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RESEARCH ARTICLE

Spatio-temporal changes in rice area at the northern limits of the rice cropping system in China from 1984 to 2013

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Abstract

Rice area has been expanding rapidly during the past 30 years under the influence of global change in northeastern China, which is the northernmost region of rice cultivation in China. However, the spatio-temporal dynamic changes in rice area are still unclear, although they may have important policy implications for environmental protection and adaptation to climate change. In this study, we aimed to identify the dynamic changes of the rice area in Heilongjiang Province of northeastern China by extracting data from multiple Landsat images. The study used ground quadrats selected from Google Earth and the extraction of a confusion matrix to verify the accuracy of extraction. The overall accuracy of the extracted rice area was higher than 95% as a result of using the artificial neural network (ANN) classification method. The results showed that the rice area increased by approximately 2.4×10^6 ha during the past 30 years at an annual rate of 8.0×10^4 ha, and most of the increase occurred after 2000. The central latitude of the rice area shifted northwards from 46 to 47°N during the study period, and moved eastwards from 130 to 133°E. The rice expansion area accounted for 98% of the total change in rice area, and rice loss was notably rare. The rice expansion was primarily from dryland. In addition, rice cultivation in marshland and grassland played a minor role in the rice expansion in this region.

Keywords: paddy rice, Landsat images, artificial neural network, Heilongjiang Province

1. Introduction

Agricultural land use, as the key topic in the "Global Scientific Research Project on Land Use and Land Cover Change (LUCC)", has drawn extensive attention in related fields (Chen *et al.* 2001; Liu *et al.* 2005; Wu *et al.* 2015). The detection of crop area changes in regions can provide a scientific basis in monitoring crop production, prediction and evaluation of crop yield and related policies (Yu *et al.* 2011; Liu *et al.* 2015). Previous studies mainly focused on the spatio-temporal variations in cultivated land (Zhong *et al.* 2011) and the spatial conversion between cultivated land

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and other classes of land use, such as forest, grassland, and urban land (Hayes *et al.* 2002; Liu *et al.* 2006; Zhan *et al.* 2010). Rice is an important food crop globally and is most widely distributed in Asia. Approximately 50% of the world's population uses rice as its staple food (FAOSTAT 2012). Rice plays an important role in food production in China, accounting for 27% of the total area allotted for food crops nationally and 35% of the total food production (MOA, 2012; Yang *et al.* 2015). Therefore, it is very important to understand the spatial distribution of rice areas and their dynamic variation over time.

The global area of rice cultivation has changed substantially in the past several decades, and has varied over different regions (Shrestha *et al.* 2016). The most widely used data sources to investigate the spatial variation of crop areas are remote sensing image data, statistical data and spatial model outputs. National statistical data and model outputs had been applied in China (Liu *et al.* 2013; Li *et al.* 2015), but the models were simply a tool for reallocating statistical data inputs. Remote sensing image data have a much higher spatial resolution than statistical data. Both Gumma *et al.* (2011, 2015) and Sun *et al.* (2009) used moderate resolution imaging spectroradiometer (MODIS) data at a spatial resolution of less than 1 km to extract the spatial distribution of rice after 2000 in Nepal, India and China. The spatial resolution of Landsat TM/ETM+ data is greater than that of MODIS in successfully distinguishing cultivated rice fields and analyzing the spatial variations in multiple periods (Yoshikawa *et al.* 2006; Gao *et al.* 2008). Gao *et al.* (2011) used the Landsat TM/ETM+ data of 1980 and 2000 to survey rice cultivation changes by visual image interpretation in Heilongjiang Province. However, it was common for the visual interpretation method to generate errors and be time-consuming due to the lack of prior knowledge.

Heilongjiang Province is the northernmost province in China. It is the most important rice growth region in China and also one of the most sensitive areas for global warming. In this study, we processed the multiple higher-resolution Landsat image data from 1984–2013 to extract the spatio-temporal distribution features of the rice area in Heilongjiang Province and to conduct an empirical study on the spatio-temporal dynamics of rice areas.

2. Materials and methods

2.1. Study area

The northern region of Heilongjiang Province was designated as the study area, involving Landsat images of 16 scenes, located in areas between 45°06′N–52°36′N and 123°42′E–134°45′E (Fig. 1). The study area covered 50 counties (cities) in Heilongjiang Province, including the northern part of the Songnen Plain, the Lesser Khingan Mountains, and the northern part of the Sanjiang Plain, which account for 54.5% of the total area of Heilongjiang Province. The region is not only the single-crop rice area located at the highest latitude in China, but it is also the northernmost region of rice cultivation in the world (Kiple

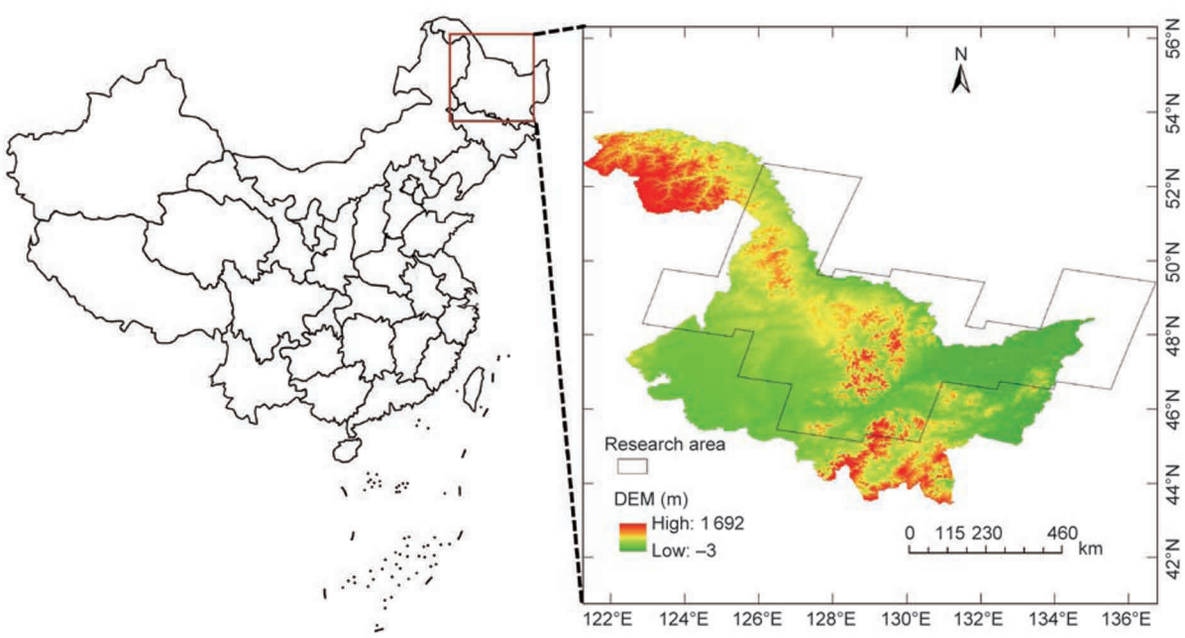

Fig. 1 Location of the study area in Heilongjiang Province, China. Paths and rows of the Landsat images used are marked in red and black respectively. DEM, digital elevation model.