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A long-term analysis of urbanization process, landscape change, and carbon sources and sinks: A case study in China's Yangtze River Delta region

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ABSTRACT

Understanding the dynamics of urbanization and induced environmental changes on a regional scale is essential for policy makers to address the growing challenges of local sustainability and global climate change. Choosing the Yangtze River Delta (YRD) region of China as a case study, this paper focuses on the long-term urbanization process, its consequences on the spatio-temporal changes on the landscape and associated carbon sources and sinks, and policy drivers behind these changes. Differing from previous research, this paper highlights a systematic analysis of the dynamic process and policies related to urbanization and associated environmental changes through the integration of interdisciplinary, region-based and data-intensive approaches. The results indicate that the urbanization of the YRD region experienced a three-staged trajectory from regressive during 1960–1978 to progressive but unbalanced development from 1978 to 2010. Landscape changes occurred at an unprecedented rate with the encroachment of urbanized terrain on cropland, cropland exploitation, and the reclamation of forest and water as the dominant types. Both carbon sources and sinks have increased significantly from 1995 to 2010, while the spatial net carbon intensity of built-up land shows a significant jump due to the faster growth of carbon emissions than the already astonishing expansion of urban land. Policy implications include improving the social welfare systems, strengthening ecological land conservation and urban sprawl control polices, and reforming the economic structure, especially in Jiangsu province, toward a low-carbon one.

1. Introduction

Urbanization has been imposing substantial global environmental changes. It affects the environment by directly fragmenting the landscape in human habitats and by indirectly changing the biophysical properties of the landscape that cause numerous environmental impacts across different spatial and temporal scales, such as ecosystem services reduction, resource and energy depletion, and climate change (Alberti and Marzluff, 2004; Seto and Shepherd, 2009; Grimm et al., 2008). Carbon sources and sinks, which are driven by urbanization and corresponding landscape changes and reflect not only anthropogenic disturbances but also the natural amenity of a region, have more profound impacts on the global environment (IPCC, 2006). It is estimated that urbanized regions have contributed to over 70% of worldwide CO_2 emissions (IEA, 2014). Additionally, landscape changes and carbon impacts are expected to be more significant due to increasing urbanization over the next few decades (Montgomery, 2008). In 2050 over 67% of the world population will reside in urbanized areas, with most of the net increase in urban residents expected to occur in the urbanized regions of developing countries such as China, India, Mexico, and Brazil (United Nations, 2013). Thus, understanding the urbanization process and its consequence on landscapes and carbon emissions on a regional scale, especially in developing countries, is crucial to addressing the significant challenges of achieving regional sustainability and mitigating global climate change.

We have learned much about the process of urbanization and corresponding induced landscape changes and carbon sources and

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sinks. In the last decades, the urbanization process has been examined by a number of studies that focus on several aspects such as the division of development stage, relationship with economic development, and challenges in developing countries (Northam, 1975; Cohen, 2006; Chen et al., 2013a). Their findings reached some basic consensus that in most of the developed countries the increase of urbanization rate is usually coordinated with their economic development, while the growth of urbanization and economy in developing countries usually is not parallel. By contrast, China's urbanization neither follows the trategory of developed countries, nor duplicates that of developing coutries (Friedmann, 2006). Some believe China's urbanization rate was under-urbanized, since rapid industrial development did not bring about a parallel growth in urban population (Zhang and Zhao, 2003). The household registration system in China divides people's identity into urban and rural ones, and the rural-to-urban migration is constrained even though the scale of urban population and its growth speed have already been astonishing since the 1980s (Zhang and Zhao, 2003; Chang and Brada, 2006). While others have the opposite opinion that China's urbanization is over-urbanized due to the excessive inflow of rural labors to cities (Zhang, 2011).

As one of the most influential consequences of urbanization, changes in landscape and associated carbon sources and sinks have attracted great attention from the whole world due to the increasingly urgent needs to mitigate the climate change and improve the integral human well being. A significant number of studies have been reported on these issues covering global (e.g. Houghton et al., 2012), national (e.g. IPCC, 2006), regional (e.g. Chen et al., 2013b; Chuai et al., 2015), and city scales (e.g. ICLEI, 2007; Tao et al., 2015). Most of these studies have been trying to pursue basically three questions: the first is the characteristics of spatio-temporal change in landscape and carbon cycle (Chen and Tian, 2007; Hutyra et al., 2011; Evrendilek et al., 2011); the second is the driving forces of these changes (Davidson et al., 1995; Turner et al., 2007; Canan and Crawford, 2007; Ou et al., 2013); the third is the low-carbon land use/cover management and planning (Makido et al., 2012; Aydin and Cukur, 2012; Jing et al., 2013).

However, human knowledge about the spatio-temporal interaction between urbanization trajectories, driving forces, and environmental changes lags far behind our rapid urbanization and, moreover, our understanding remains limited. This is especially true regarding China. In the past 30 years, the urbanization rate in China as measured by the proportion of the urban population has nearly tripled, from 18% in 1978 to 55% in 2014. This has driven the country to be the 2nd largest worldwide economy since 2010 (BBC, 2011) and the largest carbon emitter in the world since 2006 (IEA, 2014). Important changes in urban populations, landscapes, and carbon budgets usually cannot be satisfactorily explained by the classical economic, demographic and geographical theories. They are sometimes largely influenced by policies issued by the central or local government. Thus, a systematic investigation based on at least three approaches is needed to deepen our understanding of the interplay between urbanization and environmental change and, more importantly, to direct policy for sustainable development. First, the analytic framework requires an interdisciplinary approach. This is because a majority of existing studies have been conducted from economic or geographic points of view (Kontgis et al., 2014; Wang et al., 2014; Cook, 2015). However, the urbanization process and corresponding environmental changes represent a synergy of anthropogenic activities and natural conditions, which makes the research angle and methodology needed an interdisciplinary integration of economics, remote sensing, geography, and ecology, among others. Second, policy analysis requires a region-based approach. Urbanization and environmental change in different countries or regions may exhibit different outcomes because they are largely policy driven. Only through a region-based approach can we better investigate and interpret the space-time dynamics of a specific region. Third, the analysis requires a longitudinal and data-intensive approach. Given the multi-scale characteristics, the synthesis of longitudinal and heterogeneous data is essential for exploring the nature of urbanization and its consequence on the environment. The assimilation of multi-scale and multi-sector data, such as the spatial data produced by remote sensing and geographic information systems and the statistics from various sources would be indispensable.

Though each of these aforementioned approaches has received considerable attention, each approach alone is insufficient. An integration of all three approaches is necessary to provide alternative analytic frameworks, methods, and data to empower a regional study for achieving sustainability. The Yangtze River Delta (YRD), one of the most rapidly urbanizing and important economic regions in China, has been selected for a case study. Through the investigation of the process, policy drivers and environmental changes associated with urbanization, we aim to explore the following three questions via econometric methods combined with remote sensing and GIS techniques:

1) What is the change in the urban population and its correlation with economic development over the five decades between 1960 and 2010?
2) To what extent and in what ways has rapid urbanization changed the region's environment in terms of the landscape and carbon sources and sinks?
3) What are the policy implications for improving local sustainability of urban development and mitigating its impacts on the global environment?

2. Study area and data

2.1. YRD region in China

As one of the most densely populated and rapidly developing areas in China, the YRD region, according to regional planning of the Yangtze River Delta 2009–2020 (NDRC, 2010), consists of three basic jurisdictional units including the Shanghai municipality and Jiangsu and Zhejiang provinces. As shown in Fig. 1, it is situated at the lower reach of the Yangtze River in the eastern coastal part of China. It has an area of 208,140 km^2, approximately 2% of the whole country's territory. However, it accommodated 156 million people and generated 8600 billion RMB (approximately 1270 billion US dollar) in 2010, which is approximately 6% and 20% of China's total population and GDP, respectively (NBS, 2011). Despite its status as one of the most important economic engines of China, the area has also suffered a tremendous amount of growing pains. For example, discharges of waste water, air pollution, solid waste per unit of industrial added value, and CO_2 emissions per capita in YRD region were 10, 6, 3 and 1.6 times larger than the national average, respectively, which has triggered the deterioration of habitats not only in the local area but also in cross-border regions. These tremendous changes and challenges make the YRD a good case to study changes in the environment as a result of rapid urbanization and socioeconomic development.

2.2. Data description

Table 1 lists the data used for analyses. Generally, the data include socioeconomic statistics and geospatial information. First, to explore the characteristics of urban population change and