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Regime shifts limit the predictability of land-system change

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A B S T R A C T

Payment schemes for ecosystem services such as Reducing Emissions from Deforestation and forest Degradation (REDD) rely on the prediction of 'business-as-usual' scenarios to ensure that emission reductions from carbon credits are additional. However, land systems often undergo periods of nonlinear and abrupt change that invalidate predictions calibrated on past trends. Rapid land-system change can occur when critical thresholds in broad-scale underlying drivers such as commodity prices and climate conditions are crossed or when sudden events such as political change or natural disasters punctuate long-term equilibria. As a result, land systems can shift to new regimes with markedly different economic and ecological characteristics. Anticipating the timing and nature of regime shifts of land systems is extremely challenging, as we demonstrate through empirical case studies in four countries in Southeast Asia (China, Laos, Vietnam and Indonesia). The results show how sudden events and gradual changes in underlying drivers caused rapid, surprising and widespread land-system changes, including shifts to different regimes in China, Vietnam and Indonesia, whereas land systems in Laos remained stable in the study period but show recent signs of rapid change. The observed regime shifts were difficult to anticipate, which compromises the validity of predictions of future land-system changes and the assessment of their impact on greenhouse gas emissions, hydrological processes, agriculture, biodiversity and livelihoods. This implies that long-term initiatives such as REDD must account for the substantial uncertainties inherent in future predictions of land-system change. Learning from past regime shifts and identifying early warning signs for future regime shifts are important challenges for land-system science.

1. Introduction

Land systems are the terrestrial component of earth systems and encapsulate the activities and processes related to human use of land as well as the socioecological outcomes of land use. Studying land systems is therefore crucial to understanding the relationships between humans and their environments (GLP, 2005; Verburg et al., 2013). Changes in land systems have been among the most important drivers of global environmental change and have greatly contributed to the emergence of the Anthropocene (Crutzen, 2002; Ellis et al., 2013; Turner et al., 2007). The influence of human action on planetary resources is likely to persist considering the expected increase in demand for land-based products driven by human population growth, diet change and consumption of energy (Haberl et al., 2014; Rockström et al., 2009). Therefore, predictions of the evolution of land systems are important for determining the potential trade-offs between land-system changes and ecosystem services and guiding policy in managing increasingly scarce natural resources (Clark et al., 2001; Davidson et al., 2012).

However, such predictions are notoriously difficult to make because of complex human–environment interactions in land systems (Dearing et al., 2010; Liu et al., 2007). Economic

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globalization further complicates the predictive analyses of land-system change because growing global connectivity, or telecoupling, of land systems poses new conceptual and methodological challenges and may produce unforeseen outcomes (Eakin et al., 2014; Lambin and Meyfroidt, 2011; Liu et al., 2013; Müller and Munroe, 2014). For example, the increasing demand for meat-based diets in emerging and industrial countries has led to an intensification of livestock production, which in turn has caused considerable deforestation in Latin America because of soybean expansion (Fearnside et al., 2013; Morton et al., 2006). One of the challenges of land-system science is to relate underlying global and regional drivers of land-system change to local land-use outcomes and foresee the responses of land-use agents to changes in these drivers (Dearing et al., 2010; Lambin and Geist, 2006; Turner et al., 2007).

The limited understanding of how underlying drivers affect proximate causes of land-system change obscures causality and impairs our ability to forecast change (Veldkamp and Lambin, 2001). Although land-system change often occurs gradually, transitions to alternate states may occur rapidly when critical thresholds are crossed (Dearing et al., 2010; DeFries et al., 2004; Veldkamp and Lambin, 2001). The concept of regime shifts embodies such a transition and has been increasingly used to study sudden changes in ecological systems (Scheffer, 2009). Regime shifts characterize the shift in a system to alternate states that can result from a loss of resilience (Gunderson, 2000), the occurrence of stochastic events (Folke et al., 2004; Scheffer et al., 2001) or positive feedback in synergistic driving forces (Brook et al., 2013). Regime shifts are intrinsic characteristics of complex adaptive systems (Scheffer, 2009), and land systems are complex adaptive human-natural systems. As such, land systems also experience nonlinear and rapid change based on their ability to absorb and adapt to underlying drivers of change (Dearing et al., 2010; Liu et al., 2013). However, the concept of regime shifts has received little attention in land-system science.

Our overall objectives are to examine the occurrence of regime shifts in land systems with four case studies of long-term land-system change in Southeast Asia and to conceptualize and interpret the observed historical changes with the regime shift concept borrowed from ecology. We collected time-series data on land-system change from 1980 to 2012 for four case studies in Southeast Asia (China, Laos, Vietnam and Indonesia). The data allowed us to distinguish periods of linear and nonlinear change and periods of rapid and slow change; therefore, we were able to identify past regime shifts in land systems. Our hypothesis is that these land-system regime shifts were difficult to anticipate, and consequently, the predictability of land-system change and validity of business-as-usual predictions were far from guaranteed. We then discuss the implications of potential occurrence of regime shifts for Reducing Emissions from Deforestation and forest Degradation (REDD) and for governing land-systems in general.

2. Regime shifts in land systems

We define a land-system regime as a quasi-equilibrium phase during which a land system remains relatively stable in terms of overall system characteristics and ecosystem functions, such as land area used, land-use intensity, provision of habitats, carbon dynamics and biodiversity. A land-system regime is resilient to perturbation or disturbance when negative feedback and interactions allow the system to recover and maintain its equilibrium state (Fig. 1; cf. Holling, 1973; Walker et al., 2004). Land systems can reside in a regime for a long time; however, they can also undergo abrupt and unexpected state shifts that are persistent and difficult to reverse. During the transitional period between two regimes, feedback and interactions within the land system are reconstructed and reorganized. We define this process as a regime shift in land systems, in analogy with a regime shift in ecosystems (cf. Biggs et al., 2009; Scheffer et al., 2001).

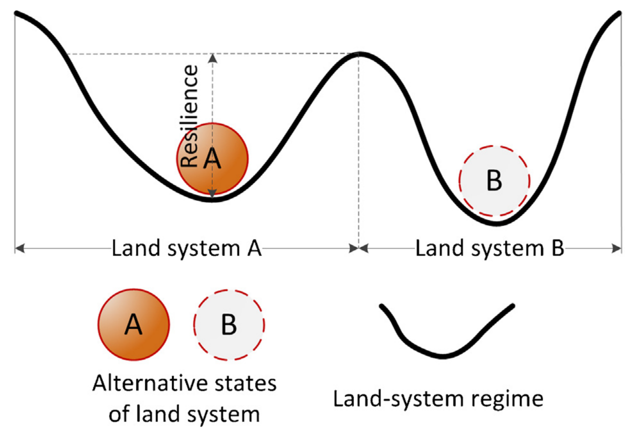

Fig. 1. Regime shifts in land systems. *Note*: The balls represent states of land systems. Land systems can shift from one regime (a stable state confined by a valley) to an alternative regime (another valley), which is illustrated by the ball shifting from A to B. The depth of a valley characterizes the resilience of a land system regime to change. The resilience can be reduced by drivers that push up the valley or improvements of enabling conditions that reduce the height of the hill. Reduced resilience increases the attractiveness of alternative regimes and may facilitate regime shifts.

Regime shifts can be a result of incremental tipping point processes, punctuated changes or the combination of both. In tipping point processes, an accretion of pressure from underlying drivers gradually increases until a threshold is passed; the system then stands at a tipping point wherein a small perturbation can precipitate rapid and large-scale change and push the system to a new state. For example, the Western Sahara suddenly shifted from nearly complete vegetation to the current state of desert approximately 6000 years ago, and the shift was triggered by a gradual variation of summer isolation (deMenocal et al., 2000). Likewise, there is some indication that population growth can build incremental pressure until the system tips over to another state (Ellis et al., 2013). An alternative explanation of systemic change in land systems is provided by the punctuated equilibrium theory in evolutionary biology (Gould and Eldredge, 1977) that postulates that periods of little change may be punctuated by influential events that unleash an episode of drastic change. An example is the formulation of a new state policy that is possibly triggered by incremental, endogenous changes in drivers that exceed a threshold for policy makers and end a longer period of stasis. The policy implementation punctuates the apparent equilibria in the land system (Rudel, 2013).

Similarly, exogenous forces such as natural disasters can lead to punctuated change that often does not have an apparent threshold. A better understanding of regime shifts in land systems is required to inform land-system governance because regime shifts may have substantial impacts on socioecological outcomes, such as land-use intensity, production technology, land-based outputs, livelihoods and ecosystem services. To detect such regime shifts, long-term observational data are required to distinguish linear from nonlinear change and gradual from rapid change to better understand the system dynamics and improve our ability to anticipate critical thresholds (Carpenter and Folke, 2006; Dearing et al., 2010). Predicting regime shifts in land systems necessitates the detection of early warning signs for likely tipping points or potential punctuations that entail rapid or nonlinear change.

Regime shifts can be triggered by socioeconomic, political and environmental changes or, as is often the case, by a combination thereof. The presence of regime shifts in land systems is not new,