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Cooling effects of wetlands in an urban region: The case of Beijing

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ABSTRACT

The cooling effects of wetlands, which form "urban cooling islands" (UCIs), are important for mitigating urban heat island effects. Ten reservoirs/lakes and five rivers in Beijing are selected to investigate UCI intensity using ASTER images. The UCI intensity is quantified by the temperature difference and gradient between the wetland and surrounding landscapes. The results indicate that: (1) the UCI intensity is correlated with the landscape shape index (LSI) of the wetlands, and the Spearman Rho is 0.679 between LSI and temperature difference, and 0.568 between LSI and temperature gradient; and (2) the UCI intensity is also determined by the wetland location in relation to the downtown, and the correlation coefficient is 0.691 between the location and temperature difference, and 0.706 between the location and temperature gradient. Our results suggest that wetland shape and location are significant indicators influencing the UCI intensity in an urban region, and are important to consider in quantifying the microclimate regulation services of wetlands as well as in designing urban landscape to mitigate UHI effects.

1. Introduction

Urbanization is a global issue, particularly for many developing countries, and about 60% of the world's population will live in cities by the year 2030 (Golden, 2004). Rapidly growing urban areas result in obvious increases in temperature in comparison to temperatures in adjacent rural regions, an effect which is known as the urban heat island (UHI) effect (Tiangco et al., 2008; Weng, 2009). As UHI effects lead to increased temperatures within cities, they contribute to worsened air quality and compromised human health (Xu, 2009; Pataki et al., 2011). In metropolitan areas, various landscape types and their spatial mosaic patterns create a complicated energy balance and microclimate system (Oke, 1982), and this landscape heterogeneity may lead to large intra-urban surface temperature differences (Buyantuyev and Wu, 2010).

Wetlands include reservoirs, lakes, and rivers, and form many "urban cooling islands" (UCIs) (Chang et al., 2007; Cao et al., 2010). The cooling effect of wetlands is regarded as an important ecosystem regulating service (Costanza et al., 1997). The environmental benefits of ecosystem regulating services have long been valued in economics (Wilson and Carpenter, 1999; Jaarsveld et al., 2005; Hein et al., 2006; Troy and Wilson, 2006; Li et al., 2010; Lautenbach et al., 2011). However, little information is available for individual wetlands because most UHI studies are implemented at the scale of an entire city. For example, we do not know how different the temperatures in wetlands are from those in the surrounding landscapes, or whether there are different spatial scales within which the cooling effects of wetlands are effectively provided. We need to know the temperature difference and influence scale of wetlands which are the determinants for the existence of UCI. Also, which factors impact the UCI intensity is still unknown. Answering these questions could help us adopt more appropriate indicators to quantify the microclimate regulation services of wetland ecosystems, and could provide us with practical measures for urban landscape design.

The UHI effect refers to the difference in air temperature above ground between urban and adjacent rural regions. Air temperature has proved to be highly correlated with the land surface temperature (LST) (Nichol and Wong, 2008; Weng, 2009). LST has often been used to assess the UHI effect because LST can be extracted easily from remote sensing data at a given moment and over broad areas (Weng, 2001; Nichol and Wong, 2008; Rajasekar and Weng, 2009; Buyantuyev and Wu, 2010). In this study, we also investigated the cooling effects of wetlands by using LST and land cover data derived from ASTER (advanced spaceborne thermal emission and reflection radiometer) images. The objectives are: (1) to devise a method to quantify the UCI intensity of wetlands, (2) to assess the impacts of wetland area, shape, and location on UCI intensity in Beijing, and (3) to discuss the implications for ecosystem services assessment and landscape design in urban regions.

2. Data and methods

2.1. Study area

Beijing city is situated in north China, has an area of 16,808 km^2, and ranges from 39°28′ N to 41°05′ N and from 115°25′ E to 117°30′ E (Fig. 1). Beijing is the capital of China and is densely populated. The

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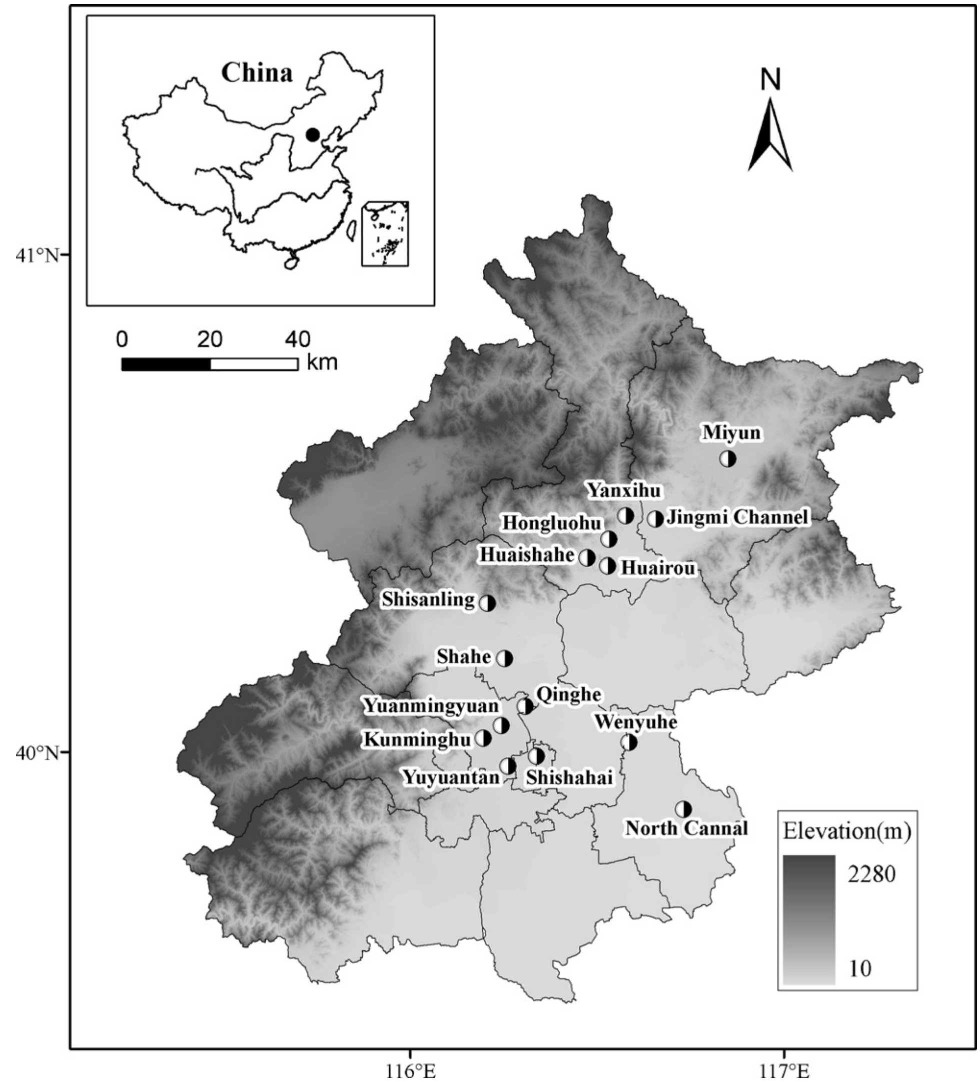

Fig. 1. Location of the 15 wetlands in Beijing.

total population exceeded 20 million and the number of automobiles reached 5 million by the end of 2010. Environmental problems are becoming increasingly serious with the expansion of built-up areas. Among these problems, the UHI effect is one of the most obvious (Liu et al., 2007; Xiao et al., 2008). Historically, about 15% of the total area of Beijing was wetland, declining to 7% in the 1960s, and covering only 3% of the total area recently (Zhao et al., 2006). It is highly important to better understand the cooling effect of wetlands for landscape design to mitigate the UHI effects.

2.2. Information on LST and land cover

This study used four ASTER images from 11:00 a.m. on August 8, 2007, covering a belt (approx. 180 km × 60 km) from downtown to the suburbs of Beijing. The ASTER images have 14 bands including visible and near-infrared bands (VNIR, 15-m spatial resolution), short wave infrared bands (SWIR, 30-m spatial resolution), and thermal infrared bands (TIR, 90-m spatial resolution) (Nichol et al., 2009). The ASTER LST products are calculated by the temperature emissivity separation algorithm (Gillespie et al., 1998), and have been atmospherically emissivity corrected by the Center for Earth Observation and Digital Earth, Chinese Academy of Sciences. To match the land cover map, the 90-m ASTER LST data were resampled with a 15-m resolution (Fig. 2a).

The ASTER VNIR data were used to identify land cover types (i.e., green land, built-up land, and wetlands). First, we obtained ground reference data for land cover classification using GPS-guided field surveys. At least 20 areas of interests (AOI) were selected for each class, with each AOI containing 50–200 pixels. Two thirds of the pixels were used to compare the spectral reflectance value for each type of land cover, and the rest were used for the classification accuracy assessment. Second, we classified green land, built-up land, and wetlands using the normalized difference vegetation index (NDVI) and spectral reflectance value. The NDVI was calculated from the near infrared and red bands of ASTER VNIR data (Jensen, 2005). The pixels were defined as green land when $NDVI > 0$ and $Band3 > Band1 > Band2$. In the non-green areas ($NDVI < 0$), pixels with $b1 < 70$ and $Band1 > Band3$ were classified as wetlands. Otherwise, the pixels were classified as built-up land (Fig. 2b).

Lastly, a standard procedure was applied for accuracy assessment of land cover classification in the ERDAS software (Jensen, 2005). The overall accuracy of the land cover classification was at 92.25%, and the overall Kappa coefficient was at 0.91. The final accuracy of land cover classification indicated that the image processing procedure developed has been effective. The total area of wetlands was 274 km^2, smaller than the areas of the green land (5825 km^2) and built-up land (2084 km^2). 5 rivers and 10 reservoirs/lakes in Beijing were extracted from the land cover map (Fig. 1). The area