Supplementary Materials: How Are Feedbacks Represented in Land Models?

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Table S1. An overview of reviews concerning feedbacks in land systems.

Authors & Year	Conclusions and Challenges Concerning Feedbacks
Agarwal et al. 2002 [10]	To incorporate social processes in modelling land use change; To tackle scale mismatch that occurs when the physical scale of an ecological system varies substantially from that of the decision making; To link biophysical and social models by valuing social economic and environmental systems with the metric of money is problematic.
Parker et al. 2003 [32]	To balance the utility of abstraction against the need to include the critical components of the system under study; To build an experimental frame that can be used to answer questions of interest to multiple disciplines; To unify models that may operate at different spatial and temporal scales.
Bousquet and Le Page 2004 [33]	To better model to decision-making and learning processes and to study the different forms of organization and interactions among different levels; To exploit the concepts of natural and social sciences on the systems of interactions between agents and their environment; To develop a new approach focusing more on the interactions between ecological and social components and taking into account the heterogeneity of these components.
Hare and Deadman 2004 [34]	To couple social and environmental models using spatially explicit environments; To represent decision making that captures local social adaptation, which can be feedback loop between activities of the agents and particular parts of the environment.
Heistermann, Müller, and Ronneberger 2006 [35]	To explicitly address scaling issues; To include feedbacks between society and environment in integrated land-use modeling; To identify suitable access points for model coupling under a transparent structure.
Matthews et al. 2007 [36]	Agent-based land use models can link social and environmental processes to provide a way of studying human-ecosystem relationships to manage coupled human-environment systems.
Schaldach and P riess 2008 [37]	To develop a deeper understanding of feedback effects on the model behaviour; To balance the attention on agricultural and urban land use change processes as drivers for environmental change; To incorporate forest and water management and their effect on the environment.
Luus, Robinson, and Deadman 2011 [38]	To represent the influence of ecosystem services on land use decision-making, not limiting to the observed environmental changes; To couple or integrate ecological models and ABMs so that feedbacks between them are reflective of real-world feedbacks between human decisions and ecological change; To match spatio-temporal resolution of model components and processes; To ensure an optimal level of complexity. For example, full (bi-directional) feedbacks increases computational intensity and requires additional processes to be modelled.
Schlüter et al. 2012 [39]	To abstract from the target system to include just enough detail, to choose the system boundary, variables, processes, and the level of aggregation that suit the research question; To study SESs as codynamic or coevolving systems by addressing the coevolutionary processes between them.
An 2012 [40]	To develop more process-based decision models to understand coupled human natural systems.
Meyfroidt 2013 [41]	Social-ecological feedbacks are mediated by environmental cognitions; Agents' re-evaluation of their beliefs, values, and functioning, and these metacognitive capabilities are crucial to understand adaptation to nonlinear and rapid environmental changes and land use transitions; Developing models that include explicit environmental cognitions of the agents should help to endogenize social-ecological feedback loops in theoretical and empirical models. Challenges: To quantitatively measure and link environmental changes and changes in ecosystem services, the cognitive features that are part of the perception, interpretation, evaluation, and decision steps, and the actual behaviors and land use practices. Future works should analyze how land use decisions differ from other environmental decisions in the role of environmental cognitions.
Filatova et al. 2013 [31]	The models that truly tackles two-way linkages between submodels, in terms of feedback mechanisms, are still under way; Challenges: To couple socio-demographic, ecological, and biophysical models; To capture spatial heterogeneity of inputs and outputs across multiple spatial scales.
Michetti and Zampieri 2014 [42]	IAMs (Integrated Assessment Models) and ESMs (Earth System Models) are skilled to frame existing feedbacks between land use and economy, and land cover, climate and other physical processes; More collaboration is required to frame feedbacks and interdependencies between society, economy and the environment within one comprehensive and robust global-to-local framework. Challenges: To tackle the mismatch between temporal dimension of the economic and political system and that of natural cycles; To tackle the mismatch between spatial resolutions of the land use change and that of the climate effects.
Rounsevell et al.	To better conceptualise the alternatives for upscaling land use and land cover change models from

2014 [43]	the local to global scale. This involves better representation of human agency, including processes such as learning, adaptation and agent evolution, formalising the role and emergence of governance structures, institutional arrangements and policy as endogenous processes and better theorising about the role of teleconnections and connectivity across global networks.
Filatova et al. 2016 [44]	To represent feedbacks between social and environmental systems in couple SES; To represent various complexity aspects such as scales, nonlinearities, and thresholds; To detect regime shift. Specific: The absence of quantitative data on interactions and social influence; To represent changes in model ontology such as agent classes, structure of relationships and feedbacks among them.