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Urban expansion brought stress to food security in China: Evidence from decreased cropland net primary productivity

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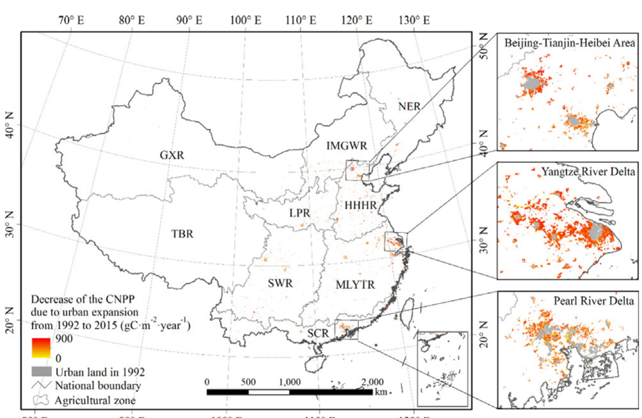
HIGHLIGHTS

- The CNPP decreased by 13.77 TgC due to urban expansion in China from 1992 to 2015.
- This CNPP loss caused a decline of 12.45 million tons of grain production.
- The mean annual grain self-sufficiency rate decreased by 2% due to urban expansion.

GRAPHICAL ABSTRACT



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ABSTRACT

Cropland net primary productivity (CNPP) is a crucial indicator of grain productivity and food security. However, assessments of the impact of urban expansion on the CNPP in China have been inadequate owing to data limitations. In this paper, our objective was to assess the impact of urban expansion on the CNPP in China from 1992 to 2015 in a spatially explicit manner. We first obtained the CNPP before urban expansion between 1992 and 2015 in China using the Carnegie-Ames-Stanford Approach (CASA) model. We then assessed the impact of urban expansion on the CNPP from 1992 to 2015 at multiple scales (the whole country, agricultural zones, and urban expansion hotspots) by combining the CNPP before urban expansion with the urban land coverage time series extracted from multi-source remotely sensed data. We found that the total loss of the CNPP due to urban expansion from 1992 to 2015 was 13.77 TgC, which accounts for 1.88% of the CNPP before urban expansion in China. This CNPP loss resulted in a 12.45-million-ton decrease in grain production in China, corresponding to a reduction in the mean annual grain self-sufficiency rate of 2%. Therefore, we concluded that rapid urban expansion from 1992 to 2015 caused stress to China's food security. We suggest that it is still vital for China to effectively protect cropland to improve the urbanization level to 60% by 2020.

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1. Introduction

Food security corresponds to the condition that "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 2016). China's food security is a significant concern to the world owing to the country's enormous population and limited cropland (Brown, 1995; IIASA, 1999; Wei et al., 2015). In 2013, the population in China reached 1.36 billion, which is equal to 19% of the global population. However, the cropland in China represents only 1.23 million km^2 (7.8% of the world's total cropland), and the cropland per capita in China is only approximately 0.1 ha (41% of the global average) (FAO, 2015; UN, 2015). Since China's reform and opening in 1978, the country has experienced rapid urban expansion, resulting in extensive cropland loss and posing a threat to food security (Liu et al., 2014). From 1990 to 2010, the built-up area in China increased from 34.3 to 60.3 thousand km^2 (growth of 75.5%); approximately 60% of the newly built-up area was converted from cropland (Kuang et al., 2016).

The cropland net primary productivity (CNPP) is the net carbon gained by plants through the process of photosynthesis and equals the difference between the gross primary production and plant respiration in the cropland (Chapin et al., 2011). The CNPP is often regarded as the crucial foundation of grain production and food security owing to its relative reflection of the cropland to produce the desired products (Barlowe, 1978; Imhoff et al., 2004; Yan et al., 2009). Urban expansion influences the CNPP by directly occupying cropland and indirectly altering its surrounding geophysical and geochemical processes, thereby stressing the sustainability of cropland productivity and food security in China (Chen, 2007; Cai et al., 2013; Seto and Ramankutty, 2016). Therefore, timely and accurate assessment of the impact of urban expansion on the CNPP is an important issue for food security in China.

Some researchers have assessed the impact of urban expansion on the CNPP in China at different spatiotemporal scales. For example, at the local scale, Xu et al. (2007) assessed the impact of urban expansion on the CNPP in Jiangyin County in China from 1991 to 2002. Yu et al. (2009) evaluated the impact of urban expansion on the CNPP in the city of Shenzhen in China from 1999 to 2005. Peng et al. (2016a) estimated the impact of urban expansion on the CNPP in Beijing in China from 2001 to 2009. At the regional scale, Jin et al. (2015) assessed the effect of urban expansion on the CNPP in the Huang-Huai-Hai River basin of China from 2000 to 2008. Lu et al. (2015) estimated the impact of urban expansion on the CNPP in the Shandong Peninsula of China from 2000 to 2010. Peng et al. (2016b) evaluated the impact of urban expansion on the CNPP in the Beijing-Tianjin-Hebei region of China. At the national level, Yan et al. (2009) and Tian and Qiao (2014) assessed the impact of urban expansion on the CNPP in the periods 1990–2000 and 1989–2000, respectively. Pei et al. (2013) assessed the impact of urban expansion on the CNPP prior to 2006. However, few studies have examined the impact of urban expansion on the CNPP in China after 2006, primarily owing to a lack of timely urban land information in China at the national scale (Liu et al., 2012; Xu et al., 2016).

Recently, nighttime light data with the spatial and temporal resolution required for large-scale urban detection have become available; these data provide timely national urban information in China (Elvidge et al., 1997; Zhang and Seto, 2011). For example, He et al. (2014) investigated the yearly urban expansion in China from 1992 to 2012 by integrating data about nighttime light levels, a vegetation index, and land surface temperature data. Xu et al. (2016) further detected urban expansion in China between 1992 and 2015 using the Suomi National Polar-orbiting Partnership's Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime light data. This advance provided reliable information to examine the impact of urban expansion on the CNPP in China over the past 20 years.

Against this background, our objective was to assess the impact of urban expansion on the CNPP in China from 1992 to 2015. To achieve this goal, we first simulated the CNPP in China before urban expansion between 1992 and 2015 using the Carnegie-Ames-Stanford Approach (CASA) model. We then assessed the impact of urban expansion on the CNPP in China from 1992 to 2015 at the national, regional, and local scales with the support of time-series urban land data from China that were produced by Xu et al. (2016). Finally, we investigated the relationships between CNPP loss, grain production, and food security during the course of urban expansion in China over the last two decades.

2. Materials and methods

2.1. Data sources

The urban land data in China from 1992 to 2015 were obtained from Xu et al. (2016) due to the launch of the rapid urban expansion in China since the 1990s (Wu et al., 2014). The urban land was extracted by integrating nighttime light data, normalized difference vegetation index (NDVI), and land surface temperature data. Such integration obviously limited the saturation effect and blooming effect of nighttime light data (He et al., 2014; Ma et al., 2014). The data have a spatial resolution of 1 km, an average kappa value of 0.60 and an average overall accuracy greater than 90% (Xu et al., 2016). These data accurately represent urban expansion in China over the past 20 years.

The National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) ten-day composite images of the NDVI from April 1992 to March 1993 were obtained from the United States Geological Survey's (USGS) website (http://edc2.usgs.gov/1KM/1kmhomepage.php, accessed August 1, 2016). These data are radiometrically calibrated, precisely georeferenced, and corrected for atmospheric effects before their release. Monthly NDVI composite images were generated by selecting the maximum NDVI value for each pixel from three periods in each month. This maximum value composition (MVC) method served to minimize the effects of cloud cover and the variability of atmospheric optical depth (Holben, 1986). The NDVI images collected for this study were further resampled to a spatial resolution of 1 km.

The land use/cover data for China in 1990 were obtained from the Data Sharing Infrastructure of the Earth System Science at the Chinese Academy of Science (http://www.geodata.cn, accessed August 1, 2016). These data were produced at a resolution of 1 km through visual interpretation of the Landsat Thematic Mapper (TM) images. The proportion of land use/cover for each pixel was extrapolated from the original 30 m pixels. These data fairly accurately represent the actual land-use/cover conditions in China in 1990, with an average overall accuracy of greater than 94.3% (Liu et al., 2014).

The meteorological data from 1992 to 2015 were obtained from the China Meteorological Data website (http://data.cma.cn, accessed August 1, 2016). The meteorological variables used in this study included monthly composites of the average temperature, precipitation, and solar radiation, which were measured by 756 meteorological stations distributed throughout China. After calculating the mean annual meteorological variables from 1992 to 2015, the point-based meteorological data were spatially interpolated to produce continuous raster images with a spatial resolution of 1 km (Pei et al., 2013; Ray et al., 2015).

Socioeconomic data in China from 1992 and 2013, including the total population, urban population, grain yield, sown area of grain crops, consumption of chemical fertilizer, irrigated area, and total power of agricultural machinery were obtained from the Statistical Database of Economic and Social Development by the National Knowledge Infrastructure of China (http://tongji.cnki.net, accessed August 1, 2016). Data about grain production, grain consumption, import of grain, and export of gain in China from 1992 to 2013 were obtained from the Food and Agriculture Organization of the United Nations (FAO)'s website (http://faostat3.fao.org, accessed August 1, 2016). The administrative boundaries for the provinces, cities, and counties were obtained