Monitoring and modelling landscape dynamics

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Introduction

Changes in land cover and land use are among the most pervasive and important sources of recent alterations of the Earth's land surface. Land changes significantly affect key aspects of Earth System functioning, for example in contributing to local and regional climate change as well as to global climate warming, impacting biodiversity and water quality, or increasing soil degradation (Vitousek et al 1997; Stohlgren et al 1998; Houghton et al 1999). Landscape dynamics studies integrating human-environment interactions and related to environmental issues have become increasingly important. Over the years these studies moved away from a focus on detecting and identifying land use and land cover changes (Lambin et al 2001; Loveland et al 1999, 2002) and understanding driving forces of landscape changes (Bürgi 2004; Antrop 2005) to modelling present land systems for predicting land cover changes (Veldkamp et Lambin 2001; Corgne et al 2004; Hepinstall et al 2008) and exploring possible futures of landscapes (Verburg et al 2004; Kok et al 2007). Such studies were and are still largely supported by national and international global environmental change programs such as the Land Use and Cover Change program (Lambin et al 1999), the Global Land Project (GLP 2005), and the US Climate Change Research Program (Loveland et al 2003). They contribute to improving the understanding of natural-human interactions and they advance monitoring and modelling of landscape dynamics needed to meet the challenges of land change science (Turner et al 2007).

Monitoring landscape and land use/cover changes is considered as an essential first step to assist the identification of driving forces (Bürgi 2004) and provide the data needed for modelling. Projection of futures landscape changes requires and understanding and integration of past landscape trends, current land change processes and feedbacks, and the incorporation of plausible assumptions or scenarios. Obviously, monitoring and modelling of landscape dynamics strongly depends on the scale and objectives of the planned applications. This, in turn, determines the different techniques needed. Thus, landscape change models should be appropriate for simulating identified social, economic, and ecological processes, and their dynamics and interactions that shape landscapes. Land change models that are founded in land use theory and that consider land use history is also important and offer new opportunities for interdisciplinary research.

Landscape dynamics studies were and are often driven by disciplines other than landscape ecology although techniques and concepts from landscape ecology have consistently contributed to landscape change studies (Naveh 1991; Bürgi and Russell 2001; Antrop 2002). For example, the remote sensing community is regularly involved in monitoring landscape dynamics. Various disciplines, such as geography, offer diversified points of view and approaches that enable understanding the dynamics of landscape structure and function at different spatial and temporal scales.. The need for the integration of landscape history, including past/current dynamics and feedbacks has been increasingly recognized (Caspersen et al 2000; Nabuurs et al 2003; Antrop 2005; Rhemtulla and Mladenoff 2007; Claessens et al 2009; Gillson 2009). This special issue focuses on multidisciplinary research in land change science that illustrate how innovative data integration, analytical methods and techniques, and perspectives from geography, ecology, agronomy and computer sciences can help foster cross-disciplinary research with landscape ecologists (Hobbs 1997).

This special issue adds to the existing literature on the state of the art on landscape dynamics studies (Turner et al 2007; Milne et al 2009; Kok et al 2007; Lambin and Geist 2006). It also illustrates both current advances and challenges for monitoring and modelling landscape dynamics. Selected papers in this volume illustrate key dimensions of land change science, highlight possible new directions of research such as the reinforcement of multi-scale (Verburg, 2006) or human/nature (Milne et al 2009) modelling approaches, and present

integrated approaches to project future landscape changes (Kok et al 2007). Most of the papers in this issue were selected from presentations at the international symposium "Spatial landscape modelling: from dynamic approaches to functional evaluations" that took place in Toulouse (France) from 3rd to 5th of June 2008 (http://w3.geode.univ-tlse2.fr/rtp-modelisation/).

Monitoring and modelling landscape dynamics: current practices, limits and new directions

Monitoring landscape dynamics is essential for understanding the complex interactions between social, environmental and geophysical processes (Munroe and Müller, 2007). Land use and land cover change studies are often based on information on landscape structure and composition at different spatial and temporal resolution that is derived from remotely sensed data (Loveland et al 2000; Goetz 2007; Coops et al, 2009). However, there are several challenges associated with developing the remote sensing inputs needed to understand landscape dynamics. The first challenge is to maintain continuous time series of low cost imagery (Turner et al 2007). The planned 2012 launch of the Landsat Data Continuity Mission, for example, extends the Landsat record an additional 5-10 years. New data acquisition systems with high spatial and temporal resolutions (i.e. Formosat, VENµS missions) are also extremely promising sources of remotely sensed data that will further enable monitoring landscape dynamics at fine spatial and temporal scales. Improvement of techniques combining multi-scale / multi-sensors / multi-source data studies show potential to rescale land cover data (Gardner et al 2008) in order to improve common landscape monitoring methods. New direction to better understand landscape dynamics include moving from land cover to land use systems such as the detection of cropping systems. The paper of Lazrak et al (this issue) in this volume lays out an innovative use of data mining techniques to detect landscape regularities over time.

This special issue also presents new directions in modelling landscape dynamics. Agent-based models have primarily been used to simulate local land use and land cover changes processes with a focus on decision making (Le 2008; Matthews et al. 2007; Parker et al. 2003; Bousquet and Le Page 2001).Valbuena et al (this issue) present an agent-based modelling approach that is also applicable at the regional scale and links individual decision making to changes in landscape structure. Innovation is not only found in new or improved models, but also in the combination of existing models. Gaucherel et al (2009) reports on research in which multiple process-based models are coupled to evaluate ecological and aesthetic impacts of landscape changes. Verburg et al (this issue) illustrate the application of multiple models at different scales to explore possible landscape trajectories in Europe. Along with with Valbuena et al (this issue), Sohl et al (this issue), and Houet et al (this issue), Verburg et al (this issue) point out the need for improved integrated land change models that connect local-to-global scales and land use pattern with land use change processes. If models are becoming more and more efficient to simulate processes at multiple scales, there is an obvious strong convergence between local scales models attempting to take into account global driving forces and regional/global models looking for finer spatial rendering at elementary landscape units (Sohl 2007; Castella et al 2007; Verburg et al 2008).

The papers in this issue also highlight land change science challenges associated with improved prediction of land use change (Lambin et Veldkamp 2001), better integration of the land system (Kok et al, 2007), and the need for advanced scenario-based studies (Verburg et al 2006). Sohl et al (this issue) and Houet et al (this issue) each propose a framework, at regional and local scales respectively, to include landscape trends and histories, to choose, parameterize, and validate models, and to explore multiple land change scenarios. Whatever the spatial scale of such approaches, data availability remains an ongoing challenge thus

reinforcing the importance of landscape monitoring using multisource data (historical maps, remotely sensed data, etc). Gibon et al (this issue) illustrates the need for an integrated and participatory approach that considers socio-ecological processes in the modelling and elaboration of scenarios. Regarding exploration of alternative land change futures, Verburg et al (this issue) assess possible future landscape changes based on contrasted scenarios. This provides a good indicator of likely future land configurations. This future dimension of landscape dynamic studies provides a helpful tool to delimit the envelope of possible landscape futures and to define the plausibility of the occurrence of futures landscape changes.

Finally, all of the papers in this special issue indicate that 'standard' monitoring and modelling techniques are not always valid or the most appropriate. Land cover monitoring does not always detect subtle changes within the landscape, e.g., changes in landscape elements and change in land management practices. Models should better represent such subtle landscape changes given the importance of such changes for the functioning of the landscape (Houet et al this issue). At the same time land use (cropping) systems that show specific landscape temporal patterns and cycles that are not easily observed from traditional land cover data, but have importance for the dynamics in the landscape (Lazrak et al this issue). Moreover, landscape dynamics studies need to go further in combining modelling approaches and techniques (Gaucherel et al this issue; Gibon et al this issue; Sohl et al this issue; Valbuena et al this issue) and projecting landscape dynamics to reduce uncertainties of the futures of landscape (Verburg et al this issue; Houet et al this issue). The temporal dimension of landscapes has to be considered as important as the spatial dimension in order to monitor, model, and assess human/nature interactions. Collectively, these considerations open new directions for research in land change science.

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