Ecological Indicators 49 (2014) 237–246

Contents lists available at ScienceDirect

Ecological Indicators

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

Nonlinear features and complexity patterns of vegetation dynamics in the transition zone of North China

Zhiqiang Zhao[a,b], Jianguo Liu[b], Jian Peng[a], Shuangcheng Li[a], Yanglin Wang[a,*]

[a] Laboratory for Earth Surface Processes Ministry of Education, College of Urban and Environmental Sciences, Peking University, Beijing 100871, China
[b] Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, MI State University, East Lansing, MI 48823, USA

ARTICLE INFO

Article history:
Received 31 December 2013
Received in revised form 25 August 2014
Accepted 27 August 2014

Keywords:
NDVI series
Determinism
Recurrence quantification analysis
Transition zone
North China

ABSTRACT

Normalized Difference Vegetation Index (NDVI) has been commonly used to estimate terrestrial vegetation distribution and productivity. In this study, we adopted recurrence quantification analysis (RQA) to investigate the spatial patterns of determinism of the vegetation dynamics ecological-geographical transition zones in North China, especially the differences between transition zone and the surrounding areas. The results indicated that there were obvious regional variances in spatial patterns of RQA indices—determinism, laminarity, entropy, and averaged diagonal line length. Remarkable differences of the determinism of NDVI time series also existed between transition zones and the surrounding areas. Moreover, the correlation analysis between the RQA indices and climatic factors suggested that the determinism of the NDVI time series was nonlinearly affected by hydrothermal conditions. Influenced by vegetation patterns, determinism reached the maximum when the annual precipitation is about 400 mm, which is the lower bound of cultivation and forest distribution, and along the 400 mm isohyet is the area where transition zones locate.

1. Introduction

Normalized Difference Vegetation Index (NDVI) has been commonly used as an estimator of terrestrial vegetation distribution and productivity (Kerr and Ostrovsky, 2003; Xiao and Moody, 2004; Evans et al., 2006; Davies et al., 2007). Since global climate change became a major topic of study, vegetation dynamics and the relationships between NDVI and climatic factors have become hot spots in academic research (Xiao and Moody, 2004; Piao et al., 2006; Xu et al., 2007; Guo et al., 2008; Luo et al., 2009; Udelhoven et al., 2009; Li et al., 2011). Several global and regional studies have used NDVI dataset to investigate the vegetation spatial-temporal characteristics (Moody and Johnson, 2001; Piao et al., 2003; Wu et al., 2009; Zhang et al., 2009) and how they relate to climatic factors (Fang et al., 2001; Piao et al., 2006; Onema and Taigbenu, 2009).

According to the Köppen climate classification (Kottek et al., 2006; Peel et al., 2007), ecological–geographical transition zones generally have semi-arid climates and exhibit some features of transition in ecological characteristics. Transition zones, known as fragile areas and sensitive to climate change, are widely distributed around the world. Located at the northern edge of the East Asian monsoon influences, transition zones of North China are one of the important areas of global change research. Many researchers focused on the change pattern, process, and landscape ecological significance, and concentrated on the relationships between NDVI and climatic factors in this area (Liu et al., 2000, 2010; Li et al., 2006a; Guo et al., 2007; Cui et al., 2009; Liu and Cui, 2009; Wang et al., 2009; Wu et al., 2009; Zhang et al., 2011; Sun and Guo, 2012).

One of the key aims of studying the temporal and spatial features of regional climate and vegetation was to estimate future performance of climate change and vegetation dynamics, because forecasting is the premise of plans and decision making. To infer the future state of climate change and vegetation dynamics we need to study the dynamic features of historical processes. However, scientists have generally recognized that the process of climate systems and ecosystems is complex and nonlinear (Turchin and Taylor, 1992; Pascual and Ellner, 2000; Green et al., 2005; Pickett et al., 2005; Li et al., 2006b, 2008b, 2011; Zhao et al., 2011). Meanwhile, many studies have discovered that NDVI–environment relationships have some complex features such as nonlinearity, scale-dependency, and non-stationarity, especially in highly heterogeneous areas (Foody, 2004; Osborne et al., 2007; Li et al., 2011; Gao et al., 2012; Zhao et al., 2014). Some measures of nonlinear dynamics have been developed to estimate the complexity of nonlinear dynamic systems, such as the correlation

* Corresponding author. Tel.: +86 10 62759374; fax: +86 10 62751174.
E-mail address: ylwang@urban.pku.edu.cn (Y. Wang).

http://dx.doi.org/10.1016/j.ecolind.2014.08.038
1470-160X/

dimension, Lyapunov exponents, Kolmogorov entropy, approximate entropy, sample entropy, and permutation entropy (Torres and Gamero, 2000; Li et al., 2006b). In 1987, the method of recurrence plots (RPs) was introduced as another approach to describe complex dynamics (Eckmann et al., 1987; Zbilut and Webber, 1992; Webber and Zbilut, 1994; Marwan et al., 2007, 2009). More recently, the quantitative measure for RPs, recurrence quantification analysis (RQA), was introduced to bivariate and multivariate analyses of complex systems and successfully applied in various fields, such as biology (Webber and Zbilut, 1994; Webber et al., 2011), economics (Fabretti and Ausloos, 2005), ecology (Proulx et al., 2008, 2009; Li et al., 2011), and earth science (Marwan et al., 2003; Li et al., 2008b; Zhao et al., 2011). This also provides us with a tool for identifying the nonlinear features of vegetation dynamics. However, few studies have focused on the nonlinear dynamics features of vegetation in these transition zones.

Transition zones are the regional boundaries where climatic conditions and vegetation distributions gradually shift from one distinctive type to another. Transition zones have a relatively high level of complexity in spatial patterns and greater species diversity. A number of theoretical and experimental studies have confirmed the stabilising effects of ecosystem biodiversity across different spatial scales (Proulx et al., 2010; Allan et al., 2011; De Mazancourt et al., 2013). Basing on the diversity–stability hypothesis, increasing landscape diversity could enhance ecosystem stability and reduce the temporal complexity of vegetation dynamics. We evaluated the determinism and temporal complexity of NDVI time-series inside and outside bio-climatic transition zones of North China to see whether the determinism of NDVI time-series was higher in transition zones. Additionally, we analyzed the correlation between the RQA indices and climatic factors to explore potential reasons for the complexity patterns of NDVI.

2. Materials and methodology

2.1. Study area

Our study area (35°–48°N, 102°–126°E) is located in North China. Its elevation ranges from 0 to 5007 m, with higher topography in the northwest and lower in the southeast. The climatic conditions are mainly dominated by the Pacific summer monsoon from the southeast and the winter monsoon from continental Inner Asia. Therefore, annual precipitation (AP) in this region decreases from the southeast to the northwest and ranges between less than 100 mm west of Inner Mongolia Plateau to >800 mm at the southeast coastal zone. The annual mean temperature (AMT) ranges from −10 °C to 15 °C. The vegetation patterns are associated with climatic conditions, chief among them moisture conditions. With decreasing AP from southeast to

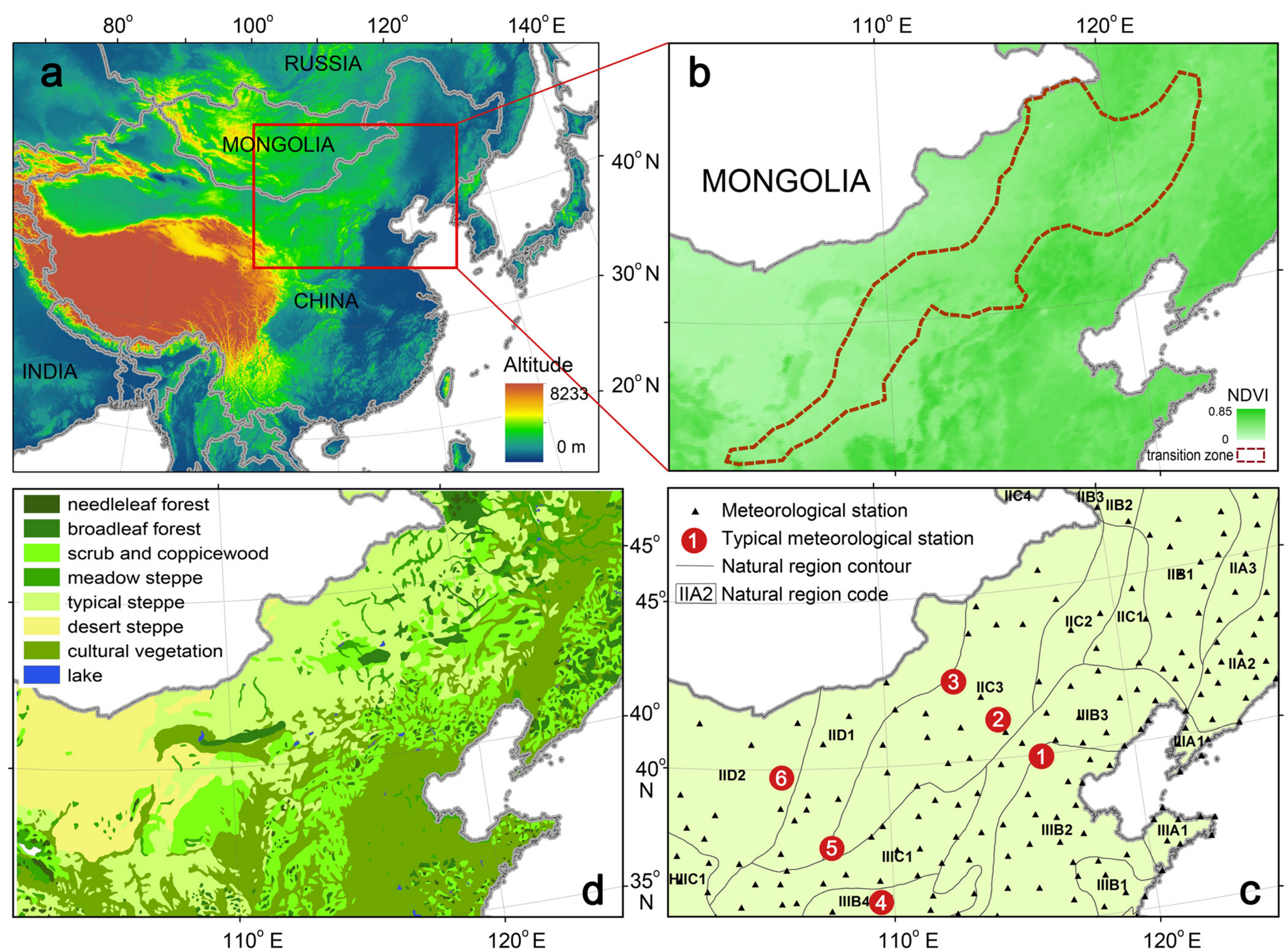

Fig. 1. Map of the study area. (a) Digital elevation map (DEM) of the study area (red rectangle) and surroundings; (b) NDVI map of the study area with the transition zone (red dashed line); (c) Meteorological stations and natural regions divisions of the study area; In nature region code, the Rome numbers represented division of temperature zone: II was sub temperate zone, III was Warm-temperate zone, and HII was Plateau temperate zone; the capital letter represented division of dry and wet areas: A was humid area, B was sub- humid area, C was sub-arid area, and D was arid area. (d) Study area showing vegetation patterns.