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Spatial variability of the adaptation of grassland vegetation to climatic change in Inner Mongolia of China

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A B S T R A C T

This study analyzes spatial variability of grassland vegetation growth in response to climate change in the central section of Inner Mongolian Autonomous Region of China. The study area consists of twelve types of plant communities and their spatial distributions reflect an east-to-west water-temperature gradient, transforming from moist meadow-type, to typical steppe-type and then to arid desert-type communities. The enhanced vegetation index (EVI), derived from MODIS at a 250 m resolution and 16-day intervals from May 8 to September 28 during 2000–2010, was adopted as a proxy for vegetation growth. The inter-annual and intra-annual changes of seven climate factors (barometric pressure, humidity, precipitation, sunlight hours, temperature, vapor pressure and wind speed) during the same period were synchronized with the EVI observations and over the twelve types of plant communities, creating a time-series panel dataset. Two panel regression models (the composite and the individual) were developed to explore causal relationships between climatic variables and vegetation growth across distinct plant communities and over time. Both panel regression models confirm that vegetation growth responses to regional climate changes are shaped by the unique characteristics of the study area, and that the interactions between vegetation growth and climate are dependent on a variety of spatially and temporally varying contextual factors.

Introduction

From a global perspective, the change of land cover and land use, the increase of carbon dioxide in the atmosphere, and the alteration of the nitrogen cycle are three well-documented contributors to climate change (Foley et al., 2005; Rindfuss, Walsh, Turner, Fox, & Mishra, 2004; Turner et al., 1990; Vitousek, 1994). From the point of view of ecosystems, phenological (seasonal) shifts, range (geographic distribution) shifts, and community shifts are important observed responses to global climate change (McCarty, 2001; NRC, 2008; Walther et al., 2002). However, there are many challenges facing the research community concerning the ecological consequences of global climate change. We cannot, for instance, eliminate uncertainties associated with predictions of climate change and its ecological impacts at regional and local scales (Marin, 2010). We cannot fully account for the interactions among individual species, communities, and ecosystems and between ecological responses and human adaptations in the event of global climate change (Hagerman, Dowlatabadi, Satterfield, & McDaniels, 2010). We have to examine multiple variables pertaining to both natural and human systems at multi-spatial and multi-temporal scales in order to explore the linkages between climatic changes and ecosystem impacts (Cutter & Finch, 2008; O'Brien et al., 2004; Root & Schneider, 1995; Schröter, Polsky, & Patt, 2005).

Geographers have a long history of investigating global climate change from human adaptation, ecosystem response and coupled human–nature interaction at multiple scales (Moser, 2010). Geographers have collaborated with researchers from multiple disciplines to address negative impacts of climate change and to promote positive approaches of mitigating these impacts. Geographical information science (GIS) and spatial analytical methods (SAM) have been adopted or integrated with mathematical modeling to quantitatively examine relationships between climate variations, hydrologic responses and land use changes

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(Tong, Sun, Ranatunga, He, & Yang, 2012). It is important to have an adequate understanding of rainfall variability and its long-term trend to help vulnerable dryland agriculturalists and policymakers address current climate variation and future climate change (Batisani & Yarnal, 2010). "The foregoing circumstances explain why Stanford ecologist Hal Mooney has suggested that we are living in 'the era of the geographer' —a time when the formal discipline of geography's long-standing concern with the changing spatial organization and material character of Earth's surface and with the reciprocal relationship between humans and the environment are becoming increasingly central to science and society (NRC, 2010, ix)".

This paper integrates remotely sensed data, vegetation maps, climate observations, geographical information approaches, and mathematical methods to examine three questions: (1) Whether there exist temporal causal relationships between vegetation productivity and different climate factors? (2) Do these relationships vary spatially across diverse vegetation communities? (3) Are these relationships reshaped by local or regional environmental contexts? In specifics, this paper derives enhanced vegetation index (EVI) from Moderate Resolution Imaging Spectroradiometer (MODIS) images as a proxy of vegetation growth. The paper applies one typical GIS analysis, spatial interpolation, to estimate the spatial patterns of inter-annual and intra-annual variability of seven climate factors (barometric pressure, humidity, precipitation, sunlight hours, temperature, vapor pressure and wind speed) over the study area. The paper also adopts the spatial database approach to integrate the EVI, interpolated climate data, and vegetation maps into a big spatiotemporal dataset. This integrated dataset supports the development of panel data analysis (PDA) based models to explore the relationships between climatic variables and vegetation growth (as observed using EVI as a proxy) across distinct plant communities and over time.

Methods

Study area and vegetation type

Steppe grassland in Inner Mongolia Autonomous Region (IMAR) of China is one of the largest remaining grasslands in the world, covering an area of up to 791,000 km^2. Our study area includes 39 Qi (counties) that fall completely within the area of MODIS EVI image (MOD13Q1: the horizontal tile index is 26 and the vertical tile index is 04, which refer to the MODIS Sinusoidal Grid Map) (Fig. 1). There are 12 major vegetation types found in this region (Chinese Ecosystem Research Network, 2009) (Table 1, Fig. 2). However, because five out of the twelve types represented a small portion of the study area (i.e., less than 0.98 percent; italicized in Table 1), they were omitted.

EVI data

With advances in remote sensing observation and analysis techniques, it is possible to study the spatial distribution and seasonal changes in vegetation from multi-temporal and multispectral remote sensing data. A number of remotely sensed data sets, including Advanced Very High Resolution Radiometer (AVHRR), Système Pour l'Observation de la Terre (SPOT), and Moderate Resolution Imaging Spectroradiometer (MODIS) are widely used to study vegetation on global and regional scales because of their broad extent of observation and short revisit cycle. Of these, MODIS has an advantage for studying grasslands due to its atmospheric correction and cloud screening algorithms (Zhang et al. 2003). Vegetation Indexes (VIs) derived from the satellite images are very useful to measure greenness of the vegetation, predict net primary production, and model vegetation carbon exchange (Gurung, Breidt, Dutin, & Ogle, 2009; Heinsch et al., 2006; Potter, Klooster, Huete, & Genovese, 2007). The two vegetation

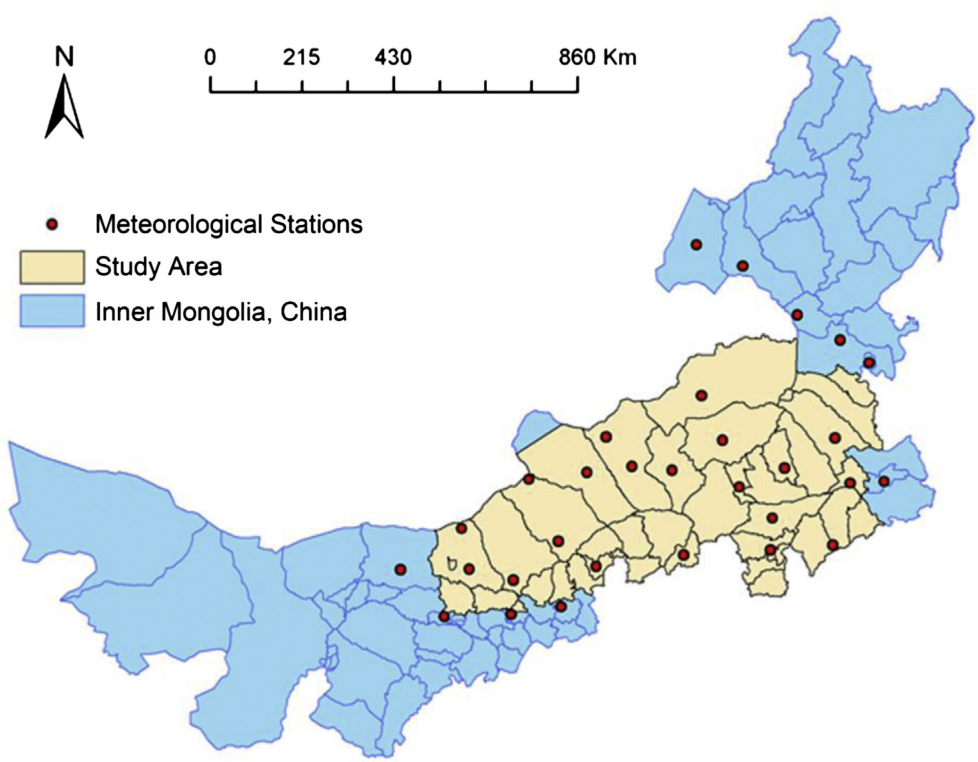

Fig. 1. Study area with meteorological stations.