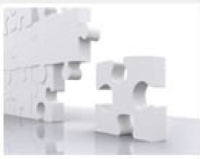

Land-use and land-cover change

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Article Topics: **Land-use and land-cover change** ***and*** **Climate change**
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Last Updated: January 31, 2007

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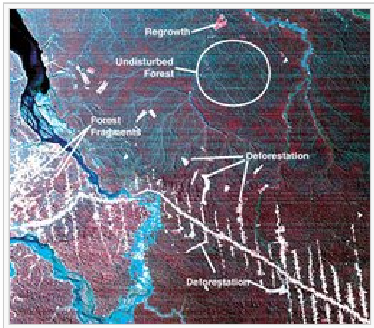
Introduction

Land-use and land-cover change (**LULCC**); also known as **land change**) is a general term for the human modification of Earth's terrestrial surface. Though humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of LULCC are far greater than ever in history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales. These changes encompass the greatest environmental concerns of human populations today, including climate change, **biodiversity** loss and the pollution of water, soils and air. Monitoring and mediating the negative consequences of LULCC while sustaining the production of essential resources has therefore become a major priority of researchers and policymakers around the world.

Land-change science



Satellite image of deforestation in the Amazon region, taken from the Brazilian state of Para on July 15, 1986. The dark areas are forest, the white is deforested areas, and the gray is re-growth. The pattern of deforestation spreading along roads is obvious in the lower half of the image. Scattered larger clearings can be seen near the center of the image. (Photo: **NASA**)

Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures. **Land use** is a more complicated term. Natural scientists define *land use* in terms of syndromes of human activities such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and **biodiversity**. Social scientists and land managers define *land use* more broadly to include the social and economic purposes and contexts for and within which lands are managed (or left unmanaged), such as subsistence versus commercial agriculture, rented vs. owned, or private vs. public land. While land cover may be observed directly in the field or by **remote sensing**, observations of land use and its changes generally require the integration of natural and social scientific methods (expert knowledge, interviews with land managers) to determine which human activities are occurring in different parts of the landscape, even when land cover appears to be the same. For example, areas covered by woody vegetation may represent an undisturbed natural shrubland, a forest preserve recovering from a fire (use = conservation), regrowth following tree harvest (**forestry**), a plantation of immature rubber trees (plantation agriculture), swidden agriculture plots that are in between periods of clearing for annual crop production, or an irrigated tea plantation. As a result, scientific investigation of the causes and consequences of LULCC requires an interdisciplinary approach integrating both natural and social scientific methods, which has emerged as the new discipline of **land-change science**.

Causes and Consequences

Changes in land use and land cover date to prehistory and are the direct and indirect consequence of human actions to secure essential resources. This may first have occurred with the burning of areas to enhance the availability of wild game and accelerated dramatically with the birth of agriculture, resulting in the extensive clearing (deforestation) and management of Earth's terrestrial surface that continues today. More recently, industrialization has encouraged the concentration of human populations within urban areas (urbanization) and the depopulation of rural areas, accompanied by the intensification of agriculture in the most productive lands and the abandonment of marginal lands. All of these causes and their consequences are observable simultaneously around the world today.

Biodiversity loss

Biodiversity is often reduced dramatically by LULCC. When land is transformed from a primary forest to a farm, the loss of forest species within deforested areas is immediate and complete. Even when unaccompanied by

apparent changes in land cover, similar effects are observed whenever relatively undisturbed lands are transformed to more intensive uses, including livestock grazing, selective tree harvest and even fire prevention. The habitat suitability of forests and other ecosystems surrounding those under intensive use are also impacted by the fragmenting of existing habitat into smaller pieces (habitat fragmentation), which exposes forest edges to external influences and decreases core habitat area. Smaller habitat areas generally support fewer species (island biogeography), and for species requiring undisturbed core habitat, fragmentation can cause local and even general extinction. Research also demonstrates that species invasions by non-native plants, animals and diseases may occur more readily in areas exposed by LULCC, especially in proximity to human settlements.

Climate Change

LULCC plays a major role in climate change at global, regional and local scales. At global scale, LULCC is responsible for releasing greenhouse gases to the atmosphere, thereby driving **global warming**. LULCC can increase the release of **carbon dioxide** to the atmosphere by disturbance of terrestrial soils and vegetation, and the major driver of this change is deforestation, especially when followed by agriculture, which causes the further release of soil **carbon** in response to disturbance by tillage. Changes in land use and land cover are also behind major changes in terrestrial emissions of other greenhouse gases, especially **methane** (altered surface hydrology: wetland drainage and rice paddies; cattle grazing), and nitrous oxide (agriculture: input of inorganic nitrogen fertilizers; irrigation; cultivation of nitrogen fixing plants; biomass **combustion**).

Though LULCC certainly plays a critical role in greenhouse gas emissions, the complexity and dynamic interplay of land use processes favoring net accumulation versus net release of **carbon dioxide** and other greenhouse gases makes it a poorly constrained component of our global budgets for these gases; an active area of current research. A further source of uncertainty in estimating the climate changes caused by LULCC is the release of **sulfur dioxide** and particulates by biomass combustion associated with agriculture, land clearing and human settlements. These emissions are believed to cause regional and global cooling by the reflection of sunlight from particulates and **aerosols**, and by their effects on cloud cover.

Land cover changes that alter the reflection of sunlight from land surfaces (**albedo**) are another major driver of global climate change. The precise contribution of this effect to global climate change remains a controversial but growing concern. The impact of albedo changes on regional and local climates is also an active area of research, especially changes in climate in response to changes in cover by dense vegetation and built structures. These changes alter surface heat balance not only by changing surface albedo, but also by altering evaporative heat transfer caused by **evapotranspiration** from vegetation (highest in closed canopy forest), and by changes in surface roughness, which alter heat transfer between the relatively stagnant layer of air at Earth’s surface (the boundary layer) and the troposphere. An example of this is the warmer temperatures observed within urban areas versus rural areas, known as the urban heat island effect.

Pollution

Changes in land use and land cover are important drivers of water, soil and air pollution. Perhaps the oldest of these is land clearing for agriculture and the harvest of trees and other biomass. Vegetation removal leaves soils vulnerable to massive increases in soil erosion by wind and water, especially on steep terrain, and when accompanied by fire, also releases pollutants to the atmosphere. This not only degrades soil fertility over time, reducing the suitability of land for future agricultural use, but also releases huge quantities of phosphorus, nitrogen, and sediments to streams and other aquatic ecosystems, causing a variety of negative impacts (increased sedimentation, turbidity, **eutrophication** and coastal hypoxia). Mining can produce even greater impacts, including pollution by toxic metals exposed in the process. Modern agricultural practices, which include intensive inputs of nitrogen and phosphorus fertilizers and the concentration of livestock and their manures within small areas, have substantially increased the pollution of surface water by runoff and erosion and the pollution of **groundwater** by leaching of excess nitrogen (as nitrate). Other agricultural chemicals, including herbicides and pesticides are also released to ground and surface waters by agriculture, and in some cases remain as contaminants in the soil. The burning of vegetation biomass to clear agricultural fields (crop residues, weeds) remains a potent contributor to regional air pollution wherever it occurs, and has now been banned in many areas.

Other impacts

Other environmental impacts of LULCC include the destruction of stratospheric **ozone** by nitrous oxide release from agricultural land and altered regional and local hydrology (dam construction, wetland drainage, irrigation projects, increased impervious surfaces in urban areas). Perhaps the most important issue for most of Earth’s human population is the long-term threat to future production of food and other essentials by the transformation of productive land to nonproductive uses, such as the conversion of agricultural land to residential use and the degradation of rangeland by overgrazing.

Methods

The methods of land-change science include **remote sensing** and geospatial analysis and modeling, together with the interdisciplinary assortment of natural and social scientific methods needed to investigate the causes and consequences of LULCC across a range of spatial and temporal scales.

Remote sensing

Remote sensing is an essential tool of land-change science because it facilitates observations across larger extents of Earth’s surface than is possible by ground-based observations. This is accomplished by use of cameras, multi-spectral scanners, RADAR and LiDAR sensors mounted on air- and space-borne platforms, yielding aerial photographs, satellite imagery, RADAR and LiDAR datasets. Data available from remote sensing vary from the very high-resolution datasets produced irregularly over extents no larger than a single state or province (by aerial photography, imaging, LiDAR, and by high resolution satellite sensors such as IKONOS and Quickbird), to regional datasets produced at regular intervals from satellites (e.g., Landsat, SPOT), to the lower-resolution (> 250 m) datasets now produced across the entire Earth on a daily basis (e.g., MODIS).

Geospatial analysis

Maps and measurements of land cover can be derived directly from remotely sensed data by a variety of analytical procedures, including statistical methods and human interpretation. Maps of land use and land cover (LULC) are produced from remotely sensed data by inferring land use from land cover (e.g., urban = barren, agriculture = herbaceous vegetation). Conventional LULC maps are categorical, dividing land into categories of land use and land cover (thematic mapping; land classification), while recent techniques allow the mapping of LULC or other properties of land as continuous variables or as fractional cover of the land by different LULC categories, such as tree canopy, herbaceous vegetation, and barren (continuous fields mapping). Both types of LULC datasets may be compared between time periods using geographic information systems (GIS) to map and measure LULCC at local, regional, and global scales.

Driving forces

Assessing the driving forces behind LULCC is necessary if past patterns are to be explained and used in forecasting future patterns. Driving forces on LULCC can include almost any factor that influences human activity, including local culture (food preference, etc.), economics (demand for specific products, financial incentives), environmental conditions (soil quality, terrain, moisture availability), land policy & development programs (agricultural programs, road building, zoning), and feedbacks between these factors, including past human activity on the land (land degradation, irrigation and roads). Investigation of these drivers of LULCC requires a full range of methods from the natural and social sciences, including climatology, soil science, **ecology**, environmental science, hydrology, **geography**, information systems, computer science, anthropology, sociology, and policy science.

Modeling

Spatially-explicit models of the social and environmental causes and consequences of LULCC is made possible by GIS and other computer-based techniques which can define and test relationships between environmental and social variables using a combination of existing data (census data, soil maps, LULC maps), observations on the ground (ecological measurements, household surveys and interviews with land managers) and data from **remote sensing**. These spatial models of LULCC drivers and their impacts can be used to establish cause and effect in LULCC observed in the past and are also extremely useful tools for land mangers and policymakers, offering forecasts of future land use changes and their effects. Models of LULCC dependence on political, economic, environmental and other changes can then be used to explore the impacts of policy decisions and other factors using scenario analysis and other computer modeling techniques, guiding policymakers and land managers toward sustainable land management decisions.

Sustainable land management

Sustainable land management is a central challenge in the sustainable management of earth systems and resources. On the one hand, land management must ensure a growing supply of food and other resources to human populations, which are expected to grow for decades to come. On the other hand, management of land to procure these resources is linked with potentially negative consequences in the form of climate change, **biodiversity** loss and pollution. Moreover, local alteration of land use and land cover can have global consequences, requiring local and regional solutions to global problems and the cooperation of the world's policymakers, land managers, and other stakeholders in land management at local, regional and global scales.

At the global scale, the Kyoto Protocol offers an example of international efforts to reduce climate change caused by greenhouse gas emissions from land. It offers incentives, such as a trade in carbon credits, that encourage land use practices which promote the storage of **carbon** on land, including the planting of trees, perennial crops, the return of crop residues to soils, and no-till agriculture,. The Protocol also promotes practices that reduce emissions of **methane** and nitrous oxide from agricultural land.

Regional efforts to modify land use practices to reduce nonpoint pollution of air and water are already in place in many areas of the world, including the USA (Chesapeake Bay Program) and China (Tai Lake Program). In developed areas, including cities and suburbs, there are now well-developed land use policies and practices to protect streams and other aquatic ecosystems from the excessive runoff and flooding produced by the construction of impervious surfaces (buildings and roads).

Management of land in support of **biodiversity** covers a wide range of policies and practices. The most basic of these is to set-aside existing biodiverse habitats as conservation reserves from which humans are excluded. Another is the establishment of preserves and parks in which local human populations and tourists participate in the less harmful economic use and preservation of biodiverse lands. More recently, efforts are being made to restore biodiverse habitats on lands stripped of their original habitat, and to manage existing agricultural and urban landscapes to enhance their suitability as habitat by practices including the planting of native plants and the restoration of habitat patches within intensively managed landscapes. Another new land use practice is the establishment of corridors of habitat between existing patches of habitat distributed across landscapes, creating larger effective habitats by connecting smaller patches together and enhancing species migrations. This will be an especially important practice in response to future changes in climate that will cause the habitat ranges of many species to migrate, mostly northward, requiring species migration through managed areas.

Protection of productive agricultural land has become a major priority in many regions of the world. Land degradation by overgrazing and intensive agriculture on marginal lands is a major driver of land loss; a number of national and international programs have responded with land reforms and incentive programs to avoid this outcome. In rapidly industrializing nations with dense populations such as China, and in the past, Korea, Japan and Western European nations, demand for land for industry and residential use is driving the transformation of some of the most productive agricultural land in the world out of production. Policy efforts to avoid this loss of production are also in place, but their effectiveness in the face of economic demand is often limited. Another threat is the wide adoption of automobile transportation in some developed nations, which has transformed large areas of agricultural land to relatively low density residential uses around cities and along highways (urban sprawl). “Smart growth” and other programs have been developed in these areas to encourage more efficient and desirable land use and to protect agricultural land.

The examples above demonstrate the variety of solutions to environmental harm by LULCC that are in progress. The effectiveness of these and other regional and national efforts to reduce the negative impacts of LULCC remain to be seen. The need for greater efforts and new methods to monitor and mediate the negative consequences of LULCC remains acute, if we are to sustain current and future human populations under desirable conditions.

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Citation

Ellis, Erle (Lead Author); Robert Pontius (Topic Editor). 2007. "Land-use and land-cover change." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published July 17, 2006; Last revised January 31, 2007; Retrieved May 3, 2007]. <**http://www.eoearth.org/article/Land-use_and_land-cover_change**>