosystem services driven by urbanization differed greatly among these three areas (Haase et al., 2012) (Fig. 1).

We separated the city into three areas (developed urban areas, developing urban areas, and rural areas). The developed urban areas have highly developed economy, and highest urbanization than other areas. The developing urban areas are areas with a less developed urbanization, but have a higher urbanization growth rates than other areas. Rural areas are pre-industrial, included large numbers of cultivated land, and hve the lowest urbanization.

In developed urban areas of China, an increase in green infrastructure maybe occurred because of greater environmental awareness (Yu, 2014). This phenomenon improved the ecosystem services to some extent. The presence of more green space reduced the risk of flooding events from rainstorms (Dunne et al., 1991) and increased carbon sequestration and air filtration (Yang et al., 2005). However, in some developed urban areas, trees and grassland have been replaced by gray infrastructure; consequently, municipal projects to renew the landscape were prevented from substantially enhance the ecosystem services.

In developing urban areas of China, natural and semi-natural landscapes, which frequently occur in these areas, have been replaced by artificial landscapes (Wang et al., 2012a,b,c). Croplands have been urbanized, leading to a decline in their associated services (Jiang et al., 2012). Unprecedented increases in water-impervious surfaces have directly increased the possibility of flood events (Eigenbrod et al., 2011) and decreased other ecosystem regulating services, such as carbon sequestration and climate regulation. Habitats have been destroyed by the conversion of cropland and forest to urban land, and by the influx of rural residents (Seto et al., 2012).

In rural areas of China, the high costs of farm labor and the demand for labor in urban construction have caused many rural workers to relocate to urban areas (Zhang et al., 2014). Most of these rural workers remained in the cities, but continued to receive some cropland. Consequently, a typical feature of accelerated urbanization in China is abandoned cropland, which has increased nationwide (Zhang et al., 2014). This phenomenon is particularly noticeable in mountainous country areas. Although abandoned cropland decreases food supply, it does increase ecosystem regulating services and supporting services because it is converted to grassland and forest (Cerqueira et al., 2015). The expansion of rural residential areas has inevitably reduced ecosystem services, but the pattern and extent of influence on ecosystem services are different from the case of developing urban areas.

Improvements to traffic networks have supported opportunities for tourism and recreational activities by residents (Brabyn and Sutton, 2013), despite urban land expansion encroaching on areas with natural landscapes; consequently, the positive or negative impact of recreation potential driven by urbanization in the three different areas is difficult to quantify.

In the current study, we used spatially explicit models to clarify how typical urbanization has influenced specific ecosystem services over time (between 2000 and 2010) in China, using the example of Nanjing City.

3. Methods

3.1. Study area

Nanjing (31° 14′–32° 37′ N, 118° 22′–119° 14′ E) is a large region (4.73×10^5 ha) in the Yangtze River Delta, Jiangsu Province, Eastern China (Fig. 2). The city is traversed by the Yangtze River. Nanjing has an average annual air temperature of 15 °C. The average annual precipitation is 1106 mm, with rainfall being evenly distributed throughout the year. The vegetation consists of subtropical, evergreen broadleaf forest, evergreen coniferous forest, and some non-native vegetation. Rice is the main crop (NBS, 2001).

There has been a rapid economic development in Nanjing since the 1970s. During the 2000–2010 period, urban and industrial land increased by 3.81×10^4 ha, with these land use types accounting for 8.2% of the total study area. The urbanization rate in Nanjing was 56.8% in 2000, but increased to 85.7% in 2010 (NBS, 2001; NBS, 2011), whereas the mean urbanization rate in China was just 47.5% in 2010 (NBSC, 2011).

3.2. Modelling

We used a spatial explicit model for the quantitative assessment of how urbanization has influenced ecosystem services at a citywide scale (Fig. 3). First, the study area was separated into three areas (developed urban areas, developing urban areas, and rural areas) based on different urbanization levels. Second, for