CHINESE GEOGRAPHICAL SCIENCE
Volume 16, Number 2, pp. 176–182, 2006
Science Press, Beijing, China

AN INSIGHT ON DRIVERS OF LAND USE CHANGE AT REGIONAL SCALE

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ABSTRACT: The studies of driving forces of regional land use change (LUC) are to reveal the real motivation behind the LUC and its interacting mechanism, so as to simulate and predict the process of LUC. Presently, studies rooting from different natural and socio-economic backgrounds and from different scales have deepened the people's understanding and cognition to driving forces of regional LUC. Biophysical driving forces are relatively stable, and have the cumulating effects. Human driving forces are relatively active, and are main driving forces of short-term regional LUC. Existing regional LUC models can answer the three main problems: which contribution (why), which location (where) and what rate (when). But, regional land use system is defined as the self-organized system, usually affected by the critical value area and sudden change, and controlled by different stages. To reduce the impact of critical threshold and break on land use system, the studies of LUC driving forces will aim at following priority areas: data linkage between remote sensing and no-remote sensing data; underlying driving force identification; driving factor quantification; driving factor scale dependence; and driving process integration simulation.

KEY WORDS: land use change; driving forces; driving mechanism; process simulation; regional scale

CLC number: F301.24 Document code: A Article ID: 1002-0063(2006)02-0176-07

1 INTRODUCTION

Land use change (LUC) involves both changes to a different function and shifts in intensity within a function. Today, researches on LUC are aiming at regional scale, and the studies of the typical regional LUC driving forces at meso- and small-scale become a key issue (VAN DIGGELEN *et al.*, 2005; CHAPLOT *et al.*, 2005). The studies of regional LUC driving forces are to reveal the real motivation behind the LUC and its interacting mechanism, so as to simulate and predict the process of LUC. However, like other problems of resources and environment fields, the most challenge of the studies on regional LUC driving forces is complex themselves. The changes in terrestrial ecosystem not only affect the original parts of the natural resources (SULLIVAN *et al.*, 2004; ZHENG *et al.*, 2005; EVANS *et al.*, 2005), but also associate closely with socio-economic sustainability problems (DUBROEUCQ and LIVENAIS, 2004; SOINI, 2005). Although some of the most important achievements on regional LUC driving forces have been achieved: human activities have been presently main driving factors of LUC, yet biophysical factors have determined the orientations of LUC at macro-environmental background (SHAO *et al.*, 2005b). And inappropriate land use practices may result in some environmental problems (MATTISON and NORRIS, 2005; ALMEIDA *et al.*, 2005). We yet know so little about these important topics and there is an even poorer understanding of the complex factors and processes that control regional LUC. The drivers of regional LUC and their prior ranks are difficultly identified. The complex interactions among socio-economic and environmental driving factors of LUC, at different spatio-temporal scales, also are difficultly understood. The present study aims to extensively assess the current studies on regional LUC driving forces, and presents some prior prospects in this study in the future. The results will be helpful to supply groundwork and knowledge for having a sound diagnostic and prognostic capability in building a strong foundation for policy-making.

Received date: 2005-12-14
Foundation item: Under the auspices of the National Natural Science Foundation of China (No. 49771073) and Key Project of Chinese Academy of Sciences (No. KZ952-J1-203)

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2 DRIVING FACTOR IDENTIFICATION

2.1 Data Acquisition

LUC happens in any spatio-temporal scale. To collect exact and valid data is the foundation of the studies of regional LUC driving forces. Recently, the data acquisition of regional LUC, including time series of remote sensing data (KING *et al.*, 2005; LIU *et al.*, 2005) and non-remote sensing data (JESSEL and JACOBS, 2005; SOINI, 2005), has made more progress. A series of remote sensing data, obtained by satellite monitor with different spatio-temporal resolutions, has been the main information source of the studies of driving forces of regional LUC. But, at present, the resolution of satellite image attained some meter level at most (e.g., multi-spectral panchromatic image data) (TSO and OLSEN, 2005), and is far from satisfying the need of practical level. Actual practical and operative data scales from higher resolution satellite image are range from 1:500 (urban land register) to 1:10 000 (land survey). Therefore, the higher resolution satellite image for data acquisition is prior to the research field in the future. Non-remote sensing data has been mainly collected through historic data statistics and field survey (CHAPLOT *et al.*, 2005; SHAO *et al.*, 2005c). But, statistical data are lack of consistency and reliability, as these data often derive from different sectors, while they are treated by different methods (VAN DIGGELEN *et al.*, 2005). To enhance their validity and reliability, sampling investigation and statistical analysis must be applied to correcting historic data. The data of field survey and household interview are collected mainly through the in-depth interview with local governmental sectors, non-governmental organizations, and farmers. These data have the characteristics with better reliability, participation, agility, etc. (REID *et al.*, 2000). The quantification, standardization, and integration with remote sensing data are very important to non-remote sensing data. Time series of remote sensing data being directly linked to non-remote sensing data, can open new avenues to better link macro-economic transformations to regional LUC.

2.2 Factor Identification

All activities for human demand are tied to land, acting within the biophysical and human framework (SEMWAL *et al.*, 2004; SHAO *et al.*, 2005b). Generally, human's demand intensity predominates their land use behaviors and decision-making (NARUMALANI *et al.*, 2004; TANG *et al.*, 2005), while human's behaviors and decision-making affect inversely regional land use patterns through opening new and/or close old options (ANTROP, 2005). Literatures showed that the driving factors affecting regional land use behaviors and decision-making, involve climate, relief, policy, value view, technology, population, urbanization expansion, regional economic development, family income, etc. (GEIST and LAMBIN, 2002; RASUL *et al.*, 2004; FNAG *et al.*, 2005). These factors are grouped in two kinds: biophysical factors and human factors. Biophysical factors are endogenetic driving forces of regional LUC. They are relatively stable, and exert the cumulative effect on regional environment (KRAAIJ and MILTON, 2006). Human factors are ectogenic driving forces of regional LUC. They are relatively active, and presently are main driving factors figuring regional land use patterns (VERBIST *et al.*, 2005). A few case studies show that regional LUC driving forces present stronger scale dependence. It appears that variations in explanatory variables of regional LUC with scale follow a consistent pattern: in spatial level, at farm scale, mostly social and accessible variables do influence land use (REIJ *et al.*, 2005; SHAO *et al.*, 2005a), at landscape scale, topography and agro-climatic potential are the key determinants (ROY *et al.*, 2005), while at regional or national scale, climatic variables as well as macro-economic and demographic factors seem to drive land use (LANT *et al.*, 2005). In temporal level, at short-term scale, human activities control the orientation of regional LUC (MEYER-AURICH, 2005). At long-term scale, biophysical factors and regional cumulative magnification effects induced by human activities at short-term scale determine regional land resources patterns (TITTONELL *et al.*, 2005). The effects of the same driving factors on regional land use patterns are significantly different at different spatio-temporal scales, including positive or negative impacts. Urbanization expansion has made negative impacts on small-scale regional land use as well as positive impact on big-scale regional socio-economic consequences, as this process is at the expense of local cultivated land, forest land, water, etc., and promotes big regional socio-economic development as well (SYPHARD *et al.*, 2005; TANG *et al.*, 2005). The effects of driving factors usually become truly global via local, regional in scale (KEYS and MCCONNELL, 2005). The drivers' scale dependence will become a primary research interest in the future.

3 DRIVING MECHANISM ANALYSIS

3.1 Biophysical Factor Driving

Biophysical factors determine the original patterns of regional land use. Initial efforts aiming at modeling regional LUC have focused primarily on biophysical attributes (e.g. altitude, slope or soil type), and given the good availability of such data (HUBACEK and SUN, 2001; GEIST and LAMBIN, 2002). As we know, the diversity of the biophysical spatial patterns results in heterogeneous natural geographical units (OSINSKI, 2003; ACKERMAN *et al.*, 2004) thus there being different land use patterns. Historically, the distribution of virgin forest, agricultural land, desert, glacier, rivers and lakes, etc., was generally driven by biophysical factors (ZHANG *et al.*, 2004; WHITE and GREER, 2006), while the allocations of subgroups of every land use types were also close relation to regional biophysical factors (SCHLERF *et al.*, 2005). Biophysical factors control the macro-tendency and -process of regional LUC. However, human activities at small spatio-temporal scale can change the orientation and speed of biophysical factor evolvement. Human-induced global warming delays the interval between glacial and interglacial period (CORTESE *et al.*, 2004), elevates sea level 0.02–0.06m in 1910–1990 (LI *et al.*, 2006), and expand main grain belts of the world towards high latitude (LIU *et al.*, 2005). In northern China, the decline of grassland area results from accumulative temperature increase induced by human activities, thus the area suitable for agricultural crop growth moving northward (LIU *et al.*, 2003). The cascade and accumulation effects of the changes in orientation and speed of regional land use transformations can produce contrary functions to regional biophysical factors. That is, frequent human disturbance strengthens the function of biophysical factors to regional land use patterns. The responses of crop yield to climatic change are pronouncedly significant. In 6–13°N, if the temperature increases 1–2℃ in the fruit-bearing stage of rice, the yield of rice decreases by 10%–20%, while this effect of temperature on rice is stronger following the latitudinal increase (LUO *et al.*, 1998).

3.2 Human Factor Driving

Human (institutional, technological, economic) factors are such forces that help to keep land use stable (KLINE and ALIG, 2005), and can adjust the coefficient of land demand in each economic department in future (LA ROVERE *et al.*, 2005). At regional scale, LUC, to some extent, is the result of evolution of traditional human factors driven by external human factors (PARDO and GIL, 2005; HIETEL *et al.*, 2005). However, the evolution of human factors is generally forced by strong signal. The occurrence of the Kyoto protocol and 21st century agenda are driven by global warming, deforestation, desertification, etc., resulting from human inappropriate land use practices (PATENAUDE *et al.*, 2005). Biological technology (SERAGELDIN, 1999), severe acute respiratory syndrome (SARS) and avian influenza (AI) control technology and the management technology of crops and injurant (LOBELL and ASNER, 2003), are developed for ensuring global food security and maintaining human welfare. The development of new material technology associates with the demand of reducing building land (SHAO *et al.*, 2005b). Chinese land-use practices, e.g., reclamation of waste land in the 1950s (YUE *et al.*, 2001), land household responsibility in the late 1970s (TONG *et al.*, 2003), and returning cultivated land to forestland and grassland in the 1990s (LIU *et al.*, 2005), resulted from the signal of food security due to population growth and urbanization expansion, and ecological security because of frequently heavy flood and drought. Economic behavior shapes present land use patterns by strong signal of supply and demand (GEROWITT *et al.*, 2003; TITTONELL *et al.*, 2005). Land resources are certainly prior to be used for these land use patterns with higher market price or investment return rate, because of the producers themselves mainly governing land use decision (MEYER-AURICH, 2005). But, human factors themselves play blur roles. At present, many of environmental problems are related to the evolution of human factors. Policies act validly in a limited period, and over this time, their action inertia can produce certain passive effects (TONG *et al.*, 2003). Moreover, some of policies for short-term economic objectives may be mistake decision-makings (ELLIS and WAND, 1997). Agricultural technology (chemical fertilizer, pesticide, weed killer, etc.) brings some environmental issues, e.g., soil and water pollution, greenhouse gas increase, land desertification, etc., as well as enhances crop yield per unit area and reduces the input of production element (SHAO *et al.*, 2005b). Urbanization expansion, deforestation, desertification, increasing input, etc., also result from economic benefit driving (GEIST and LAMBIN, 2002). The environmental problems caused by human factors will act on present and future land use.

4 DRIVING PROCESS SIMULATION

The process simulation of regional LUC has been of great interest in recent years (LOIBL and TOETZER, 2003; FANG *et al.*, 2005). Myriad different modeling techniques are now available. They can answer the three main problems, i.e., which biophysical and human variables contribute most to an explanation of land use changes (why?); which locations are affected by land use changes (where?); and at what rates do land use changes progress (when?). The multivariate statistical modeling (e.g. multiple linear regression, etc.) can understand the proximate causes of regional LUC (answering why in the past) (PAN and BILSBORROW, 2005; PURTAUF *et al.*, 2005). The spatial statistical (GIS-based) models (e. g. multiple logistic regression model, etc.) can project what places LUC will take place at short-term (answering where in the future) (MUNROE *et al.*, 2005). The transition probability models (e. g., Markov Chain, Markov-CA, etc.), when knowing where and when regional LUC happens in the past, can project the trend of regional LUC by using the transition probability matrix among states (answering when in the future (short-term) (ARAI and AKIYAMA, 2004; NEEFF *et al.*, 2005).

However, when possessing known variables, e.g., where, when and why land use changed in the past, the following models can be used to the relative researches. Generalised von Thünen models (Thuenen-Richardo model, etc.) can be used to know the underlying causes driving regional LUC in the future (answering why in the future) (HUBACEK and VAZQUEZ, 2002). Optimization models (e.g. multi-objectives linear programming, land use models in IIASA, etc.) can explain the primary drivers of regional LUC in the future (answering why in the future (underlying causes, scenarios)) (VOLD, 2005; HÖRMANN *et al.*, 2005). Behavioral models and dynamic simulation models (e.g. multi-agent models, spatially explicit landscape model, material and energy flow accounting model, etc.) can model when regional LUC will occur in the future (answering when in the future (long-term)) (BARTHEL *et al.*, 2005; SHI and GILL, 2005). Dynamic spatial simulation models (e.g. land use evolution and impact assessment modeling, etc.) can identify the main driving forces of regional LUC in the future (answering why in the future (underlying causes)) (JEPSEN *et al.*, 2005; FANG *et al.*, 2005).

Virtually, all resources allocation takes place on land. The land represents an aggregate of many different attributes. LUC is driven by the interaction in space and time between biophysical and human dimensions. Any model prediction can only be based on what is currently known about the processes of change (LAMBIN *et al.*, 2000). To understand when and where in the future (long-term), why in the future (underlying causes, scenarios) regional LUC will happen, when knowing where, when and why regional land use changed in the past, a new promising future development upon LUC models is the incorporation of dynamic feedbacks between changing land use and changing environmental conditions and vice versa. Such approaches, involving policy makers and stakeholders, can be used as decision-support systems.

5 DISCUSSION

Regional land use system is defined as the self-organized system, consisting of biophysical and human factors. The interactions and feedbacks among different factors within the system are very complex and changeable at different spatio-temporal scales (uncertainty) (ALMEIDA *et al.*, 2005). Presently, some researches, deriving from different natural and socio-economic background and the different scales, deepen the people's understanding to regional LUC driving forces. Biophysical driving forces are relatively stable, and have the cumulating effects. Human driving forces are relatively active, and are short-term driving forces of regional LUC. LUC modeling has become increasingly common, and can answer the three main problems: which contribution (why), which location (where) and what rate (when). But, land use system that is usually affected by the critical value area and sudden change, and is controlled by different stages (SCHLERF *et al.*, 2005; KLINE and ALIG, 2005). However, these stages cannot be understood through simple cause-effect relationships. Some pronounced effects of driving factors on land use system are complicated, and the interactions among these effects present multi-way changes at different spatio-temporal scales (PARDO and GIL, 2005). It is difficult to understand and project the intensity and speed of regional LUC, because sudden change happens frequently. To confirm the fit quantifiable index for embodying the effects of external driving factors, the studies in the future need to be related with a special region determined by the self-organization of land use system and the complexity of its internal driving function. To comprehensively identify the driving factors of land use system under the control of the domino effect of different states and multiple spatial-temporal scales, and to establish the dynamic models of comprehensive simulation to regional LUC, will reduce the impact of critical threshold and break on land use system.

It has to take some explanation as follows before this paper draw any conclusions. Firstly, this paper reviews only qualitatively the function mechanism of regional LUC driving forces, but does not compare quantitative research results on these aspects in recent years. Regional LUC driving forces involve biophysical and human factors. Nowadays, only parts of biophysical factors are easily quantified, other drivers' quantification, e.g., parts of biophysical factors and most of human factors, are not resolved yet (ANTROP, 2005; MEYER-AURICH, 2005). At the same time, the scale dependence of drivers can usually occur, that is, for a driver, its function intensity to regional LUC presents significant difference at different scale (UUEMAA *et al.*, 2005), and lies in cumulative effect (BUCK *et al.*, 2004). The quantification and scale dependence of driving factors are prior researches of regional LUC. Hence, before these problems are resolved, few researches involve the quantification of regional LUC driving forces. Moreover, though several researches quantify the driving factors, they only give regional cases (NEEFF *et al.*, 2005), and are short of representation. Different regional cases, at some extent, are lack of the comparability. Secondly, this paper also can not list the conclusive formulas of regional LUC process simulation models. As we know, most of regional LUC models comprise of various formulas (SHAO *et al.*, 2005b), especially optimization models, behavioral models, dynamic simulation models and dynamic spatial simulation models. Even though multi-variate statistical modeling (e.g. multiple linear regression, etc.) and transition probability models (e.g. Markov chains, Markov-CA, etc.) also include some sub-models. Nonexclusively, some of regional LUC models can possess conclusive formula (FANG *et al.*, 2005), but these conclusive formula are restricted by a set of constraint factors. Provided that conclusive formula disengages its constraint factors, there is no value that lies in conclusive formula. Hence, this paper only lists simulation methods, cannot present the conclusive formula of every model.

6 CONCLUSIONS

In the future, the studies on LUC driving forces will aim at following priority areas:

(1) Data linkage. Comparing with the remote sensing data, the non-remote sensing data have weaker spatial entity. Researches often pay more attention to the quantitative attribute, and less to the link with the specific region. Thus it results in the more difficulty in linking the remote sensing data with non-remote sensing data on the spatio-temporal frequency.

(2) Underlying driving force identification. Driving force identification should be considered with system perspectives. The interactions among different driving forces and the feedback of land use system to driving forces should be specially emphasized.

(3) Driving factor quantification. The quantitative researches on human factors are lagging, compared to that of the biophysical factors, thus blocking the synthesis quantification simulation of LUC. This becomes one of vital factors to restrict the study of LUC driving force.

(4) Driving factor scale dependence. Spatio-temporal scale determines the perspectives and methods of researches on regional LUC driving forces. But, the present researches on LUC driving forces at different scales can only explain the LUC of homologous areas, and are not able to get more understanding of the regional LUC dynamics.

(5) Driving process integration simulation. Model should be used to analyze the land use system at different spatio-temporal scale. However, present regional scale models mostly cannot display the complexity of structure and function in land use system. They usually limit themselves within single process or single discipline.

ACKNOWLEDGMENT

The authors thank Miss XU Chi-ying for comments on earlier versions of this paper.

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