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Land Change Science

Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface

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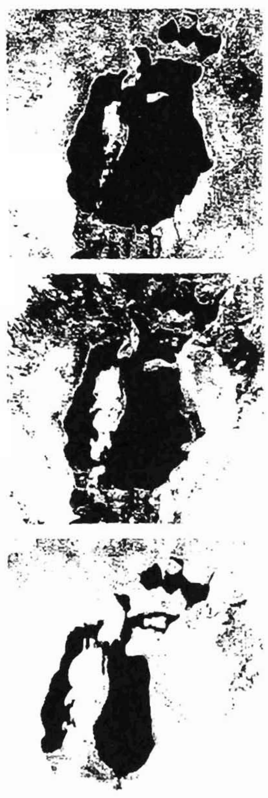

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Kluwer Academic Publishers

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KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN 1-4020-2561-0 (HB)
ISBN 1-4020-2562-9 (e-book)

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Sold and distributed in North, Central and South America
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Technical Editing:
LYNN H.J. HEDLUND
University of Virginia, College of Arts & Sciences, Charlottesville, U.S.A.

Cover Image: Change in the area of the Aral Sea (see also p. 258)

Printed on acid-free paper

Printed in the Netherlands.

TABLE OF CONTENTS

Section III Cross Cutting Themes, Impacts and Consequences

Section IV Methodological Issues, Modeling

Section V Synthesis and Lessons: Biophysical Change and Beyond

CHAPTER 1

THE DEVELOPMENT OF THE INTERNATIONAL LAND-USE AND LAND-COVER CHANGE (LUCC) RESEARCH PROGRAM AND ITS LINKS TO NASA'S LAND-COVER AND LAND-USE CHANGE (LCLUC) INITIATIVE

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1 Introduction

The study of land-use and land-cover change has a long history dating to ancient times. (Glacken 1967)[1] Early concern focused on how human activities transformed and degraded landscapes, a theme that has resurfaced at various times (Marsh 1864; Thomas 1956; Moran 2000) and currently is embedded within the larger concept of global environmental change and earth system science, especially that part addressing land-use and land-cover change (Meyer and Turner, 1994; Turner, Steffen et al., 2002). It is unquestionable that human populations have affected the structure and function of the earth system since their evolution as a distinct modern species (Thomas 1956; Redman 1999), but this impact increased in pace, magnitude, and kind with the advent of the industrial revolution (Turner et al., 1990; Meyer 1996; Steffen et al., 2003). Human-induced changes in the terrestrial surface of the earth have been substantial, especially deforestation (Watson et al., 2001; Williams 2003), and they have affected the delivery of ecosystem services and contributed to altered biogeochemical cycles that control the functioning of the earth system (Steffen et al. 2003). The human imprint on many "natural" conditions and processes is so large that separating the natural from the human not only proves difficult but analytically questionable, especially in regard to terrestrial processes (Vitousek et al., 1997; Clark et al., 2003).

To be sure, land-cover and land-use change is only one component of global environmental changes currently underway, and is superceded by fossil fuel consumption in regard to atmospheric warming (Steffen et al., 2001). Energy use, however, is tightly linked to population and its standards of consumption, and this linkage interacts with socio-political and cultural structures to create pressure on land users to produce more goods and services to meet human demands. The sources of this demand and the location of production to meet it are not necessarily spatially congruent, and large regional differences in access to land and land-based resources exist. It is precisely these kinds of disconnects and discrepancies in land change and its

[1] The literatures documenting our observations of the history of human-environment relationships is very large and its full account beyond the confines of this volume. The few references selected, therefore, serve as guiding examples and are by no means exhaustive.

G. Gutman et al. (eds.), Land Change Science, 1–15.

various consequences that require an understanding of land-use and land-cover change in which its global and local-regional dimensions are connected.

This understanding requires linkages between the biophysical and human dimensions of land cover and land use. Land cover refers to the land's physical attributes (e.g., forest, grassland), whereas land use expresses the purpose to which those attributes are put or how they are transformed by human action (e.g., cropping, ranching). As this volume demonstrates, land cover is visible in remotely-sensed data from satellite platforms, although it requires interpretation and ground-truthing. In general, use of satellite imagery for fine-resolution analysis increases the need for detailed ground-based land-use information. Regardless, land cover and land use are so intimately linked that understanding of either requires a coupled human-environment system analysis. After all, the entire terrestrial surface of the earth is claimed by someone, and significant portions of it are actively managed.

2 The Development of Contemporary Land-Use and Land-Cover Change Science

The science of global environmental change has, arguably, been responsible for the discovery of the rapid and large-scale accumulation of CO_2 in the atmosphere and the concern that this process will trigger global climate changes whose consequences could threaten the planet. Research quickly identified land-use and land-cover changes as a major element of the global carbon cycle, both as source and sink (Moore et al., 1981; Houghton et al., 1983; Woodwell et al., 1983). This role in the carbon cycle turned research interests in land change towards the human alteration and conversion of landscapes, especially forests, agricultural lands, and grasslands, which increased or reduced carbon in the atmosphere. In addition, attempts to balance the carbon cycle identified land cover as a candidate for helping explain the so-called missing carbon sink, with recent evidence pointing to such land changes as the regeneration of forests on abandoned agricultural lands as well as changes in ecosystem production due to longer growing seasons and fertilization by CO_2 and nitrogen (Schimel et al., 2001; Goodale et al., 2002). With these questions as points of departure, the reach of global environmental change research subsequently expanded to include a broad array of human-induced changes in structure and function of the earth system, including ecosystems and their services and biodiversity (Lubchenco 1998; Daily et al., 2000; Raven 2002) in which land change plays a critical, if not fundamental role. Recent evidence points to the importance of regional-to-local climate change as driven by land change (Kalnay and Cai, 2003), and the emergence of sustainability science (Kates et al., 2001; Clark et al., 2003) adds yet another strong interest in land change, with strong policy implications (Turner et al., 2003).

At the same time, there were significant advances in the use of earth observation data and information to support the science of global change and sustainability. Global scale datasets from coarse resolution sensors were making it possible to monitor and measure changes in land cover, including phenology, net primary production (NPP), and other dynamic properties (Justice et al., 1985; Tucker et al., 1985; Sellers et al., 1994; Townshend et al., 1994). Similar advances were made in the use of fine resolution earth observation data for quantification of land cover conversion rates, and to a more limited extent to assess dynamics of land use change

over continental sized areas and at watershed scales (Skole and Tucker, 1993; Skole et al.,1994; Brondizio et al., 1996; Batistella et al., 2003).

Thus, land-use and land-cover change has emerged as one of the key independent themes in the global change, climate change, earth systems, and sustainability research programs. Advances in large-area measurements from remote sensing, increased sophistication of process-level analyses from case studies, and in modeling are evidence of significantly improved capability within the research community. Land change is now recognized as a topic of study in its own right, requiring a concerted and focused program to document and understand its causes and consequences. This intellectual history of the science informs the programmatic or institutional history of land-use and land-cover change.

The institutional history of research programs devoted to land change begins with the recognition by natural and remote sensing scientists engaged with the International Geosphere-Biosphere Programme (IGBP) that understanding land-cover dynamics, be they ecosystem or climate change, was difficult in the absence of a complementary understanding of land-use dynamics. The latter, in turn, required social science expertise as it involved assessing how people made decisions about land. A joint effort among the natural, social and remote sensing sciences seemed the best means of achieving integrated understanding of land change. With this in mind, the IGBP approached the International Social Science Council (ISSC) to put together a "working group" (B. L. Turner II, chair, and David Skole, co-chair) to explore the possibility of creating a joint core project/research program at the international level to be shared between the two entities.

This effort took place in concert with various national and international efforts to broaden global environmental change research beyond climate change per se and to develop a research agenda on the human dimensions of this change. In the U.S., an effort to stake out this agenda was begun in 1989 by a committee of the Social Science Research Council (SSRC) whose deliberations and reports informed the U.S. National Research Council (NRC) and its then newly established Committee on the Human Dimensions of Global Change (HDGC), chaired by Oran Young. At the same time, Harold Jacobson led an effort sponsored by the ISSC that resulted in the creation of an international Human Dimensions Program (HDP), based originally in Geneva, Switzerland, and which later became the IHDP, currently based in Bonn, Germany. Each of these committees staked out a full range of human dimensions issues and potential research programs, exemplified in the NRC's committee volume, *Global Change: Understanding the Human Dimensions* (Stern et al., 1991). Importantly, each of these committees identified land-use and land-cover change as the top priority research topic wherein a joint effort between the natural, social, and remote sensing-geographical information sciences was most likely to pay off in the immediate future.

With this backing the IGBP-ISSC's working group recommended the creation of a core project on LUCC (Turner et al., 1993) and identified the broad course of research that it might pursue. A Core Project Planning Committee (CPPC-IGBP)/Research Project Planning Committee (RPPC-HDP) was established to create a LUCC Science Plan to guide the work, retaining Turner and Skole in chair and co-chair capacities. During this process the international human dimensions program became jointly sponsored by ISSC and the International Council of Scientific Unions (ICSU, subsequently renamed the International Council for Science but retaining the acronym, ICSU), the latter organization the sponsor of the IGBP. This tie facilitated a union of the IGBP and IHDP in supporting LUCC.

To produce the science plan, the CPPC/RPPC held meetings worldwide with different communities of researchers as well as maintaining linkages in the US with the NRC. The LUCC Science Plan (Turner et al., 1995) defined several major science questions which have been central to the joint core project during its tenure:

- How has land cover changed over the last 300 years as a result of human activities?
- What are the major human causes of land cover change in different geographical and historical contexts?
- How will changes in land use affect land cover in the next 50 to 100 years?
- How do immediate human and biophysical dynamics affect the sustainability of specific types of land uses?
- How might changes in climate and global biogeochemistry affect both land use and land cover?
- How do land uses and land covers affect the vulnerability of land users in the face of change and how do land cover changes in turn impinge upon and enhance vulnerable and at-risk regions?

The LUCC project was formally inaugurated by a 1996 Open Science Meeting in Amsterdam, hosted by the Royal Netherlands Academy of Sciences (Fresco et al., 1997). The first LUCC scientific committee was chaired by David Skole and the International Project Office (IPO) was based at the Institut Cartogràfic de Catalunya in Barcelona. During this period LUCC joined the IGBP's Global Change and the Terrestrial Ecosystem (GCTE) project in hosting a joint GCTE-LUCC international science conference in Barcelona in 1998. This well-attended meeting demonstrated the strong potential of natural science, social science, and remote sensing/GIS science communities to create an integrated science of land change and began a process of setting initial priorities for implementation of LUCC. Subsequently, Eric Lambin became the second chair of LUCC, overseeing the formulation of a LUCC Implementation Plan (Lambin et al. 1999) and an enlargement of the project's research objectives outlined in the earlier Science Plan. In 2000 the IPO moved to Belgium with support from the Belgian Government, the University of Louvain-le-Neuve, and IHDP, where it currently resides. The IPO and its three research foci offices (land use dynamics, land cover dynamics, integrative regional and global modeling) galvanize and network land-change research worldwide and undertake synthesis activities (e.g., Lambin et al., 2001; McConnell and Moran, 2001; Geist and Lambin, 2002; Parker et al., 2002).

These planning and agenda-setting activities and the early research projects that were initiated by the research community helped to foster land-change funding programs within agencies and organizations worldwide, in many cases cooperating with IAI (Inter-American Institute for Global Change Research), APN (Asian-Pacific Network for Global Change Research), START (Global Change System for Analysis, Research and Training), and GCTE (global change in terrestrial ecosystems project), among others. In the United States of America, for example, land-use and land-cover change was identified as one of the *Grand Challenges in Environmental Sciences* by the National Research Council (NRC 2001), and NASA developed its own Land-Cover

and Land-Use Change research program (see details in Chapter 2, this volume), taking elements of its Science Plan from the international LUCC programs. The last venture involved the efforts of David Skole (then Chair of LUCC) and Chris Justice (then IGBP-DIS Focus 1 leader) working with NASA officers, and the first phase results of these efforts are addressed in this volume. Land-use and -cover change subsequently began to emerge in other programs, including NOAA and NSF, and with the writing of the science plan for the next decade of the US Global Change Research Program (USGCRP), land-change science was incorporated explicitly as one of the major themes (see below).

The LUCC core project will continue through 2005. Beginning in 2002, an effort began to develop a new generation land-centric project that would merge various other programs of the IGBP, especially those within GCTE, and parts of the IHDP into a new, integrated "Land Project" (see http://www.igbp.kva.se for details on the new IGBP phase II planning). This convergence of interests is motivated by the goal of developing truly integrative research on coupled human-natural systems and producing policy-relevant research that will enhance sustainability and reduce vulnerability of land systems.

3 Insights Gained: Examples

The land-change research community has made considerable progress during the formative stages of the formal international and national programs in question (Turner 2002). Indeed, the number and range of accomplishments are sufficiently large that we make no attempt to cover them in detail here and direct the reader to the in-depth treatment found in the various chapters on this volume which highlight NASA-LCLUC sponsored work in the context of the larger land-change community. Here we provide a brief overview made on three, not necessarily exclusive, research fronts: monitoring and observing land-cover change, land-use and land-cover dynamics, and land-change modeling.

3.1 MONITORING AND OBSERVING LAND CHANGE

Both the international programs and the agency programs in the US recognize the importance of observations. Early in the development of a research agenda, it was clear that data on rates of land-cover change were missing or inadequate to form a basis for more process-driven analysis. One of the critical challenges was obtaining global, consistent measurements of land cover and its change with known accuracy. A complementary challenge for land-use and -cover change analysis was in obtaining large-area observations, at the scale of regions or continents, at the spatial resolution needed to measure fine scale changes associated with such phenomena as deforestation, fire, and degradation. At the same time, significant advances were being made with NASA-supported projects in the area of global land-cover datasets and high resolution regional land-cover change datasets (DeFries et al., 1999; 2000). The IGBP-DIS developed DISCover, a global 1 km resolution land-cover dataset, using a system of coordinated ground station acquisitions and an international consensus effort to define processing and validation methods (Townshend et al., 1994). This precursor effort has led to further development of land cover monitoring using MODIS and other new sensors (Justice and Townshend, 2002; Justice et al., 2002) with their implications for operational land cover monitoring (Townshend and Justice, 2002). The Landsat Pathfinder project focused on developing detailed measurements of rates of forest conversion in the tropics, North America, and in selected case study sites (Skole and Tucker, 1993; Steininger et al., 2001). These initial efforts focused on rather straightforward classification schemes, but provided important early direct estimates of important global change parameters.

Today, the land-use and land-cover change community has made significant advances in moving beyond classification to direct parameterization and measurement of continuous fields (Qi et al., 2000; Hansen et al., 2002). For example, work supported by the NASA LCLUC program produces fractional cover data and global percent tree cover datasets from AVHRR and MODIS, which have important significance for carbon cycle studies. Landsat is used in conjunction with fractional forest cover continuous fields analyses to measure and map forest degradation, hence moving the observational capabilities beyond the early forest-non-forest classification. In addition, important high temporal frequency land-cover changes are also monitored globally, such as fire--an important proximate cause of land-cover change. The community is also backfilling the historical record using tabular datasets from reference sources on distribution of cropland and other land covers (Ramankutty and Foley, 1999; Goldewijk 2001; Goldewijk and Ramankutty, 2003).

While global measurement and monitoring has been the intended goal, both the NASA programs and the research community have recognized the important role of regional networks and regional assessments. Through the development of networks of scientists in regions throughout the world, it is possible to improve both calibration and validation of products. Moreover, the regional context provides a framework for developing detailed case studies which provide an analytical approach to linking the patterns to the processes of change, with particular emphasis on drivers of land-use and -cover change. The importance of a regional framework is demonstrated in the initiation of several important science projects and campaigns in Amazonia, Southeast Asia, Central and South Africa and Northern Eurasia. These regional efforts have advanced the fundamental observations and science missions of the LCLUC programs and provided a framework for linking science to assessment, policy and capacity building.

3.2 LAND-USE AND LAND-COVER DYNAMICS

Observation-based efforts fuel the data used for a large array of individual research activities that have made considerable advances in the techniques and analysis used to address land change and its impact on global change. Coarse and moderate resolution data provide information for biophysical studies of net primary production and vegetation dynamics (Myneni et al., 2001; Tucker et al., 2001; Zhou et al., 2001; Nemani et al., 2003) and fine resolution data provide information to assess human impacts (DeFries et al., 2002; Taylor et al., 2002; Houghton et al., 2000). The science is now identifying important components of these dynamics, focusing on the interaction among multiple agents of land use/cover change. A recent example is the complex relationship between deforestation, selective logging and fire in the tropics (Cochrane et al., 1999; Nepstad et al., 1999b; Cochrane 2001). Land use and land cover change (in the tropics and elsewhere) arises by virtue of complex interactions, leads to unexpected feedbacks, and broadcasts ecological impact beyond the boundaries of direct human use of the land. Consider the range of anthropogenic disturbances in a tropical forest, which includes agricultural deforestation, logging, fire, and fragmentation-induced edge effects. Selective logging degrades forests, resulting in local drying of these sites. Landscape fragmentation and land cover change interact synergistically to expose more of the forest to fire and consequently raise the risk of unintended fires occurring across the entire landscape (Veríssimo et al., 1995; Nepstad et al., 1999a; Cochrane 2001; Cochrane and Laurance, 2002).

Advances in understanding the fine-scale, but large-area, patterns through remote sensing are also making substantial contributions. Skole and Tucker (1993) and Woodcock et al. (2001) advanced a technique for fine resolution observations of the rate, pattern, and extent of forest cover change over large areas. Other observation efforts reveal the dynamics of regeneration (Alves and Skole, 1996; Steininger et al., 2001) and in contrasting studies, observations are also revealing areas with increasing woody vegetation, primarily in dryland ecosystems (Asner et al., 2003). Examples include the role of different resolutions of analysis on outcomes (Lambin and Strahler, 1994; Laris 2002; McConnell 2002), detection of cryptic deforestation and various stages of successional growth (Brondizio et al., 1996; Nepstad et al., 1999a; 1999b; Moran et al., 2000; Laris 2002; Batistella et al., 2003), improved fire detection (Laris 2002; Rogan and Franklin, 2002), and various regional and sectoral studies (Lambin 1997; Lambin and Ehrlich, 1997; Seto et al., 2000; Lupo et al., 2001). An extensive collection of references to these works is found in the various chapters in this volume.

Significant interest exists in understanding the drivers of land change, recognizing their complexity and variation, in order to improve its understanding beyond the broad factors of demand for resources from increasing population and levels of consumption. Significant headway has been made including the social causes of deforestation and arid land degradation (e.g., Moran 1993; Indrabudi et al., 1998; Robbins 1998; Sierra and Stallings 1998; Reynolds and Stafford Smith 2002; Walker et al., 1999; Archer 2003; Lambin et al., 2003); the role of institutions in land-use decisions (e.g., Lambin et al., 2001; Turner et al., 2001; Ostrom et al., 2002; Klooster 2003); and understanding the reciprocal relationships between population and land change (e.g., McCracken et al., 1999; Crews-Meyer 2001; Döös 2002). Significant gains have also been made in how to link social with physical processes using remotely sensed data and in nesting data and studies from local to regional to global scales (e.g., Moran and Brondizio, 2001; Fox et al., 2002; Walsh and Crews-Meyer, 2002; Turner et al., 2003), including the means of comparing different land classifications used in various studies (Gregorio and Jansen, 2000; McConnell and Moran, 2001).

Understanding of the role of population has also changed. From thinking that more people always meant less forest, a growing number of cases suggest that forests can persist under high population densities (e.g., Ostrom et al., 2002). The role of communities and institutionalized rules of management plays a critical role in such cases, emerging from a variety of sources, among them scarcity of the valued good (Turner, MD 1999; Laris 2002). Studies have shown how political and economic structures constrain individual choices about management of land resources (e.g., Robbins 1998; Archer 2003). Cultural traditions, and land tenure rules, are critical in influencing how land can be used and by whom (Tucker 1999). A notable advance has been the growing use of orbital earth-observing satellites linked to ground research to address regional to local issues of land change (Liverman et al., 1998; Fox et al., 2002; Walsh and Crews-Meyer, 2002; Wood and Porro, 2002), contributing novel insights to the interpretation of land-cover change on topics rarely addressable with any accuracy at global or regional scales—e.g. land change in areas undergoing urbanization (Seto and Kaufman, 2003); and stages of secondary succession and their management (Brondizio et al., 1994; 1996; Moran et al., 2000).

3.3 LAND MODELING

An initial rationale for emphasizing land-change dynamics in global environment change science was to enhance earth system models. The modeling community, from economics to engineering has responded strongly to this element of land-change research. Significant advances are underway in a variety of modeling approaches, almost all of which focus on spatially explicit outcomes, aimed at explaining and projecting land-change (Lambin 1994; Rotmans and Dowlatabadi, 1998; Veldkamp and Lambin, 2001; Irwin and Geoghegan, 2002). Logit and other types of models explore the specific causes of land change drawing on various theories of the same (Chomitz and Gray, 1996; Pfaff 1999; Geoghegan et al., 2001; Vance and Geoghegan, 2002). Empirical models explore the robustness of land-cover change projections based on patterns of past change (Dale et al., 1994; Turner, M.G. et al., 1989; Turner, M. et al., 1989). Significant advances are underway in agent-based integrated assessment models in which the synergy between socially constrained human decision making and environment are linked to provide spatially explicit outcomes (Reibsame and Parton, 1994; Veldkamp and Fresco, 1996; Fischer and Sun, 2001; Parker et al., 2002; 2003). The range and amount of activity currently generated in the land modeling community is so large that it is better grasped by reviewing various sections of this volume. It is noteworthy, however, that the advances underway require new metrics by which to judge the results of the models. These, too, are being developed by the land modeling community (Pontius 2000; 2002).

4 The Future of Land-Change Research

The land-change programs worldwide continue to gain programmatic support as the magnitude, reach, and consequences of human-induced changes on the Earth's terrestrial surface are understood, giving rise to such international science efforts as DIVERSITAS, the Millennium Ecosystem Assessment, and PLEC (People, Land Management, and Ecosystem Conservation—a United Nations University Project). These efforts and those such as the NASA-LCLUC program have launched *integrated land-change science*, demonstrating the significance and understanding gained from addressing cross-disciplinary problems of global environmental change, earth systems, sustainability, environment-development, conservation and countryside biogeography, among others (Turner 2002). We suspect that the new Land Project of the IGBP-IHDP will build on the breakthroughs of the past, and ensure the advancement of policy-relevant land-change science. This future, however, is predicated on the continuance of programs like NASA-LCLUC.

Several new initiatives promise to support this future beyond NASA and such programs, e.g. NSF's Biocomplexity effort. As required by law, the USGCRP has been

formulating the Science Plan for the next decade of activities. Land-use and land-cover change appears to be a critical element in this developing program because of its stand-alone significance, and its critical role in other aspects of global change, in particular carbon cycle and ecosystem services research, and sustainability themes. The Climate Change Science Program has highlighted the critical importance of land-use and -cover change in setting new directions for global change research. The National Science Foundation is opening a new directorate-level program on Environmental Research in response to the "NSF Doubling Act" signed into law this year, which will significantly increase funding over the next five years for research linked to such themes as Complex Environmental Systems research, with a strong role for Coupled Human Natural Systems research, of which land use/cover change is key. Working with NASA and NOAA, the EPA (Environmental Protection Agency) will be putting in place new programs on regional-scale issues associated with global change. Development assistance agencies, such as USAID, are also building new programs around geographical information for sustainable development as a contribution to global change (NRC 2002), with land use and cover change research being highlighted as a core element of this agenda.

Emerging trends in science programming with respect to land-change studies are clear in their direction: increasing emphasis on place-based research, the science of forecasting, coupled human-natural systems, interdisciplinary research, and relevance to decision making. Building an agenda for *global change at scales that matter*, an emerging theme in global change and environmental research, calls for a strong role for an integrated science of land-use and -cover change.

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