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Synthesis: Land Transitions in the Tropics

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ABSTRACT

Land cover transformations in the tropics are not limited to deforestation; they include other complex transitions such as agricultural and urban expansion, pasture development, and secondary vegetation regrowth. Understanding the causes and extent of these highly variable and complex transitions requires close collaboration between biological, physical, and social scientists. Here we address three critical issues in the study of land transitions: (1) What methodological and socioecological criteria should be used for characterizing land cover categories and transformations? Results from case studies presented here call for the creation of continuous land cover classes that allow for detection of disturbance and human use dynamics and consideration of socioeconomic and biophysical criteria in characterizing and monitoring land transitions. (2) What are the most promising theoretical frameworks? Successful theoretical frameworks must bridge disciplinary boundaries, and encompass multiple spatial, temporal, and political scales. (3) Are regime shifts, constraints, and resilience of land transformations in the tropics predictable? Resilience of land use systems requires a feedback loop between ecological constraints and management decisions. This loop may be broken by policies, migration, and flow of capital from global commodity markets. In addition, land transformations may lead to novel interactions between land-use and natural disturbance leading to unpredictable regime shifts in ecosystems. Planning for sustainable patterns of land use requires some understanding of these regime transformations.

Key words: coupled human natural systems; forest transition; land use/cover change; land use sustainability; tropical landscapes.

FOR THE LAST 50 YR HUMANS HAVE CONVERTED TROPICAL LANDSCAPES to a wide variety of uses with unprecedented and detrimental consequences for biodiversity, climate, and other ecosystem services (Lambin & Geist 2006). In turn, these changes have affected the vulnerability of places and people to climatic, economic, and sociopolitical perturbations (Turner *et al*. 1990, Chomitz 2007). In response to these dramatic effects, natural, physical, and social scientists have struggled to understand land use transitions through a wide range of research efforts (GLP 2005); however, developing theories of land use and cover change in the tropics is a challenging task. The causes and extent of land transitions vary dramatically between regions because land-use change is intricately related to demographic factors, political structures, and economic development and constrained by the ecological characteristics of the landscape (Pfaff 1999, DeFries *et al*. 2004, Rudel 2005). Furthermore, accounting for net loss of forest area, the focus of much research, is not sufficient to describe land dynamics that include loss of other important ecosystems (*e.g.*, shrublands, savannas), agricultural conversion, invasive species, and forest regrowth from plantations and natural regeneration after agricultural abandonment (FAO 2005, Hurtt *et al*. 2006).

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Managing land transitions in the tropics in a sustainable manner will necessitate close collaboration between biological, physical, and social scientists. Meeting this challenge will require interdisciplinary approaches that can detect relevant land transitions, understand these changes in the context of integrated social and ecological systems, and provide information for management, particularly with regard to regime shifts and resilience of coupled human–natural systems (Folke *et al*. 2004, Carpenter & Folke 2006, Kareiva *et al*. 2007, LTER 2009). In this light our Special Section aimed to address three critical questions: (1) What methodological and socioecological criteria should we consider in establishing land cover categories and detecting changes? (2) What theoretical frameworks are most promising in the integrated study of the effects and consequences of land transformation for ecosystems and human livelihoods? (3) Can we predict regime shifts, constraints, and resilience of land transformations in the tropics?

CRITERIA FOR THE ESTABLISHMENT OF LAND COVER CATEGORIES AND CHANGE DETECTION

Land cover classes are usually defined by land surface attributes, specifically vegetation, topography, and human settlements. Spatially, many land cover transition of interest (*e.g.*, urbanization,

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growth of secondary forests, forest degradation, spread of invasive plants) are often hard to characterize into discrete classes (Small 2003, Asner *et al.* 2008, Sánchez-Azofeifa *et al.* 2009, Schneider & Fernando 2009). Temporally, these transformations are not unidirectional or permanent, highlighting the need for complex representations of the processes driving land use and land cover change (Lambin *et al.* 2006). Establishing sound technical, ecological, and social criteria for determining spatial and temporal changes in land cover is critical not only to develop sound management strategies but also to avoid pitfalls associated with simplifying assumptions. A critical first step is establishing working definitions of land cover classes, which are politically expedient, culturally sensitive, ecologically reasonable, and technologically feasible (DeJong 2009, Putz & Redford 2009). Establishing these categories in tropical landscapes highly disturbed by human activities presents cultural, technical, political, and ecological challenges (Putz & Redford 2009, Schneider & Fernando 2009). Despite recent improvements in remote sensing technologies that are increasing our ability to detect mixed land covers and subtle transitions (Asner & Vitousek 2005, Asner *et al.* 2008), linking processes that take place at different spatial and temporal scales remains a challenge particularly when we try to incorporate cultural (Lawrence *et al.* 2009), socioeconomic (Schneider & Fernando 2009), political (DeJong 2009, Putz & Redford 2009), or ecological criteria (Chazdon *et al.* 2009, Putz & Redford 2009). Results from case studies presented here call for the creation of continuous land cover classes that can detect dynamics of disturbance and human use while considering socioeconomic and biophysical criteria in characterizing and monitoring land transitions. The success of this endeavor will depend not only on the availability of data at relevant temporal and spatial scales but also on the development of new analytical tools and theoretical frameworks.

FRAMEWORKS FOR THE INTERGRATED STUDY OF LAND TRANSFORMATIONS

Linking ecological, biophysical, socioeconomic, and remote sensing analysis can contribute to our understanding of spatial and temporal dynamics of coupled natural–human systems. However, from a theoretical perspective, finding explanations for land transitions has proven to be a challenge (Lambin *et al.* 2006). This shortcoming has resulted, in part, from the complexity of causes, processes, and impacts, but also from the fact that researchers have relied in the theories of the disciplines in which they were trained (vanWey *et al.* 2005). For instance, many of the initial land use change studies were dominated by economic theory with little attempt to incorporate biophysical or institutional constraints. More recent efforts have attempted to bridge disciplinary domains (Lambin *et al.* 2006). One such attempt has been the development of Forest Transition Theory (FTT) (Mather 1990, Rudel *et al.* 2005). FTT argues that there is an association of socioeconomic development with ecosystem (forest) recovery in some parts of the world. For Mather (1990) urbanization and industrialization induced, first, a prolonged decline and, then, a partial recovery in the extent of forests. In this sense the term 'forest transition' is intellectual shorthand for a historical generalization about long-term changes in forests and the surrounding human societies. The transition takes place when deforestation disappears and reforestation commences. In practice FTT is not so much a theory (Rudel 1998, Perz 2007) as a set of empirical historical observations linking the two factors. Causality appears to be largely determined by context, be it cultural, institutional, or based on macro- or microeconomic conditions (Perz 2007). A major difficulty with FTT is how it does not explicitly address either the mechanisms that regulate the pace of ecosystem recovery or its eventual composition. It also fails to consistently specify the factors that regulate human behavior and cause the transitions from deforestation to reforestation or to alternate stable states. Whatever its shortcomings, the forest transition is a key feature of interdisciplinary studies of land change science and teasing apart its causes, consequences, and failures will contribute to a broader understanding of land transitions in the tropics (Turner *et al.* 2007). For this reason, several of the papers in this issue address FTT while acknowledging its shortcomings (Carilla & Grau 2009, DeJong 2009, Lawrence *et al.* 2009).

There are several principles that a theoretical framework for land use change should embrace (Lambin *et al.* 2006). First, it should incorporate the behavior of people (individuals) and groups (Cash *et al.* 2006, DeJong 2009, Lawrence *et al.* 2009). Second, it should be multiscale with regards to ecological (*e.g.*, stands, ecosystems), political (household, village), and biophysical units (*e.g.*, watersheds; Schneider & Fernando 2009). Third, it should connect people and land use locally, regionally, and globally (Lawrence *et al.* 2009, Schneider & Fernando 2009). Finally, it will need to incorporate the past history of people and land as well as predict the likelihood of change in the future.

REGIME SHIFTS, CONSTRAINTS, AND RESILIENCE IN THE TROPICS

Land transformation in the tropics should be studied as coupled human–environment systems which requires an approach that integrates spatial, environmental, and social sciences (Turner *et al.* 2007). In this regard, understanding regime shifts, constraints, and resilience of land transitions in the tropics is a key issue. Resilience of land use systems requires a feedback loop between ecological constraints and management decisions that enhance local knowledge (Lawrence *et al.* 2009). This loop may be broken by policies, migration, and flow of capital from global commodity markets. In addition, land transformations may lead to novel interactions between land-use and natural disturbance causing regime shifts in ecosystems (Paine *et al.* 1998, Carilla & Grau 2009). Ecological, economic, biophysical, and political factors can act singly or in concert to determine thresholds for regime shifts in ecosystems (DeJong 2009, Putz & Redford 2009, Schneider & Fernando 2009). For instance, Carilla and Grau (2009) hypothesize that the dynamic of forest grassland ecotone is controlled by the complex interactions among grazing, fire, climate, and vegetation dynamics, and that due to the effects of recurrent fires, degraded grasslands persist as an alternative degraded state, which resists tree invasion despite improving conditions of land-use and climate. These unexpected interactions will hinder our ability to ascertain the state of an ecosystem at any particular point in space or time, an issue ecologists must address if they are going to forecast the future of the biosphere (Clark *et al.* 2001).

We see three general principles emerging from these studies that could lead to sustainable management of land use transitions. First, to understand the complexity of land transition in the tropics, it is important to monitor such transitions at different temporal and spatial scales, and place them in dynamic social and institutional settings. Land transformations are not linear. Rather, they need to be considered as an intricate cycle where human decisions affect the landscape, and altered landscapes affect ecological processes and human livelihoods which in turn influence the way humans monitor and respond to that change, setting in motion a new set of social drivers. These papers illustrate this principle in several ways. Temporally, human transformations of landscapes are driven by both historical and current social, economic, and ecological drivers (DeJong 2009, Lawrence *et al.* 2009). Spatially, these transformations respond not only to local needs and concerns but also to global drivers (Lawrence *et al.* 2009, Schneider & Fernando 2009). Lack of consideration of multiple scales can lead to less resilient land use systems or unsustainable regime shifts (Carilla & Grau 2009, Lawrence *et al.* 2009).

Second, establishing valid land cover categories will be a critical component of sustainable management of land use transitions. With the increased attention and improvement to remote sensing analysis and GIS data and image processing software the results of some of the papers show the importance to expand the assessment of land covers such as secondary vegetation (Chazdon *et al.* 2009), plant invasions (Schneider & Fernando 2009), and agricultural covers such as the ones produced by shifting cultivation (Lawrence *et al.* 2009). Binary representations of land transitions limit the possibility of linking more sophisticated ecological understandings to the spatial dynamics of land cover change (Schneider & Fernando 2009). Moving away from discrete classifications of tropical land covers will require the development and application of remote sensing methodologies, which have been historically focused on the study of temperate landscapes (*e.g.*, LIDAR data). Continuous classifications will be strengthened by adding on the ground ecological data (Rindfuss *et al.* 2004).

Third, an integrated approach to understanding land transitions in the tropics provides a quantitative understanding of the relations between land transition, socioeconomic drivers, and ecological change with potential implications for human livelihoods and sustainability. Through an integrated approach it is possible to identify nonlinearities and feedbacks in the system, which are critical to describe the strength and variability of the interactions between humans and environment that lead to changes in the resilience or vulnerability of tropical landscapes. Thus, this set of papers show how the methods and approaches of land change science and ecology deriving from basic ecological research and a rich array of human–environment regional case studies will improve the understanding and modeling of critical themes in global change and sustainability studies (DeFries *et al.* 2004, Carpenter & Folke 2006).

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