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Research paper

The dynamic mechanism of landscape structure change of arable landscape system in China

Penghui Jiang[a,b], Qianwen Cheng[a,b], Zhuzhou Zhuang[a,b], Haoqing Tang[a,b], Manchun Li[a,b,c,*], Liang Cheng[a,b,c,**], Xiaolong Jin[a,b]

[a] *School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China*
[b] *Jiangsu Provincial Key Laboratory of Geographic Information Science and Technology, Nanjing University, Nanjing, 210093, China*
[c] *Collaborative Innovation Center for the South Sea Studies, Nanjing University, Nanjing 210093, China*

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ABSTRACT

The healthy functioning of arable landscape ecosystems depends on their functional structure and productivity. In view of current global climate change and constant population mobility, the global agricultural industry has to address the effects of such factors on the functional structure of arable lands. In our research on these issues, we combined information on land use/cover changes with several other datasets. These include meteorological data from 1 823 national and local meteorological stations, agrometeorological disasters from 430 national monitoring stations, and population surveys covering 9 856 townships. Our findings indicate that the arable landscape system in China shows an overall trend of fragmentation, with the extent of the core arable land decreasing by 10 336.06 km^2. This trend is affected minimally by climate differences and population changes in traditional agricultural regions. However, in eastern and western China, the trend is affected significantly by the rate of population aging, the population migration rate, and the agricultural labor scale. Urban land expansion plays a key role in changing the arable landscape system. Rapid urbanization in the form of an integral transition from arable land to construction, which is represented by large-scale increase in construction land area, is the core dynamic mechanism of landscape structure change of arable landscape systems in China.

1. Introduction

Arable lands are vital resources that play a significant role in the survival of the human species. In addition, such land resources form the basis for economic development and social stability, and constitute an important component of national security (Kastner et al., 2014). In recent years, the worldwide extent of arable land has shown a decreasing trend that is attributable to various factors, including social and economic development, the effects of natural disasters, warfare, and system reforms. Accordingly, the quality of arable lands has declined correspondingly (Foley et al., 2011; Renwick et al., 2013; Deng et al., 2015; Pribadi and Pauleit 2015; Song et al., 2015), and the agricultural production potential of various major food-exporting countries has been reduced (Zumkehr and Campbell, 2015). To compound matters, the continuous growth of the population is placing increasing pressure on global food supplies, exacerbating the food security problem (Godfray et al., 2010; Zumkehr and Campbell, 2015). Moreover, studies have indicated that the global demand for food will double by 2050, adding to the international concerns about food security (Green et al., 2005).

In this regard, China, in view of its vast population, is hard pressed to ensure national food security. In fact, food security is a critical condition for maintaining peace and stability nationally as well as internationally. The basis for ensuring food security in China and elsewhere is to protect the quality of arable lands and to pursue continuous improvement in the productivity of such land resources (Kong, 2014). Currently, the main threats to the sustainable use of arable lands in China include such lands being taken over for other uses because of urban sprawl and development, and changes to the natural environment arising from climate change (Piao et al., 2010; Song et al., 2015). The former problem has already been contained to a certain extent by the introduction of a series of policies to protect and preserve arable lands. However, the latter issue is likely to persist and, in the medium to long term, would probably have the most significant effect on arable lands in the country (Reidsma et al., 2010; Huang and Wang, 2014; Tendall and Gaillard, 2015; Narges et al., 2016)

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* Corresponding authors at: School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China.
** Corresponding author at: School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China.
E-mail addresses: jiangph1986@163.com (P. Jiang), chengqw1992@163.com (Q. Cheng), zhuangzhuzhou@163.com (Z. Zhuang), dz1627005@smail.nju.edu.cn (H. Tang), manchun@nju.edu.cn (M. Li), lcheng@nju.edu.cn (L. Cheng), 157512204@qq.com (X. Jin).

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The effects of climate change and socio-economic development on arable lands have become matters of global concern (Alexander et al., 2015; Narges et al., 2016). Research has enriched our understanding of the relationship between climate change and agricultural and economic development (Dall'erba and Domínguez, 2015; Mathilde et al., 2015) as well as our knowledge of the effects of climate change on agricultural production (Lobell et al., 2012; Cynthia et al., 2014; Delphine et al., 2016). The consensus is that climate change threatens both the steady rate of agricultural production and attempts to increase food supplies (Tao et al., 2009; Xiong et al., 2009; Piao et al., 2010; Zhang et al., 2011). However, several aspects require further study (Cynthia et al., 2014), such as the effects of system changes in arable landscapes and the driving factors of these changes, which, to date, have not been explained fully (Narges et al., 2016). Recent studies on such aspects employed data from diverse sources, and mostly focused on the effects of climate change on crop yields by employing statistical computations, model simulations, or the inversion of remote sensing data (Tao et al., 2009; Lobell et al., 2012; Mu et al., 2012; Cynthia et al., 2014). Nonetheless, other factors have been neglected, such as the effects that differences in climate characteristics and population mobility have on system changes in arable landscapes that inevitably lead to a decrease in the productivity of these arable lands.

Accordingly, this study attempted to fill these gaps from a new perspective, i.e., by proposing a classification model of arable landscape systems (ALS). The aim was to address the following questions: (i) What is the spatial change law and tendency of Chinese ALS? (ii) Regarding trends in the spatiotemporal evolution of ALS types in China and the response mechanism of ALS to climate differences, population changes, and urban expansion, can ALS changes be explained adequately by these factors? (iii) What is the dynamic mechanism of the core driving forces of changes in ALS.

2. Methods

2.1. Classification model for ALS types

According to the geographic law of attenuation with distance and the theory of edge effects in landscape ecology, the ecological functions of a particular geographic landscape unit are closely related to its spatial location. Regarding an ALS, the farther it is located from the core of that system the less stable it would be, and vice versa. Lands for cultivation located between arable and non-arable lands are extremely vulnerable to the effects of non-agricultural activities occurring at the peripheries. Consequently, such lands have distinct production or ecological functions from lands located at the core of the ALS. Similarly, if a tract of land for cultivation is located in isolation at the core of an arable landscape system and is spatially surrounded by non-agricultural landscapes, it does not have the conditions for stable agricultural production. This is because it lacks the appropriate agricultural background and environment.

Based on the aforementioned theories and the findings of related studies (Vogt et al., 2007; Riitters et al., 2009; Cheng et al., 2015a,b), the current study applied the mathematical morphology pattern recognition method to distinguish various ALS types. This application led to the definition of four types of arable land (Fig. S1):

(i) *Core arable lands*: These are spatially isolated from non-arable landscapes and are internally formed by homogeneous and contiguous arable lands. Such lands constitute the basic environment that helps maintain arable land ecosystems and stable production. The scale of core arable lands in a region directly determines the agricultural production ability and potential of such a region.

(ii) *Edge arable lands*: These lands coexist with core arable lands and are spatially distributed at the peripheries of the former. Such lands serve as the buffer or transition zone between arable and non-arable lands and are different from the complex core–edge environments that exist within core arable lands. Edge arable lands reflect the effects of external non-agricultural uses on arable land ecosystems. Increases in the number of such lands reflect the increasing magnitudes of the decrease of core arable lands.

(iii) *Perforated arable lands*: These lands are surrounded spatially by core arable lands, but are also adjacent to non-arable lands. The scale of this category of arable lands is indicative of the degree of erosion that is occurring within the core ALS. Increases in the scale of such lands accelerate the rate at which the structure of core ALS disintegrates.

(iv) *Patch arable lands*: In terms of distribution, these lands are isolated from core arable lands and surrounded by non-agricultural environments. The size of their internal habitat area is small and they do not contain any core–edge environments. They reflect the extent of fragmentation that the regional arable landscape is subject to and when such lands become the predominant arable landscape, it indicates that the overall arable landscape of a region has become fragmented.

Subsequently, we employed land use/cover data of China for the 1980s, 1995, 2000, 2005, and 2010 as the base data (resolution: 1 km; The data set is provided by Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn)). The aforementioned classification of arable lands and the relationship between four adjacent domains were used as reference for the spatial identification of ALS as well as to design the following classification method:

(i) *Classification of core arable lands*: If the central and peripheral pixels within the structure of four adjacent domains were all arable lands, the central pixel would be core arable land. The algorithm design is shown in Fig. S2.

(ii) *Classification of perforated arable lands*: Depending on the classification result of core arable lands, a hole-filling algorithm was performed to fill the internal voids of core arable lands. Subsequently, the arable land pixels similarly coexisting with core arable lands and spatially located in the ALS and adjacent to any non-arable lands were defined as perforated arable lands. In the spatial structure of adjacent domains, perforated arable lands are located in an intermediate position between non-arable and core arable lands. The algorithm design is shown in Fig. S3.

(iii) *Classification of edge arable lands*: Similar to the classification of perforated arable lands, edge arable lands were classified based on core arable lands. Through a morphological dilation on core arable lands and the exclusion of core and perforated arable and non-arable lands, edge arable lands were classified as peripheral arable land pixels of core arable lands. The algorithm design is shown in Fig. S4.

(iv) *Classification of patch arable lands*: These lands are surrounded by non-arable landscapes and are spatially isolated from the core arable lands. In the structure of the adjacent domains, patch arable lands have only an adjacency relationship with edge arable lands, non-arable lands, or other similar patch arable lands. Therefore, after the core, edge, and perforated arable lands were determined, all the remaining pixels for arable lands could be uniformly classified as patch arable lands. The algorithm design is shown in Fig. S5.

2.2. Process of change between ALS types

The Markov chain transition matrix was used to analyze the process of dynamic changes in the arable lands and their landscape structures in China. This matrix can show information on the dynamic processes of the mutual transitions between ALS types that occur between the beginning and end of a specific period (Hill et al., 2002; Solow and Smith, 2006). The theoretical concept can be expressed as follows: