Characterizing and Modeling Landscape Dynamics: An Introduction

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Introduction

In 2000, the National Research Council (NRC) described the "*Grand Challenges in Environmental Sciences*" to include (1) development of long-term, regional databases for land use, land cover, and related social information, (2) formulation of spatially- explicit and multi-sectional land-change theory, (3) linkage of land-change theory to space-based imagery, and (4) development of innovative applications of spatial simulation techniques for assessing environmental dynamics and land use and land cover change. Further, the NRC described how spatial simulations would (a) extend dynamic modeling techniques to distinct temporal and spatial patterns of land use and land cover change, (b) connect such models to extant and pending theoretical frameworks that accommodate the complexity of, and relationships among, socio-economic and environmental factors, (c) establish common validation and replication protocols necessary for determining the robustness of model outcomes under different assessment scenarios, (d) consider the value of information and the role of uncertainty in determining model outputs, and (e) examine the utility of dynamic spatial simulation models for land managers and government decision makers.

In addition to the NRC, programs such as the International Geosphere-Biosphere Program (IGBP), the International Human Dimensions Program (IHDP), the Intergovernmental Panel on Climate Change (IPCC), the Land Use/Cover Change program jointly sponsored by IGBP and IHDP, and various parts of the IGPB's Global Change and the Terrestrial Ecosystem program have emphasized the importance of characterizing and modeling land use and land cover patterns and dynamics as part of the study of human-environment interactions. And finally, NASA's Land Cover-Land Use Change program and the BioComplexity program at the NSF have further signaled the importance of linking people, place, and environment (see Walsh and Crews-Meyer 2002) by characterizing their integrative and linked affects through remote sensing, GIS, and models.

These *Grand Challenges* present an underlying context for this special issue on "Characterizing and Modeling Landscape Dynamics" for *Photogrammetric Engineering & Remote Sensing*. From over 30 submitted manuscripts in response to an open call for contributions to this special issue, we assembled a group of 10 substantive papers, a perspective article by Richard Aspinall, and this Introduction to present a view of characterizing and modeling landscape dynamics. This special issue focuses on using remote sensing, GIS, and related methodologies to represent landscape dynamics in general, and land use and land cover change specifically.

Models and characterizations are representations of reality, where the essentials of the reality are extracted and expressed in a formal structure that, in turn, are implemented in a computer form. This process involves the identification of basic entities, their state and behavior, and relationships between them (Bian, 2000a, 2000b). Characterization and modeling of landscape dynamics are particularly concerned with the representation of biophysical and socio-economic landscapes, and their changing patterns and processes within a space-time context.

This representation involves multi-resolution sensor systems, terrestrial, aircraft, and space-borne reconnaissance platforms, data integration and fusions, statistical and geostatistical analyses, spatial and temporal simulations, and more. Linking across thematic domains and spatio-temporal scales, and including exogenous and endogenous factors, are important elements of characterization and modeling — they reveal landscape patterns, the drivers of land use and land cover dynamics, and their scale dependence (e.g., Walsh et al. 1999).

The characterization and modeling process helps improve our understanding of the principles underpinning these biophysical and socio-economic systems. Based on such understandings, scenarios set to times and locations beyond direct or immediate observation can be considered for past, present, and future periods. These characterizations and model predictions are critical for understanding system behaviors, assessing the potential change in landscape form and function (e.g., Walsh et al. 2001, Messina and Walsh 2001), and ultimately effectuating the decision-making process for environmental management.

Biophysical and socio-economic processes are spatially and temporally dynamic. These changes affect the form and function of the landscape that may in turn cause further changes through a host of feedback mechanisms and critical thresholds. The nature and magnitude of these changes may depend on conditions at past or present time periods as well as for landscape conditions at certain locations. For instance, Complexity Theory speaks to the importance of non-linear systems and landscape descriptions not constrained by an *a-priori* definition (Cilliers 1998). The goal of Complexity Theory is to understand how simple, fundamental processes can combine to produce complex holistic systems (Gell-Mann 1994). Non-equilibrium systems with feedbacks can lead to non-linearity and may evolve into systems that exhibit criticality (Bak 1998). Research framed within Complexity Theory can address the rates and patterns of land use and land cover dynamics and possible non-linear feedbacks between processes of change and existing patterns of land use and land cover. Changes may depend partly on the existing patterns of land use, which may involve critical points where a small amount of land use change significantly alters feedback processes and leads to a new pattern or equilibrium.

Recent advances in remote sensing, GIS, and the other spatial digital technologies have provided an effective means to characterize and model these complex spatial and temporal changes. Evidence of such advances includes the emergence of a new generation of spatial data from satellite systems such as MODIS and IKONOS, the sophistication and rigor in analytical approaches, and creative and insightful applications. The group of papers presented in this special issue report on some of the advances in landscape characterization and modeling, and suggest some of the many challenges and opportunities for further achievement.

The 10 papers included in this special issue bring together new perspectives on the characterization of landscape dynamics, examining the patterns of landscape change, the drivers of change, and the methods to represent change. The first two papers by Kelly and Meentemeyer and by Henry and Yool analyze how natural hazards, plant disease and fire, can alter landscapes in a short period of time and set the dynamics of landscapes on new and distinctive trajectories. Papers by Jakubauskas et al. and by Crews-Meyer present harmonic

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analysis and temporal panel analysis, respectively, to represent the dynamics of land use and land cover over the time span of decades. Papers by Pontius and by Brown et al. provide insights into the stochastic aspects of land use and land cover change and its representation through statistical and geostatistical approaches, respectively. Papers by Lo and Yang and by Chen et al. focus on the drivers of urban landscape dynamics in major metropolitan areas and, through the understanding of these drivers, predict future patterns of their respective urban landscapes. Civco et al. introduce a set of concepts and tools to represent changes of biophysical and socio-economic landscapes. Loveland et al. describe a strategy for estimating land cover change across large spatial and temporal extents in the conterminous US over three decades. The eleventh paper by Aspinall addresses a different yet immediately relevant topic – a data/function infrastructure for land cover dynamics. This is an important but understudied issue in environmental modeling in general, and in land use and land cover change specifically. Collectively, these papers report on current advances and new perspectives on landscape characterization, dynamics, and modeling. We hope the remote sensing and modeling communities continue to push the sciences in these important areas. There is much to learn!

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