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*Full Length Research Paper*

# The linkages between land use change, land degradation and biodiversity across East Africa

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**Land use changes in East Africa have transformed land cover to farmlands, grazing lands, human settlements and urban centers at the expense of natural vegetation. These changes are associated with deforestation, biodiversity loss and land degradation. A synthesis of results of long term research by an interdisciplinary team reveals the linkages between land use change, biodiversity loss and land degradation. The results indicate that as native vegetation is lost, indigenous plant and animal biodiversity and plant cover are lost. Pastoralism maintains native plant and animal species more effectively than crop cultivation. As croplands expand, soil fertility and moisture drops and soils erode more easily. Farmers who grow many crops conserve native plant species better than those who grow only one crop. Increased crop diversity encourages regeneration of indigenous plant species. Moderate farming as in the less intensive low input rainfed mixed crop farming, in less forested areas increases tree cover thus increasing the biodiversity. Farmers' who combine livestock rearing with cropping, use livestock manure to replenish soil nutrients in their farms and are thus able to maintain higher productivity. Farming in grasslands, woodlands and bushland areas where there are fewer trees, increases the diversity of habitats due to introduction of agrosystems that attract new species of birds. However, if the farming is intensified and the diversity of habitats is reduced biodiversity is also reduced. This paper presents findings of the investigations on these linkages in a diverse farming and herding systems ranging from lowlands to high mountains land uses.**

**Key words:** East Africa, land use change, land cover change, biodiversity, land degradation.

## INTRODUCTION

Expansion of cultivation in many parts of East Africa has changed land cover to more agro-ecosystems and less cover of natural vegetation. These changes are fueled by a growing demand for agricultural products that are necessary to improve food security and generate income not only for the rural poor but also for the large-scale investors in commercial farming sector. Food production in Kenya, for example, is reported to have increased steadily between 1980 and 1990, but because of population increase, the food supply in calories per head fell slightly during that same period. Historically, humans have increased agricultural outputs mainly by bringing more land into production (Lambin et al., 2003). Indeed, land conversion to agriculture in East Africa has outpaced the proportional human population growth in recent decades. Natural vegetation cover has given way not only to cropland but also to native or planted pasture (Lambin et al., 2003). Also of considerable importance to land use change in East Africa is the expansion of urban centers. Between 1960 and 2000, urban population in Kenya has grown from 7 to 30% of the total population (Tiffen, 2003).

During the last few decades the area under cultivation

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has more than doubled in Kenya and Tanzania, but in Uganda the change has been moderate due to enhancement of land policy protecting large parts of Uganda as wetlands and that much of the country had already been cultivated before. (Olson et al., 2004). In Mbeere, Kenya, Olson and others report that cultivation expanded by 70% between 1958 and 2001, leaving only isolated pockets of forest and bush. Similarly, in Tanzania, (Misana et al., 2003) report a significant expansion of cultivation in the Moshi area over the same period. However, in Uganda, Mugisha (2002) reports that agriculture only expanded in the drier rangelands, not in the wetter highlands. Land scarcity in the highlands caused farmers to intensify their land use (increase inputs per hectare) because there was little land available for extension of their farms.

Globally, concerns about the changes in land use / cover emerged due to realization that land surface processes influence climate and that change in these processes impact on ecosystem goods and services (Lambin et al., 2003). The impacts that have been of primary concern are the effects of land use change on biological diversity, soil degradation and the ability of biological systems to support human needs. Crop yields have declined, forcing people to cultivate more and more land to meet their needs (Kaihura and Stocking, 2003). Grazing areas have become less and less productive resulting from over stocking of livestock. Conflicts over the use of land have increased due to increased demand for land by different sectors of the economy. Of particular concern are the conflicts among cultivators, livestock keepers, wildlife conservationists, individual land users and governments due to encroachment of humans into the protected areas (Hoare, 1999; Campbell et. al., 2003; Western, 1976; Wells and Brandon, 1992).

In this paper we present results of an analysis of the linkages between land use change, biodiversity loss and land degradation in East Africa, work that was funded Global Environmental Facility through UNEP. The paper shows the effects of different land uses in East Africa on biodiversity and land degradation by comparing the trends in multiple sites representing all major ecological production units in the region. We combine analysis of land use patterns with ground measurements of biodiversity change and assessments of land degradation to give a robust analysis of their relationships.

## MATERIALS AND METHODS

For this paper, the working definition of biodiversity is the variability and distribution of above ground, terrestrial flora and fauna species, in both natural and human managed landscapes. Emphasis was placed on measuring vegetative species and ecosystem diversity, because changes in vegetation are more easily determined and are directly impacted by alterations in land use. Changes in habitat extent and fragmentation, vegetative composition and structure and wildlife corridors were measured and interpreted in terms of their impacts on wildlife.

Patterns of land use and land cover used in this study (Olson et al., 2004) were determined by remote sensing techniques. Participatory studies were conducted to obtain the changes in area covers for classical land cover and lands use types over time; changes in spatial continuity in ground area covers for different habitat types; and the human perceptions on general changes in the environment. Indicators of changing biodiversity that were examined included the changing abundance of plant species along a land use gradient, a comparison of flora and fauna in land use/cover classes representing different types and intensities of human use and the changes in habitat extent, distribution and fragmentation determined by interpretation of remote sensing data. The indicators of land degradation examined included variation in the extent of soil erosion in different land uses; variation in soil fertility measures in different land uses and the changes in crop productivity over time.

The Methods used to link changes in land use, biodiversity and land degradation included comparing patterns of different land uses and the biodiversity measures from same sampling points; comparing the numbers and abundance of indicator species for various forms of degradation; comparing biodiversity measures with soil fertility measures and soil erosion indicators from the same site and statistical comparison of the three sets of data sets.

The paper focuses mostly on the one way linkages between land use change and biodiversity and land use change and land degradation. It evaluates the feedbacks of changes in biodiversity and land degradation on land use and addresses the two-way linkage between biodiversity and land degradation (Figure 1). It responds to the following questions below in five different linkage loops:

1. Effects of land use on biodiversity: What have been the long-term trends in diversity (wildlife) in East Africa? How and why do different types of land use change affect biodiversity? Are some types of biodiversity more sensitive to land use change than others?
2. Effects of land use on land (and water) degradation: How do changes in land use affect land degradation and what are the feedbacks?
3. Linkages between land degradation and biodiversity: How and why does land degradation (soil nutrient depletion and soil erosion) affect biodiversity (specifically plant diversity)?
4. Linkages between land degradation and poverty: Are there linkages between land degradation and poverty?
5. Future viability of land use systems in East Africa: What are the implications of changes in land use, biodiversity and land degradation for the future viability of different land use systems of East Africa?

## RESULTS

The sequence of land cover/land use change in East Africa is complex. In some places pastoralists modify wooded landscapes into more open landscapes by burning, but here, the changes are quite subtle and pastures can quickly revert to bushland and woodland when burning ceases. Figure 2, shows the changes that occur in the wetter lands when farmers convert land to cultivation. However, we highlight these changes because they represent the largest impacts that people have on the land.

### Effects of land use on biodiversity

### a) Trends in the biodiversity over time in East Africa

i) Trends in wildlife diversity over time in East Africa: Wildlife diversity is generally on the decline across East Africa. In Uganda, expansion of farming around Lake

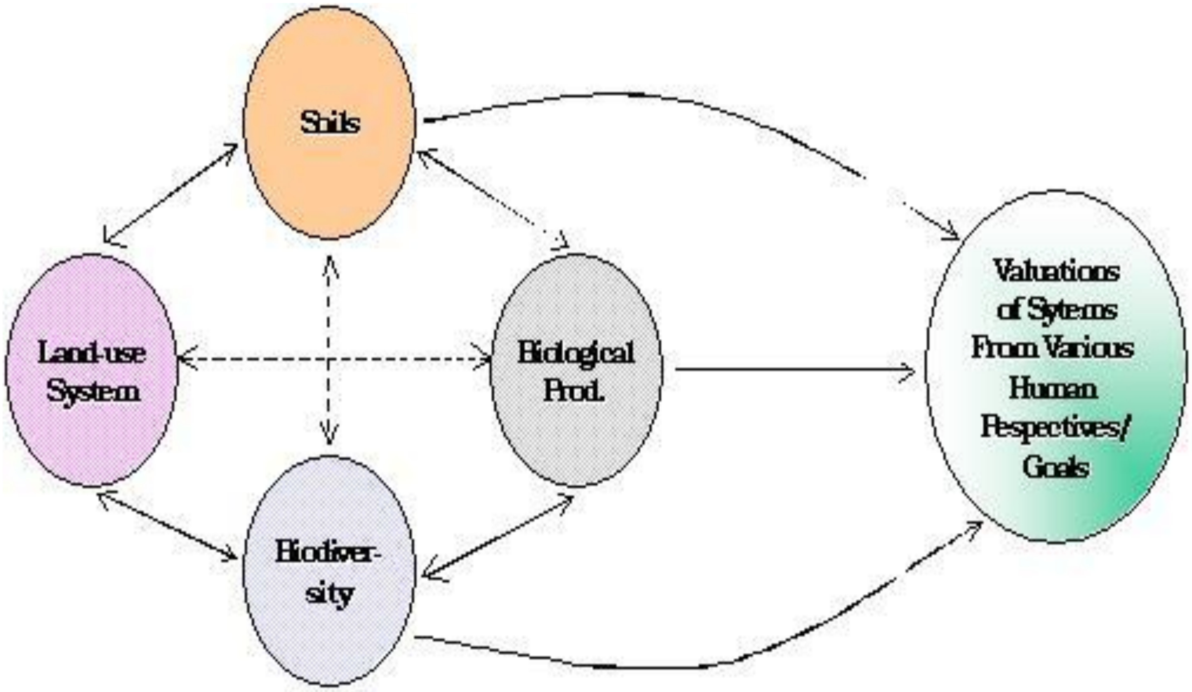


**Figure 1.** Conceptual linkages among land use, land degradation (represented by soils and biological productivity), biodiversity and human values used in this paper (Maitima and Olson, 2001)

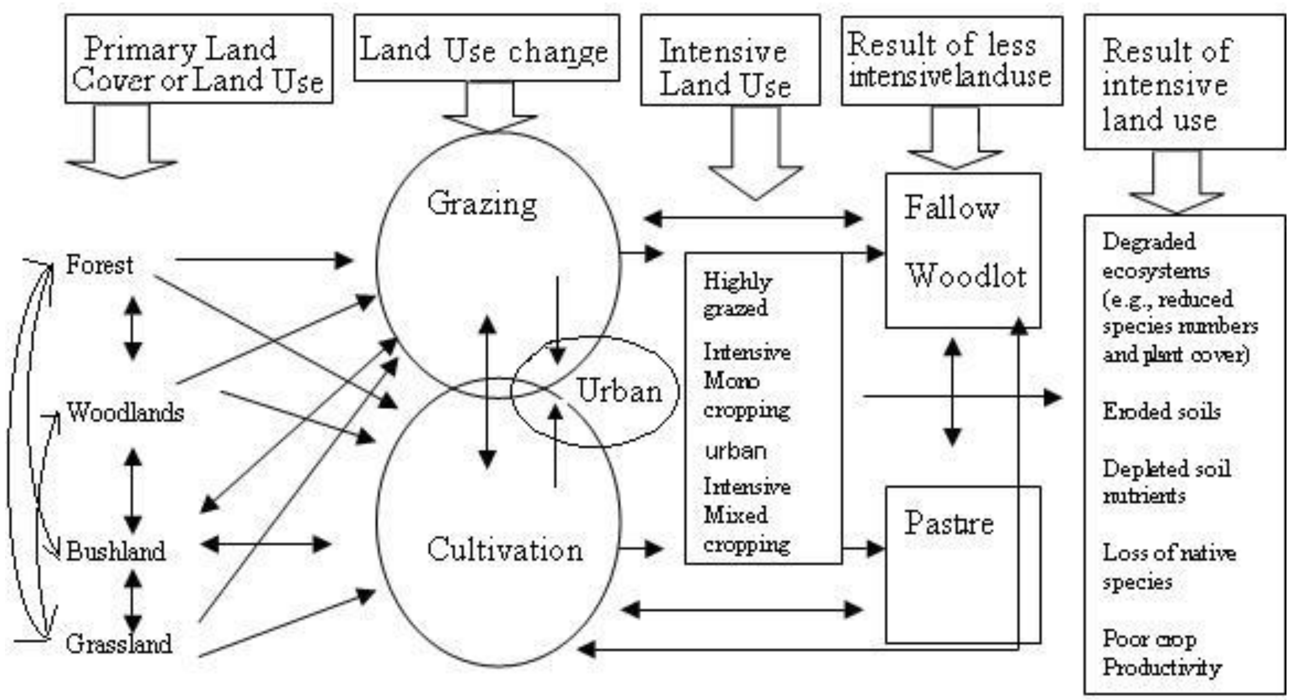


**Figure 2.** Schematic representation of land use sequences in East Africa. Source (Maitima et al., 2004a)

Mburo and armed insurrection in Karamojong have caused strong losses in large mammals in the last 20 years (Lamprey and Mitchelmore, 1996). Our results of interviews with local residents in Sango Bay, Rubaale and around Lake Mburo National Park support these findings (Nanyunja 2003). Aerial surveys show that many

**Table 1.** Total number of plant species, herbaceous (grasses and herbs) species and total plant biomass ($gm^{-2}$) between grazed and un-grazed sites. * Means significantly different at ($p < 0.05$), t-test. Sample size was 245 plant species. Source (Kamau, 2004).

| | Grazed | Not grazed | p-value |
|---|---|---|---|
| Total species numbers | 184 | 125.5 | 0.03* |
| Herbaceous species numbers | 91.5 | 49.5 | 0.03* |
| Total biomass | 91.63 | 887.8 | 0.04* |
| Herbaceous biomass | 429.09 | 387.24 | 0.48 |

species of wildlife have declined strongly around the park, particularly impala (Lamprey and Mitchelmore 1996). In Sango Bay, residents think wildlife losses star-ted in the 1970's and that some wildlife are still abundant today. Similar to Uganda, Kenyan wildlife is in strong decline. Between the 1970's and 1990's, most of the 17 rangelands districts lost over 50% of their wildlife (Serneels and Lambin, 2001). In the Mara ecosystem of Narok, 70% of the wildlife disappeared during this period (Serneels and Lambin, 2001). Wildlife in one district, Kajiado, has not changed, and in Laikipia, wildlife numbers have increased. The reasons for these losses are the expansion of subsistence and commercial agriculture in wetter areas and the expansion of settlements and fencing, changes in burning practices, drought and increased poaching in wet and dry areas (Dublin, 1995).

In contrast, wildlife in Tanzania are only in decline in the wetter farming areas. Increased poaching from farmers and expansion of farming and settlement heavily impacts on wildlife in the western Serengeti (Campbell and Hofer, 1995). Just on the other side of this park in the pastoral areas to the East, wildlife populations appears to be steady. Around Tarangire National Park, wildlife appear to be in decline, probably from over hunting and expansion of cultivation.

ii) Trends in economically useful plants over time in East Africa: In East Africa people use plants for medicine, timber, fodder and shade on the farm and in cultural rites. The identity and distribution of these medicinal plants are very well known among the herbalists who make their living by collecting and selling them. Interviews with groups or individuals specialized in gathering and trading these economically useful plants revealed that there has been a tremendous loss in plant biodiversity over the last half century (Nanyunja, 2003). This observation was consistent across all our sites in Kenya, Uganda and Tanzania (Nanyunja 2003; Misana et al., 2003; Wangui, 2003). Plant diversity has also been lost in all agro-ecological zones, although at different magnitudes depending on the intensity of land use in each area. This trend of loss in plant biodiversity is associated with the intensification of land use. In Uganda, a comparison of plant diversity in protected and non-protected areas shows that humans are responsible for the disappearance of medicinal plants in their neighbourhoods that are still present in nearby Lake Mburo National Park (Nanyunja 2003). This selective removal of plant species, often accompanied by poor methods of removal, has created disturbance leading to or contributing to fragmentation of ecosystems. Generally, the diversity of medicinal plants was highest in the uncultivated land with scrubland having the highest density. Fragmentation of land (as seen by different patches of contrasting land cover side-by-side) is more noticeable in the lowlands than in the high altitudes, only because the land in the highlands has already been completely fragmented, forming large contiguous blocks of cultivated land. In the highlands, population pressure is high and almost all available land is cultivated while within the lowlands, land is still available and continues to attract investors from the highly populated, wetter areas. Clearance of vegetation for cultivation targets areas where land is suitable for agriculture based on soil fertility, proximity to water resources and infrastructure like roads. This situation has been reported in all study sites (Misana et al., 2003, Ntiati, 2002; Mugisha, 2002).

### b) Effects of current land use systems on plants

#### i. Effects of livestock grazing on plant species diversity and biomass

Unexpectedly, there were 50% more herbaceous plant species, a higher diversity and a more even distribution of species in grazed than in un-grazed sites in Embu, Kenya (Tables 1 and 2) (Kamau, 2004). On the other hand, biomass (estimated by clipping and weighing dry vegetation matter in a plot during dry and wet season) and woody vegetation cover were greater in sites with no grazing. In our other sites, pastures (planted and native) supported more weeds than other land uses and only occasionally were homes to plant species of conservation value. There were significant differences ($p < 0.05$) in pH, organic matter, percent carbon, total nitrogen, moisture, bulk density and percent clay between the grazed and un-grazed plots. Except for the pH and bulk density that was higher in grazed area the rest were all higher in the closed un-grazed area. Off-take of biomass through grazing in the area is moderately high and appears to reduce competition for resources between different plant species, thus increasing the number of species that can co-exist in grazed sites compared to areas with no grazing

**Table 2.** Comparisons of percent plant cover of different growth forms in grazed and un-grazed sites. *Means significantly different at ($p < 0.05$), t-test. Source: (Kamau, 2004).

| Growth form | Grazed | Not grazed | p-value |
|---|---|---|---|
| Herbs and grasses | 72.5 | 17.4 | 0.04* |
| Shrubs | 40 | 62.5 | 0.04* |
| Trees | 25 | 62.5 | 0.12 |

(Kamau, 2004).

### ii. Effects of cropping, settlement and native vegetation on plant species numbers and cover

The comparisons here are between moderately used places (forest, woodland, bushland and grassland) and places heavily used by people for various activities (pasture, fallow, woodlots, mono-crops, poly-crops, annual crops, perennial crops, settlement). In general, Kilimanjaro stands out as the place where people, through intensive agriculture, encourage high plant diversity in perennial, croplands with many crops (perennial poly-culture). These farms often supported more species than nearby woodlots, bushland or pasture. About 50% of these plant species were weeds, but this is actually lower than many of the land use types that supported fewer species. These systems thus appear to be relatively biodiverse and support a significant number of indigenous species. In Embu, Kenya, annual croplands (with either single or multiple crop species) often supported the most species and certainly more than the forest and woodland plots sampled. However, these species were more than 90% weeds. Other, less used areas, like woodlands and grassland, had fewer species, but more than 50% of these were natives (Table 3). This means farming is not diversifying the flora here, natives have been lost and invasive species are common. In Uganda, farming systems are dominated by plantain plantations. These plantations support few plant species and the few they do support are more than 75% weeds. Woodlands and bushlands support more species and few of these (<20%) are weeds. Thus, these sites are similar to those in Embu and are examples of farming practices removing biodiversity.

In Loitokitok, Kenya, just on the other side of Kilimanjaro from the Tanzanian transects, a somewhat different picture appears, depending on the zone. Here, the middle zone is similar to Embu, annual croplands support the most species, but nearly all these are weeds. Less used forest, bushlands and woodlands have fewer species, but 75% of these are natives.

However, in the lowland pastoral areas, we find 50% more species than any other site we sampled and more than 55% of these are natives. This is the one dominantly pastoral site we sampled and suggests that pastoral land use heavily conserves native plant species compared with upland farms, with the exception of the perennial farms on the Tanzanian side of Kilimanjaro, which are quite diverse. Our findings indicate that cultivation affects the numbers and cover of plant species (Table 4). Tree cover varies significantly between land use types due to presence of more trees in the uncultivated areas than in the cultivated areas (Maitima et al., 2004a). Shrubs show significant variation in both species numbers and cover due to higher representation in the uncultivated than in the cultivated areas.

The comparison of grass species numbers between the various land use types was found to vary only in the upper zones. On the other hand a comparison in grass species cover between different land uses in the middle and lower elevation zones was found to vary in some areas while in others there was no variation. This difference in distribution and cover of plant species could be due to variation in production systems and land use intensities between study sites.

### iii) Effects of mono-cropping and mixed cropping on plant diversity and abundance

In Tanzania, species diversity was low in monoculture and high in poly-culture systems (Figure 3). The observed loss of biodiversity in monoculture could be partly due to management practices in monoculture systems. To maintain high quality products and good harvests, farmers have to manage the crops more closely by not allowing weeds to establish, ploughing more regularly and applying more efficient techniques. On the other hand, mixed farming systems are not highly market-oriented and those products that are sold are sold locally. In these mixed farming systems, farm management is less intensive. This therefore gives room for weed growth and maintenance of some native species, thus increasing the overall diversity of plant species and improving plant cover.

Due to changes in market prices, many farmers are changing from one mono-crop to another in many parts of East Africa. An example is the change from the traditional coffee farming system to horticulture as a result of the high market prices for horticultural products (Lyaruu, 2002). Generally, vegetable farming requires high amounts of agricultural inputs such as fertilizers which may change soil conditions. For example, the dominance of the weed *Oxalis corniculata* throughout the coffee/ banana zone may be an indication of the acidic conditions of the soil.

### iv) Effects of grazing, cropping and settlement on plant species of conservation value

In the context of this paper, we consider species of conservation concern as any species which fall in any one of

**Table 3.** Percentage of species of invasive, rare, endangered and threatened plants in different ecological zones in Kenya (Loitokitok and Embu/Mbeere) and in Uganda (Maitima et. al. 2004b; Reid et al. 2004)

| SITES | ZONE | Land use cover | Invasive | Threatened | Endemic | Endangered | Rare |
|---|---|---|---|---|---|---|---|
| Loitokitok | Middle (UM) zone | Pasture | 4.80% | | | | |
| | | Annual mono-crop | 3.30% | | | | |
| | | Annual mixed crop | 0.80% | | | | |
| | | Settlement | 4.50% | | | | |
| | Lower (LM) zone | Woodland | | 1.10% | | | 1.10% |
| | | Bushland | | | 0.70% | 0.70% | |
| | | Pasture | | 1.20% | | | 1.20% |
| | | Annual mono-crop | 1.10% | | | | |
| Embu Mbeere | Upper (LH) zone | Forest | | | 6.70% | | |
| | Middle (UM) zone | Woodland | 8.30% | 8.30% | | | |
| | | Woodlot | | 3.10% | | | |
| | | Pasture | 3.40% | | | | |
| | | Fallow | 1.40% | | | | |
| | Lower (LM) zone | Woodland | 5.60% | | | | |
| | | Pasture | 13.00% | | | | |
| | | Fallow | 4.40% | | | | |
| | | Annual mono-crop | 2.20% | | | | |
| | | Perennial mono-crop | 4.30% | | | | |
| Uganda | Sango bay = Higher rainfall at 1500 mm | Grassland | | | | | 0.80% |
| | | Perennial mono-crop | 4.90% | | | | |
| | Ntungamo = moderate rainfall at 900 mm | Woodland | 4.50% | | | | 0.40% |
| | Lake Mburo = Moderate rainfall at 850 mm | Perennial mono-crop | | | | | 6.20% |

**Table 4.** Results of a two way analysis of variance for plant species richness and percentage cover in various land uses in the upper, middle and lower zones of Loitokitok, Kenya (Reid et al., 2004).

| Life forms | Middle (UM) zone | | Lower (LM5) zone | | Lower (LM6) zone | |
|---|---|---|---|---|---|---|
| | Species | Cover | Species | Cover | Species | Cover |
| Tree | 41.45* | 20.60* | 69.58* | 10.59* | 15.23* | 6.17* |
| Shrub | 187.82* | 11.76* | 31.60* | 2.12 | 20.00* | 7.61* |
| Herb | 1.64 | 1.98 | 7.35* | 1.11 | 2.39 | 1.25 |
| Grass | 12.78* | 6.64* | 3.13* | 4.32* | 1.35 | 6.84* |

* Indicate significance at P < 0.05 (comparing between land uses within the indicated zones).

one of the following categories: Endemic species, overexploited species that are threatened (e.g. species used for timber), species with a narrow range of distribution, medicinal plants that are harvested in a destructive manner, species difficult to propagate and keystone species. Among the timber trees for example, *Olea welwitschii*, *Cordia africana* and *Albizia gummifera* were overexploited where they occurred. Although two of the cited trees are coffee shade trees, they are declining in number due to timber harvesting. Such species decrease in number as one moves from the highlands to lowlands.

Our investigations indicate that land use change reduces the number and abundance species of conservation concern.

### c) Effects of land use on bird species diversity and conservation value

The number of bird species is much lower in plantations of tea, sugar and cotton than in mixed farming systems in Uganda (Pomeroy et al., 2003) an observation also re-

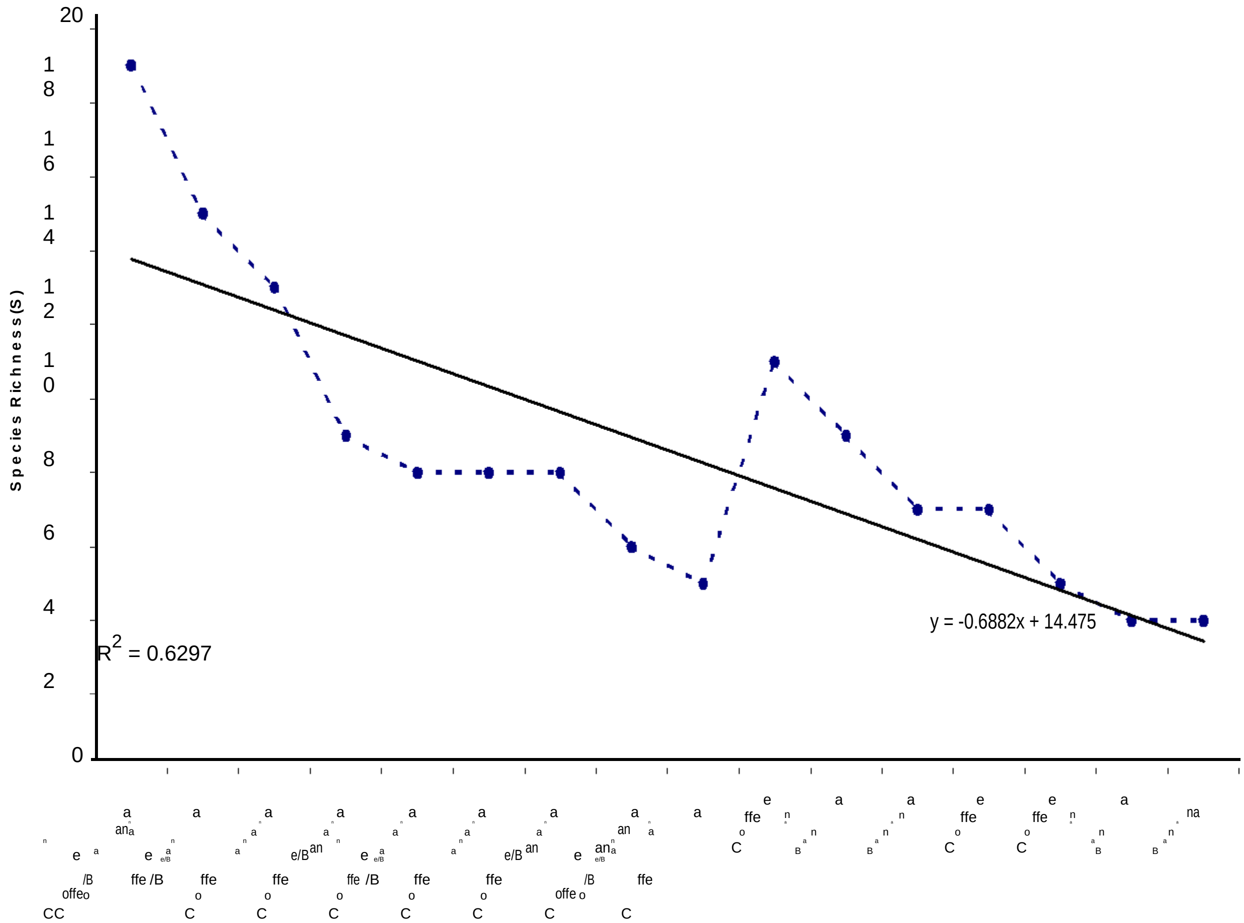


**Figure 3.** The effects of many crops (poly-culture, highest at left end of the bottom axis) and single crops (mono-culture, highest at right end of bottom axis) on the number of plant species along the Mbokomu transect on Mt. Kilimanjaro, Tanzania. (Lyaruu, 2002).

ported in Kenya (Maitima, 1998). In addition, land use change reduces woody canopy cover and at the same time alters the composition of woody plant species so that weeds replace natives. Bird species depend on the disturbed habitat for food and shelter. Reduction in their habitats therefore forces the species to migrate to other areas permanently. This has been demonstrated from our study (Figure 4) in Uganda (Pomeroy et al., 2003). The data shows that loss of tree cover strongly reduces the diversity of birds. When farming in less forested systems, farmers can actually increase tree cover, thus increasing bird species diversity (Wilson, 1997). Birds not only flock to trees planted on farms but also to the rich grain crops grown by farmers. Thus, farming does decrease bird species in forested systems, but can increase habitat for birds in grasslands, bushlands and sometimes woodlands.

A comparison between Lake Mburo National Park (LMNP) in Uganda and the surrounding grasslands found that changing land use through cultivation has a profound effect on the occurrence of flowering plants and the number of species of birds. The study confirmed that cultivation removes most of the native species, replacing them with more common weeds and non-native plants. This change reduces the suitability of the habitat for birds. It was also found that cultivation can support quite large numbers of plant species: for example, of 115 species recorded at the LMNP sites, only 28 of them also occurred in the cultivated areas, which included banana plantations, areas of cassava and fallow land. But only 15 of these can be considered as native to the area, in the sense that they also occurred in the nearby natural vegetation. Of those 15, only four were woody species, the rest were all shrubs. As would be expected, the majority of plants in cultivated areas are either for food, or they are weeds. In either case their contribution to the conservation of biodiversity is negligible in both the plants and bird species, since almost all of these species are widespread in tropical Africa and sometimes throughout the tropics.

Pastoralism maintains native plant and bird species more effectively than crop cultivation. Studies in Uganda indicate that the average numbers of species of both plants and birds are higher in pastoral than cultivated areas and within pastoral area they are higher in woodlands than in grasslands. Well-wooded sites hold more species than do open grasslands. For example, the esti-

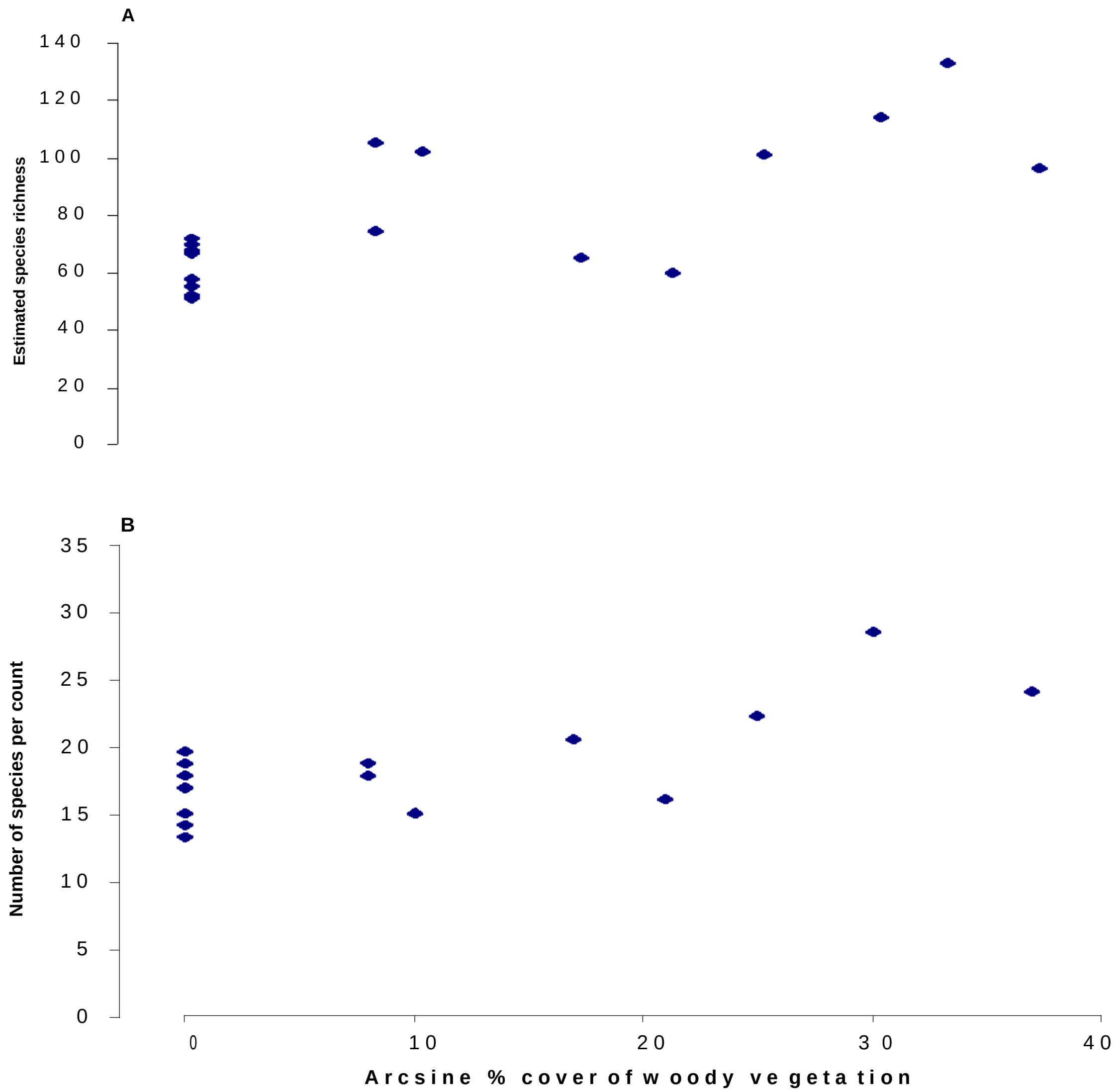


**Figure 4.** Effects of woody canopy cover on bird species numbers in Uganda (Source: Pomeroy et al., 2003).

mated species numbers of three pastoral sites studied in the Sango Bay Area arranged in decreasing order of woody vegetation cover was found to be 112, 102 and 66 respectively indicating that the lower the woody cover the lower the species numbers (Pomeroy et al., 2003). A similar trend is apparent for the natural sites in the overall means of wooded and grassland sites in the pastoral areas (Maitima et al., 2004a).

### d) Effects of land use on small and large mammals

Increasing the intensity of land use to moderate levels increases the diversity of species of small mammals due to the increase in habitat diversity. However, as land use further intensifies, species diversity of small mammals decrease as habitats start to simplify into large blocks of cropland without intermittent patches of native vegetation (Figure 5). Our study in Embu/Mbeere, Kenya, indicates that there are more small mammals where there are more plant species and then both plants and small mammals decrease in tandem as land use further intensifies.

Land use change has had a large impact on large mammals in areas outside the protected national parks and reserves. Work in Kitendeni wild life corridor (Noe, 2003) shows big declines in animal numbers and animal types due to an increase in cultivation and sedentary settlements that have interfered with animal movement. In Embu and other areas, where cultivation and human settlements densities are high, wildlife has disappeared entirely except for the pests like baboons that exist in forest remnants along rivers and around hills (Mutugi, 2003).

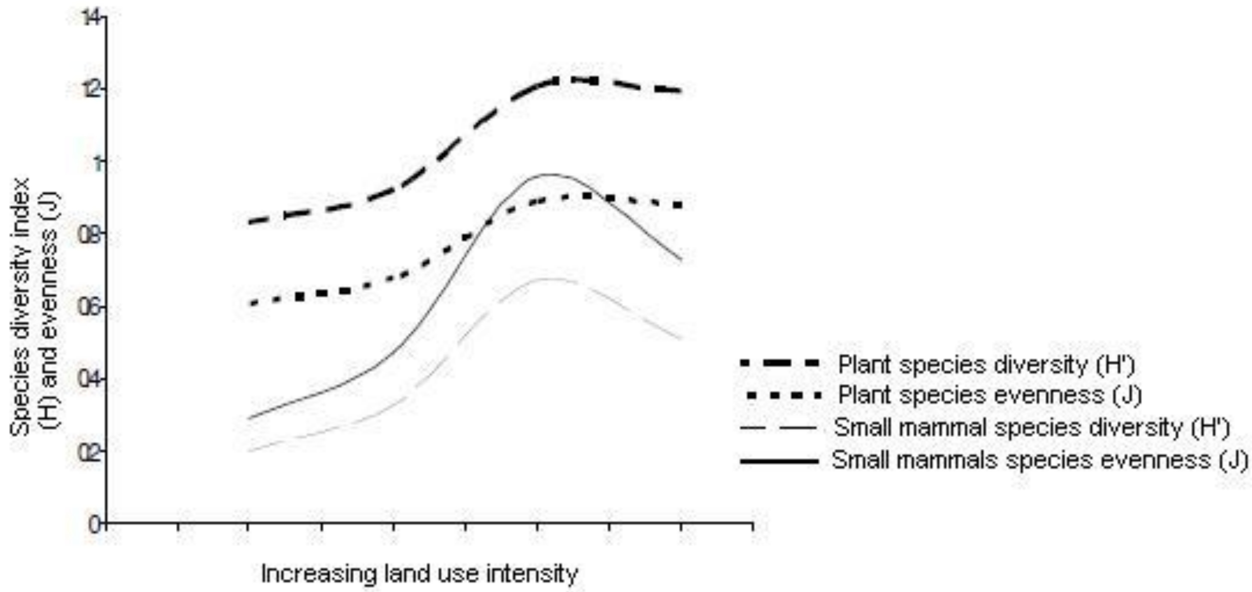


**Figure 5.** Shannon-Wienner diversity index (H) and evenness (J) of plant and small (Mugatha et al., 2003).

**e) Effects of excision of key resources on wildlife diversity and abundance**

Land use change has profound effects on key resources upon which wildlife and livestock depend. Our study in Amboseli has shown that human settlement is partly responsible for reduction in availability and quality of water resources leading to a decline in vegetative resources and wildlife. Creation of protected areas for purposes of wildlife conservation tends to limit animal movement by confining them within the park. Depending on the size of the park and the population of wildlife in the park, availability of key resources like feeds and water resources may diminish which may have negative impacts on wildlife. Land use change alters the interactions of people and wildlife. This is very well demonstrated in Loitokitok where cultivation around the swamps has blocked access to water for wildlife and increased contacts between wildlife and people. Our study has shown that wildlife are generally attracted by the presence of water, but presence of people around water point tends keep animals away (Worden et al., 2003). Land use change impedes wildlife movements. Studies on the effects of land use change in a wildlife movement corridor on the slopes of Mt. Kilimanjaro, has shown an increase in animal numbers along the corridor due to increase in cultivation on the outskirts of the corridor. This has resulted into an increase in human-wildlife conflicts (Noe, 2003). A similar observation has been made on the Imenti forest of Mt. Kenya, which also serves as a corridor for wildlife movement to and from Mt. Kenya (Gathara, 1999).

**Effects of land use on land (and water) degradation**

Long-term trends in soil nutrients in East African soils: We have observed a remarkable decline in soil nutrients (also described as a decline in soil productivity) due to deterioration of chemical, physical and biological properties. The main reasons for the decline, besides soil erosion, are: 1) Decline in organic matter and soil biological activity, 2) Degradation of soil structure and loss of other soil physical qualities, 3) Reduction in availability of major nutrients (N, P, K) and micro-nutrients and 4) Increased toxicity, due to acidification and salinisation (Gachimbi, 2003). The decline in soil productivity in most cultivated soils in East Africa leads to yield declines (Nyathi et al., 2003). This decline in yield has been attributed to the loss of plant nutrients through plant removal, erosion, leaching and deterioration of so physical conditions (Okigbo and Lal, 1979). Further observations indicate that soil organic carbon and major plant nutrients, e.g., potassium (K) and phosphorous (P) are the soil properties most affected by cultivation over time.

Effects of land cover and land use on soil chemical and physical properties: Soils in areas with continuous cultivation without appropriate management practices have low fertility levels due to over utilization (Majule, 2003, Gachimbi, 2003). A detailed description of soil fertility levels in different land use / land cover types in Kenya, Tanzania and Uganda are presented in Tables 5.

There have been changes in land use/cover associated with expansion and intensification of agricultural activities to the semi-arid areas and even in high rainfall areas

(Mugisha, 2002; Misana et al., 2004; Olson et al., 2003, 2004; Nyathi et al., 2003, O'Kting'ati and Kessy, 1991). These changes have a significant impact on soil chemical degradation. Clearing the natural forest in most parts of the upper zones for cultivation has contributed significantly to reduced levels of SOC, N, P, and K in the soil. Reduction in soil nutrients and acidification has forced farmers to abandon their fields and have converted them into woodlots dominated with *Eucalyptus* spp., usually planted for the purpose of demarcating field plot boundaries and to provide shade to coffee plants. The effects of individual land use/cover types on soil degradation in East Africa are presented in Tables 5 for Kenyan, Uganda and Tanzanian soils. Indicators of land degradation used to assess land degradation include soil nutrient levels and evidence of observed soil erosion features and crop performance assessment by farmers. An assessment of the few key chemical soil fertility indicators (soil pH, SOC%, available P and exchangeable K) revealed a variation associated with different land use categories. There is a marked decrease in soil fertility levels in cultivated fields compared with non-cultivated forest, woodlot, grassland etc.

Soil pH increases from the upper high land zones of East Africa to the lower zones and ranged from extremely acid to near basic. Low pH as in the upper zone restricts availability of plant nutrients and thus crop choices as shown in Table 5 from tea, maize, beans and coffee in Kenya. In the middle zones the soil pH is near neutral, which is optimal for wide range of crop growth. In the lower zone, extreme soil acidity was only observed in the soil in wetlands or paddy cultivation; otherwise, the other areas experienced near neutral pH value. Low soil pH in this case is probably due to nitrogen transformation associated with flooding of rice fields. Phosphorous (P) is low in upper and middle zones and high in lower zones and its amount varies with land use and length of use. Severe degradation in woodlots (middle and low zones) as well as in rice fields in Tanzania and pasture land are good examples of phosphorus depletion. Potassium is not a major limiting factor in East Africa soils due to inherent soil properties.

The amount of soil organic carbon (%) in the upper zones in Kenya is adequate in agronomic terms (Mehlich et al., 1964) and inadequate in other regions of Tanzania and Uganda. It is high in soils under tea, coffee, bananas, woodlots and pastureland due to prevailing management practices. Type of soil, coupled with moderate temperatures and available moisture in the upper zones, allows slow decomposition/mineralization of organic matter. Organic carbon contents in similar land use types found in the middle and lower zones declined where environmental factors favors' fast decomposition of organic carbon. In the lower zone of slopes of Mount Kilimanjaro in Tanzania, there is a marked regeneration in soil organic carbon in soils under pasture and maize/bean cropping, respectively, due to application of animal manures and crop residues, prevention of leaching through mulch application and terracing to prevent soil erosion.

All soils across East Africa have inherently good soil fertility. However, in many areas, they do not receive adequate nutrient replenishment to compensate for continuous nutrient mining through grazing, crop harvesting or erosion. This replenishment could come in the form of organic manures, inorganic fertilizers or biomass transfer through agro-forestry or short fallow or an integration of these technologies. The ability of farmers to combine livestock rearing with cropping activities is important to increase manure availability. In order to increase farm incomes, intensification and diversification of crop enterprises is important due to small land holdings in some of these areas.

### Effects of grazing on soil properties

Grazing increases the bulk density and moisture content through compaction and exposure of the soil to the sun, but reduces most soil nutrients through feeding and subsequent erosion due to the reduced ground cover. The soil analysis results presented in the Table 6 below compares soil chemical properties in a grazed area (open) and ungrazed area (enclosed). Grazed sites were significantly higher in soil pH and lower in bulk density, nitrogen, moisture content, percent organic matter and organic carbon than un-grazed sites ($p < 0.05$).

### Effects of irrigation on the salinisation of soils

Most of the irrigated areas in East Africa show signs of soil salinity. Most of the farmers in cultivated lands are realizing a drop in productivity as a result of increased salinity of the soil (Ntiati, 2002; Githaiga et al., 2003). These areas are likely to be abandoned within 5 - 10 years or farmers will change to other crops. This is confirmed by a study of soils in cultivated lands indicating a high Exchangeable Sodium Percentage (ESP) of strongly sodic' soils and a sodicity hazard (Touber, 1983). The swamps acts as sinks for salts (pollutants) washed out of higher elevation soils by rainfall and irrigation water. Despite some outflows from swamps, solutes accumulate in the 'sumps' of the hydrological systems rendering the water and soils on swamp margin, unsuitable for cultivation (Southgate and Hulme, 1996).

### Linkages between biodiversity and land degradation

### Effects of soil erosion on plant species numbers

Analysis on the effects of soil erodibility has shown a strong negative correlation between soil erosion severity and plant species numbers (Figure 6). Soil erosion tends to alter the natural habitat of certain species leading to their loss. Farms with more erosion are poorer in plant

**Table 5.** Linkages between land cover/land use, and soil fertility in Kenya, Tanzania and Uganda across an altitudinal gradient. (source: Gachimbi 2003)l

| Country | Major land use types | Major Soil Chemical Properties: Upper zone [a,b] | | | | | Middle zone [a,b] | | | | | Lower zone [a,b] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | pH ($H_2O$) | P* | SOC% | K† | Erosion | pH ($H_2O$) | P* | SOC% | K† | Erosion | pH ($H_2O$) | P* | SOC% | K† | Erosion |
| | Forestry | 4.0 | 6.0 | 6.55 | 0.22 | E0 | | | | | | - | - | - | - | - |
| | Woodland | | | | | | 6.43 | 57.33 | 0.87 | 1.51 | E2 | 8.0 | 049 | 3.29 | 2.98 | E0 |
| | Bushland | | | | | | 6.4 | 12.7 | 61.46 | 1.44 | E2 | 6.6 | 1.9 | 0.06 | 0.66 | E0 |
| | Grassland | | | | | | 6.6 | 13.6 | 3.39 | 1.34 | E1 | 8.1 | 37.3 | 1.1 | 1.4 | E1 |
| Kenya | Woodlots Pasture | 4.4 | 13.6 | 2.11 | 0.2 | E1 | 6.3 | 3.4 | 1.47 | 0.78 | E1 | | | | | |
| | Fallow | 4.7 | 16.2 | 4.27 | 0.7 | E0 | 6.5 | 3.6 | 1.47 | 0.94 | E2 | | | | | |
| | Cultivation | | | | | | 5.85 | 11.05 | 1.19 | 0.88 | E1 | 6.4 | 22.5 | 0.87 | 1.33 | E2 |
| | Coffee | 4.6 | 14.2 | 2.22 | 0.5 | E1 | 4.6 | 4 | 1.35 | 0.63 | E2 | | | | | |
| | Maize/beans | 5.3 | 7 | 1.92 | 0.66 | E1 | 4.1 | 21 | 1.88 | 0.24 | E2 | | | | | |
| | Tea | 4.1 | 8.8 | 4.08 | 0.17 | E0 | | | | | | 6.7 | 1.9 | 0.65 | 0.5 | E2 |
| | Forestry | 4.8 | 105 | 1.50 | 0.33 | E0 | - | - | - | - | - | - | - | - | - | - |
| | Woodland | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Bushland | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Grassland | 4.8 | 105 | 1.50 | 0.28 | E0 | 4.9 | 19 | 1.15 | 0.33 | E0 | 5.9 | 100 | 1.30 | 0.29 | E0 |
| | Woodlots | 4.7 | 127 | 2.25 | 0.32 | E2 | 3.8 | 5 | 1.25 | 0.31 | E0 | - | - | - | - | - |
| Tanzania (*Andosol*) | Pasture | 4.0 | 82 | 2.73 | 0.18 | E0 | | | | | | - | - | - | - | - |
| | Fallow | - | - | - | - | - | - | - | - | - | E0 | 5.1 | 12 | 3.50 | 0.35 | E1 |
| | Cultivation | | | | | | 5.7 | 45 | 1.30 | 0.34 | E0 | | | | | |
| | Rice | - | - | - | - | - | - | - | - | - | - | 3.5 | 14 | 0.70 | 0.36 | E0 |
| | Maize/beans | - | - | - | - | - | - | - | - | - | E1 | 5.7 | 178 | 1.70 | 0.36 | E1 |
| | Tea | 4.7 | 112 | 2.5 | 0.27 | E0 | 5.2 | 169 | 2.0 | 0.34 | E0 | - | - | - | - | - |

P*;available P in mg/kg; K † exchangeable K in $Cmol_c$/kg; a; Agro ecological Zonation in Kenya (Jaetzold and Schmidt, 1983) ; b; Agro ecological Zonation in Tanzania. Soil –critical values (Mehlich et al 1964): P (ppm) = 20 ppm: K = 0.2%: SOC = 2%

species in Tanzania. Soil erosion reduces soil fertility and water availability to the plants due to removal of the fertile topsoil that is vital for the growth of different plants species. Removal of vegetation on land through various factors such as tree harvesting for timber and building poles and conversion of natural vegetation to farmland, has a significant impact on the number and distribution of species available. On the other hand, the introduction of exotic woodlots and expansion of farmland has contributed significantly to accelerated soil erosion and loss of species.

**Effects of changes in vegetation cover on soil fertility in different land uses**

Reduction in vegetation cover reduces the amount of soil organic carbon in the soil (Figures 7 and 8). Available Soil Organic Carbon (SOC), in agrono-

**Table 5**. Contd.

| | | Ntungamo | | | | Lake Mburo | | | | Sango Bay | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Forestry | 4.0 | 6 | 6.5 | 0.22 | - | - | - | - | - | - | - | - |
| | Woodland | | | | | - | - | - | - | 8.0 | 049 | 3.29 | 2.98 |
| | Bushland | | | | | - | - | - | - | 6.6 | 0.6 | 0.66 | 0.26 |
| | Grassland | 4.7 | 38.7 | 3.73 | 0.8 | 5.2 | 5.2 | 1.78 | 0.14 | | | | |
| Uganda | Woodlots<br>Pasture<br>Fallow<br>Cultivation | | | | | 5.5 | 5.9 | 0.9 | 0.18 | 5.1 | 4.3 | 1.38 | 0.2 |
| | Coffee | 5.4 | 3.7 | 1.89 | 0.09 | 7.0 | 7.0 | 1.17 | 0.14 | 6.0 | 6.0 | 1.68 | 1.10 |
| | Maize/beans | 5.3 | 9.6 | 0.79 | 0.78 | 5.7 | 5.4 | 1.88 | 0.18 | 5.6 | 3.2 | 1.56 | 0.78 |
| | Coffee/banana | 6.0 | 18.2 | 1.06 | 0.03 | 5.6 | 2.6 | 2.5 | 0.03 | 6.3 | 7.8 | 1.5 | 0.65 |

mic terms (Mehlich et al., 1964), is adequate in forest and bush lands in the upper zones but deficient in the lower zones. This is due to reduced plant cover and high rate of decom-position and mineralization of organic matter in the lower zones unlike in the upper zones. Soil organic carbon was found to be higher in annual crops, pasture and fallow as a result of the addition of farmyard manure or use of inorganic fertilizers

### Effects of soil nutrients on plant species composition

Soil characteristics affect the distribution of plant species. The relationship between soil character-ristics and plant species composition can be used as an indicator of soil productivity. Poor soils tend to have certain specific plant species. For example, in the coffee/banana zones of Tanzania, the low plant species diversity and the poor soil conditions due to intensive land management favour *Oxalis corniculata*, *Bidens pilosa*, *Senecio abyssinica*, *Setaria homonyma*, *Digitaria scalarum* and *Launea Ananas comosus* (pineapple), *Helianthus annuus* (sunflower) and *Carica papaya* (pawpaw).

## Conclusion

Land use in East Africa is changing at a very high rate.

Based on land change analysis done by the LUCID group (Mugisha, 2002; Misana et al., 2004; Olson et al., 2004) land use has changed to more cultivated area and less bush, forests and grass-lands. These changes have tremendously reduced areas with natural vegetation where in some sites there is hardly any natural vegetation. After the primary land cover conversion from natural vegetation to cultivation or grazing, land use becomes more complicated due to intensi-fication and diversification as land for conversion becomes less and less available and farm sizes become smaller and smaller as a result of sub-division. The causes for these land use changes are well documented in several reports in the LUCID working paper series. Conversion of primary land cover to cultivation replaces natural vegetation cover with crops either planted as mixed cropping or planted and maintained as monoculture. In addition to planting food-crops there are fields planted with pastures for livestock grazing, woodlots for shade and fencing and homesteads. Within the cropped areas there are many types of crops planted and each type could have different management practices and there-fore will affect the land differently. Changes in land use are here reported to reduce plant species numbers and percentage cover for all vegetation categories and all land use types. Land use in monoculture cropping system results to more loss on species numbers than mixed cropping system. Understanding of plant species' responses to grazing pressure and seasonality needs to consider multiple scale effects and the dogmatic notions about degradation of the arid zones at the course scales. Land degradation assessments in the arid zones should focus at the

**Table 6.** Physical and chemical properties of soil between grazed and un-grazed sites (t-test). (Kamau., 2004)

| Variables | Grazed | Un-grazed | p-value |
|---|---|---|---|
| pH | 6.7 | 6.02 | 0.03* |
| Avail. P | 17.37 | 24.72 | 0.229 |
| Nitrogen | 0.26 | 0.32 | 0.03* |
| Ex K | 0.3 | 0.38 | 0.14 |
| Ex Ca | 4.5 | 5.76 | 0.159 |
| Ex Mg | 1.37 | 1.51 | 0.32 |
| Ex Na | 0.84 | 0.16 | 0.33 |
| TOM | 1.57 | 1.84 | 0.042* |
| % Carbon | 8.65 | 15.91 | 0.036* |
| Sand | 73.2 | 75.5 | 0.31 |
| Silt | 17.46 | 12.2 | 0.14 |
| Clay | 9.33 | 12.3 | 0.02* |
| Colour | 3.3 | 3.9 | 0.08 |
| Bulk density | 1.81 | 1.46 | 0.002* |
| Moisture | 1.1 | 5.32 | 0.03* |

*means significant difference at $p < 0.05$.

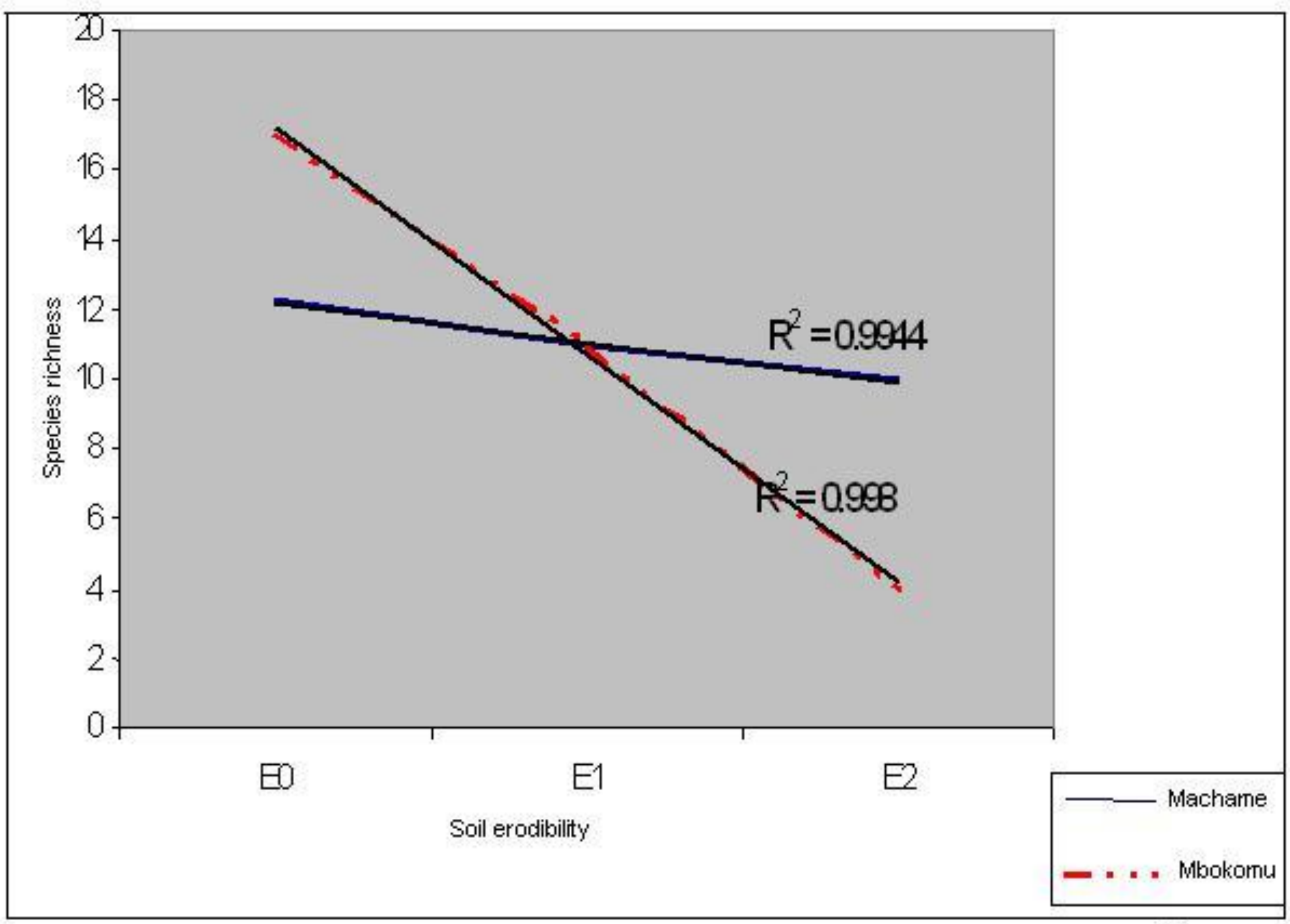


**Figure 6.** The effects of soil erodibility on species numbers in Tanzania (Majule, 2003).

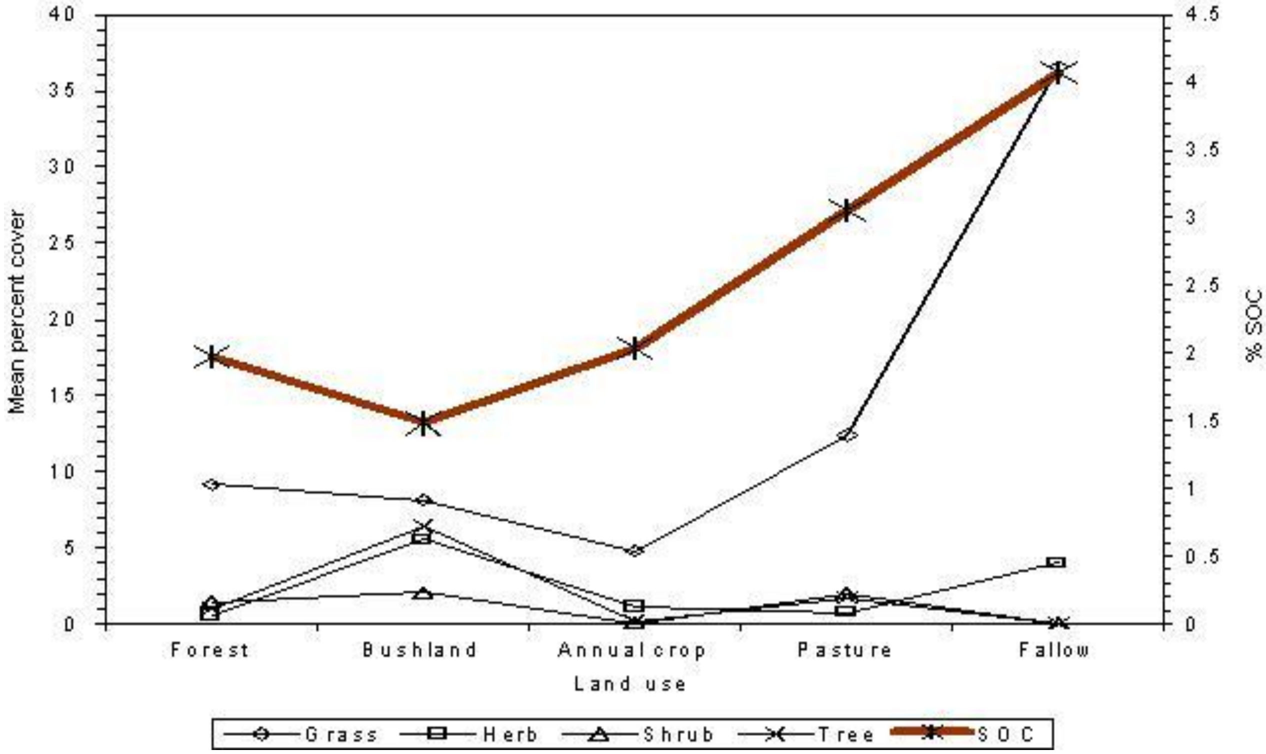


**Figure 7.** The relationship between soil organic carbon and mean percent cover of different vegetation categories in different land uses in the upper zones of the study sites in Tanzania. (Majule, 2003).

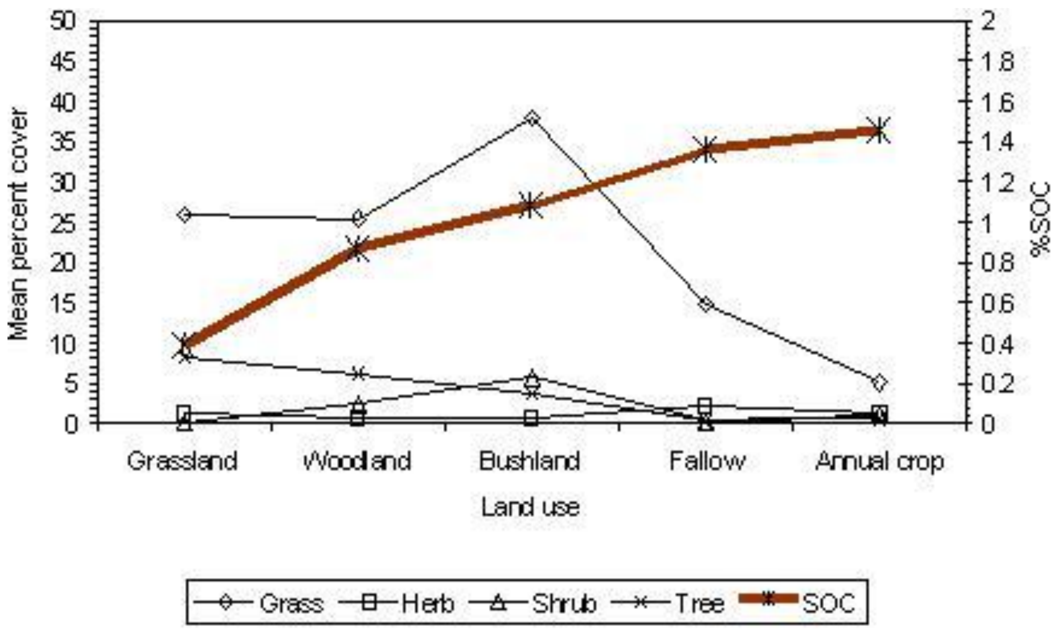


**Figure 8.** The relationship between soil organic carbon and the mean percent cover of different vegetation categories in different land uses in the lower zones of the study sites in Tanzania (Majule, 2003).

in general the spatial grazing range. As a result especially the increased contact with humans the animal numbers and the species diversity has reduced in the affected regions. In all the study sites, wildlife is reported to decline. We have observed remarkable decline in soil nutrients (also described as a decline in soil productivity in terms of crop yields) due to deterioration of chemical, physical and biological properties. The main reasons for the decline besides soil erosion are decline in organic matter (soil organic carbon), degradation of soil structure, reduction in availability of major nutrients (N, P, K) and micro elements and an increase in toxicity due to acidification and salinisation especially in irrigated farming systems.


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