Ecological Indicators 89 (2018) 213–226

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Conjugated evolution of regional social-ecological system driven by land use and land cover change

Guangming Yu[a,b,*], Mengxing Li[b], Zhenfa Tu[a,b,*], Qiwu Yu[b], Yi Jie[a,b], Lili Xu[a,b], Yongfeng Dang[b], Xiaoxu Chen[b]

[a] Hubei Province Key Laboratory for Geographical Process Analysis and Simulation, Wuhan, Hubei Province 430079, PR China
[b] College of Urban and Environmental Sciences, Central China Normal University, Wuhan 430079, PR China

ARTICLE INFO

Keywords:
Social-ecological system
Conjugate evolution
The RSES composite index
Spatial-temporal correlation analysis
Dual-source driving

ABSTRACT

The integrated study on the evolution of the regional social-ecological system (RSES) is one of many complex and classical research topics. An innovative approach of conjugate analysis is introduced to describe the RSES evolution in this paper. We select land use intensity (L), bilateral dynamic change of land use types (S), landscape pattern index (P), ecological security index (Q), and the RSES composite index (T) to describe the RSES. We analyze and express the conjugacy of the RSES evolution: for the spatial correlations, they are revealed by variance analysis, spatial autocorrelation, and regionalized variable analysis; and for the temporal correlations, they are described by the analysis of spatiotemporal correlation. We use a case study of the Hanjiang River basin in Hubei province (China) to test the conjugate evolution of the RSES. We find that the RSES evolution in this region is driven by dual-source forces, both resource driven and economic power driven. These driving forces result in the spiral rise of the RSES evolution, where L, S, Q, P, and T have high self-autocorrelations, and there are remarkable and highly positive correlations and inheritance between the RSES and their subsystems. These results can corroborate the hypothesis about conjugate evolvement of the RSES. The spatial patterns of the RSES evolution are controlled by physical factors, especially geomorphology, where as its direction is guided by human activities, and its progress is pushed forward by human-environment interactions. The analysis of the RSES conjugate evolution can provide a new perspective for the RSES management, that is, the RSES management decisions should consider conjugate effects, because these effects can directly influence regional sustainable development.

1. Introduction

The regional social-ecological system (RSES) is the syntheses of all the elements of a natural environment and the presence of human society in a region. Traditional geography describes the RSES as a set of natural and human factors in a region, and this set is an infinite element set. Because of the complexity of the RSES, it is difficult to express this set by the method of exhaustion. As a classical scientific issue, the core themes of the RSES study are its structure, function, and evolution. In terms of the system theory, system functions are determined by its structure, and the characteristics of system evolution are determined by the change of its structure and functions. The RSES is a dynamically complex large system with complex structure and function, and it is difficult to find operable and highly-comprehensive research objects and methods to study its characteristic evolution. Structural and functional indicators of the RSES were often sensitive to different types of anthropogenic activities (Yates et al., 2014).

By studying the effects of human activities on the RSES evolution, many research projects of global change attempt to identify basic rules of earth system evolution, yet they need a long time to integrate their achievements. Land use and land cover change (LUCC) is one of the important driving forces of the RSES evolution, and the Global Land Project (GLP, 2005) pushes on the research of land use/cover change and its consequences. As for the active and direct effects, the GLP induces wide exploration and application with the LUCC agent-based models (Parker et al., 2002), the value of ecosystem services (Costanza et al., 1997), and the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998), etc. Many researchers adopt spatial and hierarchical models to describe the "coupled human – natural systems" in land use/land cover research (Rindfuss et al., 2008; López-Carr et al., 2012). But at system scale, we just see the first signs of the dawn appearing on the integrated RSES research. For example, a multi-disciplinary approach is

* Corresponding authors at: College of Urban and Environmental Sciences, Central China Normal University, Wuhan 430079, PR China.
E-mail addresses: yu-guangming@mail.ccnu.edu.cn (G. Yu), zhenfatu@mail.ccnu.edu.cn (Z. Tu).

https://doi.org/10.1016/j.ecolind.2018.01.065
Received 17 October 2016; Received in revised form 15 December 2017; Accepted 30 January 2018

adopted by many researchers (Strasser et al., 2013; Pissourios, 2013) and a conceptual template for integrative human-environment research is developed by analyzing nexus concepts (Newell et al., 2005). Thus, the RSES study is still an active research field.

Drivers, responses, and feedback mechanisms of the RSES evolution are very complex. LUCC plays a key role in the RSES evolution and has complex linkages to climate variability and change, as well as biophysical resources and socioeconomic driving forces (Drummond et al., 2012). LUCC is not only an intuitive expression, but also a visual result of the RSES evolution (Yu et al., 2010a). Human-environment interactions in agricultural land use are paid more attention to Weng (2000) because they alter the RSES structure and function, in addition to impact sustainable development of human society. All the attributes of global environmental change are related to the interactions between people and their environments (Liao et al., 2012). Researchers expect to seek out laws of human-environment interaction from the RSES evolutions in the past and use them as references to study future evolutions (Dearing et al., 2006; Bennett and McGinnis, 2008; Heckmann et al., 2014; Aranbarri et al., 2015), and explore the process and consequence of the RSES evolution in the future by simulating future scenarios of human activities (Lowe et al., 2014). There is an urgent need to quantitatively monitor the spatiotemporal pattern–process interactions of coupled human–environment systems (Sun et al., 2012). The truth is that there is no simple method for studying the behaviors of complex systems (Luo et al., 2011). Human and environment interaction has resulted in the co-evolution of environment and society (Bazelmans et al., 2012). The conjugate evolvement among human and natural elements also exists among human-environmental relationships in Anthropogene (Yu et al., 2008). So we developed the hypothesis about conjugate evolvement of a regional human-environment system and used the case study of the Hanjiang River Basin to test it in this study.

In this paper, we try to introduce new research ideas to reveal the complexity of the RSES evolution, that is, the conjugate analysis of the RSES evolution. Since it was first applied to expose upper atmospheric phenomena (Oguti, 1969), conjugate analysis has been widely used to study other various conjugate phenomena (Bonis and Ruocco, 2008; Selvamurugan et al., 2011) and the evolution process of complex systems (Yang and Zeng, 2010). As a result, many operational models of conjugate gradients have been developed (Feng 2006; Bandurski and Kwedlo, 2010). Most researchers define conjugate phenomena as phenomena which occur simultaneously and in a symmetric manner in a conjugate area. This paper defines conjugate evolution as a process that the RSES and its components evolve connectedly and synergistically at the basin scale. We attempt to express the RSES in interactions, structures, and status although it is also imperfect in selecting indices. We try to answer three questions: (1) How do you describe the RSES? (2) How can you analyze and expresses the conjugacy of the RSES evolution? (3) Is there the RSES conjugate evolution in the Hanjiang River basin?

2. Principles and methods

2.1. Basic hypothesis

The theoretical hypothesis in this study is as follows: A system is related to its sub-system, but the sub-systems are different from each other in details of spatial pattern and temporal process in the RSES. In this study, we reveal the conjugate evolution of the RSES with its subsystem by these differences. We believe that the RSES evolution is conjugate and this evolution is of the characteristics of spiral rise. Driving forces of system evolution are multiple and maybe come from the internal and external RSES. Change of system constituents will result in the change of the entire system, but the RSES is stable in the evolution processes because of its conjugacy.

This study reveals the characteristic of dual source driving in the RSES evolution in the study region, that is, the resource driving and economic power driving sources. The driving mode is land use/land cover change (L), the feedback mechanism is bilateral dynamic change of land use types (S), the explicit expression of the RSES is the change of landscape pattern (P), the system status can be characterized as the ecological security (Q), and the RSES can be described as a composite index (T). T is a function of L, P and Q. To actualize our idea, L and S are selected as the driving forces of the RSES evolution, P is selected to express the external features, Q is selected to describe the intrinsic characteristics, and the RSES composite index (T) to describe the RSES and its interactions, structures, and status. We attempt to analyze and express the conjugacy of the RSES evolution: for the spatial correlations, they are revealed by variance analysis, spatial autocorrelation, and regionalized variable analysis; for the temporal correlations, they are described by the analysis of spatiotemporal correlation. By the numerical analysis of selected indices, the RSES spatial patterns are similar and inheriting with its subsystems, but it is not a simple superposition.

The direct and further proof for conjugate evolution is the correlation analysis on spatial and temporal scales. The high correlating coefficients between the RSES and its subsystems strongly verify their spatiotemporal correlativity in their evolution processes, in other words, the conjugate evolution.

2.2. The RSES composite index and its constituents

The scale and intensity of human interactions with the Earth systems have accelerated to change the face of the Earth (Chin et al., 2013). The landscapes, plant and animal species, and ecosystems have already been shaped and altered by humans for millennia (Braje and Erlandson, 2013). Ways of human interaction with environment are multifarious and one of them is land use/land cover change. For example, land use from ancient times greatly influenced what we see on the landscape today (DeLuca et al., 2013). So we select the land use intensity (L) as the index for human-environmental interactions. Then, the bilateral dynamic change of land use types (S) is used to characterize the feedback mechanism of these interactions. They can be calculated as follows (Yu et al., 2010b):

$$L = 100 \times \sum_{i=1}^{n} A_i C_i \quad L \in [100,400] \tag{1}$$

where A_i is the grading index of ith land use degree in the study region, C_i is the percentage of grading area of ith land use degree, and n is the amount of grading land use degree.

$$S = \left\{ \sum_{i=1}^{n} [(\Delta S_{i1} + \Delta S_{i2})/S_i] \right\} \Big/ (t_2 - t_1) \times 100\% \tag{2}$$

where ΔS_{i1} is the area of land use types that is transferred from ith land use type to non-ith land use type, that is, the transferring area; ΔS_{i2} is the area of land use types, which is transferred from non-ith land use type to ith land use type, that is, the increasing area of ith land use type; and S is the changed velocity of ith land use type.

Mapping landscape pattern is a way to realize the visualization of the RSES, and landscape pattern index (P) can express the spatial structures and features of this system. So P is selected as a basic element to construct the RSES composite index (T). P is composited of landscape characteristic indices (area ratio, mean patch area and patch density index), landscape diversity indices (Shannon's diversity, dominance index and evenness index), and landscape fragmentation indices (fragmentation index and splitting index) with various weights (Yu et al., 2008). The calculations of these indices are shown in Appendix A.

Ecological security is a concept with several meanings and is defined as a comprehensive status of a human-ecological system (Yu et al., 2014). In this paper, we select the ecological security index (Q) to express the RSES status. We use eleven indices to calculate Q (See Appendix B). The eleven indices express three features: the landscape threat (the population density, ratio of land cultivating, cultivated area