Land Use and Cover Change
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Introduction

Land use and cover change (LUCC) is the study of land surface change. Land use (such as agriculture, pasture, or plantation) describes human use of land, while land cover (such as forest or desert) describes the biophysical characteristics of the land surface. Land use change may affect land cover, while changing land cover may similarly affect land use. Research on LUCC is essentially of multidisciplinary nature, attracting scientists from a range of fields, including but not limited to economics, sociology, geography, GIScience (geographic information systems [GIS] and remote sensing in particular), and demography. More than twice as much land globally (over 30 million square kilometers) is in use as pasture and grasslands relative to agricultural land. The majority of the latter is cultivated in crops to feed livestock or to fuel engines rather than to feed humans. While the most-suitable agricultural lands tend to be among the first wildlands converted to agriculture, increased agricultural expansion usually entails diminishing returns on agricultural yields. With agricultural land per capita decreasing in many parts of the world, despite increasing demands for food, fuel, and fiber, LUCC remains the most salient expression of human occupation across the earth’s surface. How many people, living where, eating and consuming what, and produced how and where describes the vast majority of these human-inscribed landscape dynamics. This article begins with several sources that provide General Overviews of LUCC, and highlights several of the primary Journals publishing LUCC research. The remainder of the article divides the field into four broad sections: Patterns and Processes, Impacts and Responses, Modeling, and Synthesis. This division closely follows prior reviews of the field (see General Overviews).

General Overviews

The research plans of the joint projects of the International Geosphere Biosphere Programme (IGBP) and International Human Dimensions Programme on Global Environmental Change (IHDP) have greatly influenced LUCC research since the early 1990s. These reports are an excellent starting point for readers interested in a general overview of LUCC research. Turner, et al. 1995, in the science plan for the IGBP/IHDP joint LUCC project, outlines the research agenda for the LUCC project and describes the links between LUCC research and existing physical and social-science research programs. Lambin and Geist 2006 is a summary report done at the conclusion of the LUCC project. Lambin and Geist introduce the report by arguing that the community is approaching an “overarching theory” of LUCC. Following the LUCC project, another joint IGBP/IHDP project was initiated, the Global Land Project (GLP). The science plan for the GLP project (GLP Transition Team 2005) provides an introduction to the state and direction of LUCC research in the early 21st century, while the subsequent periodic reports of the GLP provide readers with a more focused look at important topics in LUCC research. Geist and Lambin 2002 describes the “proximate causes and underlying drivers” framework for understanding tropical LUCC, which has been highly influential. Turner, et al. 2007 discusses the emerging field of “land change science” and its role within the broader field of research on global environmental change, providing an overview of the current state and future directions of LUCC research. A number of books also provide overviews of LUCC research. Meyer and Turner 1994 provides a comprehensive overview of LUCC research just prior to the initiation of the IGBP/IHDP LUCC project. Two edited volumes, Singh, et al. 2001 and Gutman, et al. 2004, provides a bird’s-eye view, and status quo, of LUCC research, with a focus on linking LUCC data with socioeconomic and other processes on the ground and envisioning the corresponding consequences on human-environment systems. Giri 2012 is relatively more technical, focusing on remote-sensing methods and applications.

This seminal paper established the framework of proximate causes and underlying drivers for understanding tropical deforestation. Proximate causes are “local-level” activities directly responsible for forest cover change, while underlying drivers are “fundamental social processes . . . that underpin the proximate causes” (p. 143). A must-read for anyone working in LUCC research.


This book presents the state of the art, and new frontiers, in methods and techniques in LUCC characterization, mapping, and monitoring using remote-sensing technology, with empirical examples at multiple scales. This book could be used as a textbook or reference for upper-division or graduate students and experts in remote sensing.


This document outlines the goals and science plan for the GLP carried out by the IGBP and IHDP, as successor to the LUCC project (see Lambin and Geist 2006). The goal of the GLP is to focus on three areas: LUCC dynamics, LUCC consequences, and “integrating analysis and modeling for land sustainability” (p. 9). See the annual reports of the GLP for additional information online.


This book, a synthesis of a set of NASA-funded projects under the Land-Cover and Land-Use Change Program, brings together detailed case studies, regional analyses, and globally scaled efforts on mapping LUCC and understanding its driving forces and broad consequences. It is appropriate for students, land change scientists, and policymakers.


This report documents the results of the LUCC project carried out jointly by the IGBP and IHDP. In their introduction to the report, Lambin, Geist, and Ronald Rindfuss argue that researchers are approaching an “overarching theory” of LUCC “that explain[s] change in the behavior of people as well as land-cover/use change” (p. 7).


The edited proceedings of the 1991 Global Change Institute meeting (seventeen chapters), this is a good resource for an overview of LUCC research in the early 1990s, prior to the advent of the IGBP/IHDP projects. The three tutorial chapters on LUCC data analysis and modeling tools are helpful to researchers interested in technical details.

This book represents a compilation of twenty-four research articles presented at a special seminar in 1999. With goals to monitor LUCC and to “socialize the pixel” (link such changes to socioeconomic and geographic processes), this book covers a wide range of geographic regions and technical/modeling applications.


This paper presents the field of “land change science” and reviews the state of the field within four broad topic areas: “observation and monitoring; understanding the coupled system—causes, impacts, and consequences; modeling; and synthesis issues” (p. 20666). This article uses a modified version of this framework to structure its discussion of LUCC.


This report documents the research agenda for the IGBP and IHDP LUCC project. This project defined LUCC research for much of the next decade and culminated in a pivotal 2006 report (Lambin and Geist 2006).

### Journals

LUCC papers are scattered across many journals because of the multidisciplinary nature of LUCC research. A major journal is *Journal of Land Use Science*, which publishes papers related to LUCC in a relatively comprehensive way. *Land*, started in 2012, also focuses specifically on issues associated with LUCC. Policy-oriented papers are found in *Land Use Policy*. Many journals are publishing papers related to, but with emphases on different dimensions of, LUCC research. When dealing with LUCC and its relationships with (e.g., impact on) the environment and ecological systems, journals such as *Agriculture, Ecosystems & Environment*, *Landscape Ecology*, and *Ecology and Society* are excellent resources. When connecting LUCC to management and planning, readers can refer to *Journal of Environmental Management*, and *Environment and Planning B*.

*Agriculture, Ecosystems & Environment.*

This journal publishes scientific articles related to the interface between agroecosystems and the natural environment—in particular, how agricultural practice (e.g., land use) influences the ecosystem or environment (where land cover is an integral part), and how changes in that environment may affect agroecosystems in return.

*Ecology and Society.*

This online multidisciplinary journal focuses on ecological, political, and social foundations for sustainable social-ecological systems (LUCC is an essential component of such systems). Papers published in this journal could focus either on theoretical development or empirical applications.

*Environment and Planning B.*

This journal, with emphasis on generating and evaluating optional plans and policies, is an ideal venue for research papers
about planning-and-design methods, models, and theories to solve spatial problems (e.g., those related to LUCC).

*Journal of Environmental Management.*

This journal publishes original research papers that deal with all aspects of environmental management, among which human-managed use of the natural or man-made environment (e.g., land use) is of high priority.

*Journal of Land Use Science.*

Publishes original research on “the nature of land use and land cover, their changes over space and time, and the processes that produce these patterns and changes can be termed ‘land use science’” (quote from the website).

*Land.*

*Land* is an open-access journal begun in 2012 that focuses on “land resources and soil science” broadly defined, including rural and urban LUCC, and land use economics, management, change, and degradation.

*Landscape Ecology.*

This journal seeks to promote understanding of the mutual relationships between spatial patterns (often affected by land use decisions) and ecological processes (intrinsically linked to land cover). The journal aims to provide resources on how to develop and maintain sustainable landscapes.

*Land Use Policy.*

*Land Use Policy* focuses on policy issues associated with rural and urban land use. A good source for works oriented toward environmental management, land use economics, and development.

**Patterns and Processes**

Researchers monitor and analyze the patterns and processes of LUCC by using a range of approaches. Landscape pattern is often measured using satellite imagery or field surveys. As satellite sensor technology and mapping techniques continue to develop, more and more highly detailed maps of LUCC are becoming available, allowing analysts to track LUCC from local-continental scales. Social surveys, field mapping, and national census data are similarly used to track LUCC and social processes at a range of scales. By linking these population and environment data sets with LUCC maps and imagery, researches strive to gain insights on linkages among the patterns and processes of LUCC. Much research has focused on agricultural expansion, which remains a key driver of LUCC throughout the developing world. The literature remains undecided as to whether population growth tends to promote agricultural intensification (increased yield per unit of land) or extensification (increase in land area under cultivation). Early-21st-century scholarship suggests that while local factors (demographics, land tenure systems, regional-national economics) can partially determine the effects of population growth on agricultural change, international markets and regional influences are increasing in importance. The literature on LUCC in Latin America has uncovered strong connections among population mobility, agricultural expansion, and LUCC. While LUCC maps from satellite imagery have revealed expansion of agricultural lands in parts of Southeast Asia, some areas of central Asia have seen a decline in agricultural land since the 1990s. Some regions and topics are better represented than others in the LUCC literature. A substantial amount of work has been conducted in Latin America on population and LUCC, particularly in the Amazon on...
linkages between deforestation and agricultural development. Early-21st-century work has also considered ties between LUCC and rural-rural and rural-urban migration in Latin America. Migration and land tenure insecurity have been found to be important factors in LUCC in Africa as well. The major economic changes that have occurred within Asia in recent years are receiving increasing attention in the literature, particularly on the effects of urbanization on LUCC. To gain an understanding of past and current LUCC, the first section reviews LUCC Trends. The next discusses approaches for LUCC Monitoring, focusing on the role of remote sensing in measuring LUCC. Given the strong focus in the literature on links between LUCC and agricultural change, a separate section discusses patterns and processes of Agricultural LUCC in detail. Finally, another active area of research, Migration and Urbanization, is covered.

TRENDS

LUCC researchers have conducted extensive monitoring of past and current trends of LUCC. Much of this work has focused on forest change in the Amazon. Early-21st-century papers suggest that while deforestation in the Amazon continues, reforestation is observable in the data as well. Aide, et al. 2013, for example, examines deforestation and reforestation in Latin America and the Caribbean within the decade prior to its publication, finding that while deforestation predominated, some areas experienced forest recovery. Hansen, et al. 2013 presents the first global map of forest change from 2000 to 2012, at 30-meter (m) spatial resolution, finding continuing high rates of deforestation in the tropics. In the authors’ study, the tropics were the only domain, globally, with a statistically significant trend in annual forest loss, with increasing annual forest loss from 2000 to 2012. Romero-Ruiz, et al. 2012 finds agricultural expansion to be a significant driver of such forest change in Latin America: 23 percent of the land area in the Llanos Orientales in eastern Colombia has transitioned since 1987, predominantly due to the spread of rice and palm oil plantations. Nepstad, et al. 2006 finds that reserves in the Brazilian Amazon “significantly reduced both deforestation [for conversion to agriculture] and fire,” and suggests that reversing deforestation trends requires a greater focus on “the active frontier,” where forests are at the greatest threat. In central Asia, Klein, et al. 2012 find that while forest extent has declined since the early 1990s, agricultural land cover has in some areas also declined, in part due to rural depopulation following the fall of the Soviet Union. Several regional mappings of land use and cover have been produced, in addition to the global mappings of LUCC trends mentioned above. Mayaux, et al. 2004 provides a twenty-seven-class land cover map of Africa at 1-kilometer (km) spatial resolution, while Miettinen, et al. 2012 presents a thirteen-class map of land cover in Southeast Asia at 250 m spatial resolution. A current research focus is on better understanding how global-scale interconnections affect LUCC trends at finer scales. Lambin and Meyfroidt 2011 discusses the complex global dynamics that confound our ability to predict the likely effects of land use policies, making projection of future trends difficult.


Using broad-scale satellite data for Latin America and the Caribbean, the authors undertake a novel method of modeling 2001–2010 deforestation and reforestation dynamics. They determine deforestation outweighs reforestation, highlight hotspots, and pursue drivers with nonparametric regression. This source demonstrates approaches to continent-level land change analysis, discusses connections to local-scale studies and global pressures, and provides current information on forests in Latin America.


This paper presents the first global high-resolution map of forest change at 30 m spatial resolution for the 2000–2012 period. Developed with Landsat 7 imagery, the product has revolutionized forest mapping while demonstrating the importance of high-performance computing in harnessing existing archives of satellite data.

Klein, Igor, Ursula Gessner, and Claudia Kuenzer. “Regional Land Cover Mapping and Change Detection in Central Asia”
Klein, Gessner, and Kuenzer use MODIS satellite imagery to develop a regional LUCC map for central Asia. The authors find that, in Kazakhstan, the forest area decreased by 20 percent from 1995 to 2005 due to logging and livestock grazing, while, following the collapse of the Soviet Union, agricultural land extent declined and grassland extent increased.


This paper discusses the “looming land scarcity” and the complex interconnections that can lead to negative environmental impacts from LUCC, which would at first glance appear to be globally beneficial. The authors discuss several mechanisms through which this might take place, and they suggest that we look to countries that have successfully navigated the land use transition to guide our policies.


The paper presents the Global Land Cover 2000 map of Africa, providing background on previous maps, links to data, details on sources and classification, and recommendations for use.


This paper uses Moderate Resolution Imaging Spectroradiometer (MODIS) imagery (250–500 m spatial resolution, depending on the band) to produce a map of 2010 land cover, with overall accuracy of 85 percent. The final map distinguishes among thirteen cover classes, including lowland and upland forests, plantation/forest regrowth, large-scale palm plantations, open or degraded areas, and areas with a mixed agricultural mosaic.


This paper uses satellite data to compare rates of fire occurrence and deforestation in areas within and outside reserves, national forests, and indigenous lands in the Brazilian Amazon, finding that protected areas and indigenous lands are effective in inhibiting deforestation. The authors argue that indigenous lands in particular play a critical role in stemming deforestation in the Amazon.


This paper uses satellite imagery to map land cover change in the *Llanos Orientales* (Eastern Plains) in eastern Colombia since 1987. The authors find that 23 percent of the area mapped has transitioned since 1987, with the dominant change being establishment of new agriculture. In the 1980s, rice plantations spread throughout the area, while palm oil plantations began to be established in the 1990s.
Several major mapping efforts have addressed the challenge of documenting past and current LUCC. Since the turn of the 21st century, the availability of global satellite data sets has enabled mapping LUCC at a global scale, and these global efforts have in general focused on forest change. DeFries, et al. 2000 produces fractional estimates of vegetation cover at a global scale, while Friedl, et al. 2010 provides annual land cover classifications from 2000 to 2010 at a 500 m spatial resolution. A number of efforts have produced regional LUCC maps, looking in more detail at change in specific cover types. Stibig, et al. 2007 presents a detailed map including the spatial extent of different cropping systems in South and Southeast Asia. In Latin America, Eva, et al. 2004 finds increasing fragmentation in the southeast Brazilian Amazon due to agricultural expansion. In Africa, Brink and Eva 2009 finds a 57 percent increase in agricultural land area in Africa from 1975 to 2000, while Duveiller, et al. 2008 looks in more detail at forest change, estimating the deforestation rate in central Africa at 0.21 percent per year. In contrast to these regional and global efforts, a large number of studies have focused on a local scale, particularly studies focusing on biodiversity conservation and protected-area management. Semeels, et al. 2001 uses coarse- and fine-resolution imagery to monitor LUCC in concentric circles (buffers) around a Kenyan reserve. Curran, et al. 2004 also uses coarse and fine imagery, in this case to map forest loss in Indonesian Borneo, finding that protected areas are insufficient to protect critical habitats.


This paper examines land cover change in sub-Saharan Africa from 1975 to 2000, using estimates derived from Landsat satellite imagery. Brink and Eva find that the main land cover changes are a loss of forest and non-forest vegetation, and an increase in agricultural and barren land, with a 57 percent increase in agricultural land over the twenty-five-year period.


This article uses remote sensing to determine the extent of deforestation in Bornean rainforests. The authors highlight the role of international timber demand in the degradation of protected areas and thus in developing effective protection approaches.


This paper discusses an 8 km global data set of percent woody vegetation, herbaceous vegetation, and bare ground. The paper is important because it presents the first global product representing vegetation as a continuous field. This research laid the groundwork for future efforts, including later products drawing on the MODIS instrument.


Duveiller and colleagues use systematically distributed Landsat extracts to estimate the rate of central African deforestation at 0.21 percent per year, and that of forest degradation at 0.15 percent per year. Although the study aimed to compare forest change in the interior with more heavily populated coastal areas, persistent cloud cover increased the error along the coasts.

This paper uses a range of satellite sensors to map land cover in the South American continent in 2000. When the authors compared their 2002 map to prior data, they observed increasing fragmentation in the southeast Brazilian Amazon due to expansion of agriculture and settlements. Similar fragmentation was observed in the Brazilian cerrado and caatingas, and in Argentina, Bolivia, and Venezuela.


The MODIS Global Land Cover Type (GLCT) product, which has now been refined over several iterations, offers a globally consistent mapping of LUCC. While the product itself has important applications, the techniques used for developing the multitemporal GLCT classification have also seen broader application in the remote-sensing community.


Using an approach combining imagery of different spatial and temporal resolutions, the authors separate changes from year-to-year variation and land conversion, identifying rings of change around a reserve in Kenya.


This paper uses SPOT-VEGETATION imagery (1 km spatial resolution) from 1998 to 2000 to map land cover in South and Southeast Asia. The detailed regional map identifies twenty-six cover classes, allowing identification of different cropping systems and forest types. The overall accuracy of the map is on the low end (72 percent) due to the high degree of detail and the large area covered.

AGRICULTURAL LUCC

Much research has focused specifically on agricultural LUCC, given the importance of agricultural land use as a driver of global change. For background on the challenges of linking patterns and processes of LUCC, the introduction to a special issue of Agriculture, Ecosystems & Environment (Nagendra, et al. 2004) is a good starting point, and the papers in the special issue present several methods of tackling these issues. Much research on LUCC has focused on the Amazon and on associations between agricultural development and forest loss. There is a substantial literature on demographic change and deforestation (also see the papers in Migration and Urbanization). The focus is generally not on population size as a driver of LUCC per se, but rather on how household characteristics and livelihood strategies influence land use. Walker, et al. 2000 considers the process of deforestation due to cattle ranching in the Brazilian Amazon, finding that the local labor market can strongly influence forest clearance by households. Ludewigs, et al. 2009 also finds complex relationships between population and agricultural change in newly settled areas of the Amazon. The role of international markets for agricultural products in stemming/spurring deforestation is another area of active research. In Argentina, Zak, et al. 2008 finds that international trade has led to continued land conversion to agriculture, even as rural areas depopulate. Soares-Filho, et al. 2006 analyzes a range of policy scenarios in the Amazon, forecasting deforestation under each scenario and finding that “expanding market pressures” are necessary for conservation success in the Amazon. Another area of active work is on the potential for land systems that might improve agricultural livelihoods while also combating forest loss or increasing resilience to environmental change. An ongoing challenge in African agriculture, reviewed in Sanchez 2002, is dealing with declining soil fertility caused by continued cropping with insufficient fertilizer inputs. Opening new lands to cultivation (often at the expense of forests) is one solution to this problem, but new techniques can compensate for the lack of chemical fertilizers. Garrity, et al. 2010 discusses promoting the intercropping of trees with annual crops to improve crop yields in Africa. Dennis Garrity and colleagues argue that intercropping
could reduce deforestation by extending the useful life of existing agricultural lands. Sensitivity of agriculture to environmental change is another large body of research. Seo 2010, for example, examines the effects of climate change on Latin American agriculture, finding that income losses of 4–8 percent are likely. More research is needed to understand the implications of this loss of productivity on agricultural LUCC better.


This paper discusses “evergreen agriculture”—the intercropping of trees with annual crops. Evergreen agriculture can improve crop yields by providing year-round vegetative cover and by maintaining soil nutrients and soil structure. The higher yields possible with evergreen agriculture can also reduce deforestation because boosted smallholder crop production can lessen the need for farmers to bring new land under cultivation.


Ludewigs and colleagues use satellite imagery and household interviews to track LUCC and demographic change in three colonization areas in Brazil. The authors find the dynamics of agrarian change in Brazil are complex, and that newly colonized areas can develop in unexpected ways as new farmers adapt to changing conditions and evolving policies.


The introduction to a special issue of *Agriculture, Ecosystems & Environment*, this paper introduces the issue of linking patterns of LUCC to process. Though not specifically focused on agriculture, agricultural LUCC is a recurrent theme in the issue. This paper, and the others in the special issue, are required reading for those interested in linking patterns and processes of LUCC.


This paper finds that depletion of soil fertility has led to low crop yields in Africa, even with increased access to improved crop varieties. Sanchez argues that low-cost changes in land use systems, such as interplanting of legumes and transfers of leaf biomass to fields prior to planting, can replenish soil nitrogen and improve crop yields.


This paper examines the effect of land (soil, elevation, flatness) and climatic factors on choice of farming system in Latin America, focusing on the likely effects of climate change on farming systems. In warm areas, integrated systems (livestock and crops) predominate, while with increased rainfall, farmers tend to focus on crops alone. Climate change is expected to lead to income losses of 4–8 percent.


This paper determines that protected areas are not enough to preserve the Amazon, on the basis of deforestation projections. Reserve networks, private land, and market incentives are presented as key components of conservation strategy.


This paper discusses deforestation associated with cattle ranching in the Brazilian Amazon. The authors find that both small- and large-scale cattle ranchers are associated with forest clearing, but that large landholders are primarily responsible. The unique additive-modeling framework used in the paper is also notable.


This paper finds that since the 1970s, 80 percent of the undisturbed Chaco forests of central Argentina have been converted to cropland, accompanying centralization of land ownership and rural depopulation. The authors find that the primary proximate cause of the observed deforestation is increased soybean cultivation, driven by international trade and enabled in part by favorable climatic change in the region.

MIGRATION AND URBANIZATION

Migration (internal and international) and LUCC is a highly active area of research. An emphasis on environmentally induced outmigration that peaked in the early 21st century has tempered more recently. Gray 2009, for example, shows that while environmental change can affect migration behaviors, the data are mixed. The effects of in- and out-migration on LUCC, particularly on deforestation in the Amazon, has received substantial attention. Aide and Grau 2004 argues in favor of “forest transition theory,” the idea that ecosystems will tend to recover due to rural land abandonment following agricultural intensification and subsequent rural-urban migration. The behavior of rural-rural migrants is also a determinant of LUCC. Carr 2008 demonstrates this in showing that a range of household- and individual-level factors influence land clearing among in-migrant groups in a conservation zone in Guatemala. Unruh, et al. 2005 finds that new in-migrants in Zambia with low perceived tenure security clear far more land than needed for immediate use. Reid, et al. 2000 uses a local-scale case study in southwestern Ethiopia to examine the interactive effects of population pressures and land tenure on LUCC. The impact of out-migration on origin communities is one area needing further research—de Sherbinin, et al. 2008 notes that exploring the impact of migration (and remittances) and of the diffusion of cultural and fertility norms in migrant-origin communities is an important research area to connect LUCC with globalization. LUCC researchers have much to add to an understanding of the effects of urbanization on people and places. As Seto, et al. 2012 notes, urbanization has the potential to alter the global carbon balance drastically, threatening key biodiversity hotspots. Weng 2002 provides another example of how satellite imagery can be used to monitor LUCC accompanying urbanization.


Aide and Grau argue that rural-urban migration and agricultural intensification should be encouraged in Latin America to combat ecosystem degradation. Noting past research on ecosystem recovery following the abandonment of agricultural land due to rural-urban migration, they suggest rural-urban migration and agricultural intensification may allow simultaneous increases both in gross domestic product (GDP) and food production while maintaining biodiversity and forest cover.

Carr argues that the effects of rural-rural migration and frontier agricultural settlement on LUCC are not adequately addressed by “conceptual LUCC models framed in proximate and underlying causes” (p. 233). Policies must take into account the local context (including size of land holdings, and demographic factors) to be successful in stemming deforestation due to frontier agricultural settlement.


The findings of the population-environment literature are relevant to LUCC researchers, given the strong links among household- and individual-level decision making and LUCC. This paper reviews findings from this literature, focusing on studies that relate “environmental variables” and “fertility, migration, morbidity and mortality, and lifecycles” (p. 38). Of particular interest to those new to the field, four specific suggestions for future research are included.


This paper uses an individual-level data set from rural Ecuador to examine the effects of land ownership and land quality on migration. The author finds that while some types of migration are influenced by variations in land quality or environment, environmental degradation does not always lead to out-migration. Important reading for those interested in theories of environmental out-migration or “environmental refugees.”


This paper examines LUCC in southwestern Ethiopia by using a combination of social and environmental data, finding that at the local-regional scale, change in cropland area is related to many factors, including population pressures, land tenure, and disease. The authors argue that these local-landscape-scale processes, not just higher-level trends from remote sensing, must be accounted for to structure interventions that affect LUCC.


This paper examines the global effects of urbanization on biodiversity and carbon emissions, finding that substantial losses of biodiversity and increases in carbon emissions are expected given current estimates of population growth. The authors suggest that given the rapid LUCC already occurring due to urbanization, policymakers must act fast to avoid “lock-in” of inefficient technologies and infrastructure.


Unruh, Cligget, and Hay examine the clearance of land for agriculture by in-migrants in southern Zambia. The authors find that
new residents unfamiliar with land tenure systems tend to clear their entire land allocations, regardless of their immediate needs for agriculture. Therefore, while land rights are important in stemming deforestation, the perceived security of land rights can be even more important.


Weng uses Landsat imagery to document the conversion of cropland to urban land and horticulture in the Zhujiang delta in China over the 1989–1997 period. The study, which finds LUCC rapidly though unevenly occurring as the region urbanizes, is an example of the utility of using satellite data to feed relatively simple LUCC models for monitoring urbanization.

Impacts and Responses

As with the patterns and processes of LUCC, the impacts of LUCC can be complex and difficult to quantify in their particulars. Just so, developing responses can be challenging due to the time scales involved in seeing impacts and the intricacies of effects and unforeseen connections. Although not explicitly addressed here, telecoupling (see Synthesis) can tie processes and impacts, changing how a system may exhibit or respond to LUCC dynamics. The impacts can relate to habitat change and effects on biodiversity or behavior. Other impacts can be to alter forest regimes, the results of which may not always be negative or expected, as discussed in some of the following sources. In addition, researchers must consider that land cover changes may not necessarily result in significant land use changes, and vice versa. Quantifying and modeling this is discussed in Modeling. Shifting cultivation can be a response to land cover change and can create further impacts. Much of the discussion on the effects of shifting cultivation is inconclusive, and many responses to approach conservation have been implemented and discussed. A major category of response is that of protective regulations. Local, regional, and national bodies have established protected areas as a model for conservation and, in part, in response to the effects of LUCC on biodiverse regions. A variety of approaches to protected areas exist depending on their scale, purpose, strictness of definition, and designated uses, such as whether they allow the collection of non-timber forest products (NTFPs). More recently, some protected areas address conservation and local economic development in a combined people-and-parks approach, some by incorporating ecotourism or payments for ecosystem services programs. This may sometimes relate to improved economic status around those areas, but this is not always the case. Furthermore, the degree and strength of community involvement in management can be a factor affecting success of projects. In terms of ecological integrity, the efficacy of protected areas has been called into question in some areas. In addition, forest dynamics within and around protected areas have been shown to be more nuanced than previously thought. Demographic and economic factors also play a role. This section will highlight the impacts of and responses to land change, encompassing Ecological Effects, Shifting Cultivation, Forest Transition, Conservation Approaches, and Conservation Efficacy.

ECOLOGICAL EFFECTS

Burgess, et al. 2007 addresses spatial relationships between humans and biodiversity, identifying overlap on mountainous regions in Africa. Miller, et al. 2004 probes land use dynamics within protected areas in Colombia, focusing on a globally endangered primate species and uncovering patterns of fragmentation and deforestation. Vester, et al. 2007 examines the main reserve in Mexico, finding challenges to conservation. Taking a broad perspective, Zhao, et al. 2006 reviews the literature on the ecological impacts of LUCC in Asia, including new national policies to combat deforestation and soil loss due to agricultural land use. Perz 2004 considers the effects of diversified farming strategies on LUCC, and Valentin, et al. 2008 finds that continuous cropping can lead to higher soil loss than shifting cultivation.


Burgess and colleagues find a link between population density and species richness in three African tropical mountain areas, raising the question of potential conflict and the need for improved protection in terms of protected-area effectiveness and networks. The authors include hotspots and priority regions, among other approaches, in a discussion of threat and priority determination.


This source addresses fragmentation of protected forest areas and its impact on a primate species in Colombia. It finds extensive degradation of habitat and highlights the need to consider local livelihoods in environmental protection.


Using data from a household survey carried out in the Brazilian Amazon, Perz finds that agricultural diversification is associated with higher income in farming households, without significant decline in forest cover. This implies diversification is partially “compatible” with conservation because farming households could increase production through diversification without increasing deforestation. Diversification is not fully compatible with conservation, since it does not directly reduce deforestation.


This paper summarizes the results of a study of the effects of rapid land-use change on hydrology, drawing on data from twenty-seven catchments in Southeast Asia. The authors find that shifting cultivation with long fallow periods (eight years or more) does not increase soil loss, though continuous annual cropping and conversion of degraded upland areas into rice or orchards can greatly increase erosion.


This source combines remote sensing with field measurements of forest structure and butterfly diversity in analysis of the efficacy of Mexico’s biggest reserve. Concerns raised include ecologically appropriate boundaries, the role of dispersal in maintaining diversity under fragmentation, source-sink dynamics, and the variable nature of land change around reserves.


Zhao and colleagues review the literature on the rapid land-use change in Asia that has occurred with agricultural extensification and intensification since 1700. While significant challenges remain, the authors note that progress has been made in policies to combat deforestation, soil loss, and pollution in Asia, such as the Natural Forest Conservation Program in China, and new national strategies in the Philippines, Mongolia, and Japan.
SHIFTING CULTIVATION

The relative effects of alternative cropping systems on LUCC is one area that has received much attention in the literature, with a major focus on the ecological effects of shifting cultivation, particularly in Africa and Southeast Asia. Devendra and Thomas 2002 provides a detailed overview of smallholder farming systems in Asia, presenting context for the debate in the literature on the role of shifting cultivation in promoting land degradation in Asia. Bellassen and Gitz 2008 considers the potential of “compensated reduction” (CR) programs to make forest preservation profitable in Cameroon (CR programs providing a financial incentive for forest preservation under international carbon-reduction treaties). Other researchers have examined the conditions necessary for transition from shifting cultivation to sedentary agriculture, such as in Rasul and Thapa 2003. There is an ongoing debate in the literature on the impacts of shifting cultivation on soil erosion and land degradation. Earlier literature such as Douglas 1999 suggests that shifting cultivation with short fallow lengths can lead to soil loss, but Lestrelin, et al. 2012 does not find this association. Ickowitz 2006 argues there is no evidence that fallow lengths are shortening in tropical Africa, and that shifting cultivation is not promoting deforestation there. The authors of Zhang, et al. 2002, however, use a computer model to examine projected deforestation rates in central Africa under a range of population growth scenarios, finding that shifting cultivation increases deforestation rates by 1.3 percent annually.


This paper computes the carbon price at which the economic returns from forest preservation would equal those of shifting cultivation in Cameroon. The authors find that at a relatively low price ($2.85 per ton of CO₂), setting aside forested land for compensation under a CR scheme could be more profitable than shifting cultivation.


Devendra and Thomas give a broad overview of the types of smallholder farming systems prevalent in Asia. The authors note that rain-fed irrigation predominates across the continent, and that much potential exists for increased production in these areas with more widespread use of irrigation. Rice production using shifting cultivation predominates in upland Southeast Asia, where it has been associated with deforestation.


Douglas examines the impact of forest disturbance and land cover change on hydrology in Southeast Asia. Though shifting cultivation with long fallow lengths has little impact on soil retention, land degradation can occur under shifting cultivation with short fallow lengths and longer periods of continuous cultivation (three–four years). More work is needed to scale up hydrological studies to the catchment level.


Examines “the particular narrative” (p. 600) that shifting cultivation has led to deforestation in tropical Africa due to declining soil fertility accompanying decreasing fallow lengths. Ickowitz argues that existing data do not show any evidence of this decline in fallow lengths, and that fallow lengths in general have always been highly variable in tropical Africa. An alternative narrative, however, is not identified.

Uses a case study in Laos to cast doubt on the idea that shifting cultivation in upland areas is a dominant driver of soil erosion, resulting in sedimentation and siltation in lowland areas. The field evidence suggests that land degradation in Laos is more closely related to land shortage and declining soil fertility accompanying intensified shifting cultivation.


Examines the transition from shifting cultivation to sedentary agriculture in South and Southeast Asia, finding that the transition requires a combination of secure land rights, physical infrastructure to enable commercial agriculture, and “support services such as extension, credit and marketing” (p. 505). The transition has been variable across South and Southeast Asia due to regional variation in access to these supporting structures.


Uses a computer model to project LUCC in central Africa from shifting cultivation under a range of possible scenarios of population growth. Given their model results, which project increased deforestation rates in the near future, the authors suggest that agricultural intensification is required in order to slow deforestation from shifting cultivation.

**FOREST TRANSITION**

Farley 2007 points out the importance of considering prior land cover in making land use policy, such as those designed to provide ecosystem services, since certain land types may provide more carbon and water storage than forest conversion does. Looking further at land responses to policy, Peterson, et al. 2009 provides a methodological example of land change modeling in Russia, also interpreting change rates and connections to policy and highlighting Russian forests. Fehse, et al. 2002 also questions assumptions by exploring biomass at high altitudes for carbon sequestration. Lugo and Helmer 2004 examines the value of new forests, and Barlow, et al. 2007 contrasts the value of various forest types. Sodhi, et al. 2010 describes environmental issues with human land use in Southeast Asia, highlighting the need for protected areas. Perfecto and Vandermeer 2010 takes a different tack, arguing that conservationists need to consider a landscape-scale approach, the “matrix quality” model, rather than anticipating that forest transitions will stem forest loss. Redo, et al. 2012, however, argues that forest transition theory can explain observed changes in forest cover in Latin America, but that we need finer-scaled analyses and data.


This paper explores the importance of forest type in the Brazilian Amazon. Barlow and colleagues determine that secondary and plantation forest can be useful for conservation but cannot replace primary forests, and they recommend reserve networks.

Addresses páramo grasslands in Ecuador in relation to ecosystem services provided by tree plantations. Farley points out that forest transition theory needs to address land cover types in an area prior to and during transition. Depending on such factors, forests may not provide the most benefits for carbon or water storage.


Finds high levels of aboveground biomass in high-altitude secondary forests in Ecuador, indicating their potential as carbon sinks; however, the authors also point out the importance of site-specific land cover factors in productivity. Their work raises the question of whether aboveground biomass necessarily decreases with altitude.


Lugo and Helmer analyze the composition of regenerating forests in Puerto Rico, which may increase globally in the future, finding they can be useful and diverse habitat, albeit with significant differences from primary forest.


Proposes the “matrix quality” model as an alternative to the forest transition model (which proposes that agricultural intensification and rural-urban migration will lead to forest and habitat recovery following abandonment of marginal agricultural lands). The matrix quality model advocates a landscape-scale approach accounting for ecological advances such as metapopulation theory, where properly managed agricultural land can provide high-quality habitat within an “agroecological matrix.”


Combining remote sensing, regression, and Markov and cellular automata, Peterson and colleagues explore forest change in Siberia through transition rate quantification and prediction of forest type and extent. They address the importance of Russian forests as well as the role of institutions in the form of various Russian forest management approaches.


Redo and colleagues argue that forest transition (FT) theory can explain observed forest cover changes in Central America, but that FT must more carefully consider subnational trends in cover and sometimes-opposing trends in different forest types. While less developed Central American countries continue to lose forest to agricultural settlement, developed countries such as Panama have gained forest “following agricultural and pastureland abandonment” (p. 8842).

Sodhi, Navjot S., Lian Pin Koh, Reuben Clements, et al. “Conserving Southeast Asian Forest Biodiversity in Human-Modified...
**Land Use and Cover Change**

Sodhi and colleagues review the growth and impacts of deforestation and land use change on a range of groups and ecological processes in Southeast Asia, emphasizing the significant role of mature forests in conservation and encouraging native planting and forest networks.

**CONSERVATION APPROACHES**

Exploring livelihood links to protected areas, Appiah-Opoku 2011 examines ecotourism in Ghana. Shackleton and Shackleton 2004 reviews non-timber forest products (NTFPs) in South Africa, and Mukul, et al. 2010 addresses how NTFPs are used in Bangladesh and the potential for incorporation of NTFPs in conservation. Balmford 2003 reviews research and application efforts around the South African Cape Action Plan for the Environment. Liu, et al. 2003 describes the myriad challenges that protected areas face in China. A contentious policy approach that has been discussed and employed is that of relocating protected-area inhabitants. Nagendra, et al. 2006, addresses this debate, drawing attention to the relatively low impact residents may have inside reserves in India. Chowdhury 2006 analyzes change and drivers in relation to communal lands and suggests conservation sources outside reserves. DeFries, et al. 2010 shows the application of a conceptual approach for incorporating connections between protected areas and their surroundings for planning.


Appiah-Opoku discusses the trade-offs of protected areas and ecotourism for local communities, focusing on dynamics in a park in Ghana and raising the question of realized benefits versus lost access. The author presents a village that may lend insight to developing community ecotourism programs next to protected areas.


Balmford synthesizes and reviews a unique set of papers on conservation research, assessment, planning, and implementation in South Africa. He presents the papers within the flow of the systematic conservation-planning process, gleaning lessons from the real-world experience for researchers and practitioners alike to apply in other situations.


Using remote sensing, surveys, and spatial econometrics, Chowdhury explores land change and sustainable development policy in and around the main reserve in Mexico, emphasizing land transitions on communal land holdings. The author points out the potential role of community involvement in limiting forest loss within the reserve, highlighting the conservation value of communal lands outside the reserve.

DeFries, Ruth, Krithi K. Karanth, and Sajid Pareeth. “Interactions between Protected Areas and Their Surroundings in Human-Dominated Tropical Landscapes.” In *Special Issue: Conservation and Management in Human-Dominated Landscapes: Case Studies from India*. *Biological Conservation* 143.12 (2010): 2870–2880.

DeFries and colleagues put forth the concept of a “zone of interaction” around protected areas to address the larger
socioeconomic and environmental setting affecting reserves. They show its application in Indian reserves, determining that the zone varies and can be multiple times the size of the protected area.

The authors summarize the main challenges to the success of Chinese reserves, with proposed strategies to address them.

In this article, the authors delve into the significant role NTFP collection plays economically for locals around a protected area in Bangladesh. They indicate potential areas of leverage or collaboration on conservation policy development.

The authors address the controversial issue of reserve inhabitants, finding interior villages are comparatively less connected with forest degradation than residents around a reserve in India.

This source reviews the variety of NTFPs used and the extent of their incorporation in rural households of South Africa. They are an essential part of the safety net in local livelihood strategy and need to be acknowledged in conservation policy.

CONSERVATION EFFICACY

In an early contribution to the subject, Ghimire 1994 brings local livelihoods into the discussion of protected areas. A major debate is that of whether protected areas limit and damage local livelihoods. Sims 2010 pursues this, uncovering the opposite in Thailand. Messina, et al. 2006 addresses the relationships among protected areas, policy, and land tenure. Pagiola 2008 further examines conservation policy, with an in-depth look at Costa Rica’s major payments for ecosystem services programs. Liu, et al. 2008 discusses payments for environmental-services impacts on forests and lives in China, focusing on two globally significant forest programs. Struhsaker, et al. 2005 details rainforest loss to human land uses, associated impacts, and challenges for protected areas in Africa. Wynberg 2002 provides a detailed background on conservation policy and implementation in South Africa. The South Africa Cape Plan influenced the undertakings presented in Pierce, et al. 2005, which acts as an example of a systematic conservation-planning assessment and is useful for a range of researchers and planners. The sources provide insight for students, researchers, planners, and practitioners.

This article is a good source for early perspectives on the discussion of protected areas in relation to local livelihoods, focusing on developing countries. It addresses the unique aspects of protected areas in Madagascar and highlights how reserve establishment without accounting for community livelihood strategies and involvement results in losses for the environment and local residents.


This source discusses the background, impacts, and potential improvements of two major forest programs in China, some of the largest payments for ecosystem services programs in the world.


This work uses remote sensing and landscape ecology to look at the influence of policies designed to address tensions between development and conservation in protected areas of the Ecuadorian Amazon. It also encompasses issues of land tenure, road access, and migration on forest protection.


Pagiola examines Costa Rica’s main payments for environmental services program, focusing on the results of its water, biodiversity, carbon, and landscape payments. Costa Rica’s forest dynamics have changed as a result of deforestation, but Pagiola discusses how efforts to determine connections between positive forest trends and environmental services payments remain inconclusive.


Pierce and colleagues present an example of systematic conservation-planning assessment and implementation, providing details and criticism on their process to increase the report’s utility for use in other situations. Planners, researchers, and policymakers could all benefit from this resource.


Sims explores the impact of strict protection on land and locals in Thailand, using poverty mapping and remote sensing while accounting for the influence of park and sanctuary siting. Sims finds a pattern of improved socioeconomic condition with protected areas, pointing out its connection to tourism and accessibility.

Drawing from primary and secondary sources on sixteen African protected areas, Struhsaker and colleagues argue for the importance of large protected areas in conservation. They cover challenges, including migration, enforcement, and support, both governmental and international. They also identify a lack of connection between success and common approaches to community conservation and suggest strategies for improvement, highlighting the role of the international community.


Wynberg provides an overview of conservation approaches and challenges for South Africa, including protected areas, community-based conservation, and uses for biodiversity. She discusses the effects of invasive species on water availability and biodiversity and points out their challenging connections with commercial forestry and subsistence users. This is an excellent resource for a broader picture of major issues and policy.

**Modeling**

Models are important tools in LUCC for assimilating human and environmental data, for testing alternative hypotheses about system structure and function, and for projecting future LUCC. A major concern in modeling is how to establish common and scientifically sound protocols. This is of vital importance for communicating models and results among researchers. It is also essential for relating models and results to the public for policy analysis and development. Major advances have been made in LUCC modeling since the turn of the 21st century. This section looks at some of the major references in this area, focusing first on modeling Approaches. Second, Uncertainty and Accuracy Assessment addresses the topic of uncertainty in LUCC modeling. Finally, Linking Population and Environment discusses techniques for linking human and environment data sets, always a challenge in LUCC research.

**APPROACHES**

Perhaps the best current source on LUCC modeling in general is *National Research Council 2014*, a report on land change modeling. In addition to that report, this section includes examples from the literature of some of the most commonly used LUCC modeling techniques. Mertens and Lambin 2000 uses a unique economic-modeling strategy to consider trajectories of LUCC in Cameroon. Southworth, et al. 2004 considers the importance of incorporating continuous data in land cover classifications used in LUCC modeling. Spatially explicit simulation models have become increasingly common in the literature, and several examples are cited here. Entwisle, et al. 2008, a case study from Nang Rong, Thailand, uses a cellular automata (CA) model, another common approach, to examine how the spatial distribution of settlements influences patterns of LUCC. A good example of Markov modeling from the literature is Brown, et al. 2000, including how to use Markov results in conjunction with standard regression approaches. Agent-based modeling (ABM) usage has grown rapidly in the LUCC community in the early 21st century. An, et al. 2005 demonstrates the potential of ABM for LUCC modeling, in this case focusing on how rural demographic change affects fuelwood consumption, which in turn results in loss of habitat for giant panda in a protected area in China. Verburg, et al. 2006 is a more policy-oriented source, particularly relevant for those interested in modeling approaches for planning applications.


This paper demonstrates the utility of ABM for linking multiscalar data sets to examine linkages between LUCC and population. It describes an ABM relating changing demographics to fuelwood consumption, forest loss, and habitat change of giant panda.
in the Wolong Nature Reserve in China.


Brown, Pijanowski, and Duh use three-date Landsat imagery to develop Markov transition models describing LUCC in the upper Midwest in the United States. This paper introduces Markov LUCC models, including an example of how to develop regression models relating higher-scale covariates to observed transition probabilities.


This paper uses CA to model LUCC change in Nang Rong, Thailand to explore the effects of spatial variation in settlement patterns on LUCC. This is a good example of how simulation models can be used as virtual “labs” to run experiments. This paper is just one of the many from research in Nang Rong—readers are encouraged to explore the other literature from the site.


Mertens and Lambin consider deforestation in Cameroon by using a spatial model of trajectories of land cover change. The paper is unique in using economic models to consider trajectories of change between land classes, made possible by the author’s use of multitemporal satellite imagery.


This document outlines the state of the art of land change modeling. The report discusses alternative modeling techniques and discusses directions for future research. It is a good introduction for readers generally interested in land change modeling approaches, or wanting a better understanding of the current frontiers of land change modeling.

Southworth, Jane, Darla Munroe, and Harini Nagendra. “Land Cover Change and Landscape Fragmentation—Comparing the Utility of Continuous and Discrete Analyses for a Western Honduras Region.” In Special Issue: From Pattern to Process: Landscape Fragmentation and the Analysis of Land Use / Land Cover Change. Agriculture, Ecosystems & Environment 101.2–3 (2004): 185–205.

This article contributes to the discussion of classified and continuous land cover analyses by underlining the gains from a combined approach. The authors employ a complementary approach to address recent calls for continuous data incorporation. They highlight its usefulness, laying groundwork for the future.


Verburg and colleagues address scale and model selection in simulating land change for policy development in the
Philippines. They provide an excellent discussion of the application and interpretation of national-level regression and landscape-level process-based models, contrasting them with other modeling methods.

UNCERTAINTY AND ACCURACY ASSESSMENT

Analysis of the accuracy of and uncertainty inherent in LUCC models is an ongoing research area. The general overview of challenges in land change science in Rindfuss, et al. 2004 contains a good discussion of these issues. Oreskes, et al. 1994 is a classic piece on verification and validation of numerical models, and it provides background on the theoretical question of whether models can ever be validated. Robert G. Pontius has conducted considerable research on verification and validation of LUCC models. Pontius, et al. 2004 reviews such verification and validation, while Pontius and Millones 2011 presents two new measures of accuracy to be used in assessing land use classifications or LUCC model results. Brown, et al. 2005 also presents a novel approach for discussing LUCC model accuracy, reviewing the potential applications of this approach for discussing LUCC model uncertainty, and the appropriate application areas for a given LUCC model. Agent-based modelers will want to see Parker, et al. 2003, which mentions verification and validation of ABMs as a key challenge for that modeling community. In a more applied context, Fritz, et al. 2010 shows how uncertainty in LUCC data sets due to interannual variations in land cover types can affect the data sets used to drive LUCC models.


This paper discusses how to define accuracy when discussing LUCC models, and presents the idea of “variant” and “invariant” regions in LUCC model analysis. This novel idea allows modelers to separate areas in which path dependence can lead to differing final outcomes in a LUCC model (variant regions) from areas in which the final cover type is near certain (invariant regions).


This paper compares four different sources of land cover data for agricultural monitoring, of differing spatial resolutions and from different sensors. The authors find that “uncertainties in the cropland distribution in African countries are very high” (p. 2253). A large source of uncertainty when comparing data sets from different years is due to interannual variation in crop acreage, and continued work is needed in this area.


Though not focused on LUCC, this paper is still a must-read for LUCC modelers, because it is a key theoretical source regarding the verification and validation of models. The provocative first line of the abstract perhaps says it best: “Verification and validation of numerical models of natural systems is impossible” (p. 641).


This paper reviews the challenges and opportunities of ABM for LUCC research. The paper also defines the key concepts of “verification” and “validation” as they pertain to LUCC modeling, in addition to concepts from complexity theory of relevance to modelers. Key reading for researchers getting started in ABM or LUCC research.

The authors raise concerns about the progress in achieving higher-quality land change models, calling for more attention to validation. They provide descriptions and example applications of techniques using null and random models, agreement, and multiple resolutions. This is useful to researchers and students developing models or assessing results.


This paper is noted for its rejection of earlier work (including the author’s own work) on kappa statistics, which are frequently used to measure agreement between predicted and observed land use and cover maps. The authors present two simpler measures—quantity agreement and allocation agreement—to replace kappa statistics.


This article briefly describes the goals and foci of land change science and then provides an excellent discussion of major obstacles and questions that must be addressed for the study of land change to continue improving. This is essential reading for developing sound methodology and contributing to land change research.

**LINKING POPULATION AND ENVIRONMENT**

There are many challenges to linking population and environment in the analysis of LUCC. The 1998 report from a National Research Council workshop (Liverman, et al. 1998) is a good place to start on the topic of using remote-sensing data with social surveys. Moran, et al. 1994 provides an early example of approaches for combining remote-sensing classifications and vegetation data for land change modeling. Fox, et al. 2002 further describes the main challenges and approaches for linking social and environmental data sets. Zvoleff and An 2014 is an overview of current approaches for linking population and environment data sets, discussing the relative merits of alternative tools. Much existing work has focused on the local-regional scales. Carr, et al. 2009 shows how national-level statistics can be used to link population change with LUCC at a broad national scale. Wandersee, et al. 2012 demonstrates one integrated approach for LUCC research, using social surveys and statistical analysis to consider the importance of environmental perception among locals in forest conservation. Approaches drawing on political ecology (see the Synthesis section) also are prevalent in this research area.


This paper explores whether population growth and urbanization in Latin America promote agricultural extensification or intensification. The “results are ambiguous” (p. 242), although the authors note that agricultural extensification has occurred, at the expense of forest cover, throughout Latin America. Though demography affects agriculture, other factors, such as large-scale commercial agriculture, can trump the effects of population growth on agricultural land use.
Synthesis

LUCC research is an inherently interdisciplinary field, drawing on a range of methodological and theoretical approaches. However, the definition of the field has been sharpened in the early 21st century by several major works. Turner, et al. 2007 succeeds in presenting a defining framework for “land change science,” drawing in part on the body of work in LUCC research rooted in complexity theory. Liu, et al. 2013 also draws on complexity theory in the authors’ framework of human-natural systems as being “teleconnected” through space. The global effects of these couplings is demonstrated in Foley, et al. 2005, which presents a global synthesis of the effects of land use practices on ecosystems. One important area of synthesis work in LUCC research is at the intersection of the literatures on LUCC and political ecology. Integrating political ecology and LUCC
research can help in understanding the political-economic structures within which LUCC occurs. Zimmerer 1994 provides an early discussion of major changes in views of ecology within the political-ecology community, and of what those changes mean for connections with human aspects of LUCC research. Turner and Robbins 2008 assesses overlaps in land change science and political ecology, discussing what these mean for sustainability science. Early-21st-century applied examples in this vein include Adams and Hutton 2007, on African protected areas, and Coomes, et al. 2011, on land use and poverty traps. Brannstrom and Vadunec 2013 demonstrates the potential of such integrated approaches, in addition to the inherent challenges.


Adams and Hutton present major points of discussion around protected areas, drawing from numerous African examples to address historical perspectives, community-based approaches, protected-area creation and use, and the concepts of “indigenous” and “natural.” An excellent example of the value of drawing on political ecology in LUCC research, and essential reading for any discussion of protected areas.


This edited volume reflects on “integrating land change science and political ecology” (p. 1). The editors argue that land change science and political ecology are “complementary” and that an examination of the synergies and differences of the two fields will benefit both fields, and particularly research at their intersection. It is an excellent source for researchers interested in integrative approaches to LUCC research.


This article is highlighted as an example of high-quality synthesis work to address land change and political ecology. The approach is that of a combined analysis of households and remote sensing, using long-term data and a fine spatial grain. The authors identify patterns of path dependency that they term “land-use poverty traps” (p. 13925).


This paper describes the relationship between land use and ecosystem change, documenting the widespread degradation of environmental systems due to land use practices. The authors argue that “a middle ground” (p. 573), in which lands are managed to support multiple uses, may be the best pathway to meeting demands such as agricultural production while still maintaining other ecosystem services.


This paper introduces a framework centered on the idea of “telecoupling” between socioeconomic and environmental systems. Telecoupling is the idea of interactions that occur between systems “over distances.” This idea is likely to be central to future research in LUCC, as a means of capturing the increasing interconnection of human and natural systems on a global scale.

This paper, also referred to in General Overviews, is likewise important here due to its presentation of a synthesis framework for LUCC research. The paper presents a structured framework defining work in the field, and it discusses the need to view “land change as a coupled system,” an idea similar to the coupled human and natural systems (CHANS) framework discussed in Liu, et al. 2013.


In this article, Turner and Robbins provide a clear discussion of the backgrounds to land change science and political ecology. The authors use these lineages to explain the overlap of topics but divergence on framing between the approaches. They supply a useful summary and speculate on future possibilities.


Zimmerer compares old (1960s and 1970s) and what were then new (1980s and 1990s) understandings of ecology, highlighting the move toward disequilibria and complexity. He interprets these changes for revisiting approaches to human-environment relationships. The discussion and the obstacles and integrative themes he presents are essential knowledge for students and researchers.