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A multilevel analysis of effects of land use policy on land-cover change and local land use decisions

Jing Zhang [a,b], Jianming Niu [a,c,*], Alexander Buyantuev [d], Jianguo Wu [c,e]

[a] College of Life Sciences, Inner Mongolia University, Hohhot 010021, China
[b] College of Environment and Resources, Dalian Nationalities University, Dalian 116600, China
[c] Sino-US Center for Conservation, Energy, and Sustainability Science, Inner Mongolia University, Hohhot 010021, China
[d] Department of Geography and Planning, University at Albany, State University of New York, Albany, NY 12222, USA
[e] School of Life Sciences and Global Institute of Sustainability, Arizona State University, Tempe, AZ 85287-4501, USA

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ABSTRACT

Drylands, which occupy more than 40% of the Earth's land surface, are highly susceptible to degradation. It is important to understand causes, mechanisms, and environmental consequences of dryland ecosystem degradation. Land use policies are known to play a critical role in driving land cover changes, as well as in mitigating land degradation and promoting sustainable development in drylands. We analyzed the effects of different policies on vegetation cover and the attitude of local people toward policy changes in Uxin county, Inner Mongolia, China, based on remote sensed Normalized Difference Vegetation Index (NDVI) time series and household surveys. Overall vegetation in the study area was found to recover during 1987–2007. Multilevel statistical modeling results demonstrated that NDVI, density of agricultural population, density of livestock, land use, accessibility to market, and mean annual precipitation all had significant effects on re-vegetation. Changes in land use policy, which restricted farmers and herdsmen in certain land use practices and eliminated rangeland overload, were found to be an important driver of vegetation recovery during 1997–2007. Local households in the area generally approve the policy but adjust it according to their cultural traditions or land use practices.

1. Introduction

Land degradation is one of the world's most serious environmental problems (Fernández, 2002; UNCED, 1992). It is often triggered by human activities and, combined with climate change, it reduces overall biological productivity (Reynolds and Stafford Smith, 2002; UNCCD, 1994). Drylands occupy more than 40% of the Earth's land surface and are home to more than 38% of the global human population (GLP, 2005; MEA, 2005). Dryland ecosystems sustain important ecological and environmental functions (Omuto et al., 2010) and provide food, fuel wood, and pasture for communities' livelihood (Reynolds et al., 2007). Land degradation, which is often referred to as desertification in drylands (Dregne, 2002; UNCED, 1992), has occurred in about 10–20% of drylands with over 250 million people in developing countries being directly affected by this process (UNCCD, 1994).

Adequate knowledge is required to understand and monitor mechanisms of land degradation, eliminate its negative effects on environment and human society, and develop sustainable land management strategies (Pickup, 1996; UNCCD, 1994). Such knowledge on patterns of land degradation dynamics and their drivers can be effectively obtained by a combination of time series analysis of remotely sensed data and regression statistical analysis (Fabricante et al., 2009; Millington et al., 2007). One major shortcoming of previous studies that analyzed drivers of land degradation using regression models was the focus on a single scale (Verburg et al., 2003). However, land use dynamics rarely take place at a single scale (Mather, 2006), but often occur over a wide range of temporal and spatial scales (Lambin et al., 2003). Processes at these different scales are interdependent and driving factors should be analyzed via hierarchical relationships (Sun et al., 2006). To deal with such tasks multilevel statistical models were developed in 1980s and first applied in the social sciences, psychology, and education (Singer, 1998). By organizing data in a nested hierarchical

* Corresponding author. College of Life Sciences, Inner Mongolia University, Hohhot 010021, China. Tel.: +86 471 4992735; fax: +86 471 4992435.
E-mail address: jmniu2005@163.com (J. Niu).

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structures and building multilevel statistical models one can simultaneously handle driving variables at different scales. Recently multilevel statistical modeling has been introduced in ecology and land change science (Chelgren et al., 2011).

Desertification is the product of the interplay between human actions and climatic factors (Adamo and Crews-Meyer, 2006; Kellner, 2009). Human activities at local scales tend to accumulate and have significant effects on land cover patterns and processes at regional scales. The cross-scale effects have been a focus of some recent studies. Pan and Bilsborrow (2005) and Wyman and Stein (2010) analyzed the relationship between household decision-making and land degradation and found direct links with household socio-economic status, natural resources, and other geographical factors. Climate changes and local land cover dynamics influencing household land use strategies were the focus of Zhen et al. (2009) study. Gray et al. (2008) investigated links between land use decision-making and ethnic and cultural characteristics of households. However, only a few studies included policy factors which affect land use decisions and management at the local household level. Policies often play critical roles in land use and land cover dynamics. For example, they target unsustainable land use and shape land use decisions of local stakeholders, e.g., farmers, pastoralists (Lambin and Geist, 2003; Reid et al., 2006). Understanding the response of local land owners to changes in policies is also an important problem in studying land degradation at multiple scales.

In our study, we focused on desertification processes in Uxin Banner (administrative unit equivalent to a county, hereafter referred to as Uxin) of the Inner Mongolia Autonomous Region of China. The area was subject to the Household Production Responsibility System (HPRS) introduced after the launch of economic reforms in China in 1980s. Put in effect in Uxin after 1985 the HPRS contracted both livestock and pastureland, previously owned by communes, to households. This had a profound effect on land use and the environment. As a result, most households became involved in pastoral production for the market (Jiang, 2004). The drought of 1998–2000 caused significant vegetation losses and loss of income among herdsmen, which eventually triggered vegetation recovery in this region and the shift from extensive to a more intensive husbandry in Ordos. Since 2000 a new policy prohibited grazing during April–June in pastoral areas and all year around in agricultural areas and set limits to livestock numbers per hectare (Xin et al., 2008). It became common to feed livestock in pens and keep them at high densities. Our research goals were two-fold. First, we used Landsat TM data and multilevel statistical models to analyze spatiotemporal patterns of desertification in Uxin and identify major land use policy and environmental factors that drive these patterns. Spatial patterns were analyzed as a 3-level nested hierarchy of local, landscape, and regional levels. Accordingly, 3-level statistical models were constructed to investigate these multi-scale drivers of land cover dynamics. We hypothesized that: 1) Land use policies should most strongly influence land use of households at the regional scale; 2) Precipitation is the important driver of land degradation at local to landscape scales; 3) Vegetation dynamics, which are affected by practices of individual land managers who are influenced by policy incentives, is an indicator of land degradation at the local scale. Our second goal was to understand the response of local land managers to changes in policies. Specifically, the questionnaire was designed to assess the response to the grazing prohibition policy and its effects on land use decisions. We asked land managers about their choices of land use, for example, whether they pursue the grazing prohibition system, adopt rotation grazing system, or practice cultivation in response to changes in policies. The framework of our study is shown in Fig. 1.

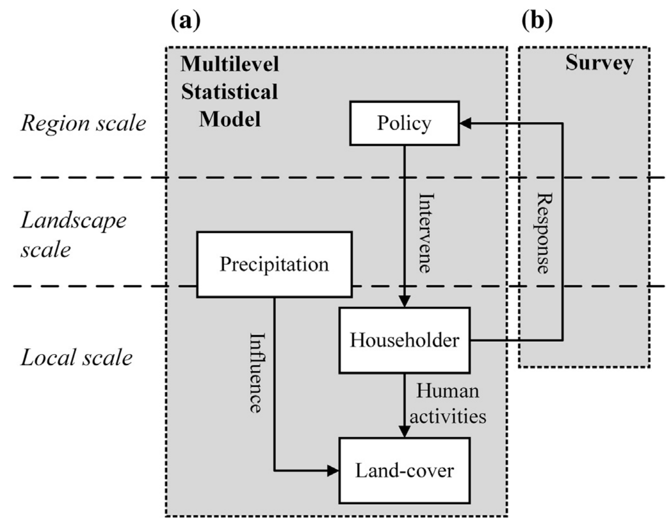

Fig. 1. The framework of the study. (a) A multilevel analysis of the impact of land use policy on land-cover change (an indicator of land degradation) is shown in the left dotted line box. Land use policy influence decision-making of household at the regional scale. Precipitation is the important driver of land-cover change at regional to landscape scales. Land-cover dynamics at the local scale are affected by land use of household influenced by policy incentives. (b) A questionnaire survey was used to study decision-making of household response to policy change.

2. Method

2.1. Study area

Uxin is located in southwestern Inner Mongolia, China (Fig. 2), covering an area of 11,645 km^2 and spanning from 37°39′N to 39°24′N in latitude and from 108°16′E to 109°40′E in longitude. Its population size was about 103,000 in 2010 with 30% consisting of Mongolian nationality. The area has a typical temperate continental climate with mean annual temperature of 6.8 °C. Annual precipitation changes from 350 mm in the southeast to 400 mm in the northwest and occurs mainly between June and September. Common soil types in Uxin are aeolian sandy soils and kastanozems. Fixed and moving sand dunes cover a major portion of its landscape. Dominant vegetation is composed of lowland grasses (e.g., *Achnatherum splendens* and *Carex duriuscula*) and shrubs (e.g., *Caragana intermedia* and *Artemisia ordosica*). Traditional land uses in Uxin have been farming and livestock husbandry, a typical combination in the agro-pastoral transitional zone of northern China (Fig. 2).

2.2. Multi-scale data

The multilevel statistical model includes dependent variables at level 1 and independent variables at the three levels. In addition we included two group (auxiliary) layers, which were used to sample lower level variables with group effects (Table 1).

2.2.1. Remote sensing data preprocessing

Three cloud-free Landsat-5 TM images were used for land cover change analysis. These images have the spatial resolution of 30 m and were acquired during growing seasons of 1987, 1997, and 2007. The three images were georeferenced using ENVI 4.7 software and 1:50,000 topographic maps as a reference. Geometric correction with the nearest neighbor resampling resulted in the root mean square error (RMSE) of less than 2 pixels. All images were