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Middle-range theories of land system change

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ABSTRACT

Changes in land systems generate many sustainability challenges. Identifying more sustainable land-use alternatives requires solid theoretical foundations on the causes of land-use/cover changes. Land system science is a maturing field that has produced a wealth of methodological innovations and empirical observations on land-cover and land-use change, from patterns and processes to causes. We take stock of this knowledge by reviewing and synthesizing the theories that explain the causal mechanisms of land-use change, including systemic linkages between distant land-use changes, with a focus on agriculture and forestry processes. We first review theories explaining changes in *land-use extent*, such as agricultural expansion, deforestation, frontier development, and land abandonment, and changes in *land-use intensity*, such as agricultural intensification and disintensification. We then synthesize theories of higher-level land system change processes, focusing on: (i) *land-use spillovers*, including land sparing and rebound effects with intensification, leakage, indirect land-use change, and land-use displacement, and (ii) *land-use transitions*, defined as structural non-linear changes in land systems, including forest transitions. Theories focusing on the causes of land system changes span theoretically and epistemologically disparate knowledge domains and build from deductive, abductive, and inductive approaches. A grand, integrated theory of land system change remains elusive. Yet, we show that middle-range theories – defined here as contextual generalizations that describe chains of causal mechanisms explaining a well-bounded range of

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phenomena, as well as the conditions that trigger, enable, or prevent these causal chains –, provide a path towards generalized knowledge of land systems. This knowledge can support progress towards sustainable social-ecological systems.

1. Introduction

Change in land use—the purposes and activities through which people interact with land and terrestrial ecosystems— is a key process of global environmental change. Understanding land-use change is central for designing strategies to address sustainability challenges, including climate change, food security, energy transition, and biodiversity loss. Land systems constitute complex, adaptive social-ecological systems (Berkes et al., 1998) shaped by interactions between (i) the different actors and demands that act upon land, (ii) the technologies, institutions, and cultural practices through which societies shape land use, and (iii) feedbacks between land use and environmental dynamics (Millennium Ecosystem Assessment (MA), 2003; Verburg et al., 2015). Elementary events of land-use changes that take place at the plot-level over short time periods, such as deforestation or substitution of one crop by another, correspond to changes in the extent and/or intensity of land use. These elementary building blocks combine to form complex, structural processes taking place over broader extents (landscapes, regions, and across countries) and longer time scales, including non-linear transitions (Lambin and Meyfroidt, 2010) and spatial reorganization of land uses (Rey Benayas et al., 2007; Kastner et al., 2014; Queiroz et al., 2014; Levers et al., 2018).

Land system science is a maturing field that has produced a wealth of methodological innovations and empirical observations (Lambin et al., 2006; Turner et al., 2007; Verburg et al., 2015). It focuses on monitoring and describing patterns of land-cover change, explaining drivers of land-use change, and understanding linkages between these two. These advances have relied on deductive approaches based on disciplinary frameworks (e.g., neo-classical economics or political ecology), abductive reasoning (i.e., starting from outcomes and retracing these to their likely causes), syntheses based on systematic reviews and meta-analyses of drivers and impacts of land system change (Magliocca et al., 2015, van Vliet et al., 2016), and "box and arrows" conceptual frameworks. The development of land system theories has been lagging due to: (i) a focus on local case studies, favoring *ad hoc* interpretations based on contingent factors; (ii) an emphasis on methodological developments involving improvements in remote sensing and other geospatial analyses; and (iii) the interdisciplinary nature of land system science, which has led to the borrowing of theories from related disciplines including geography, landscape ecology, economics, and anthropology (Meyfroidt, 2015, 2016).

Lambin et al. (2001) challenged simplistic notions about the causes of land-use and land-cover change, highlighting complex interactions, multi-causality, and the contextual character of land system processes. Here, we argue that land system dynamics can be apprehended through theoretical generalizations that transcend the place-based specificity of cases, without ignoring their complexity. We consider that theoretical formalization can further the development of: (i) testable hypotheses; (ii) process-based models simulating complex interactions; and (iii) credible knowledge that informs policy and decision-making beyond specific places while remaining sensitive to context. Theories of land systems advance our understanding of the dynamics of social-ecological systems and foster dialogue with other human-environmental sciences.

Here, we take stock of land system science knowledge generated over the last decades, focusing on theories explaining the causes of land-use change and their systemic linkages across places. We focus on middle-range theories, defined as contextual generalizations presenting causal explanations of delimited aspects of reality—events or phenomena (Merton, 1968, full definition in Section 2). This stands in contrast to both high-level, unified theories, as well as explanations relying on the singularity of a specific case. While our focus is not on theories relating land-use change to its environmental and human impacts, we account for feedback mechanisms that alter the dynamics of land use. We thus only touch lightly on the normative aspects of land system change. We concentrate on processes in agriculture and forestry, but many theories discussed here have been used for other dynamics, such as urban land uses.

Our objective is to articulate how middle-range theories can contribute to understanding land system change by:

(i) Reviewing the different theories explaining changes in land-use extent and intensity, and
(ii) Synthesizing them into middle-range theories of higher-level processes of land system changes, focusing on land-use spillovers and land-use transitions as non-linear, structural changes.

Section 2 discusses the role of middle-range theories in relation to frameworks, models, and typologies. Section 3 reviews theories of land-use expansion and intensification. Sections 4 and 5 build on these theories to synthesize middle-range theories on structural changes in land systems. We then discuss further theory development on land systems as social-ecological systems.

2. Theories, frameworks, models, and typologies

Different epistemologies have distinct visions of what a "theory" is. Here, a *theory* is defined as a general explanation or stylized facts about events, phenomena, or their attributes (e.g., spatial or temporal patterns), based on a set of factors and their causal relations. The term "*middle-range theory*", originating from social sciences, describes a process developing from observations and analyses of a specific event or phenomenon, building towards explanations of sets of similar phenomena, which can be progressively expanded to other phenomena presenting similar characteristics or linked to other mechanisms present in other theories (Merton, 1968). Here, we define middle-range theories as *contextual generalizations that describe chains of causal mechanisms explaining a well-bounded range of phenomena, as well as the conditions that trigger, enable, or prevent these causal chains* (Meyfroidt, 2016). Middle-range theories seek to balance generality, realism, and precision across the breadth of explanatory factors mobilized, to reach a middle ground between ad hoc explanations of singular cases and "grand", universal systems theories that explain all features in a stylized way (Levins, 1966; Hedström and Udehn, 2009; Hedström and Ylikoski, 2010). In contrast with grand theories, which are posited to apply to a very wide range of phenomena, middle-range theories tend to have a narrower focus and application and should be explicit about the processes it aims to explain and the limits of its reach. Over time, middle-range theories can expand their reach or be combined with each other, as the underlying mechanisms that join them are better understood. Multiple disciplinary and interdisciplinary middle-range theories have been proposed to explain land system changes (SI Appendix A, see Sections 3–4–5).

Middle-range theories can be distinguished from other generalization approaches including conceptual frameworks, models, and typologies. *Frameworks* are a collection of concepts considered as relevant for analyzing a phenomenon, which constitute lenses for looking at reality and boundary objects for inter- and transdisciplinary communication (McGinnis, 2011). They provide checklists of variables and components to include in theories, and indicate the assumed structural relations between these building blocks. In contrast with theories, these