LUCID's Land Use Change Analysis as an Approach
for Investigating Biodiversity Loss and Land Degradation Project

A Research Framework to Identify the Root Causes of Land Use Change Leading to Land Degradation and Changing Biodiversity

LUCID Project Working Paper 48

By

Jennifer M. Olson[1], Salome Misana[2], David J. Campbell[1], Milline Mbonile[2] and Sam Mugisha[3]

[1]Department of Geography, Michigan State University, East Lansing, MI 48824 USA
[2] University of Dar es Salaam, Department of Geography, P.O. Box 35049, Dar es Salaam, Tanzania
[3] Makerere University Institute of Environment and Natural Resources, P. O Box 7298, Kampala, Uganda

June 2004

Address Correspondence to:
LUCID Project
International Livestock Research Institute
P.O. Box 30709
Nairobi, Kenya
E-mail: lucid@cgiar.org
Tel. +254-20-630743
Fax. +254-20-631481/ 631499

A Research Framework to Identify the Root Causes of Land Use Change Leading to Land Degradation and Changing Biodiversity

The Land Use Change, Impacts and Dynamics Project
Working Paper Number 48

by

Jennifer M. Olson[1], Salome Misana[2], David J. Campbell[1],
Milline Mbonile[2] and Sam Mugisha[3]

[1]Department of Geography, Michigan State University, East Lansing, MI 48824 USA
[2] University of Dar es Salaam, Department of Geography, P.O. Box 35049 , Dar es Salaam, Tanzania
[3] Makerere University Institute of Environment and Natural Resources**,** P. O Box 7298**,** Kampala, Uganda

June 2004

Address Correspondence to:
LUCID Project
International Livestock Research Institute
P.O. Box 30709
Nairobi, Kenya
E-mail: lucid@cgiar.org
Tel. +254-20-630743
Fax. +254-20-631481/ 631499

Cite working paper as follows: Author. Year. Title. Land Use Change Impacts and Dynamics (LUCID) Project Working Paper #. Nairobi, Kenya: International Livestock Research Institute.

Working papers are available on www.lucideastafrica.org or by emailing lucid@cgiar.org.

TABLE OF CONTENTS

TABLE

BOX

FIGURES

I. INTRODUCTION

Scientists, governments and NGOs have a critical need to understand the reasons behind land degradation, desertification and loss of biodiversity. Development of this understanding needs to be put on a firmer empirical and analytical footing. Current data deficiencies are due to limited biophysical and socio-economic databases that often are temporally and spatially limited. The socio-economic dimensions in particular are also often too simplistically analysed, without capturing the causal processes behind changing land management and land use practices. What is needed is an approach that links biophysical and socio-economic processes with land use and land management practices, which in turn would be linked to landscape or ecosystem dynamics.

This approach to understanding the causes and extent of land degradation and loss of biodiversity would be greatly enhanced by the use of land use or land cover change analysis, coupled with ground assessments of human activities and biophysical measurements. Land use change reflects human activities and environmental processes over time and over space. It reveals the impact of the interactions of these processes on the landscape, including on biodiversity and land degradation. How and especially why land use is changing is critical knowledge for the design of effective land management programmes. It is more effective and sustainable to address the underlying, root causes of degradation or loss of biodiversity rather than trying to address the consequences.

Obtaining this knowledge is greatly enhanced with use of an analytical framework to guide the collection, analysis and interpretation of the root causes data and information. A framework is particularly useful for land use change research due to the complexity of the problem. This paper provides a guide and a framework for designing such research; technical methodological guides are available in other LUCID working papers[1] and elsewhere.

Components of the human-environment system operate and are manifest at different scales—most visibly at the field or plot level where soil characteristics can be measured and human land management is direct—but equally at broader scales. In the human system, the reasons why land use and land management change are related to forces from the individual to the international level, while in the biophysical system, soil is one part of a dynamic ecosystem whose biological components interact with climate and geophysical processes over a large area.

Despite this complexity, much is known about how human and environmental factors operate and how they interact to affect land use patterns and related changes in biodiversity and land degradation at different scales. Similarly, much has been learned about how to identify the root causes of land use change and the critical issues associated with land management that affect biodiversity and land degradation.

This report will provide a general guide and framework for this analysis. It will discuss what information can be obtained from land use analysis, provide a conceptual framework for identifying the root causes of land use change, provide a set of common issues and research questions, and discuss the implications of the analytical framework for the choice of methods and interpretation of results. It is based on insights and experiences gained from long-term research and development activities conducted by LUCID project team members across multiple sites in East Africa, and from other land use change and root causes research. This report complements other LUCID project methodological papers by providing a general analytical framework for land use change research design and the collection and analysis of information.

[1] Technical guides include the fieldwork guide for ecological and socio-economic data collection in the LUCID project (Maitima and Olson 2001), a methodological guide for linking changes in land use with biodiversity and land degradation (Maitima et al. 2004), methods for interpreting and classifying aerial photographs and satellite imagery (Butt and Olson 2002; Mugisha 2002); and multi-scale spatial data analysis (Olson, Butt et al. 2004).

II. LAND USE CHANGE ANALYSIS

The identification of the causes of biodiversity and land degradation change is greatly enhanced when the current situation and proposed strategies are examined at several scales. One entryway to identifying changing land management and its impacts on the environment is through land use/ land cover change (LULCC) analysis (Maitima and Olson 2001; Maitima et al. 2004; Olson, Butt et al. 2004).[2] This analysis usually involves the interpretation of geographical or spatial information from aerial photographs, satellite images, ground measurements or maps. By interpreting data from different time periods, temporal changes in the landscape can be determined. Linking the land use to other spatial data, such as roads, elevation or administrative boundaries in a Geographical Information System (GIS), allows for enhanced interpretation of the land use information. Land use and land cover itself is the reflection of biophysical and socio-economic factors on the landscape, and the analysis of land use change root causes forces us to consider the interaction of one set of factors upon the other.

Land use change research has evolved out of efforts to identify, predict and manage ecologically damaging land use changes such as deforestation. It provides landscape or higher level information on biophysical changes in the landscape, such as changes in the extent, location and fragmentation of habitats, degradation of forest canopies, the spreading or shrinking of ecosystems, and changes in biomass production or in vegetative species. It also provides a wealth of socio-economic information critical in the identification of the driving forces of those changes.

Interest in land use change analysis has grown due to improved availability of remotely sensed data, especially multi-spectral satellite imagery, and facilitated interpretation with geographic information systems (GIS). The combination of increased interest in environmental changes over large areas and improved data and interpretation methodologies is leading to an increasing number of studies and projects using land use change analysis. Indeed, the international global environmental change research community has chosen land use/ cover change as a major area of research because it provides broad scale data on changing carbon storage and sequestration by terrestrial plants, and because it provides an entry into understanding the human dimensions of environmental change (Turner et al. 1995; Lambin et al. 1999; de Sherbinin 2002).[3]

Land use change analysis is a particularly useful tool because it a) provides information on the wide societal forces leading to environmental change, b) land use change is a cause in and of itself of land degradation and loss of biodiversity, and c) provides information on the type and extent of environmental change (STAP 1999).

1. Utility of conducting land use change and root causes analyses

Spatial analysis of land use provides rich environmental and societal information, while associated root causes analysis can illuminate how trends in land management are affecting land degradation and biodiversity.[4] Examples of information that land use and root causes analyses can provide include:

1. Identification of the components of landscape that are changing, the reasons for those changes, and their impact on land degradation and biodiversity;

---

[2] Land use (LU) represents the human use of the land; examples of LU classes are small-scale agriculture, herding, wildlife reserves or towns. Land cover (LC) represents the biophysical cover; examples of LC classes are wheat, savanna, broadleaf forest, or built up areas. In this report, land use is used as a general terms to represent both. Land use/ land cover change (LUCC) refers to a conversion from one class to another, for example from grassland to cropping. Land management in this report refers to the human management of the land, for example crop choice, soil conservation, tree planting or park management.

[3] See http://www.geo.ucl.ac.be/LUCC/

[4] Land use change researchers often differentiate between root and proximate causes of land use change, where root causes are the underlying, often higher level forces such as changing markets for products, while the proximate causes directly impact the physical use of the land, such as crop choice. In this report, no differentiation is made between the two—root causes encompass both.

2. Determination of the effect of past policies and programmes on land management and the environment in order to obtain lessons learned from positive and cautionary experiences;
3. Recognition of critical locations, groups and situations. This may be where change is occurring rapidly ("hot spots" of change), areas where development or change is stagnant, or locations where people or the environment are particularly vulnerable to climatic or economic events;
4. Leverage points in the system to improve land management;
5. Scenarios of the impact of possible policies or programmes.

2. Land degradation and biodiversity information from LULCC at different scales

Different scales of analysis provide different types of information. Scales of analysis can range from the field to the farm, the community, the landscape, and to the national and global levels. Since societal and environmental processes operate at different scales (hierarchy theory) and different types of information are available at different scales, a multi-scale approach is necessary to fully understand trends and their causes. For example, the percentage of land that is being used for cultivation in a semi-arid area can appear different depending on the scale of analysis and type of data examined. Figure 1 of the lower Mt. Kenya area illustrates this: at the broad scale, the land is seen as sub-divided into fenced farms and is classified as agriculture whereas plot level analysis reveals that farmers have actually left many of their fields uncultivated due to low productivity and those fields have reverted to bush (Olson 2004a).

At the *household and plot level*, fieldwork is usually conducted to obtain specific information. Samples are often used to represent wider areas (as discussed in section VI.3. below, in Maitima and Olson 2001 and Maitima et al. 2004), or a small area is intensely examined. Examples of information that may be thus obtained and mapped include:

1. plant species composition;
2. soil properties, erosion estimates;
3. water quality and quantity;
4. animal species counts;
5. individual and household information, such as farm size, ethnic group or wealth;
6. land management practices such as soil conservation, fertilizer application or fuelwood collection;
7. yield;
8. indicator plants;
9. household assets, income activities, labour availability, ethnicity, gender of head, etc.
10. land use in each small field or field boundary, for example trees planted, types of crops grown, wells dug or fallow practiced
11. land use in pasture or rangelands such as patterns of transhumance, grazing intensity and management of fire.

To ensure the representativeness of the information obtained, and to permit those data that can be meaningfully aggregated or "scaled-up", it is necessary to also examine information at higher levels. The sampling framework for field level research, for example, could be based on information from maps of water catchments, agro-ecological zones or community boundaries. The next higher level also provides information not available at the plot level, particularly related to a) the contiguity of a variable across space, b) the spatial extent of phenomena, c) the spatial pattern of phenomena, and d) the relationship between components of the system.

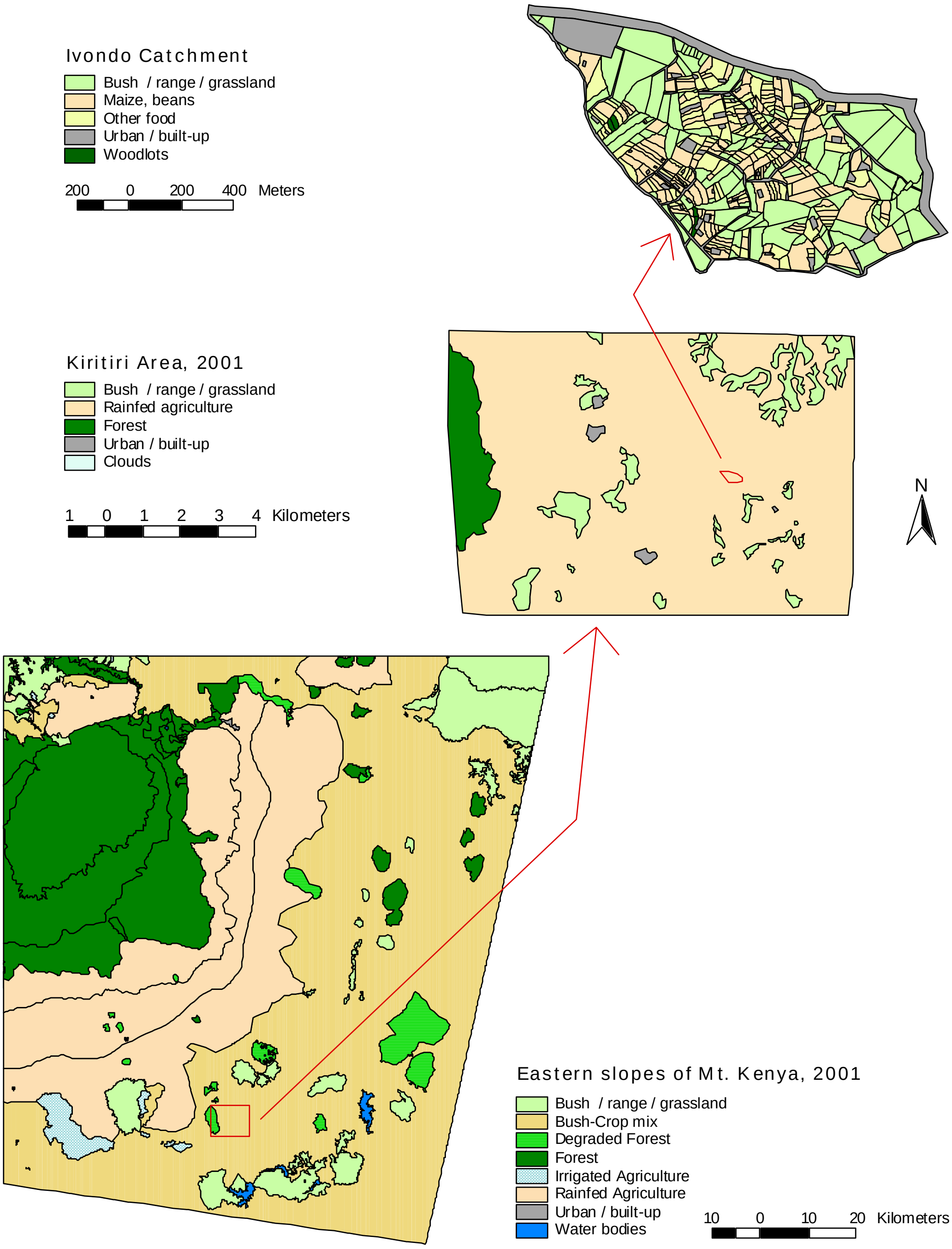


Figure 1. Land use interpretation results at different scales, Eastern Slopes of Mt. Kenya

Examples of spatial information related to land degradation or biodiversity that can be obtained from a single time period at the *meso-scale*, such as from aerial photographs, satellite imagery, maps or other sources, include:

1. the size, diversity, density, fragmentation and distribution of habitats or ecosystems;
2. the extent, type and location of ecosystem patches, edges or boundaries;
3. the location and type of ecosystem or land use gradient;
1. identification of areas likely to be species rich, and identification of biodiversity "hotspots";
4. the heterogeneity of ecosystems or land uses;
5. wildlife migration corridors;
6. sedimentation of water bodies;
7. type and degree of vegetative cover, the leaf area index;
8. area affected by salinisation or water logging;
9. topography;
10. climate;
11. soil loss, soil deposition, mass movement of soil;
12. fragmentation of fields belonging to a household;
13. the location of key resources, such as water, dry season grazing, roads, or towns;
14. the distribution of land and other resources between individuals, groups or institutions;
15. biomass productivity, pasture quality, and soil fertility or degree of erosion can be obtained from imagery spectral analysis;
16. the distribution of land uses, such as the farming system type, protected areas, or proportion of land being cultivated;
17. the intensity of land use or of grazing;
18. the extent of soil conservation techniques installed, trees planted, fences installed or vegetation burned;
19. the distribution of socio-economic variables such as settlement patterns, in-migration rates, poverty, population growth, or farm sizes;
20. land manager information, such as type of land user (e.g., small-scale farmer, government, institution).

By examining information across time periods or between variables, *processes* can be identified. Statistical analyses and modelling can then be conducted to quantify changes and relationships. Identifying causes usually requires additional, non-spatial information of the area, however. Examples of processes and relationships that can be obtained from LULCC with other data include:

1. changing size, distribution, diversity and fragmentation of habitats;
2. change in distribution of woody species relative to grasslands or thorny bushes;
3. the density and distribution of wildlife in relation to habitats;
4. the distance between water sources and houses, wildlife or livestock;
5. assessments of soil degradation based on spectral analysis (Normalised Difference Vegetation Index or other index) of satellite images of different periods, controlling for rainfall;
6. changing access to key resources by wildlife, livestock or groups of people;
7. the differential impact of policies on how land is developed or used;
8. the impact of new roads or other infrastructure on the growth of market towns, the type of crop grown, or forest logged;
9. out-migration, or the impact of in-migration on expansion of agriculture;
10. the relationship between land tenure or the type of land owner and land management practices, for example between large scale land owners (rich farmers or ranchers, institutions) and small-scale land owners in their use of fallow or planting of trees;
11. key resources that can be a source of competition between groups of people, or between people and wildlife;
12. the development of irrigation related to policies, economic development, access to markets, and land ownership.

Identification of spatial patterns and spatial processes such as those above can provide the answers to “where” types of questions, and can contribute to the understanding of “why is that happening there.” However, these are often incomplete answers if the specific study site is not placed in its broader context, and if the impact of higher level forces at the national, regional or global levels affecting local land use and management factors is excluded. *Higher level* analyses provide different types of information concerning land degradation and biodiversity that are of international or global interest. Land use and root causes analyses at the regional and global levels can provide information on, for example:

1. Trends in globally significant biodiversity, including the changing distribution of flora, specific ecosystems or habitats;
2. Status of wildlife migration corridors that cross national borders;
3. The off-site impact of the removal of vegetation. Deforestation of a watershed, for example, may lead to erosion and siltation of surface waters downstream.
4. The effects of land use/cover change on the local to global climate. Land cover conversions such as deforestation or afforestation affect the amount of atmospheric dust in the atmosphere, and the amount of carbon stocked in vegetation and in the soils. Land surface parameters such as albedo, leaf area index, soil moisture, and surface roughness are also highly sensitive to land cover conversions, and they directly affect the local and regional climate.
5. Land or agricultural policies, markets and prices, governance, public and private investments;
6. The comparison of land use and root causes between sites provides new information on general patterns and process of land use change, identification of common and specific driving forces and root causes of land use change. Such analyses permit the development of scenarios of future land use change and its impact on the environment.

From the lists above, it is clear that there is no single, optimum scale for conducting land use analyses related to biodiversity and land degradation. Different scales provide complementary sets of information that contribute to a more complete and robust analysis.

Findings from one scale can also be used to verify the interpretation of information from other scales in a *triangulation* of findings approach. For example, population census statistics on migration can be related to household survey data on when households moved to the site, or a satellite imagery interpretation of expanding forest cover can be compared to ground measurements along transects. The findings from one scale can appear to be contradictory to those from other scales but both can be correct. This has been shown to be the case when examining population density at a coarse scale and finding that densities are correlated with and therefore presumably the cause of deforestation, whereas localized studies show that tree planting and tree cover is higher in densely populated areas. The deforestation may be caused by other factors, such as logging (Olson 1994; Scherr 1995; Fairhead and Leach 1996).

Similarly, it is not often possible to “scale-up” the results from local analysis to higher levels by simple aggregation, nor to “down-scale” by ascribing group attributes to individuals. Processes at various levels may be qualitatively different. In social sciences, for example, scales are associated with hierarchies of social order, with each level having different actors (e.g., national government, local government, household, individual) with separate functions, activities and environmental management effects. Also critical to consider are interactions between scales, for example the effect of policies on communities, or the cumulative effect of local land use changes at the regional level (Turner et al. 1995; McConnell and Moran 2000). Biophysical processes also vary by level. For example, landscape ecologists describe how the nature of a spatial pattern (e.g., the distribution of individuals, or community organization) differs as the scale of analysis is changed (Wiens 1995). This phenomenon can be described in some cases by the species-area curve (Rosenzweig 1995; Scheiner et al. 2000). Soil characteristics vary over distances as small as a few metres, and many soil properties have non-linear relationships with variables such as slope or bedrock from which they are predicted. Scaling soil properties thus requires great care (Van Lynden, Liniger, and

Schwilch 2002). Questions of aggregation and disaggregation are critical in conducting spatial analysis, where different resolutions or data aggregations can lead to varied interpretations (Turner et al. 1989; Gibson, Ostrom, and Ahn 2000; Evans and Moran 2002). The preferred approach to analysing LULCC, its root causes, and the associated environmental impacts, therefore, is multi-scalar. A research methodology that enhances scaling up and down, therefore, strengthens both the interpretation of data and the utility of the research results for designing effective sustainable land management programmes (Campbell and Sayer 2003).

LULCC and other types of analyses have identified complex temporal patterns of driving forces of society-environment change. These include longer-term processes, such as population increases or economic development, and shocks such as drought or policy mandates that may trigger new directions or rates of change (Turner 2001). The ability of any land use or social system to successfully respond to the system can depend on its initial condition, but just as importantly its resilience and flexibility.

Land use change and root causes analyses thus provide a unique view of the society/ environment situation in a given location. They can provide a broad view of the changing situation, and allow the trends in one area to be placed within a broader context.

In order to generate such an understanding, however, the limitations of land use or other spatial analyses must be realized. Interpretation of maps, photographs or imagery is just the beginning of the identification of what change is occurring, and why it is occurring (Liverman et al. 1998). Problems that often arise when using or interpreting GIS analyses include:

a. The scale of analysis can be deceptively all-encompassing, providing a “global gaze” that misses much;
b. GIS and land use information may not be easily accessible due to the expense and technical expertise required;
c. It is biased towards top-down, remote management and planning;
d. It is often assumed that land use change is associated with negative ecological consequences, when the change may be associated with improved economic productivity and/ or livelihood needs being met;
e. Spatial patterns may be quantitatively described without the researcher explaining or understanding the relationship between the patterns and the underlying processes;
f. Its use may promote a tendency towards technical approaches or solutions rather than those that are locally adaptive and relevant.

Land use change and GIS analysis is thus not a replacement for ecological or socio-economic field research—the interpretation needs to be verified through ground-truthing, and many of the critical variables such as soil characteristics, plant species, land tenure policies or people’s decision making are not “visible” on images or photographs. Considering a combination of spatial and other information is thus required to avoid a common mistake in land use analyses, to assume that spatial patterns provide causal explanations (e.g., “deforestation occurs along roads, therefore roads cause deforestation”). Much as been written about linking spatial analyses with community or household level research for natural resources management, e.g., (Liverman et al. 1998; Fox et al. 2003).

A framework to guide the research questions to be asked and type of analyses to be conducted is thus helpful to ensure that the research considers the critical issues, and that the research results address the original goal of understanding how and why land use is leading to changes in biodiversity and land degradation.

One framework for environmental reporting that has been used in Europe and by the UN is DPSIR (Figure 2), which was developed in the early 1970s. It was originally designed for assessing the relationship between three types of “indicators”—environmental pressures (the human activity leading to a problem), the state of the environment (the physical condition affected by the pressure) and responses (policies adopted to resolve the problem). It was later refined to include driving forces affecting the pressures, and the UNCSD identified a "core" set of 134 indicators for sustainable development (UNCSD 1996; Rapport and Singh 2002).

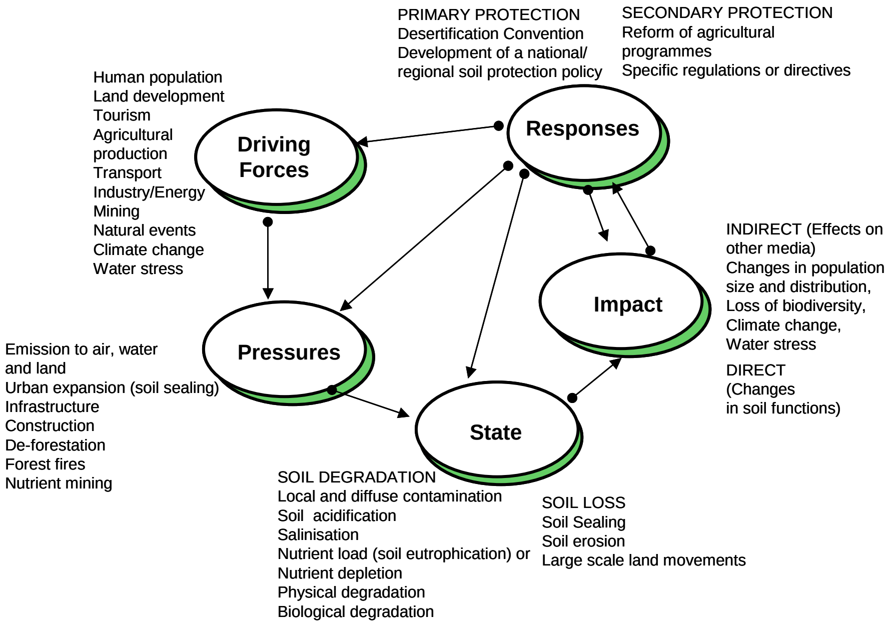


Figure 2. The DPSIR Framework Applied to Soil. Source (Blum 2004).

The framework suggests a linear, unidirectional causal chain and does not include the interactions between variables within boxes. It also does not explicitly include consideration of spatial scale or temporal trends. Establishment of causation and association is left assumed, not tested. Also assumed is that indicators, such as a political action as a response indicator, follows from the prior indicator without other factors in play. In short, it provides a logical framework for illustrating assumed factors, but is not based on socio-economic or ecological theories or concepts, and so provides little assistance in the initial identification of the critical variables, their relationship, or how they relate to the problem and its possible solution.

III. LAND USE CHANGE ROOT CAUSES ANALYTICAL FRAMEWORK

Political and cultural ecology, intensification theory, economic theories and other theories and concepts have informed LUCC research associated with the International Geosphere-Biosphere Programme (IGBP). The LUCC literature evolved out of efforts to understand, predict and manage ecologically damaging land use changes such as deforestation because of their global impact on biodiversity, carbon storage, atmospheric fluxes and other changes to ecological services and environmental resources (Skole 1995; Turner et al. 1995; Lambin et al. 1999; Turner 2001).

LUCC research has provided a wealth of case studies of land use change spatial patterns and driving forces. IGBP compilations of case studies have produced analyses of spatial and temporal patterns, and typologies of the causes of those changes (Lambin et al. 2001; Geist and Lambin 2002; Lambin, Geist, and Lepers 2003). They have identified complex drivers and patterns of society-environment change. Temporal aspects of the drivers include long-term processes, such as population increases or economic development, and shocks such as policy mandates or drought that trigger new directions or rates of change. Theories or conceptual frameworks have been applied to explain the drivers from different starting points, such as rural communities adapting their land use system to environmental conditions, or high human population densities acting as a stimulant for agricultural intensification, or colonialism or globalisation leading to increased land and labour devoted to commercial agriculture and forestry. Agricultural economists and others have explained land use change as due individuals responding to market opportunities affecting the potential value of the land's production. These approaches place varying emphasis on the role of individual actors versus the broader socio-economic context (structure versus agency), the importance of population dynamics or technology versus policy or other factors, and the effect of differential power and access to resources (Boserup 1965; Turner, Hyden, and Kates 1993; Cleaver and Schreiber 1994; Tiffin, Mortimore, and Gichugi 1994; Biot et al. 1995; Peet and Watts 1996; Scherr and Yadav 1996; Barbier 1997; Ewel 2001). No matter what the researcher's disciplinary or theoretical perspective, however, drivers are often site-specific – a driver at point A may act differently at point B – which makes generalizing and up-scaling difficult.

There has not yet developed, therefore, a universal theory "explaining" land use change. Rather, a common methodological approach to empirically identify the causes, or driving forces, of land use change has evolved (Lambin et al. 1999; Lambin, Geist, and Lepers 2003). This has been labelled pattern to process (Nagendra, Munroe, and Southworth 2004). The approach differentiates proximate drivers that directly affect land use, such as in-migration, road construction or logging, and underlying or root causes that affect land use via the proximate causes, such as land tenure policies or the international timber market. A causal "chain of explanation" is developed for each case that follows factors from the local land manager to the world economy (Blaikie and Brookfield 1987).

Statistical analyses of driving forces of land use change in studies from around the world have resulted in identification of common drivers (Geist and Lambin 2001; Lambin et al. 2001; Geist and Lambin 2002; Lambin, Geist, and Lepers 2003). The causes of land use change are usually multiple and there are feedback mechanisms between the drivers, and between the drivers and land use change. Identifying the significant drivers and their interactions, therefore, can be challenging. The most common *proximate* driver of deforestation, for example, is agricultural expansion (ranching and/or cultivation), often combined with transportation infrastructure development and timber extraction. By far the most frequent *root* cause is economic factors, followed by institutional factors such as land policies, technological factors, cultural factors, and finally demographic factors (that tend to be inter-linked with other forces).

Identifying specific drivers of land use change leading to land degradation is difficult since land degradation is the result of human combined with natural factors, and occurs at the farm or field level as well as at the landscape scale. It can be associated with agricultural land management, or occur on quasi-natural ecosystems such as grazing land. Developing a common framework to direct LULCC land degradation root causes analysis is thus critical for research results to be comparable across sites and to permit generalization and up-scaling of findings.

1. Political Ecology Framework

The LUCID Project selected political ecology as its conceptual framework to assist in identifying the causes of land use change associated with land degradation and change in biodiversity (Blaikie and Brookfield 1987; Campbell and Olson 1991; Zimmerer 1994; Peet and Watts 1996; Rocheleau, Thomas, and Wangari 1996; Olson 1998; McCusker and Weiner 2003; Zimmerer and Bassett 2003; Robbins 2004). Political ecologists use tools of critical theory to shape the process of developing hypotheses and research questions to detect the causes of environmental change. Political ecology is appropriate to the questions posed by LUCID in that its contribution has been to explicitly include the important policy and power dimensions, as well as economic and other factors, that affect different groups and their land use. A frequent starting point of political ecology studies is how rural communities manage and adapt within the changing political and economic system. It was originally articulated as an approach to better understand societal factors leading to land degradation; according to Blaikie and Brookfield (1987:17),

> "the phrase 'political ecology' combines the concerns of ecology and a broadly defined political economy. Together they encompass the constantly shifting dialectic between society and land-based resources, and also within classes and groups within society itself."

The parameters of the approach emphasize that land use change results from interactions between society, reflecting economic, social and political processes, and the physical environment. These interactions occur between different scales, and over time and space (the “Kite”, Figure 2) (Campbell and Olson 1991). While LUCID’s socio-economic analyses were based on the interactions represented in the Kite diagram, LUCID’s biophysical research expanded the Kite’s environmental corner to include biological (especially vegetation, wildlife), soil and climatic factors at various scales (Maitima et al. 2004). The conceptualisation of society-environment interaction reflected in the Kite incorporates the following principles:

- **integration** of environmental and societal processes as active components of land use systems;
- employment of a **historical time frame** relevant to understanding the temporal dimension of current patterns of interaction between society and environment;
- recognition that different processes - for example, ecological ones such as soil formation and erosion, and societal ones such as population growth or changes in government policy - have **different temporal characteristics**. Some are long term processes, such as population growth or soil formation, while others are shorter-term and characterized by sudden change, such as policy or drought. Determining the result of these patterns of interaction through time require a diachronic perspective, represented by the ***"braid of time."*** Timelines can visually represent this;
- temporal processes can have **bi-directional** changes, with for example land use intensification reversing due to changing socio-political context, and the interaction of processes can results in **feedback** effects;
- explicit examination of both top down/bottom up processes *and* the connections across sectors: a **"spiral" of interactions** between sectors and between scales;
- examination of **interactions over space,** recognizing that events in one area may have repercussions in other areas through processes such as migration, increased economic competition and institutional change;
- recognition of the **role of power** in affecting outcomes of policy and in resolving competitions and conflicts (Campbell and Olson 1991; Campbell 1998; Olson 1998).

While the implications of environmental changes are often discussed in terms of global consequences, many of the critical causes arise from interactions between societal and biophysical processes at the local level. The decisions that lie behind these actions that create environmental problems are influenced by a wide variety of interrelated driving forces that emanate from both local and external circumstances, cross boundaries between societal and environmental systems, and are driven by the exercise of power in the interests of particular objectives.

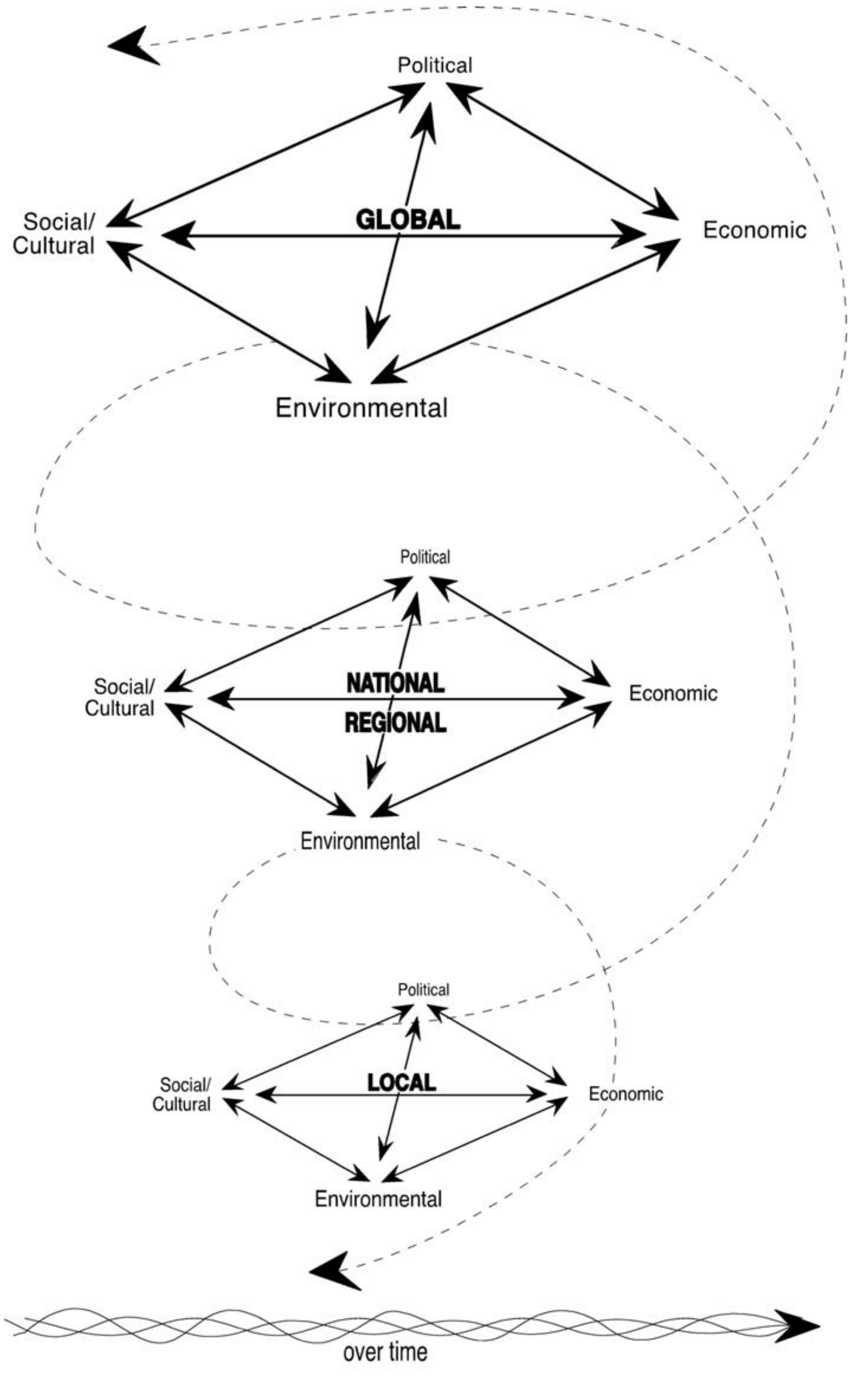


Figure 2. The Kite Framework. Source: (Campbell and Olson 1991).

2. Intensification Theory
Interpretation of the spatial patterns of changes within agricultural systems can also be examined with intensification theory within the broader causal and contextual factors illuminated by political ecology (Boserup 1981; Turner, Hyden, and Kates 1993; Turner et al. 1995; Olson 1998; Lambin et al. 1999). Intensification theory describes an evolution in land use and adoption of agricultural techniques towards higher applications of labour and capital to the land in response to rising population densities and demand for agricultural commodities. Many farming systems in Africa have experienced increasing population densities and changes in their farming system as described by intensification, such as declining use of fallow, and the adoption of higher yielding if demanding crops. Intensification studies, however, often do not include factors such as the distribution of land between households or the wider socio-economic context in which agricultural change occurs, factors that political ecology illuminates. Examining these human dimensions, such as differentiation between households and income diversification strategies, reveal forces behind changing land and soil management. The effect of household variations in resources, for example, illuminates the poverty/ land degradation synergistic relationship.

The driving forces of land use change are therefore many-faceted. They may change in relative influence over time, and their impact will vary as the context changes. Land use change analysis demands conceptual frameworks and analytical methods that are both comprehensive enough to capture the dynamics of society-environment interaction at different scales, and flexible enough to accommodate the temporal dynamics of these processes (Campbell 1998; Ewel 2001; Kinzig 2001).

3. The Application Of Political Ecology To LULCC Root Causes Analyses
In sum, the application of a political ecology approach to identify the root causes of land use and land management change involves the identification of key social, economic, political and environmental drivers at multiple scales, from the household to the international, and interaction of those drivers over time. The framework is based on a systems approach:

1. multi-scale
2. historical
3. inter-disciplinary using variety of sources and methods
4. contextual, with the temporal and causal context within which local land management occurs including:
    a. differentiation among households, groups, and regions, and
    b. explicit examination of the role of policy, and the influence of powerful individuals or institutions.
5. The identification of past policy impacts and the root causes of environment change are particularly critical for developing effective policy and program recommendations.

Concepts in political ecology that are derived from this systems approach and the application of critical theory include:

1. marginalisation, or the process leading to simultaneous impoverishment of people and land degradation. This has been a particularly applicable theme in locations of pre-disposing environment factors and difficult economic circumstances, such as locations that are remote, have low or highly variable rainfall, poor soils and/or where the people have little social power and few resources.
2. political economy, or the economic pressures that affect the land manger’s production goals, and the political contingencies that determine opportunities or limitations. This is often explained in terms of economic processes associated with, for example, colonialism or globalisation affecting labour and ownership relations. The question can be boiled down to who controls what resources, and how that affects land use and land management (Robbins 2004).

Analysis of land use change processes across a broad area requires a three level approach: determination of the spatial and temporal pattern of change, site studies to understand the driving forces and dynamics, and comparative analyses and modelling to identify the broad factors affecting land use change.

Land managers are usually the focus of the research as it is their land use that contributes to or prevents land degradation and loss of biodiversity, they suffer the consequences of productivity loss, and they will be the implementers of remedial activities.

Defining and analysing the causes at different sites, and cross-site comparisons, permits a generalized understanding of the drivers of land use change that can be linked to patterns of change at the regional scale. The root causes of the land use conversions in any one site are associated with events in other areas, competition between land users, the national and international economic and policy context, and local socio-economic and biophysical processes. Land managers' decisions are shaped by their access to resources, their social and economic status, and the opportunities and constraints defined by the institutional and policy context. Political ecology structures this analysis by defining major processes at different scales to inform the underlying research questions and analysis.

Political ecology and other approaches to land use change analysis are realizing the importance of incorporating information on field-level and household level decision making in land use change analyses. Multi-scale analyses are being shown to provide information not otherwise revealed, for example the effect of local inequalities on land use and land degradation. Quantitative analyses of variables such as differentiation between households and income diversification factors can reveal properties of the land use system and lead to better prediction and improved models, and more effective policies and programmes.

Spatial models are being developed to integrate elements of the social structure with those of the economy (e.g., commodity prices, transport costs) and the environment to predict conversions of land use (Chomwitz and Gray 1996; Walker 1997; Irwin and Geoghegan 2001; Veldkamp and Lambin 2001). Spatial modelling addresses the question of where changes will occur, and this can be combined with other information and models in a spatial nested approach that address why and the impacts of those changes.

IV. CRITICAL PROCESSES AFFECTING LAND USE AND LAND MANAGEMENT

The causes of land use and land management changes thus need to be examined in a multi-scale, multi-disciplinary context using a variety of spatial and non-spatial approaches. The analytical framework emphasizes certain factors that need to be explicitly considered, such as societal differentiation, and the role of politics and power. In addition, previous research into the root causes and environmental impact of land use and land management change, including that of the LUCID project, has identified a number of critical processes that play a large role affecting land use linkages to biodiversity and land degradation. These processes play a particularly important role in household decisions affecting land use and management, but are often overlooked in broad land use change analyses. The six critical issues/processes identified by this research are:

- Globalization
- National Policies
- Civil Strife and Insecurity
- Income Diversification and Urbanization
- Gender Roles and Labour Allocation
- Differential Poverty and Wealth.

1. Globalisation.

Globalisation can include a variety of events and processes, but those that appear to particularly affect land use and management include:

a) rapidly changing international and national markets for a variety of agricultural and industrial commodities, and changing national access to international markets,
b) increased competition between and within countries among those producing the globally marketed commodities, resulting in variable and often declining producer prices,
c) economic diversification as people respond to new opportunities, and
d) international influences on national policies and regulations, for example concerning type and quality of products exported and source of inputs (e.g., source of cotton used in textile industry) (Bebbington and Batterbury 2001).

The local impacts can be highly variable, and can include both the shrinkage of former markets and export opportunities (e.g., coffee in East Africa), and the development of entirely new opportunities (e.g., flowers). Their impact on local land use and on society can be dramatic. Gendered division of labour can be altered as families respond to the changing local and national economies (Wangui 2003). Development of and changing use of land and water resources can happen very quickly, for example the development of large scale, high-input horticultural farms affecting the availability of water for surrounding communities (Campbell et al. 2004). The positive effects of globalisation appear to be initially the greatest where natural and social resources are important and can be easily accessed and exploited, and where access to air or seaport transport is rapid. The benefits, however, often appear to be concentrated in certain segments of society, at least initially.

2. National policies concerning land tenure and access to land

A striking finding from the LUCID root causes analyses was how national governments have highly impacted land use by fundamentally changing who has access to what land. This has also been the case elsewhere, as national governments have, for example:

a) gazetted, or degazetted land as protected areas (parks, reserves), or changing the regulations of how protected areas can be used;
b) altered land tenure regulations, such as the privatisation of former communal land (e.g., grazing areas), the delimitation of group ranches, or the changing of “traditional” land tenure systems that result in altered rights over land;
c) encouraged or discouraged migration through development of settlement schemes, or by allowing (or not allowing) people from other areas to have access to land or have land user rights;
d) centralization and decentralization of the management of communal land and protected areas by the government.

3. Civil strife and insecurity

Wars, civil strife and general insecurity may have a major impact on land use and management, but are often considered unusual or temporary phenomena in land use and root causes analyses. Unfortunately, this is not necessarily the case, and regional or long-term analyses often must consider their effects. In the LUCID research, the impact on land use and management depended on the severity and length of the unrest, but included:

a) the halting of trade in agricultural and other commodities, resulting in a focus on subsistence food production and less investment soil management practices
b) out-migration of farmers to local urban centres and to the capital city, leaving their fields to become bush
c) reduced household investment in developing land and a delay in government investment in roads and other infrastructure, resulting in slower than expected economic growth and land use change.

4. Income diversification and urbanisation

Households in rural areas are often very engaged in earning income from non-agricultural sources. This often involves adult men leaving their farms to work elsewhere, such as urban centres or large farms, or members of the family conducting local off-farm work such as in commerce, service or small-scale manufacturing. These ties outside of the farm can greatly affect local land use as labour is pulled from farms so cultivation is less expansive or intense, and less labour is invested in the farm including in soil management. It is a particularly critical strategy for poor households with tiny farms or for households in marginal environments such as in semi-arid areas, permitting them to remain farming where it otherwise might be too risky or insufficiently productive to support a family. The out-migration of men can lead to altered gender roles and responsibilities. On the other hand, wealthier households with supplemental non-farm income tend to manage their farms with a high degree of capital inputs, including the hiring-in of labour (Olson et al. 2004). The degree of involvement in non-agricultural income varies across regions and across time, as people respond to local and outside constraints and opportunities.

5. Gender roles and labour allocation

Men and women have often had different roles and responsibilities in rural land use and economic systems. Who does which task is often differentiated by what type of crop it is, or whether the task is near or far from the home. High rates of male out-migration can increase work burdens and affect investment in the farm, but may not improve women's legal or traditional rights over access to land, water and other resources. Levels of wealth, farm labour availability and ability to produce commodities may vary greatly between men and women headed households. Gender and poverty often combine to greatly impact land use and land management practices. Women headed households may make significantly fewer investments due to the lack of labour and capital, and fewer farm and non-farm resources.

6. The role of poverty and wealth — land use and management relationship

The role of poverty and wealth in land use and land management has been examined across the world in a variety of situations (Blaikie and Brookfield 1987; Olson 1994; Biot et al. 1995; Scherr and Yadav 1996; Tengberg et al. 1998; Campbell 1999, 1999; Olson, Misana et al. 2004). As discussed in the gender section above, the limited labour availability, cash and other resources to invest in the farm typical of poor households directly impacts the choice of land use (crops, fallow, trees etc.), the inputs applied and soil management techniques practiced. In many places, poverty or wealth is closely associated with land degradation or improvement. The influence of these household level variables is magnified when comparing richer versus poorer regions. The association of poverty and degradation, however, varies in strength between areas and over time depending on the profitability and structure of the agricultural system.

The distribution of land between households and groups may greatly influence local land use. Wealthier households and large scale land managers generally tend to use and manage their land much less intensely—more land is under fallow, in tree crops or being used for grazing animals, for example. Their agro-diversity is often much lower than on smaller farms, but they may, depending on the system, have more native species diversity. The impact of wealth on land use may be very visible if the land is consolidated (for example in a plantation or ranch), but may be less obvious if farms are fragmented and fields dispersed. In that case, a spatial sampling strategy and collection of information on ownership for each plot would reveal the effects of wealth on land use and management. The influence of large scale land owners, including the government, is often overlooked in land use and root causes analyses, despite the amount of land they manage and that their land use may be very different from small scale farmers.

V. GENERIC RESEARCH QUESTIONS AND DESIGN OF A PROBLEM-SPECIFIC ANALYSIS

Understanding the patterns, root causes and impacts of land use change thus involves collecting a variety of information, and then analysing the linkages between components of the system to identify the causes of current trends, and to project future changes. Political ecology, as a systems framework, encompasses a large variety of variables and processes, and identifies critical components related to society/ environment interaction. A study of the root causes of land use change that affect land degradation and biodiversity leads to an emphasis on the most relevant of these factors and processes. Each location and each study will also have specific problem issues, factors and processes unique to it. The choice of research questions will, therefore, vary from one study to another. Nevertheless, adhering to a conceptual framework in research design greatly enhances the likelihood that vital questions are raised. Generic research questions to assist in this endeavour, and steps in conducting this process are described below.

1. Research questions

a. The root causes of land use change

The goal is to identify the forces behind land use change at the community, national and international levels. This involves determining the causes, trends, and trajectories of:

1. the changing rural economy (e.g., within pastoralism, from pastoralism to mixed agriculture, economic links with urban centres, changing markets for commodities)
2. demographic trends: density, distribution, growth rate, migration, urbanization
3. infrastructure development: roads, education and health facilities, markets, etc.
4. policies and programs concerning land distribution, land tenure, protected areas; also, policies affecting the economy, agricultural development, markets, migration, tourism and other relevant sectors
5. political situation, for example the distribution of power between groups or regions, governance quality, stability
6. social factors: the distribution of land and other resources between groups and generations, changing access to resources between groups, resource use competition, the decision making process, the effects of wealth differences and gender on land management at the household level.
7. climatic /hydrological factors: drought frequency and duration; access to ground and surface water
8. biological factors: incidence of human and livestock disease.

b. The linkage between land use and land management, and change in land degradation and biodiversity

The following are land use and management practices that may directly affect land degradation and biodiversity (see details in Maitima et al. 2004).

1. identification of critical changes in land management (e.g., fires, deforestation, fencing, ploughing, riparian irrigation, planting of crops, frequency of cultivation, erosion control, biological and chemical fertilizers, pesticides etc.)
2. impacts on ecosystem fragmentation and diversity,
3. impacts on vegetative cover and structure and plant biodiversity
4. impacts on soil characteristics and erosion
5. impacts on water quality
6. impacts on wildlife biodiversity: migration corridors, habitat, breeding areas, seasonal and drought refuges
7. land use within, and surrounding, parks and other protected areas.

c. Major integrative themes

Integrative questions are required to determine the relationship between society/ environment processes and changes in land use, biodiversity and land degradation. These can include:

1. what is the effect of societal differentiation on land use and management, for example the effects of poverty, wealth, gender and ethnic group
2. what is the trend in agricultural intensification, and how are those changes related to soil management, tree planting, method of animal raising, and on-farm crop and other plant biodiversity
3. are there feedback effects of land degradation on farmer soil management.

d. The site in space

1. Interaction of people, commodities, livestock, wildlife, etc across ecological gradients
2. Borders: cross-space interactions, effects such as siltation, water & air pollution, migration.

2. Placing a particular problem within the generic framework
The preceding section has spelled out the conceptual framework and has proposed general research questions. The application of the framework to particular circumstances will require that it be specified to permit problem definition, analysis and policy formulation. A sequence of activities is proposed below to this end. The initial step is a problem statement. This would then be amplified in terms of the components of the framework to arrive at a problem-specific configuration in which the relevant variables in each category are specified (Figure 3, from Campbell and Olson 1991).

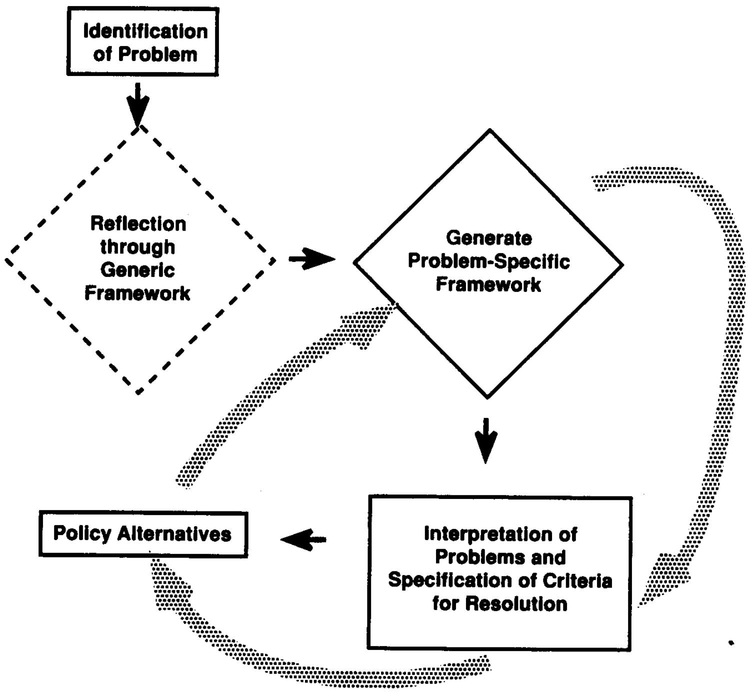


Figure 3. Specifying the Root Causes Kite Framework to a Specific Problem

In the case of soil fertility decline, the local problem may be defined in terms of interactions between environmental characteristics (soil type, vegetative cover), economic factors (crop and livestock system, markets), social conditions (farm size, population density, availability of capital to purchase soil inputs), and political conditions (presence of organizations to design soil conservation structures, land distribution). Once the key categorical variables have been defined, the analysis would proceed to analyse the processes of interaction between them. To emphasize the process of soil degradation, the changing factors and their interactions over time need to be considered.

These local factors would then be placed within their geographical context: how interactions between places affect the processes, and how the processes are active at scales beyond the local area. It may be that population growth is determined more by immigration from other areas than by local demography. National policies towards resource use may be restricting access to alternative land and thus contributing to the migration process.

At the national level, the degree of involvement by the government in soil erosion programmes or subsidizing fertilizers may be affected by how important the local area is to agricultural exports, or the availability of donor assistance.

The definition of the problem-specific configuration of the framework will be thus guided by key questions in both the categorization phase and the process phase:

1. Categorization Phase:

What elements within each point of the framework can be identified as affecting the issue under study? How do the critical processes and questions from the Root Causes framework relate to this problem?

2. Process Phase:

What connections exist between the elements identified above? What processes do these connections reflect?

How do the factors of Scale, Space, Power and Time influence the interpretation of those connections and processes?

Once these questions have been considered, the problem will have been conceived of in terms of the generic framework and a problem-specific research approach will have been created.

Re-evaluation of the problem to determine multiple causes and to derive remedy

The placement of the problem in the framework would thus permit multiple causal processes to be identified. No one causal process is usually independent of others, yet their relative importance to the issue and ease of policy intervention becomes clearer. It may be that a crucial and easily managed process will be identified; in most cases, however, recognition of a single causal process is unlikely. The identification of cause provides the basis for deriving remedies and prescribing criteria for evaluating their success.

Specify objectives/criteria for evaluating remedy

It is at this point that many of the development strategies will find their place. Technological innovations, pricing policies, and investments in infrastructure are among the array of appropriate interventions. Their adoption should be conceptualized within context of the wider system to be more effective in addressing the causes behind the problems and potential impacts of the strategies. How the interventions will affect different groups or the cause of the problem, for example, would be considered.

Consider the impact of proposed policy on the total system over time

The range of policy options may be evaluated for their likely impact by tracing their effects through the problem-specific framework. For example, a plausible policy option to address soil fertility decline is to reduce erosion by constructing terraces. At the local level, this would raise questions regarding environmental issues (nature of soil, rainfall conditions) social issues (gender of head of household), and economic constraints (opportunity costs of labour), and other issues such as previous experiences with terracing.

At this point, many facets of the framework will be brought to the forefront. For example, considerations of the role of societal differentiation will prompt consideration of groups (wealth status, ethnic groups, women, etc.). Considerations of the effects of scale may reveal that a national economic policy may be rendered ineffective due to global trends in consumption or by political forces at the local level. Considerations of the effects of scale may reveal that a national economic policy may be rendered ineffective due to global trends in consumption or by political forces at the local level. Similarly, the impact of a climate change will become visible in all its social, political economic and environmental complexity. The analyst/policy-maker will thus be able to appreciate not only the complexity of the immediate problem but also the fact that policy interventions may have both unanticipated short- and longer-term repercussions. Recognition of the complexity and uncertainty should favour policy choices that maintain flexibility in future options

VI. DISCUSSION OF METHODS

This section briefly introduces a selection of the wide variety of methods available to conduct land use and root causes analyses related to changing land degradation and biodiversity. The purpose of this discussion is to place the methods in context of using the conceptual framework, not to provide an exhaustive list of methods or a description of how to use them.

1. The use of multiple methods

Addressing the research questions and themes will require the use of multiple methods and information sources and types, and the research results will be more rigorous due to this approach. Indeed, the design of the research to provide a **triangulation** of data and information sources around critical questions is highly useful when examining complex systems such as society/ environment interaction leading to land use and management change. Below is a summary table of the variety of primary data and information that can be collected concerning changes in land use, biodiversity and land degradation (Table 1). In the analysis, this would be complemented with secondary data and information from, for example, population censuses and other government statistics, and literature reviews.

Triangulation is designing the data collection and analysis so that several sources or types of information are available on a particular topic. The information may be slightly different from each of the sources, but together they can confirm or not a conclusion. A demographic example would be gathering population census data on population growth and migration rates, gathering data from school headmasters on numbers of children enrolled over time, obtaining household histories including migration in formal surveys, and asking about changing migration patterns in the community during group interviews. Although each piece of information will provide a somewhat different view of the issue, they can be compared to ensure that a reliable estimate of migration is obtained.

Another example would be comparing plant species counts across a variety of land use types (using "space for time" substitution to estimate species composition prior to land use conversion, see Maitima et al. 2004), conducting key informant interviews with bee keepers, herbalists or other community members knowledgeable about how native plants have changed over time, and examining old reports that describe the local vegetation. Local, or indigenous knowledge, such as concerning soil types or plant indicators of soil fertility, can be critical points of the triangle when attempting to understand changes in the local land use system.

Table 1. Types of Information and Primary Data Collection Methods

	Data collection methods				
	Surveys/ Interviews			Transect (Quadrat)	GIS analysis
	Surveys	*Group Interviews*	*Key Informant interviews*		
Land use/cover change (LUCC)	X	X	X	X	X
LUCC driving forces	X	X	X		X
Ecosystem Diversity				X	X
Ecosystem Distribution			X		X
Perceptions of soil	X	X	X		
Plant indicators of soil deg.			X	X	
Soil erosion estimates	X			X	
Soil chemical and texture				X	
Plant spp. diversity			X	X	
Wild fauna diversity				X	

The approach of deliberately designing research to obtain similar information from different sources is particularly critical when the question involves societal interaction, social roles or anything related to communal resource use. Different segments of society will probably have very different opinions about how and why things have changed. Asking a variety of people—scientists, technicians, teachers, administrators, farmers and herders, men and women, and from different age and ethnic groups—will all have slightly different but equally valid information.

The use of a variety of methods ensures more rigorous results and greatly improves interpretation (Rocheleau 1995). Mixing quantitative and qualitative information, for example, provides a better interpretation than either alone. While the quantitative analysis might not be wrong, it may represent only part of the system. Placing quantitative analysis results into a wider context to better interpret the results often entails using qualitative, process type of approach such as historical narrative.

2. Site level information collection

Site level data and information collection is often the most expensive, time consuming and rewarding aspect of land use and root causes research related to changes in the environment. It is often collecting primary data and information on a different topic in a new area, so the potential is high for contributing new information. Because of the cost and time involved, however, it is critical to organize the data collection to ensure that the findings have broad applicability both across space (so research findings can represent a large area) and across types of land managers and land management situations. If there is no baseline data for that area, then researchers should recognize that they themselves are establishing a baseline for future work. Careful inclusion of the basic data required, and recording of the sampling design and data collection method used is critical for future research.

a. Sampling to ensure social and ecological representativeness

The sampling framework is therefore a critical aspect of the research design. It needs to take both ecological and socio-economic variability into consideration. Various spatial sampling approaches are useful particularly to represent ecological variability, which varies across space more predictably than socio-economic characteristics. One approach, commonly used in ecological and geographical field research is line transects that cut across multiple ecosystems or other relevant variables. Random or systematic point samples can then be examined along the transect to obtain information on the distribution of phenomena. On the other hand, a distribution of random points across an area provides a less biased representation of the area, but if fieldwork is involved, transport to each of the points may be difficult. A variation on this is clustered random sampling, in which the points to examine are clustered so easier to reach, but the clusters themselves are randomly chosen.

Stratified random sampling is an approach that can capture both ecological or socio-economic variability—point locations, such as villages or farms, are randomly chosen within a spatial organization of interest, such as agro-ecosystem, so that the sample represents those in an ecosystem, and statistically valid comparisons can be made between ecosystems. Care must be taken, however, to ensure that the sample size is sufficiently large to capture variability with the spatial unit, otherwise groups (for example, wealth groups) cannot be compared within a unit and several units need to be grouped in the analysis. Similarly, a stratified rather than strictly random sample can be conducted of groups of households when it is important to capture particular elements of society, for example to ensure that all ethnic groups, the very wealthy, very poor, women-headed or tenant farmers, are surveyed. In statistical analyses, weighting sample data by the proportion of the population that they represent can help ensure that the results better reflect the population as a whole.

Political ecology studies are often concerned with ensuring that different segments of society are represented and have a voice in the research. An example of when this may be useful is, for example, in identifying the constraints of women-headed compared to male-headed households in how they manage their land. In this case, a stratified sampling approach is preferred. In group interviews, having separate group of men and women, of ethnic groups, age groups or other, may enhance people's ability and/or willingness to speak.

b. Land and soil management at the field and household level
A short example of types of methods that can be employed is provided here. The research question being addressed is in the example is: how is land use and land management changing, and why? Information on the root causes of land use change will come from many different sources, including analyses of policies and programmes, demographics and economic factors. Primary data collection methods can include key informant interviews (e.g., of older people, of technicians), group interviews concerning patterns and causes of land use and management change, and formal surveys at the household and field level.

Due to the lack of baseline data on soil properties from soil samples in many places, the best available information on changing soil characteristics may come from the farmers and herders themselves. An important advantage of seeking this information from farmers and herders is that it is their land and soil management that is affecting the soil, and they can provide information on those practices and how they perceive them to be affecting the soil. They are also usually very aware of, and conversant with, changing productivity of their land.

There are at least two approaches to obtaining this information—using informal group interviews, and conducting a formal survey with questionnaire.[5] Each method gives different types of information that can later be compared as part of the triangulation process.

c. Surveys
Advantages of the formal household survey approach include

a) obtaining information on changing soil properties, management practices and land use histories for several fields that can be linked to other data, such as soil samples,
b) obtaining data on household resources and other characteristics that affect soil management, and
c) the ability to statistically analyse the results.

Indeed, soil degradation perception data from previous surveys has shown that statistically valid comparisons in soil degradation severity can be made between groups of farmers, types of fields and field management practices (Olson 1994; Olson, Misana et al. 2004). A disadvantage of depending entirely on perceptions of soil degradation, and not conducting soil sampling or other measurement of soil characteristics, is that the perception information is difficult to compare between regions where farming systems and other factors can be very different. Nevertheless, answers may be obtained to research questions such a "what is the poverty/ degradation relationship," "what management practices appear to prevent soil degradation," or "how are farmers responding to declining productivity?"

Questionnaires can be administered in each household at two levels: the household and the field. One household questionnaire is completed per household to gather information on resources (e.g., land, animals), household members and their economic activities, agricultural labour, and general questions on changing agricultural or herding practices. Several field level questionnaires may be completed for each household with questions such as characteristics of the field (distance from the house, land tenure), land use history, perceptions of soil characteristics and changing characteristics, and land management practices. The choice of the fields to survey depends on what variability is important to capture. For example, the distance from the home to the field often greatly affects how the field is used and its soil managed, so one can survey fields near, a medium distance, and a far distance from the home.

[5] Additional information on this type of questionnaire can be found in Maitima and Olson 2001.

Box 1. Guide to Group Interviews on Driving Forces of Land Use Change

1. What are the major land use changes that have occurred on this hill since the 1950's? Examples might include:
   - Grazing to crops
   - Seasonal crops to horticultural crops, irrigation
   - Small scale agriculture to large scale agriculture
   - Declining farm sizes
2. Where did the change occur, and why in those particular places?
3. When did those changes occur, and why then?
4. Who is responsible for those changes? For example:
   - New generations of local people (role of local population increase)
   - In-migration by other people (who, why, when)
   - Outside or local investors
5. Has this led to conflict over land, water or other resources?
6. What are the big reasons for these changes in land use?
7. What has been the role of the changing national economy in affecting land use?
   - Changing demand/ markets for commodities
8. What has been the role of the national government in affecting land use?
   - Land tenure (adjudication, privatisation, sub-division, etc.
   - Infrastructure development/ deterioration
   - Agricultural programmes
   - Enforcing, or not enforcing, rules such as park boundaries
   - War/ peace
9. What has been the role of the local government? of NGO's?
10. What will this area look like in 10 years? 20 years? What are the forces affecting future land use? Good way to get at this is to ask "What do you think the future will be for your children?"

A second method of gathering information on land use change and root causes is by conducting group or key informant interviews. Critical information may be obtained from interviews with local people concerning their impressions of the patterns of land use changes that have occurred, and the reasons behind those changes. Information that they might provide that would not be available from national level sources or statistics include the impact of local individuals or institutions (e.g., a large ranch or school), the impact of household level economies (e.g., for investment in irrigation), how the local socio-political context has affected land use, the existence of land use conflict, and what the trends are for future land use change.

These interviews are best conducted after remote sensing data is interpreted and initial land use change analyses are available, if possible. With maps of land use/ cover, the researcher can ask about specific nearby localities—for example why certain areas changed and others did not. Interviewing groups separated by gender, age group or ethnic/economic background may obtain best results. The questions asked during the group interview should be guided by the researchers' hypotheses concerning local to national level driving forces, and by the results of the remote sensing analysis. Box 1 presents an outline of basic questions.

d. Participation issues[6]

As is emphasized above, land managers are diverse; they differ by characteristics including economic class, access to resources, gender and age. Community participation facilitates assessment of these differences and their implications for programmes designed to improve livelihoods and promote ecological integrity. Researchers and development practitioners have developed community participatory approaches over the past 30 years. Their adoption of participatory methodologies can be traced to critiques of scientific epistemology and to "top-down" development initiatives in the developing world. The critiques have reshaped the approach of many researchers and practitioners to the communities in which they work to both improve understandings of rural livelihoods and the effectiveness of development projects (Chambers 1997). Participatory efforts have been influenced by Friere's "bottom-up" educational philosophy in which participation entailed an analysis allowing people to consider their own place within the web of

[6] This section is based on Smucker et al. (2004).

social relations that underlie problems (Freire 1970). Inclusion of marginalized and oppressed peoples set in motion a process of solving the immediate and practical problems they confront. Self-analysis of development problems would lead to social action and a reconfiguration of power relations within the society.

Thus, Friere's participatory methodology identified both practical and transformative dimensions of understanding social systems and addressing rural development problem. In the 1980's, participatory rural appraisal and rapid rural appraisal (PRA and RRA) emerged as means of drawing attention to local knowledge and developing understanding of problems facing local people (Chambers 1994). Participatory methods spread rapidly during the 1980's to mainstream development efforts, but a divergence grew between those who used participatory techniques for primarily research purposes and those who were more directly involved with helping marginalized groups in society to address inequality and injustice with "participatory action research"(Berardi 2002). It has particularly been useful as an approach to natural resources management at the community level (Rocheleau 1995; Pound et al. 2003).

The application of participatory methodologies to research on the driving forces of land use and cover change requires consideration of how scale, power, and social action questions may be beneficial to local people as well as an important for improving empirical field research. While both objectives contribute to the recognition of development problems, the following questions addressing the needs of the researchers and participant communities:

1. *Local interpretations of the driving forces at multiple scales*. Participatory workshops can provide an essential caveats and refinements to narratives of change developed through the analysis of survey data.
2. *Differentiated communities and the voices of participation.* Researchers may view participatory techniques as means to self-analysis leading to social change. Inclusion in a participatory research forum may, however, have mixed results particularly for the most vulnerable. Marginal groups may wish to avoid participating given fear of retribution from elites.
3. *The context and positionality of participation.* Local communities may have difficulty disassociating current with past research or development efforts. As such, outside researchers must be aware of the positionality of their research as created by past experiences. Research assistants are often local elites and may have worked for previous researchers or development agencies, and so may shade the research effort. The local government, often the vehicle for organizing forums, may further shape the way local people view the position of the research.

A central objective of land use research is to identify driving forces change at multiple scales. As such, the use participatory techniques can serve an important empirical objective of providing new information and corrected interpretations of other data.

e. Feedback Workshops

One method that meets several of these objectives is the feedback workshop. The purpose of feedback workshops is threefold: 1) to return to the community useful information that has been gathered by the project, 2) to identify and have the community and local decision makers consider policy and other implications of the information, and 3) to help ensure that the researchers are correctly interpreting the data and information that they have gathered (Campbell 1987; Smucker et al. 2004). Feedback workshops provide a tangible and often highly useful contribution by researchers to the community. In some areas, communities are insisting that researchers promise to conduct feedback workshops before they give permission for the researchers to work in their community.

The feedback workshops are thus usually held after the data has been collected, preliminary analyses completed, and initial conclusions developed. The workshops are usually open and participants include farmers and herders of the area, especially those who participated in the research, local community leaders and local government, NGO or other representatives. When the presence of local leaders may inhibit open discussion, follow-up meetings can be organised.

Researchers present results from their research that would be of particular interest to the group. Maps, graphs and other visual aids can be used to good effect. Examples of findings that may be of particular interest would be maps of land use change, survey results comparing regions or groups, or a focus on a particular problem facing the area (e.g., soil degradation, shortage of water resources, out-migration). In addition to presenting data, the researcher can present an interpretation of the reasons behind the findings in the form of questions. The ensuing discussion can then be directed towards the implications of the findings for the community, and how the community and others can respond. An approach for this type of community participatory development is based on Freire (1970).

3. National level information

Macro-level analyses both contextualize site level information within the national, regional, and international frameworks, and provide information on higher level root causes of land use change affecting land managers at the local level. Examples of information to examine at these levels include:

1. Population census data: demographic patterns and processes including migration,
2. Other socio-economic data such as changing agricultural production, income, and land tenure
3. Economic and policy analysis: Economic trends and policies that affect the sites such as information on policies and programmes in protected areas, land tenure policies, economic restructuring, and international economic and environmental agreements.

Some of this may be analysed spatially in a GIS, others statistically, but in general the critical policy information and economic analyses will be found in secondary sources such as government documents or analytical documents.

4. Spatial analyses and modelling

The analysis of land use data, usually from aerial photographs or satellite images, is a crucial component of this type of research. Spatial analysis can, for example, answer the “where?,” “why there?” or “what pattern” questions, provide information on interactions across space, the impact of distance, and how variables affect each other over time and space. Nevertheless, there are methodological and epistemological challenges to integrate political ecology and geospatial technologies. Determining who defines and interprets the classes, or what scale of analysis is used, can greatly affect the results (Zimmerer and Bassett 2003). For example, the definition of “degraded woodland”, and its utility, can depend on who you are (a farmer, herder or ecologist).

An approach that can reduce these complications and improve root causes analyses is to interpret data using both a *land use* and a *land cover* classification scheme (McConnell and Moran 2000; Butt and Olson 2002). It is important to differentiate land use from cover because cover may alter under same “use”. For example, the land cover inside a park (use designation) may change as the forest is thinned yet the use designation remains.

The land use designation aids in the analysis of the root causes of change—what landscapes will change, and why? The land use designation includes information on the type of land ownership and who manages the land, i.e., who makes the decisions on how the land is and will be used. For example, small scale agriculture (farms less than 5 acres) is separated from large scale agriculture (farms larger than 5 acres) and from institutionally owned and managed farms. The land cover designation is important for ecological work, e.g., for carbon storage determination, and for describing biodiversity and land degradation.

Chapter II above lists the variety of information that can be obtained from land use analyses concerning changing biodiversity or land degradation, and various LUCID reports provide land use interpretation methodological information (Butt and Olson 2002; Mugisha 2002; Olson, Butt et al. 2004; Olson, Misana et al. 2004). In addition to those types of analyses, spatial statistical analyses of satellite imagery can provide additional information useful in agriculture or natural resources management. Publications with information about satellite image spectral analysis to assessing land degradation include (Justice et al. 1998; Pickup, Bastin, and Chewings 1998; Bridges and Oldeman 1999; Diouf and Lambin 2001; Lal 2002; Moran et al. 2002; Shepherd and Walsh 2002; FAO 2003; Runnstrom 2003). Publications with information about using satellite image spectral analysis or other types of spatial analysis for examining biodiversity and landscape ecology include (Conroy 1996; Skidmore et al. 1997; Kepner et al. 2000; Qi et al. 2000; Serneels, Said, and Lambin 2001; Hunt et al. 2003; Redford et al. 2003; Hernandez-Stefanoni and R. 2004; Nagendra, Munroe, and Southworth 2004; Metzger et al. 2005). Many of these methods take advantage of the multi-temporal, multi-spectral qualities of imagery such as AVHRR or MODIS to derive phenological and inter-annual variability, and spatial variability and pattern information.

By combining imagery analysis products with ground measurements collected with a relevant sampling strategy, the results of the ground measurements can be up-scaled to a broader region. Examples of this include:

- Calibration of image with soil samples to generate maps of soil characteristics;
- Combining habitat information from imagery with ground and air wildlife counts;
- Soil sampling and vegetation species counts collected along transects to represent ecologically defined areas (Maitima and Olson 2001).

A rapidly growing activity in land use change and root causes research is the use of spatial modelling of land use to better quantify past and current root causes and spatial patterns, and forecast future changes. The models are generally constructed to address general questions and rarely attempt to represent the complexity of the real system. They are also usually functional at a single scale, for example at the field plot level, the household level or a regional view.

Many of the spatial models were developed originally for agricultural development or for urban zoning and other planning purposes, but have been adapted for environmental analysis (notably for predicting deforestation). A brief summary of types of models is presented below.

1. *Field or catchment models* to estimate soil erosion risk based on physical parameters (USLE) and some management variables (soil and water conservation). Many estimate potential, not actual, erosion so are useful for planning but not monitoring purposes, whereas others include field measurement data. This type of analysis has been conducted at broad scales, for example to identify desertification risk.

2. *Spatial allocation models* of land use conversions, for example deforestation. Several types of models have been developed that focus on patterns of LUC in relation to a limited set of surrogate variables (e.g., roads, rivers, population density) that are correlated with *where* land use change occurs. See Figure 4 for an example of forecasted land use change in Loitokitok, Kenya based on these variables. Some of these model are successful in statistically “explaining” past land use change with these limited variables and can then apply similar rules of interaction to forecast change in the short term. These models can also point to the impact of some policies such as road construction and, through an analysis of the “residuals” of the models, the impact of logging concessions or wildlife conservation policies. These types of models are not meant to determine *why* land use change occurs but their predictions can elicit stimulating hypotheses about the role of drivers such as policy changes or a push factor from outside the region leading to in-migration.

Recent models use neural nets which train on data to numerically solve spatial interactions between surrogates of LUC drivers; these neural nets can then effectively generalize across datasets and spatial regions to scale-up from site results to a larger region (Latham 2001).

3. *Process models*. Many root causes or drivers of LUC are related to socio-economic processes (e.g., market growth, policy changes, migration) that are often not captured by surrogate variables. To better answer the *why* question with such processes in mind, different types of models are employed, many based on von Thunen or Ricardo principles (Lambin, Rounsevell, and Geist 2000). Some attempt to represent decisions people make as they respond to economic considerations. For example, a model can determine the "rent" or potential return of competing uses of the land based on distance decay to markets, commodity prices and agronomic potential. When the potential return of a piece of land changes due to, for example, a price change, the land will convert to a different use. See Figure 5 for an example of model results again for Loitokitok that used a variety of rent data for the competing land uses of rainfed cropping, irrigated cropping and pastoralism. It indicates that rainfed cropping is more profitable than pastoralism across the study site, a result that may be the case in good rainfall years but does not fully take into account how people must be risk-averse. Nevertheless, the model provides scenarios of land use change that are highly provocative and provides a basis for discussion of the effect of various economic policies and programmes.

   Many of models have been limited in the past by not being grounded in economic or other socio-economic theory, while economic theory has not lent itself to spatial modelling. Recent efforts, however, are working towards developing a structural model of land use decision making based on economic theory (Irwin and Geoghegan 2001).

4. *Agent-based models.* These models attempt to represent different "agents" or individual land managers by including as variables certain characteristics that affect their land use decisions (e.g., rich versus poor farmers, the government, farmers versus herders). The models estimate the probability of a land use conversion in particular cells by including a wide variety of factors affecting decision making such as the household's access to various resources, the value it places on different uses, the level of integration into the market or its aversion to risk. In some models, agents purchase land from other agents, which can lead to a land use conversion, and can represent fragmentation or consolidation of land holdings (Box 2002; Pijanowski et al. 2002; Lambin, Geist, and Lepers 2003).

Increasingly, groups of researchers are working together to cluster different types of models to obtain a deeper understanding of the forces of change. Use of a combination of models, for example a stochastic economic model with an agent based model, permits each to inform the other. Similarly, the systems-type of problem that land use change presents results in any modelling being a representation of only a piece of the whole. In addition, verification of model results is becoming more of an issue (Kok et al. 2001). An increasingly common approach is to use expert appraisal of model results using knowledge elicitation techniques (Yamada et al. 2003). Experts of the area being modelled can provide an appraisal by critiquing the results based on their knowledge of the forces of change in the region, and they can also choose the most likely of the predicted scenarios.

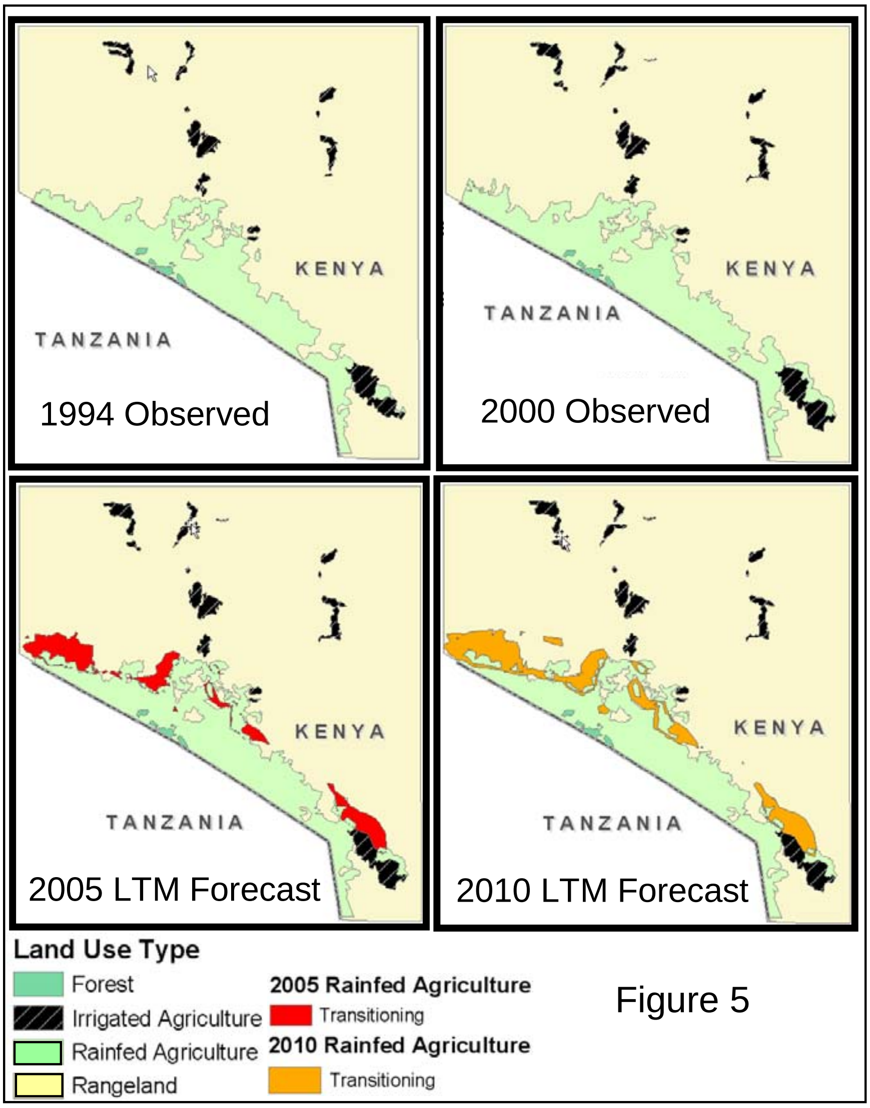
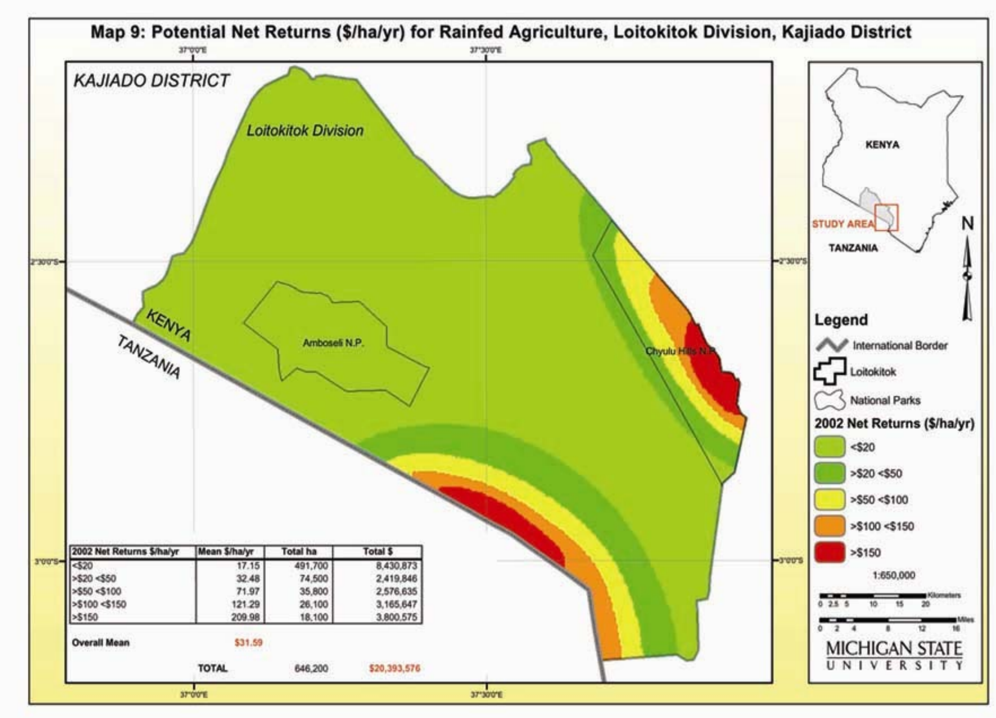


Figure 4. Land Transformation Model (a spatial allocation model) projection of land use change around Loitokitok, northern slopes of Mt. Kilimanjaro. Source: Pijanowski 2003.



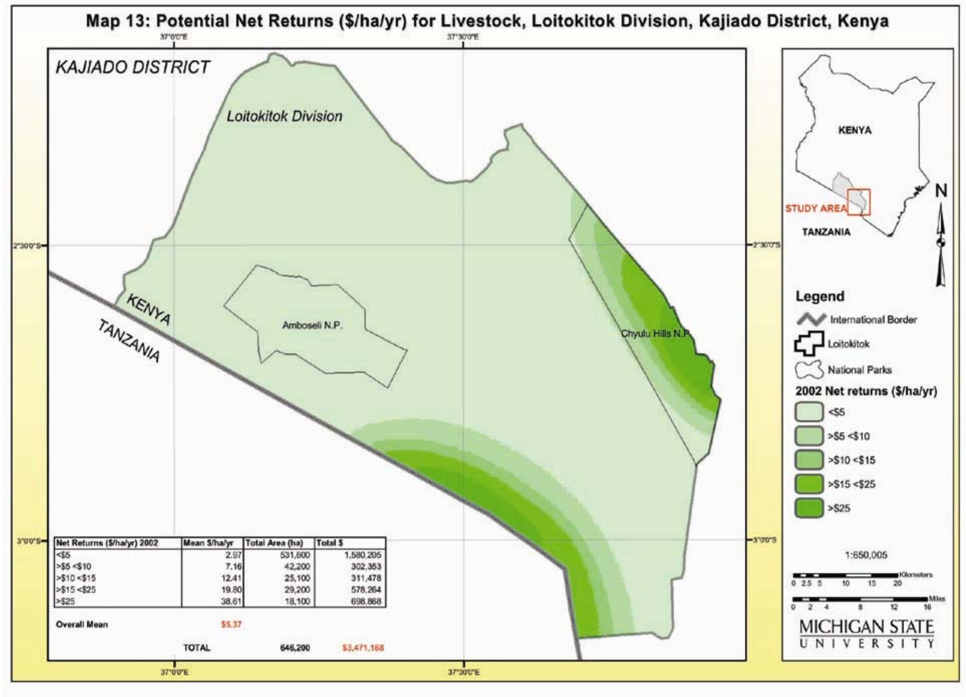


Figure 5. Results of econometric model of land rents for rainfed agriculture and livestock in the area around Loitokitok, northern slopes of Mt. Kilimanjaro. Source: (Norton-Griffiths and Butt 2004).

5. Data analysis considerations
As documented above, land use and root causes analysis is by its nature complex and multi-faceted. Any data collection, analysis and interpretation will necessary reduce this complexity. How this is done, however, can greatly affect the quality of the findings. There is a danger of being limited by what data one has, and what it illustrates. Usually, there is a need to supplement any interpretation with additional information and adopt a triangulation approach that examines an issue from different analytical perspectives and examines the degree and nature of coalescence in the outcomes.

In addition, the scale of analysis affects the research results. Not only are different types of information available at different scales, but also the dominant actors, processes and interactions vary across scales.

Other issues arise from the temporal scale/interval adopted by land use change analysis. These include:

1. Often, changes are missed because they occur between the years for which data is being interpreted. For example, a forest on the slopes of Mt. Kenya was completed cleared then re-grew into a secondary forest between 1987 and 2003, the years for which the images were interpreted.
2. important changes occur between the years for which imagery is being interpreted, and the analyst does not know when the changes occurred.
3. Changes occur but are misinterpreted or not captured because they were unexpected by the land use change analysts.

Temporal patterns and related driving forces are therefore difficult to determine solely from imagery interpretation. Limiting analysis to interpretation of remotely sensed information can lead to the wrong questions being posed or make wrong assumptions being adopted. Examples of this include:

1. Change is seen, but it is assumed to be due to a chronic process rather than a transitional or specific event (or visa versa).
2. The important role that individuals or groups make affecting land use change is often not expected since most “root causes” are be related to slow, evolving socio-economic processes
3. The direction of change may not be evident. For example, is the forest being cleared, or it is recovering?
4. Cultural values may override economic or other expected root causes.
5. Speculation may affect land ownership, but not change the land cover immediately, there may be a lagged effect.

These problems point to the importance of fieldwork and ground truthing of land use interpretations using local expertise and secondary data. It again points to the importance of verification and triangulation of sources.

VII. CONCLUSION
Land use change trends in many developing countries are both extremely rapid, and the direction of change and rates are in flux. The pattern and root causes of these trends need to be identified, and their impact on land degradation and biodiversity understood, before remedial policies and programmes can be effective in the long term across wide areas. The research situation in many areas is, however, a patchwork of case studies being conducted in relatively small areas and often focussing on one or other aspect of the ecological or social system. What is needed is a wider analysis of the societal and ecological trends across space to permit a generalisation of patterns, processes, and root causes to be made, and general lessons to be learned. Remedial strategies to address issues such as land degradation and loss of biodiversity would then be able to focus on

fundamental causes and processes of change, not symptoms, and thus increase the probability of their being effective. This objective would be greatly enhanced by the adoption of a common analytical framework to conduct such analysis and cross-site comparisons. This report has outlined one such framework that takes a systems approach to the understanding of the interaction of social and environmental processes over time and space. It is based in political ecology, a conceptual approach to understanding human/environment interaction, and is both multi-scale and temporally dynamic. Critical processes found to affect land use change related to change in biodiversity and land degradation were discussed, and generic research questions suggested. Methods to conduct such analyses range from complex spatio-temporal analyses and modelling techniques, to participatory workshops. Use of a multiplicity of methods, of several methods to gather information, is essential to provide a triangulation of information that enhances the reliability of interpretation.

ACKNOWLEDGEMENTS
The authors would like to express their sincere thanks to the United Nations Environment Programme and the Global Environment Facility for their generous support and encouragement of the LUCID project. They would also like to thank their own institutions—Michigan State University, the International Livestock Research Institute, Makerere University and the University of Dar es Salaam, for their financial, logistical and intellectual support. The students and other LUCID scientists who conducted research with the project have contributed vital insights and research findings reflected in this report. Finally, this report, and many of the other LUCID reports, benefited enormously from comments by Dr. Len Berry of Florida Atlantic University.

REFERENCES

Barbier, Edward B. 1997. The economic determinants of land degradation in developing countries. *Phil. Trans. R Soc. London* 352:891-899.

Bebbington, A.J., and S.P.J. Batterbury. 2001. Transnational livelihoods and landscapes: political ecologies of globalization. *Ecumene* 8 (4):369-380.

Berardi, Gigi. 2002. Commentary on the challenge to change: participatory research and professional realities. *Society and Natural Resources* 15:847-852.

Biot, Yvan, Piers M. Blaikie, Cecile Jackson, and Richard Palmer-Jones. 1995. Rethinking Research on Land Degradation in Developing Countries. Washington, D.C.: World Bank.

Blaikie, Piers, and Harold Brookfield. 1987. *Land Degradation and Society*. London: Methuen & Co., Ltd.

Blum, Winfried E.H. 2004. Indicators For Sustainable Land Management – Sharing Knowledge Between Science, Stake Holders And Politics. Vienna: University of Natural Resources and Applied Life Sciences, Vienna Department of Forest- and Soil Sciences.

Boserup, Ester. 1965. *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*. London: George Allen & Unwin Ltd.

———. 1981. *Population and Technological Change: A Study of Long-Term Trends*. Chicago: The University of Chicago Press.

Box, P. 2002. Spatial Units as Agents: Making the Landscape an Equal Player in Agent-Based Simulations. In *Integrating Geographic Information Systems and Agent-Based Modeling Techniques for Simulating Social and Ecological Processes*, edited by R. H. Gimblett. New York: Methuen.

Bridges, E.M., and L.R. Oldeman. 1999. Global assessment of human-induced soil degradation. *Arid Soil Research and Rehabilitation* 13 (4):319-325.

Butt, Bilal, and Jennifer M. Olson. 2002. An Approach to Dual Land Use and Land Cover Interpretation of 2001 Satellite Imagery of the Eastern Slopes of Mt. Kenya. Nairobi, Kenya: International Livestock Research Institute.

Campbell, B.M., and J.A. Sayer. 2003. *Integrated Natural Resources Management: Linking Productivity, the Environment and Development*. Wallingford, UK: CABI Publishing.

Campbell, David J. 1998. Towards an Analytical Framework for Land Use Change. In *Carbon and Nutrient Dynamics in Tropical Agro-Ecosystems*, edited by Bergstrom and Kirschmann. Wallingford, UK: CAB International.

———. 1999. Response to Drought among Farmers and Herders in Southern Kajiado District, Kenya: A Comparison of 1972-1976 and 1994-1996. *Human Ecology* 27 (3):377-416.

———. 1999. A Socio-Economic Perspective on Land Degradation and Linkages to GEF Focal Areas - Biodiversity, International Waters and Climate Change. Paper read at The Global Environment Facility Scientific Technical Advisory Panel Workshop, at Bologna, Italy.

Campbell, David J., David P. Lusch, Thomas A. Smucker, and Elizabeth Edna Wangui. 2004. Root causes of land use change in the Loitokitok Area, Kajiado District, Kenya. Nairobi: International Livestock Research Institute.

Campbell, David J., and Jennifer M. Olson. 1991. Environment and development in Kenya: Flying the Kite in Kajiado District. *The Centennial Review* XXXV (2):295-314.

———. 1991. Framework for Environment and Development: The Kite. East Lansing: Center for Advanced Studies in International Development, Michigan State University.

Chambers, Robert. 1994. All power deceives. *IDS Bulletin* 25 (2):14-26.

———. 1997. *Whose reality counts? Putting the last first*. London: Intermediate Technology Publications.

Chomwitz, Kenneth, and David A. Gray. 1996. Roads, Land Use, and Deforestation: A Spatial Model Applied to Belize. *World Bank Economic Review* 10 (3):487-512.

Cleaver, Kevin, and Gotz Schreiber. 1994. Reversing the Spiral: The Population, Agriculture and Environment Nexus in Sub-Saharan Africa. Washington, D.C.: World Bank.

Conroy, Michael J. 1996. Mapping of Species Richness for Conservation of Biological Diversity: Conceputal and Methodological Issues. *Ecological Applications* 6 (3):763-773.

de Sherbinin, A. 2002. Land-Use and Land-Cover Change. In *A CIESIN Thematic Guide*. Palisades, NY: Center for International Earth Science Information Network of Columbia University.

Diouf, A., and E. F. Lambin. 2001. Monitoring land-cover changes in semi-arid regions: Remote sensing data and field observations in the Ferlo, Senegal. *Journal of Arid Environments* 48:129–148.

Evans, T.P., and E.F. Moran. 2002. Spatial integration of social and biophysical factors related to landcover change. *Population and Development Review* 28 (Supplement).

Ewel, K.C. 2001. Natural resource management: the need for interdisciplinary collaboration. *Ecosystems* 4:716-722.

Fairhead, James, and Melissa Leach. 1996. *Misreading the African Landscape: Society and Ecology in a Forest-Savanna Mosaic*. Cambridge: Cambridge University Press.
FAO. 2003. Data Sets, Indicators and Methods to Assess Land Degradation in Drylands: Report of the LADA e-mail Conference 9 October - 4 November 2002. In *World Soil Resources Reports*. Rome: Food and Agriculture Organisation.
Fox, Jefferson, Ronald R. Rindfuss, Stephen J. Walsh, and Vinod Mishra. 2003. *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS*. Boston, MA: Kluwer Academic Publishers.
Freire, Paulo. 1970. *Pedagogy of the oppressed*. New York: Herder and Herder.
Geist, H.J., and E.F. Lambin. 2001. What Drives Tropical Deforestation? A Meta-Analysis of Proximate and Underlying Causes of Deforestation Based on Subnational Case Study Evidence. Louvain-la-Neuve, Belgium: LUCC International Project Office, University of Louvain.
———. 2002. Proximate Causes and Underlying Driving Forces of Tropical Deforestation. *BioScience* 52 (2):143-150.
Gibson, C.C., E. Ostrom, and T.K. Ahn. 2000. The concept of scale and the human dimensions of global change: A survey. *Ecological Economics* 32:217-239.
Hernandez-Stefanoni, J. Luis, and Ponce-Hernandez R. 2004. Mapping the spatial distribution of plant diversity indices in a tropical forest using multi-spectral satellite image classification and field measurements. *Biodiversity and Conservation* 13 (14):2599-2621.
Hunt, E. Raymond, Jr., James H. Everitt, Jerry C. Ritchie, M. Susan Moran, D. Terrance Booth, Gerald L. Anderson, Patrick E. Clark, and Mark S. Seyfried. 2003. Applications and Research Using Remote Sensing for Rangeland Management. *Photogrammetric Engineering & Remote Sensing* 69 (6):675–693.
Irwin, Elena G., and Jacqueline Geoghegan. 2001. Theory, data, methods: Developing spatially explicit economic models of land use change. *Agriculture, Ecosystems and Environment* 85:7-23.
Justice, Christopher O., Eric Vermote, John R. G. Townshend, Ruth Defries, David P. Roy, Dorothy K. Hall, Vincent V. Salomonson, Jeffrey L. Privette, George Riggs, Alan Strahler, Wolfgang Lucht, Ranga B. Myneni, Yuri Knyazikhin, Steve W. Running, Rama R. Nemani, Zhengming Wan, Alfredo R. Huete, Wim van Leeuwen, Robert E. Wolfe, Louis Giglio, Jan-Peter Muller, Philip Lewis, and Michael J. Barnsley. 1998. The Moderate Resolution Imaging Spectroradiometer (MODIS): Land Remote Sensing for Global Change Research. *IEEE Transactions On Geoscience And Remote Sensing* 36 (4):1128-1149.
Kepner, William G., Christopher J. Watts, Curtis M. Edmonds, John K. Maingi, Stuart E. Marsh, and Gonzalo Luna. 2000. A Landscape Approach for Detecting and Evaluating Change in a Semi-Arid Environment. *Environmental Monitoring and Assessment* 2000 (64):179–195.
Kinzig, A.P. 2001. Bridging disciplinary divides to address environmental and intellectual challenges. *Ecosystems* 4:709-715.
Kok, Kasper, Andrew Farrow, A. Veldkamp, and Peter H. Verburg. 2001. A method and application of multi-scale validation in spatial land use models. *Agriculture, Ecosystems and Environment* 85:223-238.
Lal, R. 2002. Soil Carbon Dynamics in Cropland and Rangeland. *Environmental Pollution* 116:353-362.
Lambin, E.F., X. Baulies, N. Bocksteil, G. Fischer, T. Krug, R. Leemans, E.R. Moran, R.R. Rinkfuss, Y. Santo, D. Skole, B.L. Turner II, and C. Vogel. 1999. Land-Use and Land-Cover Change (LUCC) Implementation Strategy. Bonn, Germany: International Geosphere-Biosphere Programme and the International Human Dimensions Programme on Global Environmental Change.
Lambin, E.F., M.D.A. Rounsevell, and H.J. Geist. 2000. Are Agricultural Land-Use Models Able to Predict Changes in Land Use Intensity? *Agriculture, Ecosystems and Environment* 82:321-331.
Lambin, E.F., B.L. Turner, II, H.J. Geist, S.B. Agbola, A. Angelsen, J.W. Bruce, O. Coomes, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X. Li, E.F. Moran, M. Mortimore, P.S. Ramakrishnan, J.F. Richards, H. Skånes, W. Steffen, G. Stone, U. Svedin, T.A. Veldkamp, C. Vogel, and J. Xu. 2001. The Causes of Land-Use and Land-Cover Change: Moving Beyond the Myths. *Global Environmental Change: Human and Policy Dimensions* 11 (4):5-13.
Lambin, Eric F., Helmut J. Geist, and Erika Lepers. 2003. Dynamics of Land-Use and Land-Cover Change in Tropical Regions. *Annual Review of Environmental Resources* 28:205-41.
Latham, John. 2001. AFRICOVER East Africa. *LUCC Newsletter* (7):15-16.
Liverman, Diana, Emilio F. Moran, Ronald R. Rindfuss, and Paul C. Stern, eds. 1998. *People and Pixels: Linking Remote Sensing and Social Science*. Washington, D.C.: National Academy Press.
Maitima, J.M., Robin Reid, L.N. Gachimbi, A. Majule, H. Lyaruu, D. Pomery, S. Mugatha, S. Mathai, and S. Mugisha. 2004. A methodological guide on how to identify trends and linkages between changes in land use, biodiversity and land degradation. Nairobi: International Livestock Research Institute.

Maitima, Joseph M., and Jennifer M. Olson. 2001. Guide to Field Methods for Comparative Site Analysis for the Land Use Change, Impacts and Dynamics Project. Nairobi: International Livestock Research Institute.

McConnell, William J., and Emilio F. Moran. 2000. Meeting in the Middle: The challenge of meso-level integration. An International Workshop, October 17-20, 2000, Ispra, Italy. In *LUCC Report Series*. Bloomington, IN: LUCC Focus 1 Office.

McCusker, Brent, and Daniel Weiner. 2003. GIS representations of nature, political ecology, and the study of land use and land cover change. In *Political ecology: an integrative approach to geography and environment-development studies*, edited by K. Zimmerer and T. Bassett. New York: The Guilford Press.

Metzger, K.L., Boone R.B., Coughenour M.B., and Reich R.M. 2005. Effects of seasonal grazing on plant species diversity and vegetation structure in a semi-arid ecosystem. *Journal of Arid Environments* 61 (1):147-160.

Moran, M.S., Kerr Y., Hymer D.C., and Qi J. 2002. Comparison of ERS-2 SAR and Landsat TM imagery for monitoring agricultural crop and soil conditions. *Remote Sensing of Environment* 79 (2-3):243-252.

Mugisha, Samuel. 2002. Root causes of land cover/use change in Uganda: An account of the past 100 years. Nairobi: International Livestock Research Institute.

Nagendra, Harini, Darla K. Munroe, and Jane Southworth. 2004. From pattern to process: Landscape fragmentation and the analysis of land use/ land cover change. *Agriculture, Ecosystems and Environment* 101:111-115.

Norton-Griffiths, Michael, and Bilal Butt. 2004. The Economics of Land Use Change in Loitokitok Division of Kajiado District, Kenya. Nairobi: International Livestock Research Institute.

Olson, Jennifer M. 1994. Farmer Responses to Land Degradation in Gikongoro, Rwanda. Ph.D., Geography Department, Michigan State University, East Lansing.

———. 1998. A Conceptual Framework of Land Use Change in the East African Highlands. Paper read at Earth's Changing Land: Joint Global Change and Terrestrial Ecosystems and Land Use and Land Cover Change Open Science Conference on Global Change, at Barcelona, Spain.

Olson, Jennifer M., Bilal Butt, Fred Atieno, Joseph Maitima, Thomas A. Smucker, Eric Muchugu, George Murimi, and Hong Xu. 2004. Multi-scale analysis of land use and management changes on the Eastern Slopes of Mt. Kenya. Nairobi: International Livestock Research Institute.

Olson, Jennifer M., Salome B. Misana, David J. Campbell, Milline J. Mbonile, and S. Mugisha. 2004. The Spatial Pattern and Root Causes of Land Use Change in East Africa. Nairobi: International Livestock Research Institute.

Peet, R., and M. Watts. 1996. *Liberation Ecologies: Environment, Development, Social Movements*. New York: Routledge.

Pickup, G., G.N. Bastin, and V.H. Chewings. 1998. Identifying Trends in Land Degradation in Non-Equilibrium Rangelands. *Journal of Applied Ecology* 35:365-377.

Pijanowski, B.C., D. G. Brown, G. Manik, and B. Shellito. 2002. Using Neural Nets and GIS to Forecast Land Use Changes: A Land Transformation Model. In *Computers, Environment and Urban Systems*.

Pound, Barry, Sieglinde Snapp, Cynthia McDougall, and Ann Braun. 2003. *Managing Natural Resources for Sustainable Livelihoods*. Sterling, VA: Earthscan Publications Ltd.

Qi, J., Weltz M., Huete A.R., Sorooshian S., Bryant R., Kerr Y.H., and Moran M.S. 2000. Leaf area index estimates using remotely sensed data and BRDF models in a semiarid region. *Remote Sensing of Environment* 73 (1):18-30.

Rapport, D.J., and A. Singh. 2002. Framework for the State of Environment Reporting. Paper read at UNEP-SCOPE workshop on " Making science more policy relevant", at Prague.

Redford, K.H., Dinerstein E., Groves C., Mace G., Maginnis S., Mittermeier R.A., Noss R., Olson D., Robinson J.G., Vedder A., Wright M., Coppolillo P., Sanderson E.W., and Da Fonseca G.A.B. 2003. Mapping the conservation landscape. *Conservation Biology* 17 (1):116-131.

Robbins, Paul. 2004. *Political Ecology: A Critical Introduction*: Blackwell Publishers.

Rocheleau, D., B. Thomas, and E. Wangari. 1996. *Feminist Political Ecology: Global Issues and Local Experiences*. New York: Routledge.

Rocheleau, Dianne. 1995. Maps, numbers, text, and context: mixing methods in feminist political ecology. *Professional Geographer* 47:458-466.

Rosenzweig, M.L. 1995. *Species Diversity in Space and Time.* Cambridge: Cambridge University Press.

Runnstrom, M. C. 2003. Rangeland Development of the Mu Us Sandy Land in Semiarid China: An Analysis using Landsat and NOAA Remote Sensing Data. *Land Degradation and Development* 14:189–202.

Scheiner, Samuel M., Stephen B. Cox, Michael Willig, Gary G. Mittelbach, Craig Osenberg, and Michael Kaspari. 2000. Species richness, species–area curves and Simpson's paradox. *Evolutionary Ecology Research* 2:791–802.

Scherr, Sara J. 1995. Meeting household needs: Farmer tree-growing strategies in Western Kenya. In *Tree Management in Farmer Strategies*, edited by J. E. M. Arnold and P. A. Dewees. Oxford UK: Oxford University Press.

Scherr, Sara J., and Satya Yadav. 1996. Land Degradation in the Developing World: Implications for Food, Agriculture and the Environment to 2020. Washington, D.C.: International Food Policy Research Institute.

Serneels, S., M. Said, and E. Lambin. 2001. Land-Cover Changes Around a Major East-African Wildlife Reserve: The Mara Ecosystem (Kenya). *International Journal of Remote Sensing* 20 (17):3397-3420.

Shepherd, K.D., and M.G. Walsh. 2002. Development of reflectance spectral libraries for characterization of soil properties. *Soil Science Society of America Journal* 66:988-998.

Skidmore, Andrew K, Wietske Bijker, Karin Schmidt, and Lalit Kumar. 1997. Use of remote sensing and GIS for sustainable land management. *ITC Journal* 1997 (3/4):302-315.

Skole, David. 1995. Land Use and Land Cover Change: an Analysis. *IGBP*:4-7.

STAP. 1999. Report of the STAP Expert Group Workshop on Land Degradation (Prepared by the Scientific and Technical Advisory Panel). Washington, D.C.: Global Environment Facility.

Tengberg, Anna, Jim Ellis-Jones, Romano Kiome, and Michael Stocking. 1998. Applying the Concept of Agrodiversity to Indigenous Soil and Water Conservation Practices in Eastern Kenya. *Agriculture, Ecosystems and Environment* 70:259-272.

Tiffin, Mary, Michael Mortimore, and Francis Gichugi. 1994. *More People, Less Erosion: Environmental Recovery in Kenya*. Chichester: John Wiley & Sons.

Turner, B.L II, Goran Hyden, and Robert W. Kates, eds. 1993. *Population Growth and Agricultural Change in Africa*. Gainesville: University Press of Florida.

Turner, B.L., II. 2001. Land-Use and Land-Cover Change: Advances in 1.5 Decades of Sustained International Research. *GAIA-Ecological Perspectives in Science, Humanities, and Economics* 10 (4):269-272.

Turner, B.L. II, David Skole, Steven Sanderson, Gunther Fischer, Louise Fresco, and Rik Leemans. 1995. Land-Use and Land-Cover Change Science/Research Plan: International Geosphere-Biosphere Programme.

Turner, M., R. O'Neill, R. Gardner, and B. Milne. 1989. Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology* 3 (3-4):153-162.

UNCSD. 1996. Indicators of Sustainable Development: Framework and Methodologies. New York: United Nations.

Van Lynden, G.W.J., H.P Liniger, and G. Schwilch. 2002. The WOCAT map methodology, a standardized tool for mapping degradation and conservation. Paper read at ISCO Conference 2002, at Beijing.

Veldkamp, A., and E.F. Lambin. 2001. Predicting land use change. *Agriculture, Ecosystems and Environment* 85:1-6.

Walker, R.T. 1997. Land Use Transition and Deforestation in Developing Countries. *Geographical Analysis* 19:18-30.

Wangui, Elizabeth E. 2003. Links between Gendered Division of Labour and Land Uses in Kajiado District, Kenya. Nairobi: International Livestock Research Institute.

Wiens, J. 1995. Landscape mosaics and ecological theory. In *Mosaic Landscapes and Ecological Processes*, edited by L. Hansson, L. Fahrig and G. Merriam. London: Chapman & Hall.

Yamada, Kuniko, Jane Elith, Michael McCarthy, and Andre Zerger. 2003. Eliciting and integrating expert knowledge for wildlife habitat modelling. *Ecological Modelling* 165:251–264.

Zimmerer, K. S. 1994. Human geography and the new ecology: the prospect and promise of integration. *Annals of the Association of American Geographers* 84 (1):108-125.

Zimmerer, Karl S., and Thomas J. Bassett. 2003. *Political Ecology: An Integrative Approach*. New York, NY: The Guilford Press.