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Dynamic variations in ecosystem service value and sustainability of urban system: A case study for Tianjin city, China

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ABSTRACT

Rapid urbanization and industrialization in China have seriously threatened the ecosystem and urban sustainability. This paper estimated the dynamic variations of ecosystem service value (ESV) in response to changes of land use/land cover (LULC) under rapid urbanization, and it analyzed their impacts on sustainability of urban system. Tianjin, the largest coastal city in China, was selected as the study area. The total ESV of Tianjin was approximately 8791.86 million Yuan in 2003, 7948.04 million Yuan in 2007, and 8378.53 million Yuan in 2011. By taking the total dynamic ESV as one of the key factors, we calculated the indexes of urban sustainability from 2003 to 2011. It was found that the dynamic variations of ESV in response to LULC changes had significant impacts on the sustainability of urban system. Therefore, in order to increase the capacity for urban sustainable development, there is an urgent need to lighten the heavy burden on the ecosystem through rational land use management during rapid urbanization.

1. Introduction

Currently, urbanization has become one of the most important and significant trends around the world, and the accelerated urban expansion indicates that the whole world has entered "the century of the city" (Anonymous, 2010). Cities are the most concentrated areas of human activity, and they are typically social–economic–natural complex ecosystems (Ma & Wang, 1984). As the material base and natural capital of human society, ecosystem services provide vital benefits supporting the stable operation and development of social and economic systems (Chase, Pielke, Kittel, Nemani, & Running, 2000; Costanza, Cumberland, Daly, Goodland, & Norgaard, 1997; Costanza, d'Arge, et al., 1997; Daily, 1997; Lambin et al., 2001) and play an extremely important role in sustainability of urban system. However, the ravenous appetite of cities for land resources has adversely affected landscapes and ecosystems at the local and regional scales (Cheng, Yang, Zhao, & Wu, 2009; Wu, Xiang, & Zhao, 2014), and this phenomenon is particularly prevalent in developing countries (Dewan & Yamaguchi, 2009; Geymen & Baz, 2008; Henríquez, Azócar, & Romero, 2006; Kumar, Pathan, & Bhanderi, 2007; Liu, Liu, Zhuang, Zhang, & Deng, 2003; López, Bocco, Mendoza, & Duhau, 2001; Wei & Ye, 2014). China is the largest urbanizing nation and developing country in the world (Kamal-Chaoui, Leman, & Zhang, 2009); its urbanization is attracting more and more worldwide scholarly attention due to its astonishing pace, uniqueness and complexity. Admittedly, China has witnessed unprecedented economic growth and social development during rapid urbanization. However, due to the short-sighted behavior of the local governments and the lack of useful tools for guiding sustainable land use management, many natural and semi-natural lands have been converted into construction lands (Liu, Zhan, & Deng, 2005; Liu et al., 2003). Urban built-up areas have increased at an alarming rate in the past few decades, especially in large coastal cities (Wei & Ye, 2014). The dramatic LULC changes have placed heavy pressure on ecosystems and seriously threaten urban sustainability.

With growing public awareness of sustainability, ecosystem service valuation has become a hot topic in academia. Since Costanza, d'Arge, et al. (1997) published their pioneering work on the economic valuation of global ecosystem services, a vast body of literature has estimated the variations of ESV in the context of worldwide rapid urbanization (Estoque & Murayama, 2012; Kreuter, Harris, Matlock, & Lacey, 2001; Mendoza-González, Martínez, Lithgow, Pérez-Maqueo, & Simonin, 2012). Based on the work of Costanza, d'Arge, et al. (1997), Xie, Lu, Leng, Zheng, and Li (2003) developed a more specific and practicable method for China's terrestrial ecosystem service valuation. Thereafter, a large number of studies on ESV variations in response to China's rapid urbanization have emerged (Li, Li, & Qian, 2010; Liu, Li, & Zhang, 2012; Qi, Ye, Zhang, & Yu, 2014; Su, Xiao, Jiang, & Zhang, 2012; Wan et al., 2015). Li (2002) argued that willingness to pay (WTP) is the core concept of ecological valuation, and

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people's WTP is affected by socio-economic factors. Therefore, ecosystem service valuation should reflect the temporal dynamics of social and economic development. Otherwise, its significance in practical application will be weakened (Zhao & Yang, 2007). According to Pearl's S-shaped growth curve, Li (2002) proposed a method for temporal dynamic ecological valuation; based on Li's method, a growing body of literature has estimated the regional dynamic ESVs in China (Feng, Ma, Wang, & Xu, 2013; Hu, Hong, & Wu, 2013). Although the importance of ESV as a useful tool in guiding sustainable land use planning and urban management has been widely recognized (Atkins, Burdon, Elliott, & Gregory, 2011; Barral & Oscar, 2012; Fisher, Turner, & Morling, 2009; Gómez-Baggethun & Barton, 2013; Sun, Zong, Ke, Wang, & Wang, 2011; Tang et al., 2007; Vihervaara, Kumpula, Tanskanen, & Burkhard, 2010), there seems to be a blind spot in the literature on the issue of the actual use of ecosystem services economic valuation (Laurans, Rankovic, Billé, Pirard, & Mermet, 2013). Most of the studies focus only on ESVs themselves or their variations; however, they rarely pay attention to the issue of how to integrate ESV into actual use for guiding sustainable development. The knowledge gap on how to communicate information to policy makers and the general public is one of the challenges on the application of ESV (Wu, Ye, Qi, & Zhang, 2013). The problem of information communication can potentially be solved by indicators. As the empirical and indirect interpretation of reality, indicators can effectively communicate related information to decision makers and the public (Spangenberg, Pfahl, & Deller, 2002), thus promoting a better understanding of complex phenomena (Repetti & Desthieux, 2006). Due to this advantage, indicators have been utilized in the assessment on urban planning and environmental management with increasing frequency (Li et al., 2009; Merkle & Kaupenjohann, 2000). By taking the rural ecosystem service value as one of the key factors, Liu, Wang, and Long (2010) put forth the method of the calculation of the index of rural sustainability in Jiangsu Province of China, which provided new ideas and inspiration for the application of ESV.

The present study focuses on Tianjin city, which is the largest coastal city and a famous international port city in China. Serving as one of the most important engines of China's economic growth, Tianjin has experienced rapid urbanization during the past few decades. Meanwhile, huge areas of natural and semi-natural lands have been converted into built-up areas to satisfy the needs of accelerated urbanization and economic development. Since the local government put forward the development goal of the eco-city construction and accordingly adjusted the land policy in 2006, the local ecological environment has gradually improved. All these reasons mentioned above have made this city a meaningful case study. Comprehensive studies on the impacts of LULC changes on the regional ecosystem and sustainability are very scarce in this area. This paper depicted the LULC dynamics and the corresponding variations of ecosystem service value (ESV) from 2003 to 2011. By taking the total dynamic ESV as one of the key factors, we established an indicator of urban sustainable development state and analyzed the relationship between LULC change, regional ESV, and urban sustainability. Based on our results, this paper provides useful information and advice for sustainable development in Tianjin. Furthermore, we hope this case study will provide a valuable reference to other coastal cities in China.

2. Methodology

2.1. Study area

Tianjin (38°34′N to 40°15′N, 116°43′E to 118°04′E) is located in the northeast part of the North China Plain, near Beijing (Fig. 1). It covers a total area of approximately 11919.7 km^2 and has a coastline of 130 km. Tianjin has a semi-humid and continental monsoon climate, with four distinct seasons. The temperatures range from −2 °C to 28 °C, and the annual average temperature is approximately 14 °C.

Tianjin is an economic and logistics center of the Bohai Rim region and northern China, from which products from a vast area within northern and northwestern China can be exported overseas. During the past few decades, Tianjin has experienced rapid urbanization and economic development. The urban area and the population have dramatically expanded, and the regional GDP increased from 19.82 billion Yuan in 1978 to 1130.73 billion Yuan in 2011. However, the areas of cropland, grassland, orchard, and unused land have significantly decreased.

2.2. Land use classification

The data sets on land use of Tianjin from 2003 to 2011 were taken from the Tianjin statistical yearbook (Tianjin Municipal Bureau of Statistics, 2012). According to the land use classification system established by the China National Committee of Agriculture Divisions (1984) and the Tianjin statistical yearbook (Tianjin Municipal Bureau of Statistics, 2012), the data sets were classified into eight land use/land cover (LULC) categories that included woodland, grassland, orchard, cropland, wetland, water body, unused land, and built-up.

2.3. Assignment of ESV

According to the work of Costanza, d'Arge, et al. (1997) and Xie et al. (2003), Li et al. (2010) assigned the ecosystem service value of unit area of each land use category in Shenzhen based on the nearest equivalent ecosystem. In this paper, this assignment method was adopted to obtain the annual average ecosystem service value of unit area of each land use/land cover (LULC) category in Tianjin (Table 1).

2.4. Calculation of ESV

Once the annual average ecosystem service value of unit area of each LULC category is determined, the ESV of Tianjin can be calculated through the formulas shown as follows:

$$ESV_k = \sum_f A_k \times VC_{kf} \tag{1}$$

$$ESV_f = \sum_k A_k \times VC_{kf} \tag{2}$$

$$ESV = \sum_k \sum_f A_k \times VC_{kf} \tag{3}$$

where ESV_k, ESV_f, and ESV refer to the ecosystem service value of land use/land cover category k, the ecosystem service value of function type f, and the total ecosystem service value, respectively. A_k is the area (ha) of land use/land cover category k, and VC_{kf} is the value coefficient (RMB Yuan/ha) of land use/land cover category k, ecosystem service function type f. To ensure that all the ESVs were comparable across time, we set 2003 as the base year and calculated the ESVs for different years with the value coefficient in 2003.

2.5. Dynamic adjustment of ESV

With the development of society and the improvement of living standards, people will pay more attention to ecosystem services, leading to an increase of their WTP for ecosystem service. Thus, the static ESV should be adjusted through the coefficients of social