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Introduction to the special issue

From pattern to process: landscape fragmentation and the analysis of land use/land cover change

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Abstract

The incorporation of landscape ecological and fragmentation analyses within remote sensing science has expanded the inferential capabilities of such research. This issue presents a series of papers on the use of landscape ecological techniques to explore the relationship between land cover and land use spatial pattern and process in an international, comparative context. Methodologically, researchers seek to link spatial pattern to land use process by integrating geographic information systems (GIS), socio-economic, and remote sensing techniques with landscape ecological approaches. This issue brings together papers at the forefront of this research effort, and illustrates the diversity of methods necessary to evaluate the complex linkages between pattern and process in landscapes across the world. The analyses focus on major forces interacting at the earth's surface, such as the interface of agricultural and urban land, agriculture and forestry, and other pertinent topics dealing with environmental policy and management. Empirical analyses stem from many different ecological, social and institutional contexts within the Americas, Africa, and Asia.

Keywords: Remote sensing science; Geographic information systems; Landscape fragmentation; Land cover change; Land use

1. Introduction

The goal of this special issue was to frame a series of broad-based papers on the use of landscape ecological techniques combined with remote sensing science that all explored the relationship between land cover and land use spatial pattern and process in an international, comparative context. This issue grew out of a set of organized sessions at the 98th Annual Meeting of the Association of American Geographers Meeting, Los Angeles, CA, in March 2002. Methodologically, such research integrates geographic information systems (GIS), socio-economic, and remote sensing theory and methods to study landscape pattern, thus linking spatial pattern to land use process. The ideas of this issue were built, in part, on the special issue focusing on 'Predicting Land-Use Change' which appeared in this journal in June 2001 (Agriculture, Ecosystems, and Environment, vol. 85, pp. 1–292). The past issue focused on linking hypothesized driving forces through various modeling techniques in order to predict land

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use change, and discussed developments within this arena (Goeghegan et al., 2001; Walsh et al., 2001). The incorporation of landscape fragmentation as a methodology used to link pattern to process seemed to develop naturally from this first set of research papers. In this issue we chose to concentrate on the development and inclusion of landscape fragmentation in LUCC studies; in many instances this work also combined statistical and simulation modeling techniques explored in the prior issue. The studies in this issue focus on the interaction between agricultural and urban land, agriculture and forestry, and other pertinent topics dealing with environmental policy and management, with empirical examples from the Americas, Africa, and Asia.

Over the past decade, research on the human dimensions of global change has clearly demonstrated that social uncertainties dominate over biophysical uncertainties in their impact on future environmental scenarios (NRC, 1999). There is a strong need to better understand the dynamics of the feedback mechanisms that relate environmental pattern to social process. Anthropogenic changes in land use and land cover are being increasingly recognized as critical factors influencing global change. Though related, there is a clear distinction between land use and land cover. While land cover refers to the biophysical earth surface, land use is shaped by human, socio-economic and political influences on the land (Geist and Lambin, 2002). In essence, "land use links land cover to the human activities that transform the landscape" (NRC, 1999, p. 12). It is essential to integrate the patterns of land cover change with the processes of land use change, if we are to understand and hopefully mitigate human impacts on the environment.

Although there is an increased awareness of these linkages, and a rising interest in investigating them, a definitive understanding of the human processes impacting patterns of land use and land cover change remains to be achieved. This deficiency is not for lack of effort, but rather, it is because this task is far from easy, conceptually, as well as methodologically. Given the spatial and temporal dynamicity of the biophysical and socio-economic forces shaping land cover and land use, disentangling the complex web of interactions between pattern and process is conceptually challenging (Bian and Walsh, 2002). Methodologically, land cover data is most frequently derived from satellite images, which provide a single snapshot of land cover at one point in time. The unit of observation is a pixel, and does not correspond in any straightforward fashion to social, economic or political units of organization (Mertens et al., 2000).

How do we best use the ever expanding range of increasingly accessible satellite data for land use/land cover change research? GIS and spatial pattern analysis provide analytical methods to create a spatio-temporal analysis framework that facilitates this task. The field of landscape ecology is founded on the recognition of the strong linkage between spatial pattern and ecological process (Gustafson, 1998). Landscape ecological research has contributed to the understanding of the impact of landscape fragmentation on biophysical factors (e.g. biodiversity, wildlife habitat, extent and configuration of natural lands), but such research can also contribute greatly to our understanding of socio-economic activity (Forman, 1995; Wickham et al., 2000). Socio-economic consequences of landscape fragmentation may be of paramount importance in some areas (Entwisle et al., 1998). Increasing land use diversity can result in more conflicting edges and opportunities for externalities to positively or negatively affect neighbors (Geoghegan et al., 1997; Parker and Meretsky). Land use returns and incentives can also be impacted by spatial pattern. Analyzing landscape pattern has been found to provide an indication of economic factors (Wickham et al., 2000), population dynamics (Entwisle et al., 1998), urban sprawl (LaGro and Degloria, 1992), household developmental cycles (Moran and Brondizio, 1998) and patterns of agricultural and swidden land use (Southworth et al., 2002; Nagendra et al., 2003) impacting the landscape.

2. Structure of the issue

The goal of this special issue is to explore the ways in which landscape pattern can be used to gain more information on processes of land use from images of land cover. This issue brings together papers at the forefront of this research effort, and illustrates the diversity of approaches necessary to evaluate the complex linkages between pattern and process, in landscapes across the world. The analyses contained in this issue are inherently comparative, with empirical analyses from many different ecological, social and institutional contexts. Two of the papers also provide further theoretical development for overarching links between pattern and process (Pontius et al.; Parker and Meretsky). The common thread across these diverse papers is that they clearly demonstrate the importance of landscape fragmentation, across many diverse regions. Within tropical developing countries fragmentation issues of emphasis seem to relate typically to deforestation and loss of forest cover. In contrast, in western urbanized countries, issues of city planning and urban/sub-urban development appear to dominate the discussion.

The issue is divided into four sections. The first concerns landscape fragmentation in tropical environments. In all of these cases, the most pressing issue is the clearing of forest for agricultural land uses. Forests and other natural lands are impacted by traditional swidden or shifting agriculture patterns, which often leave fragmented, degraded forests in their wake. Forestlands constitute a crucial carbon store, as well as providers of local habitat, protection against erosion, and countless other environmental benefits. The ultimate viability of their role in this regard depends strongly on their spatial configuration. The papers in this section (Pan et al.; Laney; Crews-Meyer; McConnell et al.; Southworth et al.) explore the driving forces of landscape fragmentation in several developing countries, often explicitly accounting for changing land use incentives and associated temporal effects, linking such changes to changing landscape patterns.

The second section includes two empirical examples from North America. Urban growth and development in smaller cities or peri-urban communities is an increasingly important component of land use change in the western urbanized countries. Of mounting concern to policy makers is the threat of urban or residential growth leading to greater fragmentation of other land uses such as forest or agriculture. The strength of the two papers in this section is that they both focus explicitly on private land use management and the impact on the surrounding environment. Given that residential land conversion on the urban-rural fringe is now the biggest contributor to loss of open space in North America, successful land use policy must effectively target private landowners. Platt considers the edge density of urban development as measure of urban sprawl in a rapidly growing mountain region, and Croissant compares private parcel boundaries to the patterns of non-industrial private forestry in a midwestern setting.

The third section contains two theoretical contributions to the issue. It has been extensively argued (see Turner et al., 1995) that landscape pattern does fundamentally relate to land use, but explicit theoretical linkages are relatively underdeveloped. Parker and Meretsky relate observable macro-level patterns to individual decision-making processes via an agent-based simulation model which explicitly captures the effect of land use externalities in determining the extent and configuration of urban and agricultural land use. Pontius et al. consider the inability of prior landscape research to identify and characterize systematic land use change processes in the face of land use persistence. Their paper presents an analytical tool to separate systematic changes from random ones, and explores using these techniques at multiple scales of analysis.

The final section of the issue contains three empirical investigations of the impact of land management policies on land use change and issues of environmental concern. The first paper, by Fairbanks, considers the impact of the former apartheid system of governance and land development on patterns of land use and avian diversity in South Africa. Tyler and Peterson make use of landscape metrics along with a forestry simulation model to construction a study of the impact of forest policies in the Pacific northwestern US on landscape pattern. Lastly, Hudak et al. compare the impact of varying fire management regimes on the vegetation in a game reserve in South Africa, using landscape pattern as means for separating assumed baseline fire patterns from the impacts of land management and prescribed burning.

3. New directions and challenges addressed in this issue

The papers in this issue use a variety of techniques, ranging from the application of frequently used metrics of landscape fragmentation, to the exploration of other innovative approaches including geographically weighted regressions (Platt), continuous approaches for fragmentation analysis (Southworth et al.), cross-tabulation transition matrices (Pontius), agent-based models (Parker and Meretsky), generalized linear mixed models (Pan et al.), discriminant analysis (Laney) and panel data on change trajectories (Crews-Meyer) to link pattern and process. These papers illustrate a variety of approaches to integrate landscape ecology theory and practice with other landscape science techniques, particularly those related to land use analysis. They emphasize the complementarity between remote sensing and socio-politico-economic analyses for improving our understanding of the human dimensions of land use and land cover change.

The advent of landscape fragmentation analysis techniques provided a new thrust to remote sensing science, greatly expanding the inferential capabilities of such research. While ecological systems are characterized by dynamics, disturbance, and change, and landscapes are seen as shifting mosaics, analyses of spatial heterogeneity have often been conducted in a static framework (Gustafson, 1998). Several papers in the issue explicitly consider how best to expand the temporal dimension of such research (Crews-Meyer; Laney; Southworth et al.; Pontius et al.). Southworth et al. also explore the use of continuous measures of spatial heterogeneity to capture more subtle variations in forest change that categorical techniques might miss. Increased spatial and temporal richness is critical to understanding ecological and social processes occurring on the landscape (Gustafson, 1998).

There are a variety of driving forces that impact land use and land cover, and these interact dynamically to give rise to different sequences and trajectories of change, depending upon the specific environmental, social, political and historical context in which they arise. Given the complex nature of the feedback loops between pattern and process, it is difficult to separate correlation from causality, and distinguish effect from cause. The papers in this issue have approached this problem in different ways (Pontius et al.; Pan et al.; Hudak et al.; Fairbanks; McConnell et al.). Many papers further address the critical issue of distinguishing the different driving processes that influence pattern at multiple scales, from the local to the regional and national (Platt; Laney; McConnell et al.). Finally and crucially, given the inherently applied nature of this research, many of the papers in this volume add value both to the basic science and to the body of knowledge needed as a basis for monitoring environmental and policy decisions (Croissant; Tyler and Peterson; Hudak et al.).

4. Future directions and research needs

While the papers in this issue provide a rich array of examples of the usefulness of land fragmentation analysis in LUCC research, much work remains to be done. Can these in-depth case studies of the linkage between pattern and process be integrated to assist global projections of use in international management, as is being increasingly attempted (NRC, 1999)? Given the uncertainties associated with such global projections, and the context dependent nature of LUCC that is clearly illustrated in the research presented here, developing ways to make comparative analyses more meaningful are sorely needed to understand how the driving forces of global environmental change vary over time and space in different regions of the world. To go beyond the limitations provided by categorical data derived from remotely sensed data and to incorporate and address temporal dynamics more clearly within analyses. Further, given the societal applications of this research, scenario building for improved decision making is a crucial and much desired output. There is a need for further dialog between the remote sensing and modeling communities to assist in the linkage of deductive, inferential analyses with inductive analyses, and clearly identify dependent variables from independent, to help us further disentangle the complex web of cause and effect.

Lastly, continued effort to develop and maintain spatio-temporal datasets in different regions will aid in the identification of contributing factors in LUCC. Improved incorporation of methodologies to integrate temporal information into such analyses, and into LUCC research in general is of utmost importance. Particularly because matching the relevant ecological unit of analysis to the appropriate socio-politico-economic unit of analysis is such an arduous task (Bockstael and Bell, 1998), reconciling these issues across locations over time represents a remaining challenge for researchers concerned with landscape science.

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