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Discrepant impacts of land use and land cover on urban heat islands: A case study of Shanghai, China

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ABSTRACT

The most visible aspect of urbanization is that more and more natural landscape is replaced by anthropogenic land cover/land use, which is the driving force of many ecological and environmental consequences such as urban heat islands. However, the difference between land use and land cover and their implications in ecology is often overlooked. The impacts of urban land cover composition and configuration on land surface temperature (LST) have been extensively investigated, but few studies have explored the relation between LST and land use category. This research takes the inner city of Shanghai as a case and comprehensively investigates the discrepant impacts of land use and land cover on LST. Land use and land cover data are derived respectively from aerial photography and high-resolution satellite imagery (ALOS), and the LST is estimated from Landsat TM images. There are five dominant land use types (new residential, old residential, villas, industrial, and institutional land use) and two major land cover types (vegetated and impervious land cover) in the study area. For most land use types, the land cover composition and configuration are varied. By contrast, no statistical difference is observed among old residential, industrial and institutional land uses for LST. The mean LST of new residential and industrial land use is significantly different, although their land cover compositions and configurations are quite similar. These results indicate that the key factors affecting urban LST are not only land cover patterns, but also other anthropogenic forces. Therefore, the explanation of urban LST by land cover alone is inadequate. Especially at fine spatial scales, information on land use is more meaningful than that of land cover to indicate the impacts of urbanization on ecosystems.

1. Introduction

It is well known that urbanization is one of the most powerful and visible anthropogenic forces on Earth (Cohen, 2004; Chen et al., 2010; Angel et al., 2011). The most evident aspect of urbanization is that more and more natural landscape is replaced by anthropogenic land cover/land use, which causes many ecological and environmental problems, such as the phenomenon of urban heat islands (Chen et al., 2007; Wiedmann et al., 2013). Therefore, better understanding of the driving forces of urban land cover/land use change and their impacts on ecosystems is critical for urban ecosystem research and sustainable urban planning (Grove, 1997; Breuste et al., 2008).

Notably, the difference between land use and land cover and their implications in ecology is often overlooked. Land use generally refers to how people use the land in terms of social-economic functions, whereas land cover defines the physical pattern of land surfaces. Thus, it is important to distinguish between the two surface landscape indicators, which can reveal the linkage between biophysical features such as land cover and anthropogenic features such as social-economic activities (Hubacek and Sun, 2001; Chen et al., 2006; Chen and Chen, 2010; Han et al., 2014).

Numerous studies have investigated urban land cover patterns using multi-resolution remote sensing imagery (Griffiths et al., 2010; Redo and Millington, 2011; Taubenbock et al., 2012; Schneider, 2012; Wu and Zhang, 2012; Ramachandra et al., 2012; Lasanta and Vicente-Serrano, 2012; Sexton et al., 2013), but few studies have quantified urban land use distribution at fine scales.

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Urban heat islands, as the most evident negative impact of urbanization, have been widely attributed to land cover/land use change (Jones et al., 1990; Grimm et al., 2008). Generally, urban heat islands can be characterized by air and land surface temperature (LST). Because of the limitation of in situ air temperature monitoring across large spatial-temporal scales, remote sensing provides a powerful way to quantify LST. Many studies have examined the relationship between LST and land cover composition and configuration on multiple scales (Zhang et al., 2009; Buyantuyev and Wu, 2010; Zhou et al., 2011; Li et al., 2011, 2013; Connor et al., 2013; Lazzarini et al., 2013). Most studies found the consistent result that urban vegetation could decrease LST, while impervious land cover increases LST. By contrast, the correlations between LST and land cover configuration were found inconsistent or contradictory in many studies (Zhou et al., 2011; Buyantuyev and Wu, 2010; Li et al., 2013; Connor et al., 2013), and were mostly explained by the scale effect (Zhou et al., 2007; Li et al., 2013). However, due to the notable effects of urban socio-economic activities on LST, the use of land cover pattern as the single driving factor for LST might be inadequate. In recent years, some studies have begun to explore the impacts of anthropogenic factors such as population density and night light on LST at the city or multi-city spatial scale over a region (Diamond and Hodge, 2007; Smith et al., 2009; Sailor, 2011; Peng et al., 2012; Zhou et al., 2012). Yet, a comprehensive study on the influence of anthropogenic factors on LST at fine scale is still lacking.

This study takes the inner city of Shanghai, the largest metropolis in China, as a case to comprehensively examine the relations of urban land use and land cover with urban heat islands. The specific objectives are to: (1) quantify LST distribution among different land use categories; (2) investigate whether there are discrepant relations of LST with land use and land cover; (3) analyze the driving forces of anthropogenic factors on LST. This study expects to gain a better understanding of urban LST by analyzing the interactions of the biophysical and socio-economic drivers in term of land use and land cover. Results from this study can support urban land developers and managers in taking concrete measures to regulate urban social-economic activities and landscape patterns to mitigate urban heat islands.

2. Material and methods

2.1. Study area

Shanghai is one of the largest and most important industrial centers of China. It is located in East China, between latitudes 30°82′30″ N and 31°82′70″ N, and longitudes 120°85′20″ E and 121°84′50″ E, surrounded by the Yangtze River estuary to the north, the East Sea to the east, and the Hangzhou Bay to the south. Shanghai belongs to a subtropical monsoon climate. The average total precipitation is 1067 mm per year, and average monthly temperature ranges from 2 to 27 °C. The total area of Shanghai is about 6340.5 km^2 and the total population of the city is about 23.0 million (Shanghai Municipal Statistics Bureau, 2011). Shanghai has experienced rapid urbanization since the implementation of the Reform and Open Policy in 1978. The urban area of Shanghai has increased from 149.85 km^2 in 1982 to 998.8 km^2 in 2010 (Shanghai Municipal Statistics Bureau, 1982, 2010).

The study was conducted at the urban core of Shanghai, which is the origin and heart of this mega city (Fig. 1). The inner city is located within the out-ring road of Shanghai, covering 670 km^2, with very intensive and concentrated urban human activities. The landscape pattern is highly heterogeneous and the impacts of various human activities incur many ecological and environmental problems, such as urban heat islands, water and air pollution (Li et al., 2009, 2012; Ball et al., 2009; Wang et al., 2013).

Table 1
Land cover and land use category of the study area.

Categories of urban landscape		Description
Land cover	Impervious land cover	Artificial lands such as roads, roofs and parking lots paved by impenetrable materials such as asphalt, concrete, bricks, etc.
	Vegetated land cover	Natural and artificial lands paved by penetrable vegetation such as arbor, shrub and grasses
	Bare soil	Bare soil or sand not covered by vegetation or impervious lands
	Water	Land covered by water body such as river, ponds and lakes
Land use	New residential	Lands used by families for private residences or dwellings, with the age less than 15~20 years old, high-rise apartment buildings and some open space
	Old residential	Lands used by families for private residences or dwellings, with the age older than 15~20 years, dense low-rise apartment buildings and less open space
	Villas	Lands used by single or multiple families for private residences or dwellings, with free-standing homes and greater open space
	Industrial	Lands for industrial purposes, usually with multi-builds for different industrial activities, such as workspace, factories or warehouses and associated infrastructure
	Institutional	Lands for schools, colleges, universities and research institutes, and associated infrastructure

2.2. Land cover and land use pattern

Land cover and land use have quite different meanings in urban ecosystems, as explained above. This study extracted the main land cover and land use types of the site by applying high resolution Advanced Land Observation Satellite images (ALOS imagery) and aerial photography. All the images were registered to a 1:10,000 scale topographic image.

We chose land use classification to represent different socio-economic activities. For land use mapping, the classification system was set up considering both the ecological effects of different urban socio-economic activities and the existing national standard for land use classification (GB/T 21010-2007). Thus, five dominant land use types were identified in the study area, including new residential, old residential, villas, industrial and institutional land use (Table 1, Fig. 2). The visual interpretation was applied to map urban land uses by integrating the aerial photography taken in June 2010 with a spatial resolution of 0.3 m and the cadastre resources (Fig. 3). The visual interpretation ensured that land use patches were properly classified and represented the land use category.

For land cover mapping, four major land cover types were identified to characterize the biophysical features of urban landscape, including impervious land, vegetated land, bare land and water body (Ridd, 1995). The ALOS imagery with a spatial resolution of 2.5 m was acquired on May 2010, and the object oriented classification method was applied to classify land covers. The overall accuracy of land cover classification was 85.3%. Specially, the user's accuracy for vegetation, impervious, bare land and water body were 80.47, 88.37, 74.29 and 78.57%, respectively. The producer's