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Interaction of ecological and social factors affects vegetation recovery in China

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ABSTRACT

Global environmental problems have significant natural and socioeconomic consequences. However, the consequences are often evaluated independently by ecologists and social scientists. In an effort to integrate the consequences of the two types of problem during ecological restoration and thereby improve future development of environmental policy, we used regression analysis and remote sensing to calculate the relative contributions of human activities, climate change, and socioeconomic development to land use and cover change during China's huge investments in ecological restoration since the 1980s. We performed this analysis both for China as a whole, and for eight regions with distinctive ecological and social characteristics. We found that China's fast socioeconomic development and decreasing rural population were dominant factors in ecological restoration, whereas direct human intervention was a paradoxical factor that did not always lead to recovery. However, the changes in vegetation cover and the dominant causal factors differed among the regions of China as a result of differences in local conditions. Because of the complexity of ecosystem restoration, a region-specific strategy based on integrating ecological and socioeconomic factors should be developed. In particular, we urge caution when considering single, monolithic approaches (such as the afforestation that is currently the main approach) because these approaches ignore the local limits imposed by ecological factors such as climate and soils and human factors such as socioeconomic characteristics; such approaches can be dangerous if they neglect key social or natural factors.

1. Introduction

Land degradation is a global environmental problem with important political and socioeconomic ramifications (D'Odorico et al., 2013). These ramifications result from complex combinations of several factors, including natural factors such as ecological and climatic variations, and anthropogenic factors such as human activities (Sivakumar, 2007; Steltzer et al., 2009) and restoration policies that lead to changes in vegetation cover (Cao et al., 2011). As a result of this complexity, we often cannot tell whether a given policy instrument has succeeded or failed, or the reason why (Carpenter et al., 2009). Given these complexities, finding solutions that are both equitable and ecologically effective is even more challenging (Ostrom et al., 1999). Although models and a conceptual framework for social–ecological systems exist, few are explicitly designed to guide long-term interdisciplinary research (Collins et al., 2011). Typically, a call to action is accompanied by one or more illustrative case studies that provide a general rationale for why such research is needed, yet such papers rarely define a specific road map that can lead to the implementation of a quantifiable research hypothesis for studying social–ecological systems and developing management recommendations that account for both aspects of these systems. For example, it is widely accepted that environmental degradation and poverty are linked and that conservation and poverty-reduction should be tackled together. However, success with integrated strategies has been elusive (Cao et al., 2009).

In an effort to halt soil erosion, desertification, and sandstorms, which are critically important problems in many regions of China, the Chinese government has launched a series of land conservation programs and developed a series of policies to address the problem

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from both socioeconomic and ecological perspectives (Yang, 2004). Among them, the Six Key Forestry Programs (since 1978, the Three Norths Shelter Forest System Project and the Wildlife Conservation and Nature Reserves Development Program; since 2000, the Natural Forest Conservation Program, Sand Control Program, Grain for Green Project, and Forest Industrial Base Development Program) were unprecedented in world history in terms of their geographic extent, the government budget, and the magnitude of the mobilization of social factors by these programs (Dai, 2010). China has invested nearly RMB 700 billion (US$120 billion) in these programs, covering more than 97% of China's counties (State Forestry Administration, 1952–2013). In addition, 15% of the country is now included within some 2700 nature reserves (Cyranoski, 2008). Although these programs have had significant ecological and socioeconomic consequences, the consequences have generally been evaluated independently by ecologists and social scientists (Liu et al., 2008). Cross-disciplinary research to tackle the complexities of managing China's hybrid socioeconomic and ecological systems to achieve multiple goals has been rare (Cao et al., 2009), and the lack of such research poses severe challenges for effective policy development. For example, from 1952 to 2011, 32.3% of China's territory (nearly 3.1×10^6 km^2) was afforested to provide wood for the forest industry, for ecological conservation, and for water conservation, among other goals (State Forestry Administration, 1952–2013). However, this massive "greening" effort has been less effective than expected in some geographic regions (Cao et al., 2011). In addition, these studies have not integrated a sufficient number of dimensions of sustainability, and they have not adequately integrated the socioeconomic and ecological effects of the policies (i.e., that farmers and herders who can no longer farm or raise livestock must find other ways to earn a living) (Schwilch et al., 2009; Cao et al., 2010). Therefore, we lack a firm methodological basis for multidisciplinary research and a strong body of statistical data generated by multidisciplinary research that researchers can build on (Cyranoski, 2009).

Since the dynamics of land use and land cover change are central to the study of how ecosystems respond to natural and anthropogenic environmental change, any ecological restoration strategy must be assessed by understanding these dynamics at a range of scales, from local to national, and from both human and ecological perspectives (Xu et al., 2010; Zhou et al., 2012). Analyzing the trends in land use and cover change at multiple scales and from both perspectives can help to reveal the linkages between the ecological and social changes promoted by these policies, and the relationships between the driving forces and the resulting changes. However, there have been few detailed and systematic assessments of policy success from this perspective despite China's huge investments in ecological restoration, the long-term effects of these programs, and the huge area covered by the programs (Cao et al., 2009). Therefore, it is necessary to begin studying the dynamics of land use change and land degradation in China from a more integrated, holistic perspective to support the development of appropriate policies that can promote more sustainable land use and that can counteract the negative ecological and social impacts of undesirable land use changes (Zhang et al., 2007).

2. Research framework and hypotheses

Changes in vegetation cover result from multiple and possibly confounded driving factors. Unsustainable human activities such as over-grazing, over-reclamation of land for agriculture, and over-cutting of natural vegetation are primary causes of desertification and rehabilitation, though they have undoubtedly been exacerbated by trends resulting from long-term changes in China's climate (Zhang et al., 2007; Wang et al., 2008). However, there is little understanding of which factors will best predict the ecosystem impacts and the associated vegetation cover change. If we know the strengths of the contributions of the different driving forces and how their dynamics affect vegetation cover, ecological restoration policy can be made more effective.

To understand how these factors have affected vegetation cover, we analyzed specific driving factors that our literature review suggested would be primary factors responsible for vegetation cover change (Li et al., 2006; Cao et al., 2009, 2011; Zhang et al., 2007; Wang et al., 2008, 2010, 2013; Dai, 2010): the rural population, grain yield, rural net income, livestock population, area of farmland, area of forest in which agriculture and grazing were forbidden, reforestation area, mean annual temperature, total annual precipitation, and infrastructure (roads, railways, and mining). We hypothesized that these factors would differ in their effects on vegetation cover, that certain key factors would explain most of the overall effect, that the key factors and magnitude of their effects would differ among the regions of a country as large as China, and that identifying these differences would provide empirical evidence to support improved policy development. We divided the driving forces into five groups of factors: social (the rural population), economic (grain yield, rural net income, livestock population, area of farmland), policy (area of forest in which agriculture and grazing were forbidden, reforestation area), infrastructure (roads, railways, and mining), and climate (mean annual temperature, total annual precipitation). To improve the precision of our analysis, we eliminated one of each pair of parameters that were strongly correlated from the regression analysis that we used to identify the key factors in each group (see Section 3 for details). We selected four models (see Section 3) that are frequently used in econometrics to reflect the impacts of China's restoration policies and of the different social and environmental drivers.

In the present study, we selected the maximum normalized-difference vegetation index (NDVI) during the growing season as an indicator of vegetation cover conditions in China, since this parameter represents a good proxy for vegetation cover that can unify the impacts of climate change and human activities on the success of ecological restoration. We then used this information to quantify the relative roles that these factors have played in ecological restoration. Based on the results of this analysis, we discuss key socioeconomic and ecological issues for China as a whole and for each of eight regions of China, and the lessons learned from China's ecological strategy. The results will provide important information to guide sustainable development in China and in other nations that are facing similar problems. Because government data is primarily consolidated at a provincial level, it is difficult to obtain reliable data for smaller areas. Therefore, even though high-resolution geographic and climatic data is available, we have not used geographically weighted regression techniques in our analysis because most of the data for the other driving factors is not available at a sub-provincial scale for each province. However, to detect potential differences among the regions, we defined eight regions (each composed of several provinces) that had similar climate and socioeconomic characteristics, and used this division instead of geographically weighted regression analysis to compare the eight regions.

3. Methods

To understand how the driving factors have affected land use and cover change (thus, the success of China's ecological restoration efforts), we analyzed the processes responsible for the changes of vegetation cover since 1983 in China. To do so, we used NDVI as a proxy for vegetation cover, and compared changes in NDVI with changes in the underlying forces that are driving land use and cover