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Spatio-temporal evolution of the early-warning status of cultivated land and its driving factors: A case study of Heilongjiang Province, China

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ABSTRACT

Scientific identification of the early-warning status in relation to cultivated land system security (CLSS) is essential for future food security and sustainable development. It is important to establish the early-warning status of cultivated land as it may signal forthcoming problems and even large-scale environmental catastrophes as an effective means to understand both the current status and future development trends of the CLSS. However, the systematic assessment of the early-warning of status of CLSS has not been previously been conducted at the municipal level, and an in-depth study and discussion of its fundamental driving factors is lacking. Thus, we introduce the biological immunity mechanism by way of analogy and demonstrate the feasibility of its application in the early-warning of CLSS. A novel conceptual early-warning index system is developed and this framework applied to 12 cities in Heilongjiang Province of northeast China using adopting fourteen possible indicators. The spatiotemporal evolution of the early-warning status had been explored over the period 1995–2014 using rescaled range (R/S) analysis. Furthermore, the fundamental factors of the early-warning were explored by establishing a rational panel data model. The results indicate that 1) CLSS early-warning status initially rose and then decreased over the last 20 years. 2) The severe level warning areas are mainly found in the southeast and west of the region, while the secure and relatively secure areas are mainly concentrated in the middle-north and southern areas. 3) The observed patterns indicate that, with the exception of Yichun and Suihua, the early-warning status of the province will develop in the future along the same lines as it did so historically. 4) The results of regression analysis indicate that rational panel data model construction should be verified so as not to produce pseudo-regression and that four main driving factors (natural population growth rate, agricultural waste load per unit area of cultivated land, natural disasters index, and industrial wastewater load per unit area of cultivated land) are significantly positively correlated with the early-warning status; one factor (forest cover) is negatively correlated. Policy-makers need to consider the key factors affecting the early-warning status of cultivated land and its spatiotemporal evolution in different regions to formulate appropriate measures in order to mitigate against future threats.

1. Introduction

Cultivated land is a fundamental resource and condition for human survival (Xie et al., 2014), which is especially important in developing countries, including China with 22% of the world's population, but only 7% of the world's cultivated land (FAO, 2011). With ongoing population growth and industrialization, urban expansion into cultivated land is taking place at an unprecedented scale in China, leading to a serious shortage of cultivated land per capita (Deng et al., 2006; Jiang et al., 2013; Kong, 2014). In order to ensure that cultivated land suffered no further decline, in 1997 the Chinese government initiated the policy of 'Dynamic Equilibrium of Total Cultivated Land' which directs that, within a given period and administrative unit, any area taken out of cultivation must be offset by setting at least an equivalent area into cultivation. As a result of this policy, some 39600.25 km^2 of cultivated land was gained by land exploitation, reclamation, consolidation and rehabilitation during 2000–2014 (Ministry of Land Resources of China, 1996–2015). This policy has played an important role and has been viewed as a crucial attempt by the Chinese government to maintain the quantity of cultivated land. However, despite achieving a balance in cultivated land quantity and holding the "red line" restriction after the implementation of the policy (Jiang et al., 2015; Lichtenberg and Ding,

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2008), a more serious crisis has emerged, because low quality cultivated land that has been newly added using a flawed method cannot, in terms of productivity potential, offset the cultivated land that has been lost as a result of cultivated land being converted for construction of urban and rural residential and public facilities, industrial and mining land, traffic and water conservancy facilities etc. (Cumming et al., 2014; Kong, 2014; Shi et al., 2013). Moreover, the excessive application of chemical fertilizers and pesticides used in modern agriculture exacerbates deterioration of the cultivated land environment and results in the decline of soil quality (German et al., 2017; Oliver and Gregory, 2015), which seriously impacts the integrity of cultivated land and threatens national food security. Environmental threats, including climate change, biodiversity loss and degradation of cultivated land and freshwater are intensified by modern agricultural practices (Foley et al., 2011; Power, 2010). Heilongjiang Province is the principle grain producing area in China. It is therefore important to study the status of cultivated land security here and to develop early-warning systems in order to take more effective measures to protect cultivated land.

Cultivated land security has received considerable attention in China because of the great challenges of population growth, shrinkage of available areas, degradation of soil fertility, water scarcity, climate change and resultant food insecurity (Khan et al., 2009; Shi et al., 2013; Song and Pijanowski, 2014; Wang et al., 2009). Research has focused on the close relationship between the loss of cultivated land and rapid urbanization because of the scale of conversion agricultural land due to the growth of cities and associated industrialization in countries in East Asia, North America and Europe (Deng et al., 2015; Li et al., 2015a; Liu et al., 2015; Song, 2014). Cultivated land conversion leads to soil degradation (Valera et al., 2016; Liu et al., 2017), decline in grain productivity (Song and Pijanowski, 2014), threatens food security (He et al., 2008; Oliver and Gregory, 2015) and impacts biodiversity (Yi et al., 2014).

A variety of models have been deployed to describe the dynamics of cultivated land quantity, soil quality (García-Díaz et al., 2016; Zhang et al., 2017), eco-environment (Banos-González et al., 2015; Li et al., 2010), and food security (Nie et al., 2010; Oliver and Gregory, 2015; Ye and Van Ranst, 2009) but there is little systematic research on the development of an early-warning system in relation to cultivated land security. Early-warning systems are, however, widely used in the context of natural disasters (e.g. floods, drought, earthquakes) and the economy (e.g. stock market etc.) (Naumann et al., 2014; Manzoor, 2017). In recent years, with increasing research on land use change, a focus on early-warning systems has emerged and provides a useful foundation for more scientific assessment of this concept in relation to the what is known as the cultivated land system security (CLSS). Research on the theory, index systems and methodology used to develop more reliable early-warning in relation to cultivated land security is still in its infancy (Li et al., 2010; Song and Lian, 2012; Liu et al., 2003). Cultivated land is a complex system and early warning needs to be assessed and implemented in a more comprehensive and systematic manner. Many studies to date have ignored issues such as the issue of hysteresis in the early warning response (Li et al., 2010; Scheffer et al., 2001; Wepener et al., 2005). In order to address these shortcomings, we define here the concept of a cultivated land system (CLS) from a systematic perspective, and establish an early-warning index system for the CLSS that employs an analogous biological immunity mechanism in order to describe and analyze the spatiotemporal variation of early-warning in CLSS in relation to a case study.

The spatiotemporal dynamics of cultivated land are complex (Long et al., 2009; Zhong et al., 2011) and are affected by both natural and socioeconomic factors (Chou et al., 2015; Liu et al., 2013; Song and Pijanowski, 2014; Chen et al., 2015). Urbanization, population and domestic product per capita are commonly selected as socioeconomic indicators of the impact on cultivated land quantity (Deng et al., 2015; Qing et al., 2015); climate indicators, such as temperature and precipitation, are also considered because of the important role of climate change in agriculture (Douglas, 2009; Jiang et al., 2013; Wang et al., 2009). However, researches on the fundamental driving factors of the early-warning of CLSS are scarce, and the assessment indicators of the early-warning of CLSS are generally regarded as its fundamental driving factors, which leads to being unable to develop scientific and reasonable measures for alleviating the early-warning of cultivated land system security. Therefore, the main aim of this paper is to identify and explore the fundamental driving factors impacting spatiotemporal evolution of an early-warning system for cultivated land security using a rational panel data model in relation to a case study from Heilongjiang Province, north-eastern China.

2. Theories of the early warning status in CLSS and biological immunity mechanism

2.1. Definition of CLS and CLSS

The CLS is defined as a composite system formed by the natural-ecological subsystem (from which cultivated land resources are derived) and the socio-economic subsystem (human activities) in a specific area. This is a self-organizing system because, when it is impacted by changes in the natural-ecological subsystem (i.e. hazard) and disturbance due to human activity (i.e pressure), it can remain stable through self-adjustment and self-renewal (i.e. immunity). Meanwhile, society attempts to reduce environmental risk through economic or environmental measures, land policy or decision making, or management interventions to adjust and restore the system (i.e. response). The conceptual model of the CLS is shown in Fig. 1. Based on this, we define CLSS as a particular area where the CLS can realize a sustained and sufficient supply of cultivated land resources, thereby ensuring human survival, economic and social development, and the health of the ecological environment by self-adjustment (immunity) and human society regulation (response), even when the CLS itself suffers as a result of its vulnerability to an external challenge (hazard) and disturbance caused by human activities (pressure).

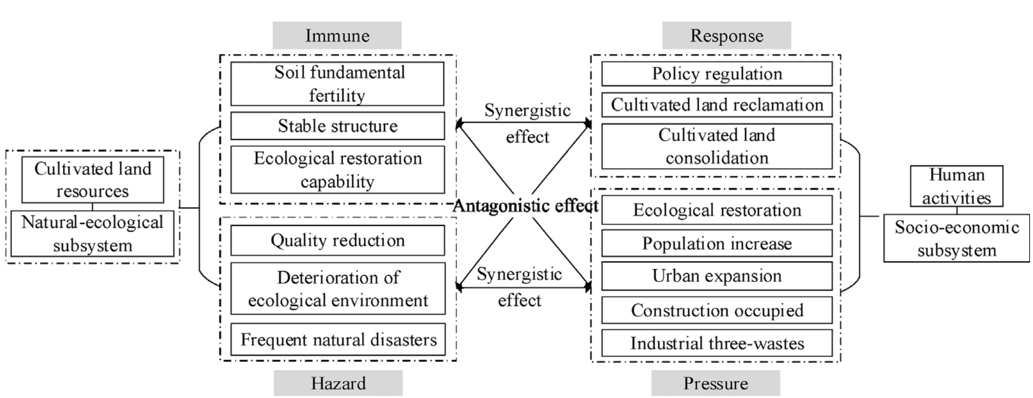

Fig. 1. Conceptual model of cultivated land system.