



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

**A methodological guide on how to identify trends and linkages
between changes in land use, biodiversity and land degradation**

LUCID Working Paper Series Number: 43

by

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June 2004



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Regional synthesis paper:

A methodological guide on how identify trends in the linkages between changes in land use, biodiversity and land degradation

The Land Use Change, Impacts and Dynamics Project
Working Paper Number: 43

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

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EXECUTIVE SUMMARY

This paper reports on the methodological framework used to analyze the linkages between land use change, biodiversity loss and land degradation. This summary presents the major methodological approaches used in the analysis of linkages. The framework of analysis presented here is replicable and is meant to guide similar analysis in other areas. The following is a summary of highlights for the framework.

- **Sampling different components of land use, biodiversity and land degradation indicators on spatial and temporal perspectives.** The linkages could be affected by many factors some of which could be site or time specific. It is important to identify and isolate these effects in order to understand the effects that are due to the linkages. Sampling of different components of biodiversity and indicators of land degradation in different states of land use both spatial and temporal can reduce variability due to site and time.
- **Sampling across different agro-ecological zones**
Effects of a particular land use on biodiversity and land degradation will vary with agro-ecological zones due to different ecological conditions in different zones. The sampling must therefore be designed to group land uses within and between agro-ecological zones (AEZ). In this study sampling was done at plot level but analysis is done at (AEZ) level.
- **Space for time analysis**
Analysis of changes across a large spatial scale gives a possibility of capturing different land cover types, some representing conditions with natural vegetation, and a wide range of other land uses with different histories of usage and periods of cultivation since the original conversion from natural habitat. This was found to be a good method to substitute the sequential temporal dynamics that is usually not available.
 - **Transect analysis for linking vegetation and soils across agro-ecological zones**
We used transect analysis to sample different land use types within agro-ecological zones. Using an agro-ecological zone as the basic sampling unit we distributed four subtransects at random and perpendicular to the main transect across the zones. In each subtransect all land uses were sampled at least twice to have a minimum number of samples per land use with AEZ as eight. In some cases where the land use was very rare and thus not captured in the subtransect, the one nearest to the subtransect was sampled.
 - **Sampling vegetation by quadrats**
Vegetation in different land uses was sampled using quadrats of different sizes depending on the life form of the vegetation sampled. Trees, shrubs and herbs were sampled by 20x20m, 10x10m and 1x1m quadrats respectively both in natural and in cultivated areas. The minimum number of quadrats sampled per land use / land cover per agro-ecological zone for each lifeform was eight. We use square quadrats but we recommend this to be reviewed in respect to changing views of the choice between square and circular quadrats as reported in plant ecology literature. In all the sites similar sample sizes were made to enable across site comparison. To enable linkages between vegetation data and soils data both were sampled on the same quadrats.
 - **Key informants**
To get information on changes in key resources like medicinal plants, we held discussions with key informants like herbalists to note their experiences on the changes in abundance of species they use for traditional medicine. Similarly our discussions with local elders gave very useful information on the historical changes at

landscape level in regards to land cover, biodiversity, general crop productivity, and the history of land use especially changes in the crops planted.

- **Uniformity in land cover and land use classification**

To enable comparison across sites we adopted a uniform classification of vegetation, land uses and land cover. This is important because different sites were sampled by different people.

- **Identifying the linkages**

In order to identify and establish the linkages between land use change, biodiversity loss and land degradation it is necessary to do the sampling of the three components in an interactive system where changes in each is expected to be influenced by the other two.

- The linkages can be established if measurements on the three components are made on same plots. Using land use types as the basic units of analysis any variability in biodiversity composition and abundance within a land use type can be compared to variations in soil physical and chemical characteristics while taking into account the effects of varying environmental. The effects due environmental conditions can be minimized by using AEZ the graphical areas of analysis.
- Land use types should be categorized based on crops or combination of crops or land covers and land management practices. Since crop combinations in farms and land management practices could be very diverse and all could affect soil characteristics in different ways or magnitudes it is important to develop functional combinations based on either growth periods (annuals or perennials), crop lifeforms (herbs/ shrubs/trees), traditional practices in cropping systems (mono vs mixed cropping,

- **Sampling of animal biodiversity**

The groups of animal biodiversity studied in the LUCID project include small mammals, large mammals, and birds. Other animal groups like invertebrates, insects, reptiles and amphibians could be important but they were not sampled in this study. Methods used to sample animal biodiversity varied with the groups of animals being sampled. The most important consideration in sampling animal biodiversity is to make sure that the analysis can be linked to habitats or land use / land cover types. Being able to understand how different land uses or land cover types affect the composition, abundance and distribution of different animal groups is very important.

- **Sampling of soil characteristics**

Two categories of soils were required: one was information on soil erosion and the other was information on soil chemical composition. Soils were analyzed for chemicals that show the status of soil fertility. Information of soil erosion was obtained by visual observation of indicators of different forms of erosion within the quadrats sampled for vegetation or land use.

1.0 INTRODUCTION

Land use in East Africa varies widely on the type of crops planted, the size of plots per land use type, land management, and cropping systems. Farm sizes vary from small vegetable gardens in the back yards of many homesteads through a multiple of medium sized mixed farming systems to large commercial mono crop farming and livestock production systems. All these land use systems were developed from initial land covers of natural vegetation that was less or not disturbed by man. By converting the initial land cover that was more self-regulating within natural processes, man modified the ecosystem to suite his own needs with little or no regards to the effects these conversions had on the natural processes. The modified ecosystems are to a large extent very different from what would have been there if the human disturbance had not occurred. Some of the modified ecosystems are in many cases a change not desirable or not sustainable leading to degradation and thus affect the ability of the same ecosystem to deliver the goods and services that man intended to earn from the activity.

It has been observed that land quality in these man modified ecosystems degrades over time resulting into higher demands for farm inputs in order to sustain productivity. Loss of biodiversity has also been observed in all these areas of land use change. It has therefore become important to know how land use contributes to land degradation and how land use change leads to biodiversity loss.

It is necessary to assess trends of change in various categories of land use systems and to determine levels of land degradation in these systems in order to know how land use change links leads to land degradation. Since biodiversity is affected by land use change (e.g., conversion, land clearing) and land degradation (e.g., decline in crop productivity and), (FAO, 1983) it is necessary to investigate how changes in land use affect biodiversity and vice versa.

Currently there is no methodology of how to use land use change analysis to assess changes in biodiversity and land degradation. The work presented here is intended to contribute to this deserving need. This report is a synthesis of methods used by the LUCID Team in investigating the linkages between these three domains.

Questions about the magnitude and trends of change in ecological resources are of global importance as changes at local level aggregate to regional and global scales. Some examples include whether certain land use types are more degrading than others; whether biodiversity is decreasing or reducing over large regions; and whether changes in ecological communities resulting from changes in land use are reducing the ability to deliver goods and services. Good answers to these questions depend upon having good measurements using appropriate statistical designs to sample environment and appropriate statistical techniques to estimate trends. Although the concept of trends and change appear simple, the ecological and statistical issues associated with good design and analysis are quite complex.

Trend is defined as a long-term change in the mean. Long terms depends on the temporal scale of the study and the relevant ecological dynamics. It is difficult to separate long-term trends from the components of temporal variations, including multi-year variations, within year seasonal variations and occasional erratic fluctuations. Trend can be net or gross (Urquhart, et al. 1998), site specific or regional. It can appear as an indicator or in a population summary. This report focuses on how to analyze gross regional trends of the relationships between land use change, biodiversity loss and land degradation, across time, where time is viewed discretely (e.g., annually) and region is an infinite geographical location represented by specific sites across the region.

Another complexity is defining an appropriate spatial coverage. Most land use studies are intensive studies of single (sentinel) sites. If spatial variation among sites is small, trends at a single site may be representative of much larger areas. Unfortunately, large amounts of spatial variation is the norm especially for ecological quantities like species composition and biodiversity types. Making generalizations about regional trends requires more spatially complete data either from networks of

sites or from complete spatial coverage. This requires that the concept of change be expanded to include spatio-temporal trends summarized across the region. The ecologically interesting trend may be the change in spatial distribution across a region, not as change in the average amount.

1.1 Summary of analytical framework for linkages

1.1.1 Definitions of land use, land use change, biodiversity and land degradation

Land use represents the human use of the land (for example, small-scale agriculture, grazing, wildlife reserves or industrial zones). **Land cover** represents the biophysical cover (for example, savannah, broadleaf forest, tea or built up areas). Land use change is the use of a particular land is changed from one to another over time, (e.g., from natural vegetation/ forest to cultivation; cultivation to grazing or from swamp to cultivation). **Biodiversity** is defined by the Convention on Biological Diversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (<http://www.biodiv.org/>). In this project, we define **biodiversity** at both the species and ecosystem levels, recognising the importance of the genetic diversity that we did not measure.

The LUCID project adopted the U.N. Convention to Combat Desertification definition for land degradation, which is the definition adopted by GEF, is as follows:

Land degradation is a ‘reduction or loss, in arid, semi arid and dry sub humid areas of biological or economic productivity or complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including process arising from human activities and habitation patterns such as: soil erosion caused by wind and /or water; deterioration of the physical, chemical and biological or economic properties of; and long term loss of natural vegetation.

1.1.2 Linkages between land-use, biodiversity and land degradation: key concepts

Figure 1 shows the general conceptual linkages that we will address in this paper. We will focus most of our attention on the one way linkages between land-use change and biodiversity and land-use change and land degradation, but we will also discuss the feedbacks of changes in biodiversity and land degradation on land use. We will also address the two-way linkage between biodiversity and land degradation.

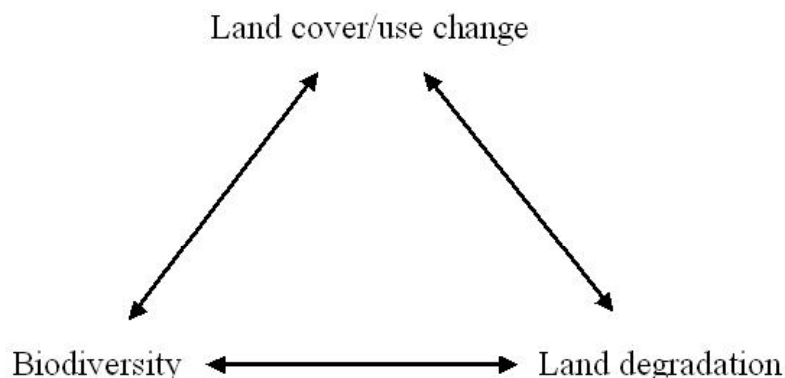


Figure 1: Conceptual linkages between land cover/use change, biodiversity and land degradation that will be covered in this paper.

This simple conceptual model is made more realistic (and complicated) when we add some key concepts. This triangle fits into the ‘environmental’ part of the KITE framework that appears in our LUCID ‘driving forces’ paper (Campbell and Olson 1991; Campbell *et. al.* 2003). As such, one key concept is that these linkages differ depending on the *spatial scale of resolution*. At the

fine scale of an individual farmer's field, for example, declining soil fertility can reduce plant species diversity as farmers shift from coffee cultivation to maize in a single field, or from long fallows to short fallows. However, at the broader scale of the entire kihamba system of a Chagga family on Mt. Kilimanjaro, the loss of fertility and plants species in a maize field may be balanced, at the whole farm level, by increases in fertility and plants species richness through integration of the maize with other crops and trees, in comparison to a farm with a maize mono-crop. At a broader scale, the juxtaposition of many different types of family farms may create very complex systems of small-holder farming that are very different than large commercial farms that grow maize alone. Thus, in order to understand the emergent sustainability of the system, we must consider these linkages at several scales of resolution.

Second, we need to consider the concepts of **bi-directionality** of some of our processes. Just as land use does not always intensify over time (it can 'dis-intensify' too, see Conelly 1994), we should not assume that intensifying land use universally causes land degradation and biodiversity loss. It is possible that expansion or intensification of human land use will result in expansion of forest in place of savanna (Fairhead and Leach 1996), more soil conservation methods (Tiffen et al. 1994), and better grazing lands for wildlife (Reid et al. 2001). Thus, we must allow (and search for) positive synergies between people, land and biodiversity, despite the many negative examples.

It is important to be clear that processes are often *not linear* and that one process can *feedback* on the other. For example, expanding croplands may have no effect whatsoever on the diversity of large mammals until the croplands prevent animal access to critical key resources (like the swamps in Amboseli) or key corridors (like elephants in the Kitendeni corridor on Kilimanjaro). This is a *non-linear threshold* effect, with the potential for rapid change in wildlife populations over short periods of time once a threshold is reached (Hoare 1999). This means that it is important to understand these linkage relationships over a wide range of circumstances if we hope to have information of robust scenarios for the future. In addition, feedbacks may also create unexpected connections. For example, while we recognise that land-use clearly can affect biodiversity, we are less aware of the feedback between biodiversity and land use.

Finally, it is critical to recognise the *dynamism* of land-use systems over time and the that the speed of change can vary strongly from place to place and process to process (e.g., there are *fast and slow* variables). For example, a classic slow variable, climate change, will likely gradually change the relationship of land use and biodiversity in our sites, as some sites become wetter and others drier over the next several decades in East Africa.

2.0 POSING LINKAGE QUESTIONS

2.1 The importance of questions that require information from different disciplines

This work being a guide to assist researchers and other investigators into using land use change analysis as a method for investigating, biodiversity loss and land degradation it is important to reflect on the questions that can guide in choosing the right methodologies in various approaches. The questions will lead us to the problems we intend to investigate and also guide on selection of methods that will eventually enable integration of the different disciplines to identify the linkages. The following is a summary of the guiding questions in each of the three disciplines.

In land Use change analysis, investigations should be centered around analyzing the changes in land use that have taken place over time in different study sites and different agro-ecological zones. It is therefore imperative to know:

- 1) How has land use in various sites changed over time? This leads to investigations on for example, how much land has been converted from indigenous vegetation such as forests, woodlands, bush, grasslands etc. to cultivations, grazing lands, settlements and vice versa? What are the trends in land use change over time and space?

- 2) How have the land use changes described above affected the composition and distribution of plant species? Reference is here given to species richness in trees, shrubs, herbs and grass vegetation components. Relative percentages of different land cover – species, vegetation types, and bare ground. What are the relative proportions of cultivated and uncultivated areas?
- 3) How have the changes in land cover resulting from changes in land use affected ecosystem diversity in the study areas? Investigations to respond to this question will provide information as to whether the changes in land use have increased or reduced ecosystem heterogeneity at landscape level.

Investigations on changes in biodiversity. Since biodiversity comprises of many components many of which require different sampling methods and specialized expertise, we recommend first a reconnaissance survey to establish the biodiversity components that are relevant in the study area. In some areas for example wildlife may be the most important in regards to land use, while in other areas birds, or insect pests may be the most important. The issue here however, is the type of land use and the biodiversity component that is most affected. In a multi site study like different sites can investigate different components of biodiversity. The important questions in investigating the effects of land use on biodiversity are:

- 1) How have the land use changes affected the composition and distribution of plant species? Reference is to species richness in trees, shrubs, herbs and grass. Relative percentages of different land cover per species and vegetation types like bush, forest or plant growth form like trees, shrubs and herbs.
- 2) How has changes in habitats resulting from the changes in composition and distribution of plant species affected animal populations, e.g., birds, small mammals, and large mammals?

In addition to quantifying changes in land use and biodiversity we need to investigate on the levels of land degradation associated with the changes in land use and biodiversity as outlined above. Assessment of land degradation could be done in many ways: 1) assessing the changes in soil fertility; 2) assessing levels of soil erosion; 3) assessing changes in ecosystem complexity and 4) assessing changes in ecosystem or land use productivity. In all these assessments a change from high to low is taken as an indicator of land degradation. Questions that can guide these investigations include:

- 1) Have the changes in land use lead to changes in biodiversity at plot or landscape levels?
- 2) Have the changes in land use and biodiversity lead into increase in land degradation?

Investigations on the linkages of these changes in land and the resulting changes in biodiversity to land degradation need to be made in order to understand how they have affected or contributed to land degradation. Pertinent questions in this regard include:

- 1) How has changes in land use reported above affected soil fertility and soil erosion potential and how do these changes vary in different agro-ecosystems?
- 2) How has changes in land cover resulting from changes in land use affected the quality and availability of environmental goods and services?, (e.g., honey, medicinal herbs, wood resources, native plant species, rare and threatened plant species, etc.,
- 3) How has the changes in soil fertility resulting from changes in land use affected the agricultural potential (e.g., crop production)?

3.0 HOW AND WHY DOES LAND USE AFFECT BIODIVERSITY?

All forms of land use involves utilization of land resources for human benefit. Biodiversity is a land resource that is more often the target for human utilization. Land use may therefore have direct effects on biodiversity especially when the form of land involves harvesting or modifying

the land cover. There may be other indirect effects of land use on biodiversity like land use based pollution (e.g., pesticides) to distant places or land use effects to non-target organisms. In summary the following are the major land use changes observed in our study sites and the associated effects on biodiversity.

- 1) Conversions of land cover from natural vegetation to cultivations.
Cultivation involves clearance of natural vegetation to create farmlands. Farmlands comprise of agro-ecosystems that are modified by man by removing the native species and replacing them with crop plants and other exotic plant species that are fast growing and commercially valuable. These conversions result into:
 - a. Loss of native species in natural habitats
 - b. Destruction of habitats for animals
 - c. Exposing soils to water and wind erosion
 - d. Reduction in shade on soils
 - e. Increase in abundance of unpalatable grasses and introduction of new species.

- 2) Conversion of land cover from natural vegetation to grazing. This is a common change especially the rangelands. Livestock grazing is the major land use. The most common activity is removal of tree and bush cover to increase grass cover for livestock grazing. Associated effects on biodiversity include:
 - a. Loss of tree and shrub cover
 - b. Loss of habitats for animals
 - c. Selective reduction of palatable grass species

- 3) Change from grazing to cultivation. These are common land use changes in crop livestock areas where livestock keeping and cultivation is practiced. Among the agro-pastoral areas cultivators move in and clear some designated areas for crop cultivation. This change in land use leads to:
 - d. Loss of grass cover
 - e. Exposure of soils to erosion
 - f. Increased land use intensification

- 4) Change from one cultivation type to another.
Vegetative cover is only obtained from grass and forage crops. In the case of row crops only part of the soil is covered, and in the case of broadcast crops such as small grains the cover may be uniform but it is not dense, and so in both cases the effect of variations in the amount of cover is important as it has implications on soil erosion. It is evident that small differences in cover from different or same crop can cause big differences in soil erosion. Removed grass cover by overgrazing or cultivation exposes soil to raindrop impact and subsequent soil erosion. If the soil is covered by annual crops, there is a period when the ground is bare just before the rains and this makes it prone to serious erosion, which is reduced when the crop grows to a good level. Some of the changes in crop types that has direct effects on biodiversity include:

- a. Change from mono crop to mixed crops and vice versa
- b. Change from annual crops to perennial crops and vice versa

3.1 How and why does biodiversity affect land use?

Cultural preferences for different types of biodiversity lead to different land use systems in the same environments across cultures/countries (e.g., *matoke* vs. maize/coffee). Cultural adaptations to food production has evolved within communities to be not only food crop specific but also specific on the types of habitats where best to grow their crops. At a broader scale cultivators tend to focus on areas with thick vegetation where soils are richer with more organic matter, and more reliable rainfall, while livestock (cattle) keepers tend to select open grasslands where their herd will get more pastures. These selections are based on biodiversity

assessments as an indicator for potential productivity. During drought, pastoralists travel long distances following biodiversity trends to feed their flock

Landscape diversity affects the choices available for land users (agro-ecological zones at a broad scale, swamps at a landscape scale, termite soil at the field scale). The distribution of biodiversity across the landscape is never homogeneous. It is characterized by punctuations of varying microhabitats that host plant species with specific preference for the habitat. These micro habitats are as a result of many factors like soils, elevation and aslope, and water availability.

Invasions by pests (quelea, moles, striga) or wildlife diversity (elephants) affects what land-use (cultivation) and crop choices (millet) are viable. In many areas production of some cereal crops like wheat is not practiced in a small scale because of birds that eat the crop when it is ready. Wildlife like elephants that move from place to place in a definite annual route in search of food make cultivation within the route impossible because of crop destruction. Within these routes land use excludes perennial crops like mango trees, bananas that are eaten by elephants and concentrate on quick maturing crops that are harvestable before it is time/season for the elephants to arrive. The same problem is caused by notorious wild animals like baboons especially for the farms bordering natural forests with baboon populations.

Biodiversity in an area may include some disease vectors like tsetse flies and mosquitoes that are responsible for the transmission of trypanosomiasis and malaria respectively. These diseases especially animal trypanosomiasis has been known to be a guardian of the wild for preventing human occupation in the infested areas. The same case applies for several other disease like bilharzia that is transmitted by a species of snails found in swamps and the disease has kept people away from cultivating in wetlands.

Some traditions have cultural restrictions preventing people from utilizing places of high value in biodiversity (Khaya forests, sacred forests). In many cases it is due to the uniqueness of the biodiversity (forests) and physical features (waterfall) that the surrounding communities have developed cultural or religious values and hence the need for their protection. These places are comparable to the modern wildlife conservation areas except that utilization in tourism activities is not as high.

3.2 How and why does land use affect land degradation

Increased evapotranspiration from soils reduce the amount of water available to primary producers including crops and hence stress during plant growth. Soil moisture is crucial for the productivity of crops and the general well being of vegetation. Ground cover reduces evapotranspiration so that soil can retain their moisture for longer periods. Removal of vegetation as a result of land use change will obviously lead to loss of soil moisture and hence less ability to support plant growth. Loss in flora will consequently lead to loss of habitat for animals and therefore lead to a degraded ecosystem.

Land use reduces ecosystem complexity and diversity by replacement of more complex natural vegetation with less complex agro-ecosystems with fewer species. Changes in the complexity of an ecosystem could be measured by assessing the level of stratification of trees, shrubs or herbaceous canopies. The more stratified an ecosystem is (the three canopies being represented) the more complex it is. Removal of tree or shrub covers in the case of grazing areas will reduce stratification and hence reduce the complexity leading to degradation. Selective removal of certain species e.g., species of economic value will also reduce both the species diversity, the complexity as the canopy covers they were part of is removed especially in logging and charcoal burning that affects large trees.

Our studies (Mugatha 2002, Worden *et al* 2003, Ogotu *et al.* 2004) has shown that the distribution of vegetation types, key resources within the habitats affects both the composition

and distribution of animal species. A study of the effects of land use intensity on species diversity of small mammals indicate that more intensive land uses have less abundance and diversity of small mammals as the very specialized rare species tend to disappear. Similarly the less an ecosystem is endowed with key resources like water, the less diverse are the animal species found in it. Ogutu, et. al. (2004) working in Mara National Reserve found that animals graze around a certain range within the water sources beyond which both the density and diversity of animals reduce.

Increased soil erosion due to removal of vegetation cover

Land use/cover, soil type, slope, slope length, rainfall amount and intensity influences the rate of soil erosion in an area. Tea fields have a good copy cover on the ground that intercepts raindrops preventing chances of gully formation, unlike the situation in most annual crops, which leave open areas that become subject to soil erosion. The nature of the soil determines soil erodibility potential. Sandy soils for example are prone to erosion compared to clay-loamy soils. Gentle slopes are less prone to erosion compared to steep slopes. Rainfall amounts and intensity determine the amount of soil detached and thus rate of erosion in an area. Classes for identifying the severity of observed erosion in an area have been established by FAO (1983). Erosion intensity was assessed according to four classes of erosion in different agro-ecological zones and land uses within the study area (Figure 2). Erosion classes were: E0= no visible evidence of soil erosion or slight sheet erosion, E1= slight to moderate sheet erosion (or shallow rills), E2 = moderate to severe sheet wash soil erosion; E3 = severe erosion with gully development.

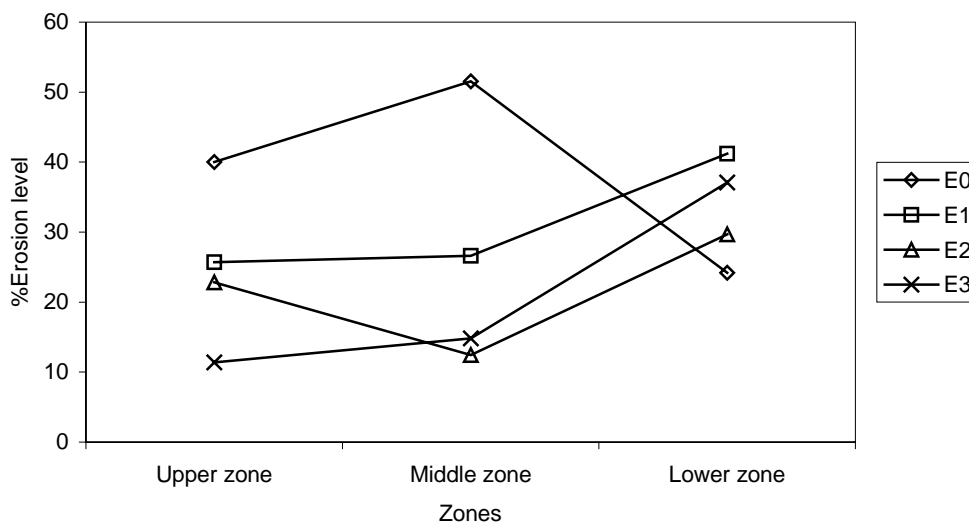


Figure 2: Mean rate of soil erosion in high, middle and lower zones of the study areas.

Soil erosion prevalence in Kenya and Tanzanians was common in the three major agro-ecological zones but varied with land use type and in severity. Despite high rainfall amounts and intensity in the upper zones, soil erosion varied from slight to moderate in forest, woodlots and cropped land. In the middle zone where land use is usually annual crops, coffee or bananas, there was slight visible erosion in Tanzania and moderate sheet wash in Kenya. There is increased evidence of gullies in the lower zone than in the upper zones with sheet wash being dominant. Observed soil erosion in the lower zones particularly in the land under bushland, grassland, fallow and maize/beans (annual crops) could probably be due to soil properties. Soil in the area is prone to erosion. The soils vary from sandy to sandy loam and lack appropriate soil and water conservation measures as observed in other areas (Thomas *et al* 2003). Variable levels of soil erosion observed in different land uses is due to different levels of conservation management

practices implemented by individual farmers especially in cropland. Farmers need to create favourable conditions to prevent soil erosion (e.g. terracing, trash lines etc).

3.3. How have changes in land use affected soil fertility and how do these changes vary in different agro-ecosystems?

Soil fertility (*Mehlich et al 1964*) differs with land use, agro-ecological zones (lower, midland and highland zones). This in effect has different effects on vegetation cover. Available soil organic carbon (SOC) though adequate in forests decreases with the clearing for cultivation, pasture, fallow fields or bushland as shown in figure 3. However, it increases in annual crops due to management factors in the upper zones while in the lower zones soils are deficient of soil organic carbon and other major nutrients as shown in Figure 4. The study shows variability of major soil fertility nutrients along the transect from the high land to the low lands along agro-ecological zones in Kenya and the same applies in Tanzania. As soil is exposed to the sun or raindrop direct impacts during the rains lead to soil erosion resulting to nutrient losses. This however, differs with agro-ecological zones and land uses. The low SOC along the transect from highland to lowlands is due to high rate of decomposition and mineralization of organic matter in the lower zones unlike in the upper zones

The low pH in the highland zones in Kenya makes P be fixed by the clay fractions making it unavailable to the plants. As the pH increases down the AEZ (Figure 4), phosphorous availability from the soil increases but its amount decreases due to many factors e.g. erosion, continuous cropping leading to nutrient removal by the plants etc. This was evident in the visual observation on the fields where yellowing and purpling of the crop signifies deficiencies in nitrogen and phosphorous respectively. K- levels are adequate in agronomic terms from upper zone to lower zones.



Figure 3: Effect of different land uses on soil fertility (soil organic carbon) in the upper zones in the study sites and their implications on different vegetation covers.

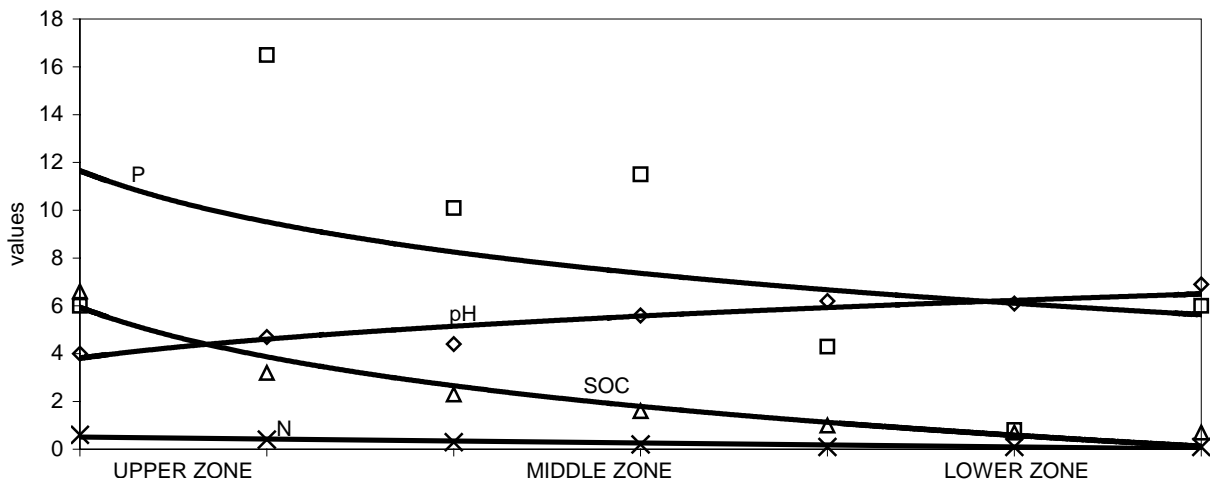


Figure 4: Variation of pH, soil organic carbon (SOC), Nitrogen (N) and Phosphorous (P) across the agro-ecological zones (AEZ's) in the upper to the lower zones

Soil fertility problems have been contributed by many factors including population pressure. This has led to decrease in crop production per unit acre of land as shown in figure 5 . The figure shows maize yield trends according to Embu-Mbeere District Agricultural office annual reports (DAO, 1980- 2001)

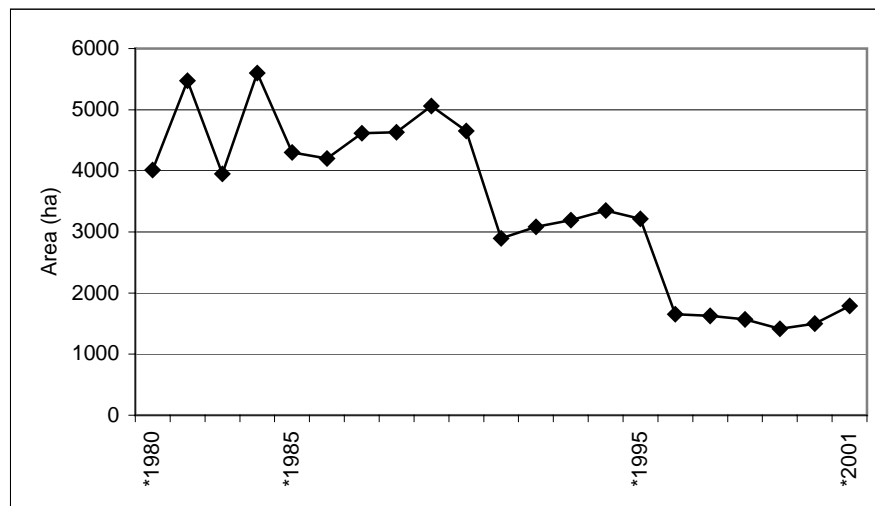


Figure 5: Maize yield trends in Kenya study site i.e. Embu-Mbeere transect

In investigations on biodiversity changes, research should focus on addressing the following questions:

3.4 *How and why does land degradation affect land use?*

3.4.1 *Declining soil fertility due to nutrient depletion as land use intensifies*

One year nutrient depletion measurements (Jager *et al.*, 2001, Nandwa *et al* 2000) in two different sites from Kenya (Embu and Machakos) revealed that full nutrient balances at farm level were negative for nitrogen (-53 and -55 kg N/ha/yr and to a lesser extent for potassium (-10 and -15 kg K/ha/yr). The phosphorous balance varied from neutral to positive. There were significant variations in nutrient balances between crop, individual farms and land use. The study in Embu found that considerable amounts of mineral nutrients are applied to high earning cash crops, such as tea, coffee and nappier grass (dairy farming) as these crops give the best economic return for money spent on fertilizers and as a result nutrients are neutral to positive. Very few inputs are applied to fields of staples, such as maize and beans, where the negative nutrient balance results in declining soil fertility and serious infestation by pests and diseases.

Contributing factors to fertility decline include the removal of crop residues from the fields for sale by 14% of farmers, limited access to markets and inputs (64%) and shortage of labour by 98%. Farmers consider nappier grass to be high value crop as they use it as fodder for milk production. They apply fairly large quantities of manure to land under nappier grass but still have a significant negative balance because so many nutrients are lost when biomass is removed from the field, while the manure produced with the fodder is applied to other areas of land. The most seriously depleted nutrient in all fields is nitrogen, which is lost in large quantities through leaching, volatilization and erosion.

3.4.2 *Decline in crop productivity due to degraded soils and choice of crops suitable to specific fertility levels of the soil*

Farming is a dynamic practice and the type of crops that farmers grow or introduce into their farming system is a reflection of prevailing biophysical characteristics, current farmer's food and cash needs as well as socio-cultural fulfillment. In the study area, 79% of the respondents reported that they have cultivated their farms for over five years and that more than 80% of them grew maize and beans as the major food crops when they first settled on their farms (Gachimbi *et al* 2003). However, other crops such as miraa (*Catha edulis*), cassava, sorghum, fruit trees and millet have been introduced into the farming systems. The reason why farmers changed their cropping practices over time are many and diverse. Farmers reported that they introduced new crops to generate more income and improve food security (67%), to counter frequent crop failures due to the change of weather or poor soil fertility, diversification of food sources (diet), vegetable supply and to be self-reliance. Some specific crops can only do well in soils of specific pH levels e.g. Tea and coffee. Tea will do well in high altitude soils with certain chemical properties e.g. pH range of up to 5 while coffee will do well when the pH ranges above 5.3. this is why there is hardly any tea crop in the lowland areas even with good rainfall amount.

We have also observed that there is a decline in animal numbers and types (wildlife) due to reduced carrying capacity in degraded ecosystems. This can be understood as degradation because they lead to a reduction in ecosystem heterogeneity. Animal surveys in Amboseli National Park has shown that areas with less vegetation cover have fewer animal counts (Worden, 2003).

3.4.3. *Necessity to allow periods of fallow due to a decline in soil fertility*

Central to fallow period is its length and effects on soil fertility. A short lived fallow indicates poor resources or unsustainability of the system possibly due to shortage of land. Similarly, short fallow periods are taken to indicate environmental degradation or increasing population pressure and thus declining sustainability (Gichuru *et al* 2003). The planting of fallow, particularly with nitrogen-fixing species, speeds the process of fertility restoration thus shortening the period of optimum fallow length (Gichuru, 1994). A lengthened cropping period, due to population pressure and small land holdings has led to shortened fallow period in the study area.

3.5 How and why does biodiversity affect land degradation?

It has been explained earlier in this paper that reduction in vegetation cover reduces the capacity of soil to retain moisture for plant productivity. This is a direct link of how biodiversity loss leads to land degradation. Reduction in vegetation cover also leads to an increase in soil erosion and thus to loss in soil fertility. These changes lead to land degradation.

Changes in plant biodiversity especially those leading to loss in vegetation complexity affect the potential of the soil to replenish its nutrients particularly the soil organic matter. However, not all areas with the least biodiversity are necessarily areas of high degradation. Some forests for example may have very low biodiversity but their soils may have higher amounts of organic matter than some woodlands with higher biodiversity.

Biodiversity (animals- as primary consumers) remove nutrients from ecosystems by harvesting the vegetable materials thereby reducing the amount of nutrients re-cycling within the ecosystem. In the livestock grazing systems this applies mainly in areas where animals are grazed in a free ranging environment, or are fed by cut and carry of forage.

3.5.1 Animals induce soil erosion by trampling and disaggregating surface particles increasing erodibility potential.

Soil erosion is a common phenomenon in the intensively grazed areas and this is linked to the continuous grazing without appropriate soil and pasture management practices such as terracing, contour planting of appropriate fodder crops and trash lines. Expansion of livestock farming practices and the increase in their number and in some places mixed with rainfed agriculture in low potential areas has led to soil erosion. These practices tend to remove vegetation cover thus leaving the land bare subjecting it to severe sheet wash and gully erosion (O’Kting’ati and Kessy, 1991; Nyathi *et al.*, 2003; Majule, 2003). Soil erosion significantly contributes to soil fertility loss and thus leading to poor crop yield increasing poverty levels.

4.0 METHOD CHOICES

4.1 How to assess changes or variations at landscape (gradient: temporal and spatial)

Changes in variations on landscape can be assessed in a number of ways. In many areas there are topographic maps showing many features of the landscape some time in the past. Such maps can provide a good starting point in assessing changes over time by comparing features on the map and those on the ground. Such changes however, will be affected by the scale of the map available and the method the map was prepared. Analysis of satellite images taken at different times is the most classical way to assess changes in landscape. This method is the main subject of another synthesis methods paper in this series. (Olson *et al.* 2004; Maitima and Olson 2001) Analysis of information on topographic maps and satellite images should be accompanied by ground truthing to ascertain or associate land covers on the ground with image appearances and determine boundaries for colour or shade separation on the ground as represented in the image.

Changes in landscape can also be assessed using Participatory Rural Appraisal (PRA) techniques by use of questionnaires, semi-structured interviews, group interviews (focal group discussions), literature survey from libraries, archives and internet. Our experience in the field shows that communities are very informed on changes not only on their individual farms but also changes at landscape level. This is particularly so in the areas where human occupation goes back to the desired time span. In Embu for example the farmers insisted that we should start our analysis from 1940 rather than 1960 as we had earlier wanted in order to conform with the date of earliest satellite image from the area.

Group discussions were found to work very well as respondents could correct each other and come to an agreed group opinion as to for example the boundary forest edge, introduction of non-indigenous crops in the area, changes in wildlife, forest patches and many others. For this to work best respondents must be selected of the right age groups that were mature enough at the time information is reconstructed. Also the group should comprise of people who have no communication barriers between themselves due to any social divide, like ethnicity, education, political etc.

It is advantageous to peg past time periods based on popular events in the area or nation like in our case the date of independence; times of hunger; times of drought; times of floods and times of age group initiations. These may vary from place to place based on the community in the area. The purpose for making these memorable time periods in the past is such that they can describe how the landscape then was different than now.

This exercise can be taken a step further by developing community maps of how the landscape appeared at some point in the past by locating some important features like forest boundaries, landmark trees, swamps, grazing areas, roads and distribution of wildlife in the region.

Birds

The classical method for sampling the composition and distribution of bird species is the timed species counts (TSC). This method requires at least two people one observer and one recorder. The observer must be someone with good knowledge of the taxonomic identity of birds to be able to identify them from a distance. The observer walks along a belt transect usually twenty meters wide, and the recorder behind him taking notes of all the birds identified by the observer. A time is set when the counting starts and the time when each observation is made. The record will include: species name, number of individual birds observed, habitat found, and the time observed. All birds found within the belt are identified and counted and those not in the belt may be identified and counted but are excluded from the count. The observations are counted separately from those in the transect.

Animals.

Unlike birds many animals are large and can be counted even from some fine resolution remote sensed data. Where resources are available such large animals can be counted by use of a low flying aircraft from which individual herds or solitary animals can be identified and counted or their numbers estimated in the case of large herds.

However, other animals are small like in the case of small mammals. For these animals trapping is the best way to sample. There are different trap types and trapping techniques depending on the type and size of the animal. Depending on the primary objective of the study and the type of animals being studied there are methods for estimating the population size such as capture mark release and recapture method, random walk counting method and use of pitfall traps as well as indirect estimates that employ the use of foot prints and fecal pellets.

Finally changes in biodiversity can be assessed by comparison of data collected from same place at different times. Data existing in grey literature in archives, on shelves, reports, etc. can be used but efforts should be made to employ similar methods as used in the past.

4.2. *How to assess changes in biodiversity. (plants and animals including birds and small mammals)*

Spatial and temporal changes at landscape level are best analyzed by use of geographical information system (GIS) and remote sensing (RS) analysis. Distribution of ecosystems can be determined by analysis and interpretation of satellite imagery. If these analyses are done

for different years, changes over time in area covers for each ecosystem or land use type can be determined.

In the analysis of landscape variability, one most important aspect is the gradient. Gradient in reference to this study refers to the spatial variability in biotic and abiotic factors in the landscape. When defining landscape patterns three types of environmental variables or gradients need to be considered: 1) the direct factors that do not necessarily have a physiological influence on the species (e.g., elevation); 2) the direct factors that have a direct influence on the physiology of the species but are not consumed as a resource (e.g., temperature, pH etc.) and the resource gradients that can be used directly by species (e.g., nutrients)

4.3 Gradient-oriented transect sampling.

The transect sampling design adopted in this project is a gradient based transect that was designed to cover as much ecological variability of land uses as possible within the study site (Maitima and Olson 2002). Similar approach used by Orloci and Stanek 1980 and as outlined in the Nature conservancy report (1994). The approach is based on the distribution of patterns along environmental gradients to give a description of the full range of biotic (e.g., vegetation) in a region by sampling along the full range of environmental variability. Within each agro-ecological zone, four sub transects were randomly located perpendicular to the gradient transect. Vegetation in each of the land use and land cover types along the subtransect were sampled by use of quadrats of different sizes for different vegetation lifeforms (Kent and Coker 1992). For each land use at least two quadrat samples were collected per subtransect giving rise to eight samples for each land use per agro-ecological zone.

Variation in elevation in a gradient influences ecological conditions, such that places of higher elevations are generally wetter and cooler and places of lower elevations are generally drier and hotter although exceptions occur mainly due to micro climatic conditions. Micro climatic conditions such as soil types or alluvial regimes affect this relationship such that in some areas the pattern may be less gradual or punctuated with some intermediate sequences missing. In all our study sites, assessment of the variability in gradient had been done earlier to determine agro-ecological zones used in the cropping system. The zones are based on their probability of meeting the temperature and water requirements of the main crops i.e. climatic yield potential (Jaetzold and Schmidt, 1983). Where the system is not well defined like in the case in Uganda, gradient could be inferred by the nature of vegetation growing in the area or by the type of crops grown. In many cases rainfall ranges are used to determine agro-ecological zone.

Assessment of changes in land use / land cover over time (temporal) was done by analysis of satellite images taken from the same place but at different years. This analysis requires that the variables be the same over the years so as to compare changes in spatial area covers over the years. Methods of how to analyse land use change are outlined in lucid working paper No. 15 (Maitima and Olson 2002) and detailed in another regional synthesis paper in this series.

Temporal analysis of changes in biodiversity including vegetation could be done using two approaches: 1) comparison of single point over time (space chronological sequence data) or 2) comparison of multi point spatial sequence data referred to in the LUCID working paper number 15 (Maitima and Olson 2002) as space for time analysis. The first approach requires that data is collected over the years from the time before the original vegetation was cleared and during the time every type of land use was made through the entire study period. In many cases data over time may not be available due to the long periods of study needed. We have proposed the second approach “space for time approach” as an alternative if the long-term data is not available. The space for time approach compares data sets in different land

use types including that from land covers considered close to natural vegetation that would represent land use/ land cover before conversion. It may be difficult to get a land cover that is close to natural, but certainly there will be a sequence of land uses which if arranged in the order of stages in vegetation succession (the more the mature the dominant vegetation is the closer to natural vegetation) or arranged in the order of land use intensity would give some synoptic perspectives of biodiversity associated with historical changes in land use. Space for time approach could be improved by remote sensing to identify areas of change over time and to determine a chronological sequence of land cover conversions over time.

Spatial variation in land use is influenced by many factors: history of human settlement and land tenure, agro-ecological settings, means (technology) of production and the awareness on the options available which includes access to markets. For example in the Embu site, land use was much more variable than in the Loitokitok site due to all the factors listed above. Study design must be such that the variability in the land uses is well captured in the representative sample as much as possible and that each land use is sampled adequately to allow statistical analysis.

Problems might arise with very rare land use types being represented with very few samples due to their scarcity especially if transects and quadrats are located at random. To reduce this problem we recommend that the field enumerators survey areas around the transects to identify rare land uses that have not been adequately sampled in the transect. For these land uses the one that is closest to the transect is sampled one after the other until the required sample size per transect, or per agro-ecological zone or per any unit area of analysis that the study wishes to address is attained.

In addition to the quantitative data gathered using the methods described above, qualitative sampling is used to get information on changes in biodiversity by use of participatory rural appraisal technique (PRA), focused group discussions or interviewing key informants. This approach focuses on specific groups of plants or animals e.g. rare or endemic species, species of conservation significance, species categorized by IUCN/ CITES as being threatened or endangered, species of economic importance, e.g., medicinal plants or timber etc., landscape keystone species, e.g., figs and Acacias and desert dates (*Balanites aegyptica*) in arid ecosystems.

4.4. *How to assess land degradation*

In order to discuss methods for land degradation assessment it is important to summarize the working definition of land degradation as used in this paper (section 1.1 of this report):

Land degradation is defined as a 'reduction or loss, of biological or economic productivity or complexity of cropland, or range, pasture, forest and woodlands resulting from land uses or from process including those arising from human activities such as: soil erosion caused by wind and /or water; deterioration of the physical, chemical and biological or economic properties of; and long term loss of natural vegetation.

Land degradation assessment will therefore seek to evaluate the status of biological and economic productivity in an area, assess the complexity of the ecosystem being investigated to understand the changes or trends over time to determine whether there is a loss and if so by how much. Assessment on the loss and the magnitude of the loss will require comparison of data sets collected in different time periods or collected in a spatial pattern as described elsewhere in this paper.

Assessment of changes in biodiversity should include large and small mammals, birds, insects, microbial organisms, etc, in addition to vegetation. Where data on animal counts at different time periods or different land use patterns is available quantitative analysis can be

made. Where data on biodiversity counts is not available qualitative assessment can be made by use of questionnaires and other techniques described above.

In addition to assessment of overall trends in biological and economic productivity there are certain indicators of degradation that can be assessed in different land use patterns. These indicator species are for example: plants to indicate: 1, changes in hydrologic regimes in a forest (forest health) by the use of epiphytes such as mosses, Bryophytes, lichens, orchids etc.; 2, changes in soil reaction (acidity/ alkalinity) due to salinization or acidification such as *Sueda monoica*; 3, changes in nutrient status of the soil such as fertile or poor soils; 4, the level of successional stages of a landscape such as land left bare after a major landslide or volcanic activity; sediment accumulation or siltation; 5; magnitude of disturbance in a given ecosystem (e.g., indicators of cultivation – *tagetes minuta*, *bidens pilosa*, *bidens schimperii*, *Senecio abyssinica*, fallows – *trichodesma zeylanicum*, *Physalis peruviana*, trampling – *Solanum incanum*, grazing – several grass species, previous settlement – *Datura stramonium*, *Opuntia vulgaris*, *Euphorbia candelabrum*, etc. Such information could be derived from the local communities in indigenous knowledge systems or from literature or a combination of both.

Analysis of changes in the types and abundance of key species as an indicator for land degradation is best if applied to groups of individuals who are specialist of some certain uses like the herbalists, bee keepers, livestock herders and hunters where the activity is permitted. These individuals have historical understanding of changes in the availability of the species they use, habitats they are found and may also suggest why the changes have occurred especially if they have been practising in their specific trade over a long time.

4.5. *Increase in soil erosion.*

Soil fertility decline (also described as soil productivity decline) is a deterioration of chemical, physical and biological soil properties. Soil erosion is usually caused surface runoff in open fields with little vegetation cover. The main contribution processes, besides soil erosion, are: decline in organic matter and soil biological activity; degradation of soil structure and loss of other soil physical qualities; reduction in availability of major nutrients (N, P, K) and micro-nutrients and increase in toxicity, due to acidification and salinisation (FAO, 1983).

4.5.1 **Observations on present erosion:**

The most common agent for soil erosion in East Africa is water. To identify areas affected by water erosion, certain features like soil removal, signs of water run ways like rills and gulleys, accumulation of soil or sedimentation could be quite obvious on the landscape.

Estimation of soil and water erosion

- Soil loss; Estimation is based on universal soil loss equation (USLE) depending on specific land use.
- Sedimentation; Use sediment load estimation in rivers or dams.
- Soil accumulation; Estimate exposed stones/rocks or clumps of vegetation/roots and along fences or other barriers.

Erosion classification in the field

Class

EO: No visible evidence of erosion or very slight sheetwash.

EL: Slight - moderate sheetwash.

E2: Moderate - severe sheetwash.

E3: Moderate - severe sheetwash.

Other erosion visual indicators

Rills, sheet wash, gullies, pedestals, armour layer, deposits of soil on gentle slopes, exposed roots or parent material, muddy water/mudflows during and shortly after storms, sedimentation in streams and reservoirs, dust storms/clouds, sandy layer on soil surface, parallel furrows in clay soil or ripples in sandy soil, bare or barren spots, nutrient deficiency/toxicity symptoms evident on plants, decrease in yields/productivity, poor response to fertilizers and increased soil surface sealing, crusting and run-off; reduced soil water.

Nutrient availability

The broad question of the supply of nutrients is here divided into two land qualities: nutrient availability, and nutrient retention which is the capacity of the soil to retain added nutrients e.g., nitrogen (N), phosphorous (P), potassium (K) and soil organic carbon. These two qualities are not entirely distinct, but involve a difference of emphasis and can be assessed either separately or jointly. Nutrient availability involves the following aspects:

- Determination of the quantities of nutrients present in the soil.
- The form in which they are present and the tendency of the soil towards fixation in forms unavailable to plants.

4.5.2 Assessment

Nutrient availability can be assessed by one or more of the following methods:

- Quantities of major nutrients present in the topsoil.
- Indicators of nutrient availability/fixation: pH reaction, free iron oxides, allophane in the clay fraction
- Indicators of capacity for nutrient renewal: content of weatherable minerals in the soil; available N, P and K.
- Crop/vegetation indicators

Soil nutrient content is the simplest and most common method of assessing nutrient availability through soil sampling and analysis. The nutrient content of the soil being sampled may be considerably influenced by its preceding use and management. Soil properties, which influence the availability of nutrients, or conversely the tendency towards fixation, are:

- i. Soil reaction: nutrient availability is the highest in the pH range 6.0-7.5 and is reduced at both high and low values;
- ii. Presence of free iron oxides: a high content of free Fe_2O_3 leads to strong P fixation;
- iii. Presence of allophane in the clay fraction, as in andosols.

A further significant property is the presence of weatherable minerals within the profile, which influences long-term fertility through the capacity of the soil to renew nutrient supplies. This can be assessed from field profile description, mineralogical data or by total element analysis.

Crop/vegetation deficiency symptoms provide an indirect but rapid method of diagnosis preferably used in combination with other methods. Indicators/symptoms include field observations on: plant (plant growth is vigorous, plant growth is normal, plant growth is stunted), colour of plant/leaves is dark green, colour of plant/leaves is yellowish throughout affected leaves, colour of plant/leaves is yellowish at the tips and along the edges or colour of plant is purple.

5.0 How to link land use, land degradation and biodiversity.

Linkages through data collection and management

Linking studies in land use, biodiversity and land degradation is very important in order to understand how they affect one another. In linking vegetation and soils we have collected vegetation and soils data from the same sampling points. Since vegetation is sampled using

quadrats, linkage in the field is achieved by collecting data on erosion sampling soil for fertility analysis from the same quadrat in a known land use type. Data on all land use types studied are linked so that the three; i.e., land use, vegetation and soil characteristics (erosion and fertility) are representatives of the same sampling unit. The three data sets are then arranged according to the agro-ecological zones they are collected from. It is to be noted here that the unit of analysis is the agro-ecological zone and that the sub-transects within agro-ecological zones are used only to randomize and scatter the quadrats within the zone. Data on the three variables is then arranged according to agro-ecological zones they were collected such that if there are more than one zone like in many of our sites, all the land uses in each zone along the transect have data on vegetation and soils. Agro-ecological zonation in Kenya have been standardized according Jaetzold and Schmidt (1983) . However, in Tanzania and Uganda such standardization is not yet done but maps are available to show crops grown in different areas. For the purpose of regional cross-site analysis it is important to describe each zone based on the main crops in the area, and to indicate average annual rainfall and length of the growing season in the sampling site.

The second step in linking land use, vegetation and land degradation data is achieved during data analysis. Data on plant species richness and species cover is compared with data on soil erosion and data on soil fertility from the same sampling point and expressed as per land use type within an agro-ecological zone. Since there are always more than one land use type in an agro-ecological zone, it is possible to compare these relationships to determine which land use leads to less biodiversity and degraded soils. Sometimes the same land use type is found in more than one agro-ecological zone in which case it is possible to determine how a land use affects land degradation across an agro-ecological gradient.

Information obtained through human perceptions is also useful in linking changes in land use, biodiversity and land degradation. Human perceptions for example will give information on changes in crop productivity over time. Such information could be quantitative like average number of bags harvested per hectare of a certain crop and what this used to be 10 years ago and beyond if the farmer can remember. However, much of the information obtained from PRA is more accurate if expressed in a qualitative form like, a reduction in crop harvest, a reduction in tree cover, a reduction in the number of bird species, a reduction in wildlife and expansion in cultivation.

Linkages using indicators plant species.

As indicated earlier certain plant species are good indicators of soil conditions especially on soil fertility levels. Some plants are found only in fertile soils while others are found in poor soils. Analysis of how these indicator plant species vary with land use types within an agro-ecological zone can give inferences on which of the different land uses lead to land degradation and which do not or which are less degrading. It is possible to categorize land uses in the field into either fertile or poor based on the presence or absence of the plant indicators. Certain indicators are known to indicate more severe conditions while others do indicate less severe conditions.

A similar analysis can also be made for identifying places with eroded soils and other expressions of degradation. This is done by analyzing the abundance, presence or absence of plant indicators for eroded soils, plant indicators for saline soils, and plant indicators for soil acidity. At landscape level indicators of bird species can be used to assess levels of disturbance of ecosystems (Söderström, *et al. in press*) especially in relation to plant cover.

Linkages through statistical analysis

Data collected on vegetation and soils can be linked to other indirect data available within agro-ecological zones like temperature and rainfall. Using appropriate statistical methods it is possible to regress the variables: land use types, plant species numbers, and cover, and soils data to determine how land uses vary with the number of plant species and soil characteristics.

5.1 Sampling design/frames

The table presented here is obtained from LUCID working paper No. 15 (Maitima and Olson 2001) to give a summary of the methods used to collect data in various sectors of the study.

Table 1: Cross-site field level and other information

	Study methods				
	Surveys/ Interviews			Transects and quadrats	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 changing soil fertility	X	X	X		
Plant indicators of soil deg.			X	X	
Soil erosion estimates	X			X	
Soil chemical and texture properties				X	
Veg. species diversity			X	X	
Biodiversity (Bird, wildlife) types and abundance				X	

Chronology of field research

1. Sampling frame for transect completed: transect chosen, random sample points for the subtransects within each AEZ chosen, identification of land use types in each subtransect made and two quadrats on each of them studied. Location of more detailed sampling site (e.g., in a semi-arid area) chosen.
2. Indicator plants of changes in soil fertility was determined during group interviews with key informants (elders, people who know the area well) in each AEZ.
3. Conduct transect survey: need someone with expertise in vegetation who can identify plant species, someone to examine soil erosion indicators; need GPS, soil sampling and other equipments.
4. Group interviews with beekeepers and herbalists or other experts in local flora concerning changes in wild plant biodiversity and reasons for those changes, using guide and interview sheet.
5. Group interviews with farmers and herders in various locations (esp. where the transects or other surveys have been done). Some of these questions might be more effectively addressed if people are stratified by age, gender or ethnic group.
 - a. Land use changes, and their root causes
 - b. Opinions of impact of those changes on soil fertility, and on plant and animal biodiversity
 - c. Opinions of future LUC, soil and biodiversity changes (in 10, 20 years)

6. Household and field level surveys of farmers and herders on changing land use and soil management on their land; changing soil properties on their fields, and household characteristics including economic activities and labor availability.
7. Depending on particular site: wildlife counts, bird counts, water quality analyses...
8. Feedback workshops and seminars after field research and land use change preliminary analyses completed—with farmers and herders, and with decision makers
 - a. present and verify results, discuss interpretation of the results
 - b. discuss implications re land management, policy

5.2 *Recommendations for sampling methods*

Vegetation sampling

Vegetation is sampled for various reasons, one is to determine the species composition and species cover as part of biodiversity in a given land use or land cover; another could be to obtain proxy data on which land degradation inferences can be made especially in relation to soil conditions and to some extent animal biodiversity. It is therefore necessary to quantify plant species composition and their patterns of distribution across landscape. To do this many sampling techniques are available (Maitima and Olson 2001, White 1983; Lyaruu 2002). We used square quadrats whose size varied with vegetation lifeforms. For trees we used a 20x20 meter quadrat, shrubs a 10x10 meter quadrat and herbs a 1x1 meter quadrat.

In each land use we recommend at least 8 quadrat samples per agro-ecological zones. To maintain a spatial distribution and reduce bias in site selection four randomly selected sampling points can be made in every agroecological zone. On each of the randomly selected points a sub-transect can be made extending about 500m on both ways perpendicular to the main transect. It is along this 1km sub-transect that quadrat samples of land use types present are collected. Where the sub-transect omits some land use types, the one nearest to the sub-transect line should be sampled.

Substituting space for time:

Analysis of trends in temporal perspectives refers to changes in a particular place over time. Such analysis will require comparison of same variables in land use, biodiversity and land degradation at different times (at least 3 time scenarios) to establish trends of change. The actual time interval may vary from one land use system to another depending on the history of land use system itself. In many cases data from back years may not be available or may not be in the format to address our new objectives.

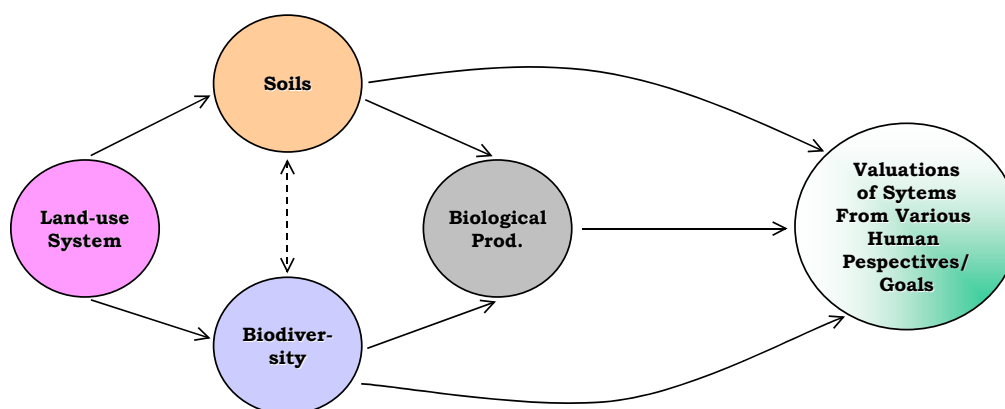


Figure 6. Conceptual framework for investigating land degradation

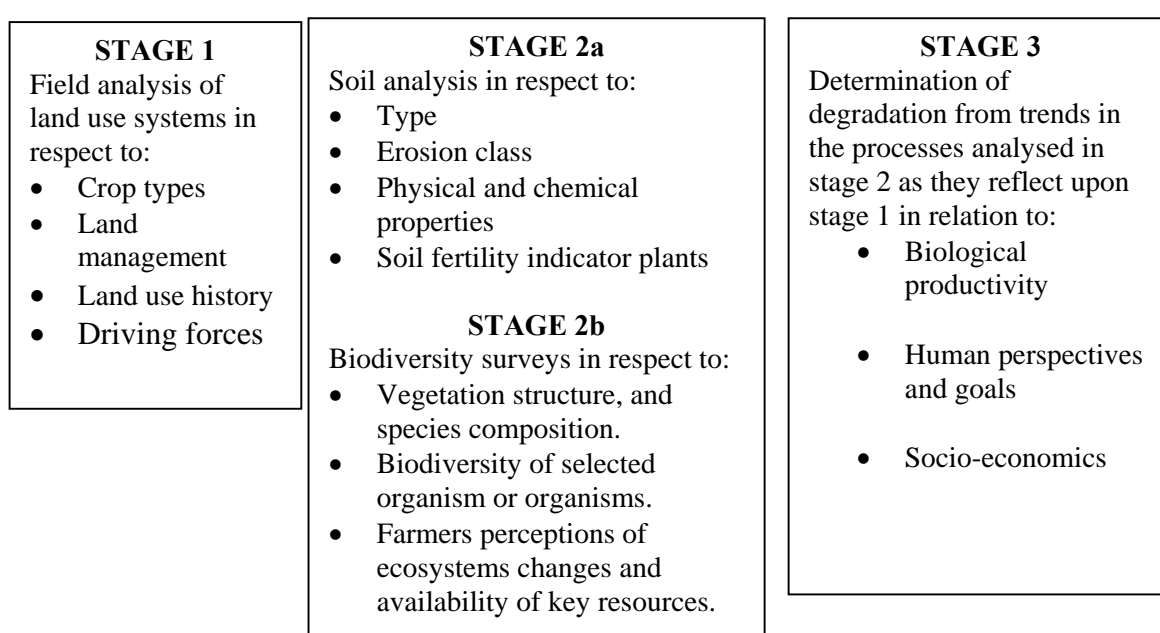


Figure 7. Stages in analysis to identify land use/ land degradation linkages

In situations where we have no data on the past years substituting space for time would provide for change analysis. Comparing data from cultivated and non-cultivated areas for example would give the variation in both places. In our study we used variations in spatial patterns as a substitute for time.

For all regional projects it is important to use a similar sample sizes in different places so that the samples can be compared across sites. In vegetation sampling quadrat sizes must be similar for similar vegetation types. In cases where different people are sampling in different places, there must be clear consultations between each so as to agree on comparable sample sizes (quadrat numbers) and quadrat sizes. Because sampling of vegetation and biodiversity in general is a dynamic subject and there are improvements over time, we recommend considerations to be made on methods that are emerging e.g., Stohlgren *et. al.* 1995.

The overall objective for sampling vegetation is to derive information on plant species composition and cover per species per unit area. It is to be remembered that sampling has to be as inclusive as possible and the sample population should be a representative of the vegetation as much as possible.

In ordinary circumstances vegetation is sampled in three categories based on the three life forms; i.e., trees, shrubs and herbs. The most important here point is that the three lifeforms are sampled in different quadrat sizes for two main reasons: one is to work with a quadrat size that is feasible in terms of identifying all the species in the quadrat and counting all the individual plants for every species, the second reason is to vary the size of the quadrat so that the varying structure of different lifeforms can be sampled adequately. For this purpose we used 1x1 meter quadrat size to sample herbaceous vegetation including grass species. To sample shrubs we used 10x10 m quadrats while trees were sampled using 20x20 m quadrats.

Transect data collection

The purpose of the transects was to provide primary data on biodiversity, soil characteristics and land use/land cover in the same locations and in a systematic sampling along a gradient of agroecological zones. Statistical analysis of the data permitted identification of the relationship (causal or otherwise) between these three factors. It was important that each site collect this data using similar methods in order to permit comparison of the data between sites; small variations in data collection methods often leads to data incomparability.

Transect sampling framework

Along the transect, stratified random sampling was conducted to locate 4 points within each AEZ where sub transects perpendicular to the main transect was be established. All transect data was collected within these subtransects. Land use types within each subtransect was studied with at least two quadrant samples for each land use type in the subtransect. In a case where a prominent land use type in the AEZ was not well represented in the subtransect, sampling was made on the plot nearest to the subtransect. The stratification was done according to agro-ecological zones (AEZ) as identified by Jaetzold and Schmidt (1983) in Kenya and Tanzania. The AEZ are based on seasonal precipitation, temperature and dominant crop in the zone. In most of the LUCID study sites, the AEZ's parallel the elevation gradient, due to the strong orographic influence on rainfall and temperature.

The following land cover classes were suggested for transect vegetation analysis. For the natural vegetation especially in the semi-arid areas where uncultivated areas may still exist, a physiognomic description of vegetation types is presented to assist in differentiating natural vegetation in addition to that in the cultivated areas.

1. Coffee or tea dominant
2. Currently cropped with seasonal crops
3. Riveraine, marsh or swamp vegetation
4. Edge types – roads and field boundaries
5. Grassland – areas with open grasslands or at least 75% covered with open grasslands
6. Scrub – dwarf or short bushes. See dwarf shrubland in the physiognomic description below.
7. Fallow - areas about 1-5 years without cultivation
8. Bush – areas containing thickets approximately 2-5m that have never been cultivated. Also see Bushland in the physiognomic vegetation description below.
9. Planted trees, woodlots

Guide to Vegetation Classes

For the natural vegetation, a physiognomic description of vegetation types is presented to assist in differentiating natural vegetation outside of the cultivated areas. The following physiognomic vegetation description is adapted from field methods for vegetation mapping 1994, prepared by the Nature Conservancy Nature conservancy 1994. The relative percent cover of the tree, shrub, dwarf shrub, herbaceous, and non-vascular strata defines formation classes.

- **FOREST** - Trees usually over 5m tall with crowns interlocking (generally forming 60-100% cover). Shrubs, herbs, and non-vascular plants may be present with any cover value.
- **WOODLAND** - Open stands of trees usually over 5m tall with crowns not usually touching (generally forming 25-60% cover). Shrubs, herbs, and nonvascular plants may be present with any cover value.
- **SPARSE WOODLAND** - Trees usually over 5m tall with widely spaced crowns (generally forming 10-25% canopy cover). Shrubs herbs and non-vascular plants may be present with any cover value.
- **BUSH** - Shrubs and or small trees usually 0.5-5.0 meters tall with individuals or clumps not touching or interlocking (generally forming > 25% canopy cover). Trees may be present, but with cover 10% percent or less. Herbs and non-vascular plants may be present at any cover value.
- **SPARSE BUSH** - Shrubs and/ or small trees usually 0.5-5m tall with individuals or clumps widely spaced (generally forming 10-25% canopy cover). Trees may be present, but with cover 10% percent or less. Herbs and non-vascular plants may be present at any cover value.
- **DWARF BUSH**– Low growing shrubs and/ or dwarf trees usually under 0.5m tall (though known dwarf forms between 0.5 –1.0m can be included), with individuals or clumps not touching to interlocking (generally forming >25% cover). Trees and shrubs greater than 0.5m may be present, but with canopy cover 10% or less. Herbs and non-vascular plants may be present at any cover value.
- **SPARSE DWARF BUSH**- Low growing shrubs and/ or dwarf trees usually under 0.5m (though known dwarf forms between 0.5 –1.0m can be included), with individuals or clumps widely spaced (generally with 10-25% cover). Trees and shrubs greater than 0.5m may be present, but with cover 10% or less. Herbs and non-vascular plants may be present at any cover value.
- **HERBACEOUS** – Graminoids and /or forbs (including ferns) generally forming >10% cover. Trees, shrubs, and dwarf shrubs may be present, but with cover 10% or less. Non-vascular plants may be present at any cover value.
- **SPARSE VASCULAR VEGETATION/ NON-VASCULAR** – Vascular vegetation is scattered or nearly absent. The cover of each vascular life form (tree, shrub, dwarf shrub, herb) is at most 10 percent. Cover of non-vascular plants (mosses and lichens) may be absent to continuous.

In the semi-arid zones, a more extensive sampling can be ade with more quadrants to provide a more complete picture of the impact of recent land use changes on biodiversity and land degradation. In all LUCID sites, the higher rainfall, cooler AEZ's are characterised by a long history of high population densities and intensive cropping. Clearance of natural vegetation occurred many years ago, in most cases over 50 years ago. The semi-arid areas, in contrast, are in the process of experiencing a land use transition from more natural vegetation, often grasslands used for grazing, to permanent cropping, and more opportunities exist for the project teams to examine first hand the relationship between land use change and change in biodiversity and land degradation. The areas undergoing this transition, therefore, will receive more focus and a higher density of sample points.

In the semi-arid zones, more sample points will be chosen within the same AEZ, attempting to control for climate, soil and topography but with varying land uses. For example, within the semi-arid AEZ of particular interest, a large block with similar soil, climate and topography should be delimited. Within that area, sampling should be done at random, ensuring that the major land use classes are represented by at least 10 quadrants. The number of sampling points will be determined by the number of land use classes on the subtransect. The more the land use classes per subtransect the more the quadrants to a minimum of two quadrants per land use class.

For each quadrant, data was collected on its location, characterisation of the site and land use, as well as measurements of vegetation and soil characteristics.

In this sampling methods there are a number of issue that were observed that would be of use to remember when designing the sampling framework. These are:

1. Recurrence of some land use categories being very low in some transects and subtransects resulting into very small sample sizes. It is important to ensure that all land use types are sampled adequately and have sufficient number of samples acceptable in statistical analysis. If a particular land use is very rare or is much more sparsely distributed, transect sampling might fail to capture a sufficient number of samples. In our case we overcame this problem by requesting field teams to go beyond the sub-transect to identify any land use that is not covered in the sub-transect line. In a case like this we suggested that the field team should sample such land use that is closest to the transect.

Despite this precaution we found in a few cases that some land use types had only 2 or 4 quadrat samples because the land use was very rare in most of the area around most of the subquadrats. Although one could argue that a small sample size could correspond to the scarcity of the land use itself, it is necessary to work with a sample that is statistically significant. The most recommended way is to replicate enough so that differences between land uses can be captured. This problem could also be overcome by developing a check list of land uses while in the field and sampling and making sure that there are sufficient number of quadrat samples for each land use. Another alternative to solving this problem is aggregating land use types such that the minor land use types are contained in larger characterization of land use types.

2. Use of different gradients. In Uganda we used a different gradient approach where three sites were in distant locations rather than being continuous like in other sites. Since these three sites are in different ecological settings they indeed form a gradient but since there may be other ecological settings in between, comparison with other sites need to be done carefully noting that the continuity of ecological gradient may be broken in this case.

5.3 Selection of study sites

The selection of area to collect new data should be based on the following principles.

1. Where the team is already working and has existing data (land use/cover and other data). As much as possible we should keep to the sites where data already exists so that any other data collected will be additional. Investigations on land use and biodiversity changes requires data and information from as many time periods as possible in order to develop trends of change over time. If baseline data on land cover and biodiversity before land use change is available they would provide an ideal situation for cause effect analysis. A site that has previously acquired data on any of the disciplines involved would be best for the project. However, care should be taken to ensure that methods used to collect the data are satisfactory to the project goals and that the new data are comparable.
2. Along the ecological gradient. As to the overall objectives of the project and the general design all the sites data are collected along an ecological gradient across agricultural

- ecological zones (AEZ) and on different land use / land cover types in each ecological zone. In most of the sites, the gradient will cross elevation zones.
3. Selection of transect locations: the location of one or more transects crossing the ecological gradient should be selected to represent typical ecological characteristics and land uses of the area.
 4. Along the transect, the sub-transects chosen randomly will contain the vegetation/soil quadrats.
 5. The sites selected must represent the heterogeneity in land cover types in the study area, e.g., wetlands, forests etc. Although this heterogeneity may not be replicated in many sites it is important to capture their landscape scenarios so that they could serve as representatives of similar land use changes in the region.
 - There has to be a consistency in classifying different land cover and land use types in all the three sites, e.g., scrubland /bushland and grassland (need to stick to an internationally accepted description of land cover types).
 - It is desirable to have similar parameters to sample (e.g., birds, mammals, etc), however, funds are always a limitation on how much we can do especially in biodiversity where there are many components requiring different tools and expertise. In situations like this it is advisable to use indicators in different sites like for water quality analysis we use one Kenyan site as a representative.
 - It was realized that sampling methods in biodiversity are evolving rapidly improving the efficiency and representation of population by the sample. Use of square quadrats for example is now thought to be inadequate and that rectangular quadrats are emerging to be more popular because they have minimal edge effects (Stohlgren *et. al.* 1995)
 - Use of square quadrats rather than rectangular quadrats to minimize edge effects.

5.4 How to measure biodiversity, land degradation and land use at different scales of resolution in time and space

- Historical context, policy context.

Historical changes in biodiversity and land degradation were measured by conducting interviews with selected informants among the local communities. Selection of informants was gender sensitive and was made so as to ensure that the respondents have a good knowledge of the changes in the environment including the time or year when implementation of the various policies that may have influenced the changes were made. In all the sites we developed an historical trends of changes in environment, policy and administrative interventions both at local and national levels.

- Integrating quantitative and qualitative methods

Both qualitative and quantitative methods of data collection were applied (table 2). In many cases the two data sets were analyzed separately and the information derived from the analysis were compared. For example qualitative data on changes in key plant resources like medicinal plants and indigenous food plants compared very positively with quantitative data on changes in natural vegetation (Maitima *et. al.* in prep). Similarly qualitative data on changes in soil erosion compared positively with quantitative data on decline in vegetation (Majule, 2003).

- Use of gradients

We used gradient analysis to capture spatial patterns of both land use and biodiversity. Information obtained from the sampling points within the gradient were used as benchmarks for the scaling up to landscape level. In all of our sites the gradients contained indications of both spatial and temporal changes because they were along an altitudinal cline from higher elevation in the montane forests through the middle zones to the lowlands. In Uganda we worked in three sites which are separate from one another but representing different agro-ecological zones and could be categorized as high middle and low based on annual rainfall amounts in the three sites.

Table 2. Methods used to measure biodiversity and Land degradation and their scales of resolution.

Biodiversity Component or Land degradation Indicator	Methods of Measurement	Type of Measurement	Scale of Measurement
Ecosystem Diversity	Transect	Quantitative and qualitative	Landscape
	GIS	Quantitative	¹ Local, ² Landscape and National
Ecosystem Distribution	Key informant interviews	Qualitative	Local, Landscape
	GIS	Quantitative	Landscape, National
Perceptions of changing soil fertility	Surveys	Qualitative	Plot or local
	Key informant interviews	Qualitative	Local
	Group interviews	Qualitative	Local
Plant indicators of soil deg.	Transects and quadrats	Qualitative & quantitative	Country
	Key informant interviews	Qualitative	Local
Soil erosion estimates	Survey	Quantitative	Local
	Transect, quadrats	Quantitative	Local
Soil chemical and texture properties	Transect, quadrats	Quantitative	Local and landscape
Plant species diversity	Transect quadrats	Quantitative	Local and landscape
	Surveys	Qualitative	Landscape to National
Biodiversity (Bird, wildlife) types and abundance	Transects, counts and surveys	Quantitative	Local to landscape
Diversity of cropping systems	Transect	Quantitative	Local to landscape
	GIS	Quantitative	Landscape to National
	Interview with farmers	Qualitative	Local to landscape

5.5 Use of indicators

5.5.1 Indicators of land degradation

There is no commonly accepted measure of land degradation; indeed a group of CG scientists has spent several years attempting to produce a measurable definition and common indicators. Many projects, such as the UNEP-GEF PLEC (People, Land, and Environmental Change) project, confine their measurements to traditional soil chemical properties and soil erosion indicators without using a broader measurement of land productivity, and without measuring the process over time. Some recent research projects are testing alternative measures, such as soil spectral properties, enzymes, microbial DNA and fatty acids/ lipids, that may provide signals of the process of soil deterioration.

The LUCID project followed the commonly accepted tests for soil productivity (chemical and physical analyses and erosion indicators) and, by sampling quadrats with different land use

¹ Local refers to village or neighbourhood comprising of a few households

² Landscape refers to a large geographically similar areae.g., a catchment basin.

histories but similar biophysical characteristics, “substitute space for time” to estimate the impact of land use on soil properties. In addition, farmer perceptions provided valuable information on changing agricultural productivity of the soil, and the causes of those changes. Where available, other information such as government statistics of changing yields were considered. Finally, by analysing satellite images, we were able to determine the change in potential “productivity” of the land for natural flora and fauna by measuring habitat fragmentation, wildlife corridors, access to water sources, etc.

The indicators of land degradation presented below are based on what was perceived as possible in the LUCID 2001 workshop given our project objectives, expertise within research teams, financial resources available and the time to complete the activities. While we concentrate on assessing land degradation based on our definition, and the rather limited sets of observations, it is important to bear in mind the broader context of land degradation that would embrace other factors that we will not be measuring in the LUCID project. This is important because some of these factors might be directly or indirectly influencing the parameters we will measure. For example we will not be measuring beneath ground soil biodiversity but it is known that microbial organisms in the soil may influence not only the chemical composition of the soil but also the physical properties and thus the vegetation as well. Ground water is another example of non-LUCID measured parameter influencing vegetation. Being aware of these factors and taking note of field observations that may suggest such influences will be very important, especially when doing cross-site comparisons. At the field level indicators for land degradation that we will be measuring can be categorized into an onsite and offsite indicators.

5.5.2 Use of plants as indicators of soil degradation

The reason for using wild plants as indicators of changes in soil fertility, or soil degradation is because plants are sensitive to soil conditions, and because farmers are knowledgeable of which wild plants indicate good or bad soil fertility (this section from Olson et al. 2004). Use of plant indicators was one of our best methods of determining soil fertility and changes in the soil due to land use change, because we did not have historical soil testing data to compare with our new soil analyses in all the sites. We used plant indicators during the transect walk. In each quadrat, we determined whether any indicator plants are growing in the quadrat, and identified them.

The plant indicators vary across agro-ecological zones, due to differences in growing conditions. We needed, therefore, to determine the plant indicators for each zone across the transect. Similarly, the indicators probably differed between research sites, for example between the Kenya and Tanzanian sides of Mt. Kilimanjaro.

Box 1. Guide to Interviews on identifying plant indicators

1. Has soil fertility changed during the past 20 years
2. a. What wild plants (weeds) appear in cropped fields that indicate that soil fertility is poor? Or that soil fertility has declined?
b. What are the best 3-5 plants that we could use that show that soil fertility has declined? What are their particular characteristics (e.g., grows where over cultivated, or grows on rocky soil). Be sure to identify the botanical name and/or collect samples of the plants.
3. a. What wild plants (weeds) appear in cropped fields that indicate that soil fertility is good? Or that fertility has improved? Be sure to identify the botanical name and/or collect samples of the plants.
b. What are the best 3-5 plants that we could use that show that soil fertility has improved? What are their particular characteristics (e.g., appears after apply manure, or grows on red soil, etc.) Be sure to identify the botanical name and/or collect samples of the plants.
4. a. What wild plants appear in pasture lands that indicate that the quality of pasture is bad? Or that it has deteriorated?
b. What are the best 3 plants that we could use that show that pasture quality has declined? What are their particular characteristics (e.g., shows overgrazing unpalatable, annual vs. perennial grasses, etc.)
5. a. What wild plants that appear in pasture lands that indicate that the quality of pasture is good? Or that indicate that it has improved?
b. What are the best 3 plants that we could use that show that pasture quality has improved? What are their particular characteristics (e.g., shows overgrazing, etc.)

Therefore, we first needed to learn from knowledgeable local people what were the plants that indicated good or bad soil fertility or changes in soil fertility (Box 1, from Olson et al 2004). The older people, especially those who in the past chose what land to crop each year (before land privatisation), were probably the most knowledgeable about wild plants and plant indicators. It was best to have a group of around 10 people to discuss among themselves what plants are the best indicators, because of differences of opinion and experiences. The same plant may be cited by different people as indicating improving and declining fertility, so it was best to have a group discuss which plants are best for the team to use.

In arranging the group meeting, therefore, request to speak to people knowledgeable about cropping, soils, and wild plants. Present to the group the purpose of the research (to understand the linkages between land use change and changes in the soil), what field methods will be used and where, and how their answers will be important during the research. Since this meeting will occur before the transect walk, it may be a good opportunity to introduce the project to elders and leaders of the community.

Record comments that may affect how we interpret the presence of the indicator plants (e.g., is there a difference between plants that indicate poor soil, and those that indicate deteriorating soil? Is the plant more prevalent in a particular type of soil).

Note also the various names of the plants, and try to determine whether the name they use is for a general type of plant, or several species. If possible, gather a sample of the plant to determine its botanical name.

Let the group know that you will be returning to them after the transect and other work, to share with them the results of that work and to discuss more specific issues about why land use has changed, why soil fertility has changed, and why wild plants have changed.

Indicators for degradation could be either for land surface immediate to the location of the indicator itself or for a site far from the indicator. Here we separate the two into on site indicators and off site indicators respectively:

Onsite indicators of land degradation

- Soil erosion
- Deterioration of:
 - Physical properties of soil (texture)
 - Chemical properties of soil (nutrients, carbon, etc.)
 - Vegetation
 - Plant indicators of degraded soils
 - Stakeholder perceptions on changes in soil productivity and other soil characteristics

Offsite indicators of land degradation

- Siltation: This is important and may be easily detected in the field as alluvial deposits in river catchments or recent sedimentation of soil materials deposited by either surface runoff or wind.
- Pollution of reservoirs: This will be measured in Kenya Kilimanjaro site where water pollution by farming systems will be studied.

Methods of how to measure land degradation

- Ground surveys and sampling on soil erosion, soil fertility plants and biodiversity composition
- Comparing list of plants from degraded and non degraded soils
- Interviews with local communities

5.6 How to analyze linkages

Linkages between land use change, changes in biodiversity and land degradation were established by comparing trends of changes in each of these data sets from the same site. Analysis of land use change from satellite imagery analysis over time (images from the same site taken at different years) gives the trends of changes in land use and land cover over the time interval between the years the images were taken. Depending on the availability of resources several images should be analyzed to give a more accurate rates of change in land cover. Biodiversity on the other hand is analyzed by field assessments on each of the land cover identified in the satellite imagery to determine species composition and abundance. Trends on changes in biodiversity and land degradation can be obtained from human perceptions on the changes in their surroundings over time or by substituting space for time. This compares data from different land cover types, land use types, agro-ecological zones. In this space for time approach you get an opportunity to compare data to show the changes that result from a changes from one land use to another, from one land cover to another within the same agro-ecological zone.

6.0 INTERPRETATION OF LINKAGES

How are changes in land use causing land degradation and by what magnitude?

By comparing data on biodiversity status, soil chemical and physical characteristics and information on productivity in different land use / land cover patterns over space and if data is available over time, we can get a very good idea on changes in land degradation associated with changes from one land use to another. If a change from one land use to another results into a reduction in biodiversity the change is causing land degradation. A reduction in biodiversity could be either in the number of species, lower populations within species or in the case of plants lower

percentages of land cover. The magnitude of change may be by the extent of changes in these measurable parameters.

Changes in ecosystem services like wild food resources and medicinal herbs, due to changes in land use are also interpreted as indicators of land degradation caused by land use. However, care must be taken to differentiate as far as possible changes that may be due to natural processes like drought, wildfires and climate change.

How are changes in biodiversity affecting land degradation and how does it vary from one biodiversity group to another and from site to site?

To understand the linkages between biodiversity and land degradation one needs to analyze how changes in biodiversity affect land degradation. Changes in biodiversity that lead to reduced complexity of ecosystems either in vegetation structure (e.g., canopy stratification), species composition and abundance, and ecosystem's to deliver services are understood to be changes to more degraded lands. These changes are measurable by field surveys, in different land use types across the landscape

Feedback workshops

We have used feedback workshops to know how our interpretations on changes in land use, biodiversity, and land degradation reflect on the views of the local people. Local people have historical perspectives on major general changes in their surroundings and the chronological sequences of these changes. Information from feedback workshops could provide useful links on the cause and effect between land use changes including effect on land degradation.

7.0 RECOMMENDATIONS

It is important to make a good selection of sites across the region in order to capture a good representation of the diversity of landscapes, land uses and ecological variability. To achieve this we selected gradients across which a range of agro-ecological zones are represented. We recommend that sites must be selected to provide both comparative and complementary data across the region.

Research methods to collect data on biodiversity and land degradation are variable from one biodiversity group to another and one degradation aspect to another. There are also variabilities even within the same biodiversity group. For example, methods to sample vegetation are diverse and often researchers have their own preferences for certain method, which may not be preferences for others. In a regional project these methods must be reconciled such that same biodiversity groups are measured in the same way across the sites. This is particularly important in situations where different sites are surveyed by different researchers. We therefore recommend that researchers involved in each study component should consult each other widely to refine and reconcile their field sampling methodologies. After sampling they should consult each other to identify how different experiences in the field would affect their data or would result in difference in data across the sites.

Time periods are very important in study of linkages between land use, biodiversity and land degradation changes. We recommend that same time periods be adopted across the sites in order to have comparable data that will allow regional synthesis of results.

Land use or land cover classification is important in order that data can be comparable and that similar grouping of land use classes are used in every site.

Data analysis should be harmonized across sites. We recommend that different researchers across should analyze their data similarly so as to generate commonalities and variabilities on regional basis.

8.0 ACKNOWLEDGMENTS

The authors acknowledge with gratitude UNEP/GEF for granting financial resources (GF/1030-01-01) that enabled these multidisciplinary investigations at the sites and the regional synthesis of the site results. We also extend our thanks to all the institutions that supported us by providing time for the investigators to participate in all aspects of this research. The institutions include, the International Livestock Research Institute, Michigan State University, University of Dar Es Salaam, Makerere University, Kenya Agricultural Research Institute, National Museums of Kenya and Bordeaux University in France for contribution to the greater effort in LUCID goals. Finally we would like to thank many individuals who provided technical skills and material resources to enable completion of this work.

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