



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

**Forage Diversity and Impact of Grazing Management  
on Rangeland Ecosystems in Mbeere District, Kenya**

**LUCID Working Paper Series Number: 36**

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January 2004

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## Abstract

Composition, biomass and vegetation cover in Mbeere rangeland was assessed for comparison of the effect of grazing and other human interference in open and enclosed sites. A total of 245 plant species were recorded. Clipping and preference unit technique were used to estimate herbaceous and trees and shrub biomass respectively. Canopy cover was done by visual estimation for three growth forms while forage preference was through direct observation. Grazing reduces above ground biomass in communal lands mainly through overgrazing and elimination of palatable species. Forage productivity on the other hand largely depends on availability of rainfall and disturbance. Grazing management systems used in this particular rangeland have a direct impact on forage diversity. T-test results shows that total species richness and herbaceous richness in the open site were significantly different ( $p < 0.05$ ) from the enclosed site. Species diversity and evenness were higher in open than in enclosed sites. Biomass and shrub cover were also significantly higher ( $p < 0.05$ ) in enclosed site than in the open site. There were significant differences ( $p < 0.05$ ) in pH, organic matter, percent carbon, total nitrogen, moisture, bulk density and percent clay between the enclosed plots and open plots. Goats and cattle were observed to have complementary feeding habit thereby reducing forage competition.

## 1. INTRODUCTION<sup>1</sup>

Rangelands comprise about 50% of the world's land area and include natural grasslands, scrublands, savannas and deserts provide the majority of range ecosystems. In most African countries, rangeland livestock production is a form of extensive grazing system practiced by nomads of the arid regions. The management systems vary from nomadic pastoralism through mixed subsistence farming to commercial ranching. Considering the demand for foodstuffs due to the growing human population, increasing livestock productivity gains importance particularly under harsh environmental conditions in arid and semi-arid areas. Whatever the objectives regarding livestock, the immediate expectation from the rangeland itself is the supply of edible, palatable fodder of sufficiently high nutrient quality (Walker, 1993).

Grazing animals may exert beneficial or mutual influences on the vegetation for their own good but on the other hand, large concentration of them often have harmful effects on the plants because of selectivity and overgrazing. Quantifying the impact of livestock grazing on natural communities (forages) has become a major issue in the management of rangelands especially where grazing is very widespread and its impacts may be in conflict with conserving biodiversity (Landsbery *et al.*, 2002; Fleischner, 1994).

Grazing according to Lamprey (1979) is among the important agents, which influence distribution of some vegetation types. In most rangelands ecosystems, grazing, browsing and other factors such as fire and climate contribute to vegetation change. Grazing animals influence species composition, changes in biomass and distribution of biodiversity (Oba *et al.*, 2001; Zerihun & Saleem, 2000). Grazing increased, reduced or lacked consistent effect on plant diversity (Zervas, 1998; Welch & Scott, 1995). However, the influence depends on the extent of grazing. A number of studies on impact of grazing on vegetation show that grazing increase species diversity (Oba *et al.*, 2001; Lamprey, 1979). However, discussions on the effect of grazing livestock on plant species diversity have not led to consensus (Osem *et al.*, 2002; Oba *et al.*, 2000d; Zervas, 1998).

Studies by Shackleton (2000) showed that protected areas considered for preservation of biodiversity as their primary goal were characterized by significantly fewer plant species than the adjacent highly utilized communal lands. In Kenyan rangelands most of the research concentrates on the seasonal enclosure. This is partly due to lack of permanent protected sites from grazing and

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<sup>1</sup> This paper is derived from a M.Sc. thesis by the author from the University of Addis Ababa Department of Botany.

again due to increasing human pressure on the rangelands initially protected for conservation (e.g. Osem *et al.*, 2002; Oba *et al.*, 2001; Oba, 1995; Ekaya, 1991). This has shown to portray different patterns of forage diversity from that of permanent enclosure.

It's important in the maintenance of arid rangelands resources to know how the grazing animals make use of the forage produced and their preferences for different plant communities (Low *et al.*, 1981). In areas of less intense grazing, grazers are able to exercise preference between different species available. Studies have shown that mixed stocking with two or more species of different feeding habits make more effective and often more profitable use of vegetation (Mwilawa *et al.*, 1996).

### **1.1 Rangeland resources**

Rangeland resources are influenced by a variety of site characteristics. About 80% of Kenya's land is classified as rangelands, which is characterized by scanty and unreliable rainfall (Herlocker, 1999; MEC, 1999). Rangeland resources are enormous but the ecosystems are fragile requiring appropriate management strategies to ensure sustainable productivity. Animal production through pastoralism and wildlife management is the main form of rangeland use with few agropastoralism.

Rangelands carry over 25% of Kenya's human population, support more than a half of the total livestock population and a large number of various species of wildlife (MEC, 1999; Brown, 1994). These wildlife species and the human population have co-existed without adverse effects on the range resources for a long time. However, recent management practices have led to environmental degradation of the arid and semi-arid land areas mainly through increased wildlife and livestock numbers beyond the carrying capacity (MEC, 1999; Bekure *et al.*, 1991). This overstocking and overgrazing not only encourage soil erosion, but also a selective increase in unpalatable and poisonous plant species (Herlocker, 1999).

Rangelands play an important role in the national economy of the country, with a large number of the population depending on these native forage producing lands for their livelihood (Nemati, 1986). Rangeland vegetation has multiple uses. These include forage for livestock (especially herbage for grazers) which is usually seen as the principle product of rangelands. Rangelands also provide a variety of other important products, services and values. These include, habitat, biodiversity, products such as charcoal, gums and resin, honey and traditional plant uses (medicine, etc), water production and aesthetic values (Friedel *et al.*, 2000; Herlocker, 1999; Heady and Child, 1994). Expansion of dryland farming has increased the grazing pressure on the remaining areas and has reduced the area of good rangeland. The absence of satisfactory range management practices or legal control of stock movement has destroyed or reduced productivity of these rangelands (Oba *et al.*, 2000d).

### **1.2 Herbivory and plant diversity**

Disturbances influence plant species richness and diversity (Cumming, 1982). The effect of grazing by large herbivores on the diversity of plant communities has been investigated in different terrestrial ecosystems (Oba *et al.*, 2001; Milchunas and Lauenroth, 1993). Grazing increased, reduced or lacked consistent effect on plant diversity (Zervas, 1998; Welch and Scott, 1995). These contrasting patterns of response have frequently been attributed to differences in grazing intensity, with greatest diversity expected at intermediate level of grazing (Grime, 1973). Usually diversity is low in environments with very low availability of resources (i.e. where few species can survive) and increases with increasing resource availability (Osem *et al.*, 2002).

The impact of grazing on diversity differs along gradients of primary productivity (Milchunas *et al.*, 1998) but there is no general consensus about the process involved in this interaction (Osem *et al.*, 2002). Grazing intensity affects the quantity and quality of organic and mineralised materials that are delivered to the litter and soil as vegetative residues, urine, and manure (Mannetje, 2000). Grazing also affects the quality of herbage in the sward and this ultimately impacts degradation rate of litter, soil organic matter, and soil nutrient mineralisation rates. Huston (1979) predicted that grazing could change diversity in opposite ways in resource-poor versus resource-rich ecosystems.

Changes in plant species composition are central to range management for sustainable production and off-reserve conservation. Plant species can be characterized as “increasers” or “decreasers” corresponding to their shifts in relative abundance in response to grazing (Dyksterhuis, 1949). According to Crawley (1997) grazing-sensitive or highly preferred species decline in abundance (decreaser) while grazing-tolerant or unpalatable species became more abundant (increaser). On the other hand, there are noxious weed, which are not palatable/preferred by animals (invaders) that encroach the whole system. Generally the decreasers are the high quality pasture plants and the increasers are the less valuable (lower digestibility and nutrient content).

Grazing intensity is also important and according to Harper (1977), at low intensities; diversity might be low because of competitive exclusion by the dominant plant. Plant diversity peaks at intermediate grazing intensities when the dominant is suppressed but other species are not substantially affected. Diversity may be low at the highest grazing intensities if there is only a small pool of grazing tolerant (or avoided) species (Crawley, 1997). Diversity may be reduced either by competitive displacement (and eventually exclusion) or by a high frequency of population reduction, which does not allow some competitors to recover between disturbances (Milchunas *et al.*, 1988; Huston, 1979).

Differences in plant diversity inside and outside of enclosures were observed for several community types in the Serengeti (Belsky, 1986b). Diversity declined in all enclosure while equitability dropped sharply, although species richness was not significantly different. McNaughton (1986) attributed this to replacement by tall species in ungrazed areas formerly dominated by short species when the area was being grazed. Pattern diversity, rather than point diversity was found to be the major contributor of stand diversity (Milchunas *et al.*, 1988).

The negative effect of herbivory on plant growth and fitness approaches a paradigm in ecology (Belsky, 1986b; Harper, 1977). Removal of leaves, stems, sap, inflorescence, or roots reduces photosynthetic surfaces and by extension, nutrient and carbohydrates supplies, seed production, or surfaces for absorption of water and nutrients. Because plants are integrated organisms, reduction in area or biomass of one organ often leads to reduction in others. Since plant size influences the ability of the individual to capture solar energy, nutrients and water, reduction in size usually reduces the plant’s competitive success. Hence herbivory is usually assumed to be harmful to the grazed individual (Belsky, 1986a).

It is difficult to generalize about the impact of herbivory on plant diversity because so few detailed long-term studies have been carried out with inconsistent results (Crawley, 1997). Several studies have shown increased plant species richness under herbivory (Oba *et al.*, 2001), a few have shown reduced species richness, and several have shown no effect of herbivory on species richness at all (Crawley, 1997).

Studies by Shackleton (2000) protected areas considered for preservation of biodiversity as their primary goal were characterized by significantly fewer plant species than the adjacent highly utilized communal lands at both the plot and point scale. Literature search showed that this kind of research has not been conducted in the Kenyan rangelands partly due to absence of permanent sites protected from grazing and also due to increasing human pressure on the rangelands initially protected for conservation. Most of the research concentrated on the seasonal exclosures of rangelands (e.g. Osem *et al.*, 2002; Oba *et al.*, 2001; Oba, 1995; Ekaya, 1991), which may portray different patterns of forage diversity from that of permanent enclosure. Investigation for species diversity in permanent enclosures is necessary in order to know whether the biodiversity is being conserved or if it is been lost with the age of enclosures. The study was carried out using a range management system where permanent grazing exclosures and open areas display visually different spatial patterns of plant-species richness and biomass production.

### **1.3 Grazing management systems**

Humans have interfered with natural processes of ecosystems. In developing countries increase in human population leads to corresponding increase in livestock numbers. This may naturally lead to



depletion of natural resources, particularly in Arid and Semi-Arid Lands (ASALs) including natural vegetation. In response, pastoralism evolved as one of the earliest professions in which people traditionally moved their livestock from place to place in search of forage and water. This migratory life style helped vegetation to periodically recover from heavy utilization by domesticated animals (Bonham, 1989). Livestock mobility also relieves areas of concentration and allows herds to exploit grazing resources that are unevenly distributed in time and space (Oba, 2000d).

The exclusion of domestic livestock from grazed rangeland often initiates secondary succession. If left undisturbed this succession may culminate in a plant community with a relatively stable composition (Brand and Goetz, 1986). Range managers have often used exclosures, cemeteries, churchyards and other areas inaccessible to livestock to determine the potential for improvement on grazed rangeland. According to Zerihun (1985) floristic richness and the efficiency of the vegetation as an energy trapping system tends to decrease as aboveground biomass becomes concentrated in a few species. The opposite apparently occurs in the grazed sites. Hence, a greater aboveground herbaceous production and a greater grass height characterize ungrazed vegetation.

Some plant species in arid environments actually require regular grazing. According to Oba (1995) *Indigofera spinosa* is highly persistent in Turkana arid ecosystem because of its adaptation to herbivory. In the absence of grazing, the shrub accumulates dead necromass, while under continuous grazing it maintains production of green phytomass (Oba, 1995) offering available forage during the dry seasons. Hence, if the over all goal of the pastoralists in the world is to optimise the current year's crop, extended deferral beyond 1-2 growth seasons offers no superior advantage over continuous grazing.

Long-term strategies of grazing management are closely linked to the longer-term variations in forage supply. Therefore livestock management is essentially grazing management, water development and marketing (Bekure *et al.*, 1991). Enclosures are primarily intended for preservation of forage, but they may also be important in conservation. Hatton and Smart (1984) described the effects of a 24 year exclusion of wild herbivores from a Ugandan savannah. Under natural conditions, elephants prevented the persistence of woody populations through their feeding and clearing activities. Once elephants were excluded, an increase in *Acacia* occurred and these extracted nutrients from the soil profile and deposited litter on the soil surface. Compared to unprotected sites, top soil of protected sites showed up to a five-fold increase in exchangeable cations, a 50% increase in nitrogen and up to a 30% increase in organic matter (Coppock, 1993; Hatton and Smart, 1984).

A different perspective of the climate-plant-herbivory interaction model predicts that the removal of grazers (e.g. both domestic and wild ungulates) will neither improve range production nor range condition in the longer term i.e. greater than 5 years (Oba, 1995). Rather, an extended lack of grazing may result in the accumulation of "old" vegetation, a decline in live plant cover, the loss of species diversity, and reduced plant production (Oba *et al.*, 2000d). Rangeland plants that are grazed continuously may have lower residual biomass and ground cover, but they may have greater production and better survival than ungrazed plants (Oba *et al.*, 2000d). Consequently, grazing rather than being destructive is necessary for proper management of arid zone pastures.

#### **1.4 Objectives**

1. To study the effect of grazing on forage production and diversity in enclosed and open sites
2. To investigate forage preferences of domestic livestock (cattle and goats) both in dry and wet seasons
3. To study the effect of grazing on soil properties

#### **1.5 Research hypotheses**

Grazing intensity has an impact on rangeland vegetation but increases floristic diversity depending on the grazing pressure exerted. On the other hand, lack of grazing led to accumulation of high biomass, bush encroachment leading to a loss in biodiversity. Forage diversity and availability

influenced by the growing season (wet and dry) determine the forage preferences and acceptance by the livestock.

## **2. MATERIALS AND METHODS**

### **2.1 Study Area**

#### **2.1.1 Location and description**

Mbeere district is one of the 12 districts of eastern province in Kenya. Borders with Embu district to the NW, Tharaka/Nithi to the north, Mwingi district to the east, Machakos district to the south and SE and Kirinyaga district to the west (MEC, 1999). The district lies in latitude 0°20' and 0°50' south and longitude 37°16' and 37° 56' east and has a total area of 2097km<sup>2</sup> (GOK, 1986).

The study was carried out at University of Nairobi's Machang'a field station farm in Mbeere district covering an estimated area of 500 ha. The station is located in Mavuria location, Gachoka division of Mbeere district in eastern province of Kenya; about 160 km northeast of Nairobi (Fig 1). The farm is divided into two sections; in one section there is no grazing at all (i.e. permanent enclosed site) for conservation of rangeland biodiversity. The site has been protected from grazing for a period of 12 years and covers approximately 200 ha (farm manager, pers. comm.). The other section is the open site that is under permanent grazing where livestock graze year round without any restriction and measures approximately 300 hectares. This study site falls in ecological zone IV Pratt and Gwyne (1977) in eastern province of Kenya at an elevation of 1200 m above sea level. A barbed wire fence runs along the boundary except for the southwestern and southern side that borders banks of river Thiba and Kamburu dam respectively.

#### **2.1.2 Climate**

The area is semi-arid receiving an annual rainfall of 610-892mm (Mete dept, Embu; GOK, 2001). The general pattern of rainfall in this area is bimodal (GOK, 2001; GOK, 1986; Fig. 2.). The long rains come between end of March and May and again from October to December (Fig 2). April and November experience the heaviest rainfalls. The dry spell is normally in January and February, and June through September (GOK, 2001; GOK, 1986). The rainfall is however not very reliable and most parts receive less than 550mm of the rainfall per year, giving the area a marginal status. There are slight climatic variations in some parts of the district, especially the southeastern region due to proximity to the Kiambeere, Masinga, Kamburu, Gitaru and Kindaruma hydropower electric dams in this area (GOK, 2001).

The mean monthly temperature ranges from 20°C to 28°C, and the mean annual temperature is about 24°C (GOK, 2001). August is usually the coldest month with average monthly minimum temperature of 15°C. March is the warmest month with average monthly maximum temperature rising to 32°C (GOK, 2001).

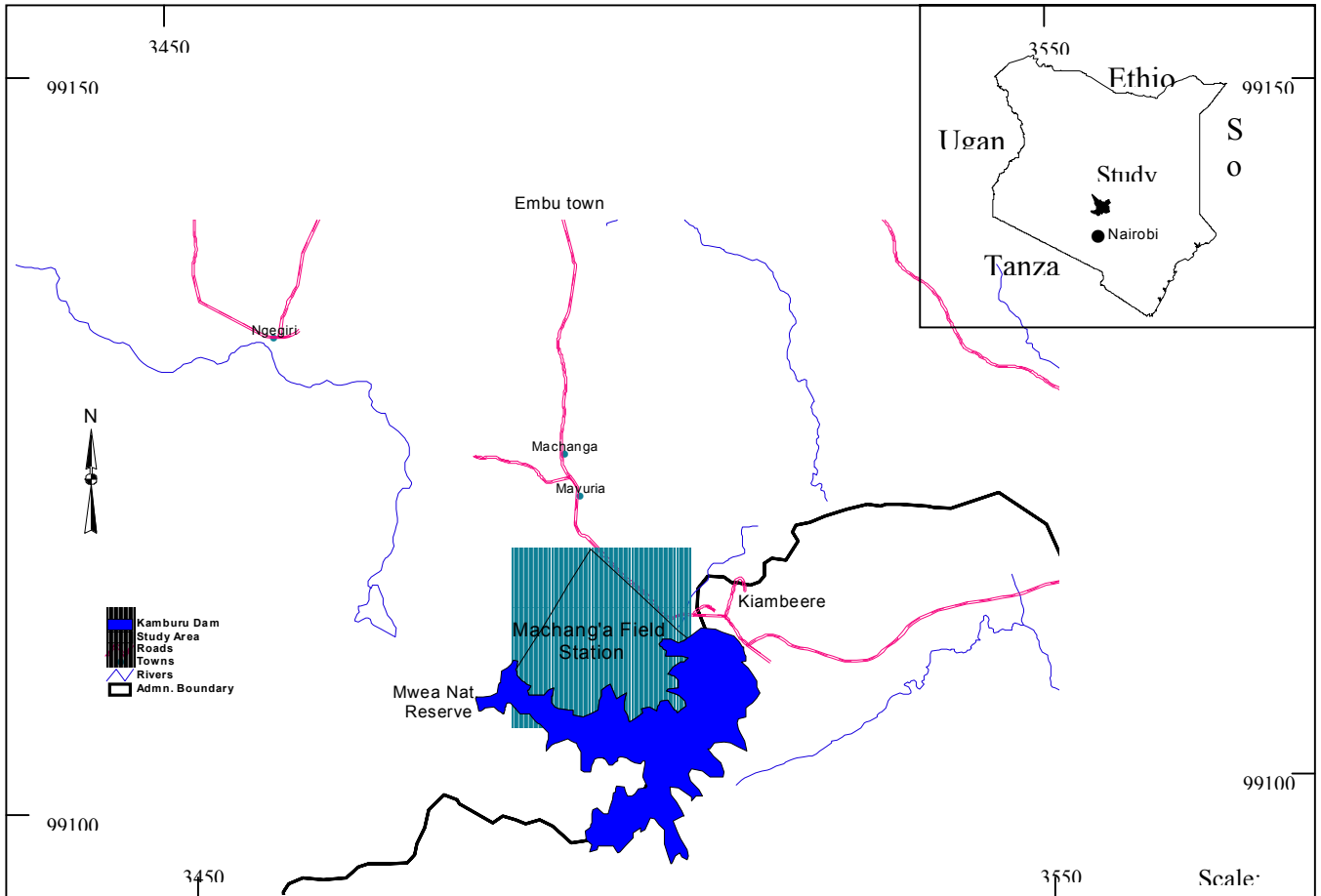
#### **2.1.3 Topography**

The district slopes in a SE direction rising gradually from about 515 m above sea level at the river Tana basin in the east to over 1200 m above sea level (GOK, 1986). The slope is however broken by existence of a few hills such as Kiambere, Kiang'ombe and Kianjiru, which rise above this general height. The Mwea plains cover the southern part of the district and then gradually rise northwards culminating in hills and valleys to the northern and eastern parts of the district. Five permanent rivers serve the district that includes Tana, Ena, Rupingazi, Thuci and Thiba all of which flow on a general southeasterly direction (GOK, 2001; Riley and Brokensha, 1988).

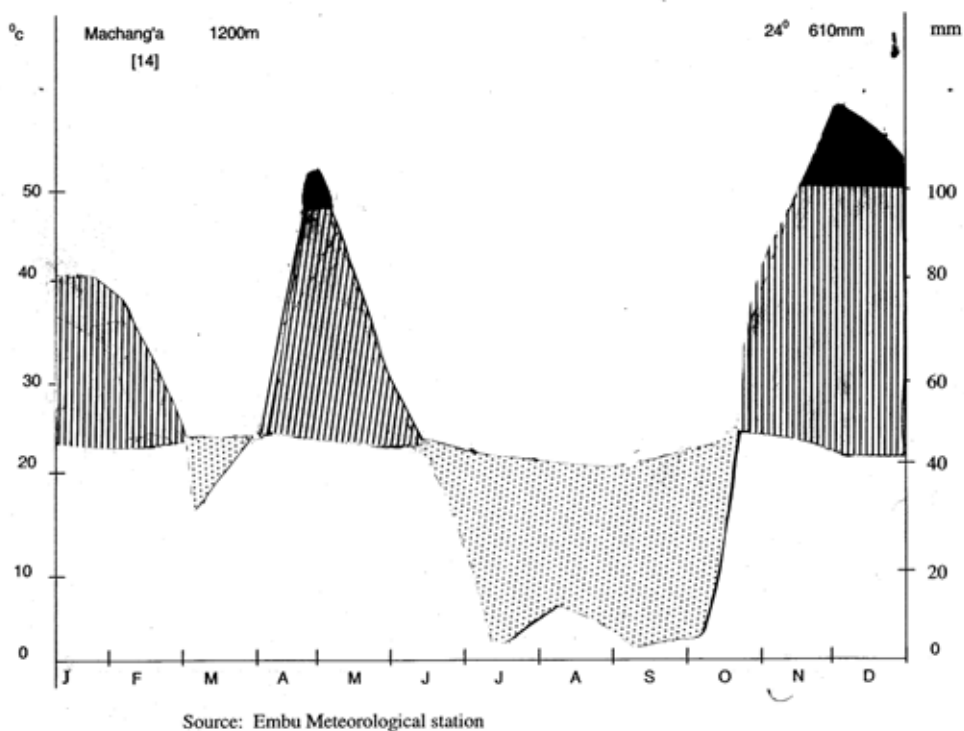
#### **2.1.4 Soils**

The altitude and climate, coupled with the differences of the underlying geology, have given rise to varying soil types, which in turn influence land use patterns (GOK, 2001; Riley and Brokensha, 1988). The soils are generally sandy, loamy, blackish grey or reddish brown whose fertility ranges from low to moderate and fertilizers are needed for optimum crop production. The northern side of the district is covered by clay soils of different types.

**Figure 1.** Map of the study area showing Machang'a field station.



**Figure 2.** Climate diagram of Machang'a field station. Source: Embu meteorological station (1989-2002)



### 2.1.5 Land use

Livestock production is the most significant economic activity undertaken by the Mbeere community (GOK, 2001; Riley & Brokensha, 1988). This is because of the dry rolling plains, most of which have thorn shrub, fertile soils are rare and water has been a perpetual problem in most parts (GOK, 1986). The main livestock reared include cattle, sheep, goats and poultry. The district is suitable mainly for beef cattle as the exotic dairy cattle can hardly survive in the marginal areas. However, food crops such as maize, beans, sorghum and millet are grown mainly for subsistence (Riley & Brokensha, 1988). The main cash crops grown include cotton, tobacco and to a lesser extent sunflower.

### 2.1.6 Vegetation

The natural vegetation cover ranges from moist, broad leaf, wooded savannah, *Combretum-Acacia* (with *Cordia*, *Faurea*, *Bauhinia* and *Terminalia*) to a dry thornbush scrub of *Acacia-Commiphora* (with *Boscia*, *Delonix* and *Maerua* and xerophytic *Terminalia* species) covering most of the area (Brokensha & Riley, 1986). The lower dry zones to the plains contain much shrub vegetation of short thorny trees growing in predominantly grassy areas (Riley & Brokensha, 1988; GOK, 1986). Some areas of the lower zones either have tough and dry grass, at times with isolated shrubby trees or tufts of grass with nothing growing except sandy plains or huge expanse of rocky ground. River valleys and hill slopes are covered with thick bushes at places where natural vegetation is relatively undisturbed by human activity.

Stratified random sampling design was used. Forty and fifty quadrats were sampled in enclosed and open sites respectively. Each quadrat was measuring 10m x 10m with an interval of 50m. Four sub-quadrats each measuring 0.5m x 0.5m were established at each corner for herbaceous biomass measurements (Whalley and Hardy, 2000; Mannetje, 2000; Brand and Goetz, 1986). The total standing above ground biomass ( $\text{g/m}^2$ ) was estimated by clipping for the herbaceous layer and use of reference unit technique for shrubs and trees in the entire quadrat (Bonham, 1989). Percent canopy cover was estimated visually in every quadrat for the three plant growth forms (herbs, shrubs and trees).

## 2.3 Vegetation data

### 2.3.1 Herbaceous biomass production

Changes in biomass are usually determined by harvesting plant material at time intervals suited to the growth pattern of the species under investigation, usually about one month (Roberts *et al.*, 1993). In this study plant material were first harvested during the dry season (October 2002) and this was repeated in the wet season (January 2003). Herbaceous vegetation in each sub-quadrat of (0.5m x 0.5m) was clipped at ground level using a secateur according to Mannetje (2000); Bonham (1989) and Zerihun (1985). It was then mixed together, sorted according to species or species group e.g. *poaceae*, packed in labelled brown bags, weighed and recorded. The fresh herbage was air dried and then oven-dried at 80°C for 48hrs and finally re-weighed (Whalley and Hardy 2000; Roberts *et al.*, 1993; Brand and Goetz, 1986).

### 2.3.2 Trees and shrubs biomass

Biomass yield of trees and shrubs was estimated using the reference unit technique Bonham (1989); Kirmse and Norton (1985) in the entire quadrat measuring 10m x 10m. A small unit of plant such as a shoot of a given dimension was designated as a reference unit (Bonham, 1989). The size of the reference unit was estimated to be 10-20% of the foliage weight of the average plant according to Kirmse and Norton (1985). Few reference units (5-7) were clipped and average green weight determined (Bonham, 1989). The number of counted/estimated reference units was multiplied by the average weight of clipped reference units to estimate biomass production according to Bonham (1989); Kirmse and Norton (1985). The whole reference unit was oven dried at 80°C for 48hrs and weighed. The total dry biomass of each species was estimated by multiplying the number of the units counted/estimated for a particular plant by the weight of the dry foliage in the reference unit (Kirmse and Norton, 1985). Finally the ratio of dry to fresh weight was calculated to get the actual biomass.

### 2.3.3 Canopy cover

The canopy cover was estimated visually for the three plant growth forms i.e. herbaceous, shrubs and tree layers in each quadrat before clipping was done and expressed as percentages. Finally the mean cover scores for each plant growth were determined both for enclosed and open sites.

### 2.4 Forage Preferences by Cattle and Goats

Direct observation of animals using feeding minutes (Bjugstad *et al.*, 1970) was adopted to assess forage preferences by timing the animals as they feed. Five goats and five cattle were randomly selected from a herd and marked for identification. In each alternative day, one of the selected goat/cattle was observed for four hours (0800-1100hrs) as the herd grazed.

### 2.5 Soil analyses methods

Soil sample were collected randomly at the plots where the vegetation had been clipped for biomass estimation. Twenty soil samples were collected from enclosed site and thirty samples from the open site. The soil samples were labelled and sealed in polythene bags and taken to Jomo Kenyatta University, horticulture laboratory for physical and chemical analysis. Each soil samples were analysed according to Gupta, 1999, Allen, 1989, Blake and Hartge, 1986, Page, 1982 and Juo, 1978.

### 2.6 Data analyses

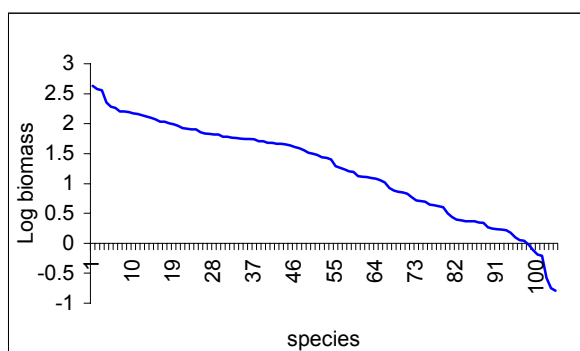
Data was classified using the package SYNTAX (Podani, 2000) with agglomerative hierarchical technique correction as a resemblance index. Shannon- wiener diversity index was used for computation of plant species diversity. T-test was used to test for significant differences in total species richness, herbaceous richness, cover abundance, standing biomass for combined species and for herbaceous biomass across the four treatments.

## 3. RESULTS

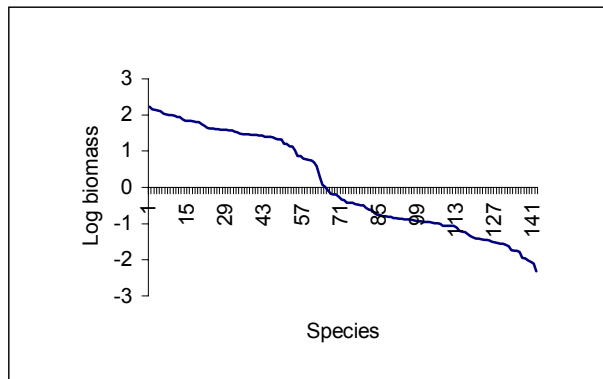
### 3.1 Biomass

When the species were plotted against the log normal the results revealed that biomass was accumulated in some species, which were the most dominant ones. There was partitioning of resources among the species and more species were encountered during the wet season in both sites. The biomass accumulated in the enclosed sites was significantly higher ( $P < 0.05$ ) than that of open plots (Figures 3-6). The biomass has been plotted on a log normal scale for different treatments. The X-axis represents species in a descending order of biomass and Y-axis represent log biomass.

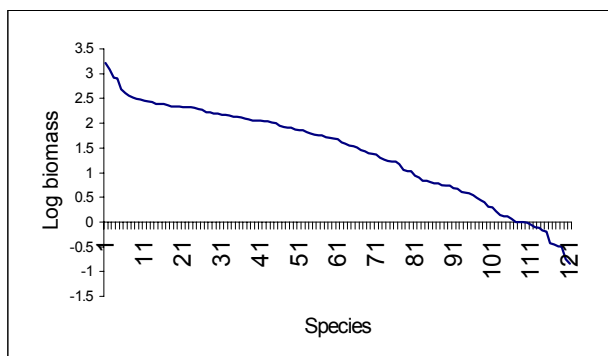
**Figure 3.** Log normal plot of species biomass for dry season in enclosed site



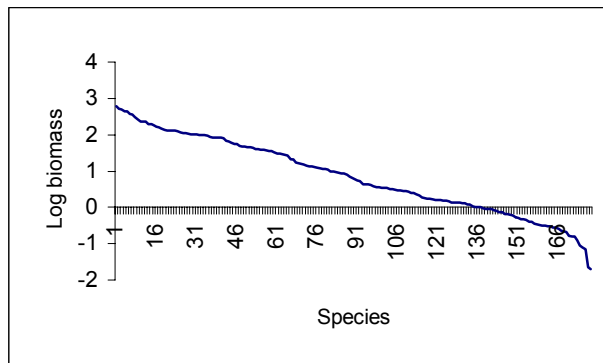
**Figure 4.** Log normal plot of species biomass for wet season in enclosed site



**Figure 5.** Log normal plot of species biomass for dry season in open site



**Figure 6** Log normal plot of species biomass for wet season in open site



### 3.2 Species diversity

A total of 245 species were recorded from the study site. Total species richness in enclosed and open sites had a significant difference ( $p < 0.05$ ) (Table 1a). Higher species richness was encountered in the open site than in the enclosed site. Species richness in enclosures varied from 122-129 species while in open site it varied from 167-201 during the dry and wet seasons respectively. There were 93 and 18 plant species that were site specific in open and enclosed sites respectively.

**Table 1a.** Comparisons (t-test) between total and herbaceous species richness, biomass ( $\text{gm}^{-2}$ ) between the enclosure and open site.

	<b>Open</b>	<b>Enclosure</b>	<b>p</b>
<b>Total species richness</b>	184	125.5	<b>0.03*</b>
<b>Herbaceous species richness</b>	91.5	49.5	<b>0.03*</b>
<b>Total biomass</b>	91.63	887.8	<b>0.04*</b>
<b>Herbaceous biomass</b>	429.09	387.24	0.48

\* Means significant difference at ( $p < 0.05$ )

### 3.3 Herbaceous species richness and biomass

There was a significant difference in herbaceous richness between open and enclosed sites ( $P < 0.05$ ) Table 1a. There was no difference between herbaceous biomass in the enclosed and open site.

The data of species richness (N), diversity ( $H'$ ) and evenness (E) of dry and wet seasons, open and enclosed sites are tabulated in (Table 1b). The wet seasons showed higher species diversity and evenness than the dry season.

**Table 1b.** Comparisons of plant species richness, diversity and evenness between four treatments

<b>Treatments</b>	<b>Species richness (N)</b>	<b>Species diversity (<math>H'</math>)</b>	<b>HMax</b>	<b>Evenness</b>
<b>Dry-open</b>	143	2.939	4.963	.592
<b>Dry-enclosed</b>	119	2.620	4.779	.548
<b>Wet-open</b>	179	3.930	5.187	.758
<b>Wet-enclosed</b>	114	3.819	4.736	.806

### 3.4 Canopy cover

The results show that, there is significant difference ( $p < 0.05$ ) in percentage cover for herbs and shrubs (Table 2).

**Table 2.** Comparisons of % cover of growth form in enclosed and open sites.

<b>Growth form</b>	<b>Enclosed</b>	<b>Open</b>	<b>p</b>
<b>Herbs</b>	17.4	72.5	0.04*
<b>Shrubs</b>	62.5	40	0.04*
<b>Trees</b>	62.5	25	0.12

\*Means significant difference at ( $p < 0.05$ )

### 3.5 Forage preference and acceptance

Cattle and goats shifted between forage classes i.e. grasses and browses as seasons changed. Goats preferred browse during the dry season and grass during the growing season. Cattle preferred grass in both seasons, but browsed occasionally in the dry season.

### 3.6 Effect of grazing on soil properties

The soil analysis results are presented in (Table 3). The open site and the enclosed site were tested for significant differences in chemical and physical properties of the soils. From the results there was significant difference in soil pH, bulk density, nitrogen, moisture content, percent organic matter and organic carbon at ( $P < 0.05$ ) in enclosed and open sites.

**Table 3.** Comparisons (t-test) of physical and chemical variables of soil between open and enclosed sites

Variables	Open	Enclosed	P
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  $P < 0.05$

## 4. DISCUSSION

### 4.1 Biomass

In the log normal transformation there is sequential breakage where the resources are sequentially split within the species. The results revealed that the most dominant species contribute the highest amount of biomass. This kind of arrangement can also be considered in terms of resource partitioning where the dominance/abundance of a species is the same way equivalent to the portion of niche it has occupied (Magurran, 1988). Herbs seem to acquire less in biomass mostly due to competition from the higher plants. Despite their low acquisition of biomass, herbaceous layers play a major and important role in forage diversity.

### 4.2 Plant species diversity

Species richness increased monotonically with the increase in biomass in the grazing site. Oba *et al.* (2001) reported similar findings. The expected increase in biomass as a result of enclosure was verified. An increase in biomass in the enclosed site did not automatically result in an increase in species richness. This could be attributed to reduced disturbances from human and livestock interference in the enclosure, which allow species to develop large-scale local populations (Huston, 1979). Open site during the wet season had the highest diversity. This means that moisture had an influence in species diversity as well as grazing. The enclosed site during wet season had the highest species evenness meaning that those species in the site were highly evenly distributed.

### 4.3 Herbaceous species richness

The results showed that grazing promotes herbaceous species richness though it depends on the grazing pressure exerted on the vegetation. High number of species diversity in the open site means that livestock play an integral role in the maintenance and dispersal of herbaceous species. Again herbaceous species are easily dispersed through seeds due to their generally smaller size. On the other hand since most of the herbaceous species are annuals they survive the unfavourable conditions as seeds which sprout quickly after the onsets of rains and hence their high occurrences during the wet season (Zerihun & Saleem, 2000). It was observed that herbaceous species are more influenced by the amount of rainfall and disturbance in a particular area. Herbaceous species richness declined in the enclosed area probably because of the period of enclosure and this has been demonstrated in the Serengeti grasslands (McNaughton, 1979).



#### **4.4 Canopy cover**

High cover of herbaceous layer in open site could be related to the sprouting of the annuals immediately after the rains. The results also indicate that the secondary succession is still taking place in this rangeland protected since 1990 when grazing exclusion was started. The results also show successful replacements of forbs and grasses as grasslands are slowly transformed into bushlands. Absence of grazing for a long time is also followed by an increase in bush cover (Oba *et al.*, 2000b). A high shrub cover compared to herbaceous cover in the enclosed site also suggests a progressive shift towards trees and shrubs in the absence of grazing (Roques *et al.*, 2001).

#### **4.5 Forage Preference and acceptability**

Goats shifted their preference between browse in the dry season to grass during the wet season. These findings support those of (Kefa, 2000; Ekaya, 1991; Pfister & Malechek, 1986). Goats were observed to be capable of switching from one source of browse to another when the main sources declined. Goats were observed to assume a bipedal stance while feeding thus increasing their feeding height and again this increases the volume of browse potentially available to them. This was seen as a resources utilization strategy by goats.

Goats make maximum use of the grass when it is still growing and high in nutrient content before suddenly declining in quality with advancement in maturity. These preserve the browse, which declines less in quality for the critical dry season. Cattle were consistent in their preference for grass. These two types of livestock were observed to have a complementary feeding habit and hence there was no competition between them.

#### **4.6 Impact of grazing on soil properties**

Available phosphorous remains more or less constant in both the grazed and ungrazed plots (Appendix 1), with an indication of possible decline in enclosed plots. Rock weathering may be the only significant source of additional phosphorous for range soils (Heady and Child, 1994). This uniformly low content is attributed to the fact that this element is stored in unavailable forms to plants Juo (1978)  $H_2PO_4$  which becomes available to plants at low pH. It also suffers from fixation by hydrous oxides and silicate minerals. This element is doubly critical, because of low total amount and a very low availability.

Quantities of exchangeable cations were relatively low in both enclosed and grazed plots. The availability of the cations depends on the parent materials. This can be attributed to the fact that the soil in all the plots was more or less acidic with low pH values (Oba *et al.*, 2000a). Except for calcium that showed a slight increase in the enclosed plots all the other nutrients remain low. These inorganic nutrients are only made available through the active release of cations from the additional litter accumulating under trees (Skarpe, 1991; Hatton and Smart, 1984).

There was an appreciable increase in organic matter content in the enclosed plots as compared to grazed plots (Appendix 1). Organic matter and organic carbon are correlated within any single type and as the results indicate there was an increase in the amount of organic carbon in the enclosed sites. Similar finding are reported by Hatton and Smart (1984). This was expected in the enclosed site that was dominated by trees and shrubs that deposits litter on the soil. Through decomposition, the organic matter is returned to the soil and hence the percent carbon also increases.

Both temperature and moisture regime affects the equilibrium of organic matter contents of soils. Increased temperature decreases organic matter content while increased moisture increases organic matter (Sikora and Stott, 1996). Again in sites where there was no disturbance it is expected that the microbial activity and other decomposer populations would be more intense, and the role of these organisms as agents of litter breakdown and humus formation is well known (Skarpe, 1990).

There was a significant difference in the percent moisture content with a range of 1.4-6.6% and 0.2-3.8 % in enclosed and open site respectively. This can be attributed to the fact that the soils in the enclosed sites are not directly exposed to the sun due to the canopy cover, which prevents evaporation rates. Litter deposition/accumulation from the trees and shrubs additionally keep soil

covered most of the time and hence reduces heating of the soil which would cause the reserved water to evaporate. In addition, the shade from the trees and shrubs play a major role in moisture retention (Skarpe, 1991). Again, the high amount of organic matter in the enclosed site maintains the moisture at a higher level. In most cases grazing induces shortage of moisture, reduces infiltration rate and other nutrients and to some extent causes soil erosion.

Total nitrogen was higher in the enclosed site (Appendix 1) than in the open site. The increase in the total nitrogen is as a result of the increase in organic matter content of the soils in the protected sites. The low level of nitrogen content in the grazed sites can be attributed to low nitrate content which are easily lost through soil erosion (Belsky *et al.*, 1989). The total nitrogen is often a good indicator of the degraded rangelands and in this it indicates a higher level of land degradation in the grazed sites as opposed to the enclosed sites.

Bulk density was higher in the grazed plots than in the enclosed plots. The soils with high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space. In the enclosed sites due to high proportion of organic matter the pore space is higher hence the low bulk density. The bulk density range in the enclosed site was 1.2-2.3 g/cm<sup>3</sup> while in the open site it was 1.3-3.0 g/cm<sup>3</sup>. In the communal grazing sites grazing increases bulkiness of the soil through the soil compaction and hence the higher bulk density. Due to exposure of the soils in open sites the evaporation rate is high reducing moisture content and soil density changes with moisture content (Sikora and Stott, 1996).

The composition of the particle size assay was relatively uniform except slight variations in the clay contents. The high amount of clay content in the enclosed site can be attributed to the hydropower dam which spills off water during the rainy season to the adjacent enclosed site. This water is always carrying different types of soil which is eventually deposited in the study site. Again river Thiba that borders the study site is another potential source of clay soil. In general all the soils in both sites were either loamy sand or sandy loam.

There was no significant variation in the soil colour. In all the soil samples the hue (the dominant spectral colour or quality was consistently 5YR. The value (apparent lightness as compared to absolute white) varies significantly from 3-8. The chroma (the apparent degree of divergence from neutral grey or white) varies from 3-7. The general colour of the soil ranged from red to brown.

The comparison of the soil data from the grazed and ungrazed plots indicates nutrient enrichment of the soils in enclosed site, in part this could be due, to nutrient inputs by tree litter. On the other hand, trees transport nutrients from the surrounding surface and subsurface soils to their canopy and drop the nutrients in leaf and stem litter (Belsky *et al.*, 1989). 12 years of grazing exclusion can conclusively be said to be useful in relation to the soil properties whereby most of the nutrients are relatively higher in the enclosed site than in the open site. Poor nutrients content, is a symptom of land degradation in the open site. This was more pronounced in the plots which were falling in the more degraded area.

Low soil nutrients values indicate that natural process such as weathering are unable to replenish soil nutrients at a sufficient rate to replace those lost by the direct or indirect effects of grazing. Nitrogen and cation concentrations decline at a more rapid rate than can be explained by grazing effects (McIntosh, 1997). Processes like nutrient loss, continued grazing without nutrient inputs are unsustainable. To maintain or improve soil nutrient balance, new approaches to soil and vegetation management will be required.

From the ongoing discussion, the study results are consistent with the general pattern that pastoral development enhances richness of plant species at a local scale providing opportunities for increasers species to establish. Conversely, it has the potential to decrease it at a regional scale by removing the most grazing sensitive decreasers species from the regional species pool (Landsberg *et al.*, 2002). Those species, which were substantially less abundant in open sites than in the enclosed sites, were presumably the most sensitive to grazing overall.

Some plant species, such as *Andropogon greenwayi* and *Sporobolus ioclades* (*poaceae*) and *Indigofera cliffordiana* Herlocker (1999) and *I. spinosa* (dwarf shrub) have adapted to grazing and browsing to the extent that they depend on it for their existence (Oba, 1995). However, overgrazing reduces ground cover vegetation, plant height, forage quality and productivity. The impact of grazing on rangeland vegetation depends on three factors: first, the type of herbivores (grazers and browsers), secondly the number and type of animals utilizing an area, and lastly the distribution of use in time and space (Pratt and Gwynne, 1977). Cattle and sheep, which are primarily grazers and goats and camels, which are primarily browsers directly affect the herbaceous and woody components of the vegetation respectively.

Walker (1993) suggested that in arid rangelands lack of grazing is ineffective in inducing revegetation until the right combination of weather conditions occurs. Grazing has a greater influence on species composition, perhaps suggesting a better adaptation of vegetation of the study site to grazing as a result of the long association of plants and livestock and to some extent small mammals like rabbits and dik dik.

Long term grazing exclusion studies attempt to test the hypothesis that grazing causes degradation. Several studies comparing the effects of excluding grazing with those of continuous grazing have been conducted world wide, including in arid zones of sub-Saharan Africa, for more than a century (Oba *et al.*, 2000c). According to the current study grazing exclusion did not improve or increase range production any more than continuous grazing. This is because forage production is influenced more by rainfall than by herbivory. These studies support the findings of Oba *et al.* (2000d).

Areas of rangeland where grazing has ceased have been invaded by woody plants. A ban on livestock grazing in the rangeland would almost certainly result in the loss of this species-rich habitat. A similar trend was observed in the study site where grazing exclusion did not increase species richness though there was substantial increase in above ground biomass. The hypothesis that grazing history is the main factor determining plant community composition in the rangeland was supported by the species richness, vegetation cover and high level of organic matter and moisture contents because these factors are likely consequences of herbivory (Crawley, 1997).

The forage yield of the grazed rangelands was significantly less than that of the ungrazed ranges in both seasons. The most interesting fact concerning the dried forage yields of the investigated rangelands was that the yield differences in the grazed areas for both seasons (i.e. dry and wet) were negligible. This lack of difference is another indication of the heavy and uncontrolled grazing taking place in the common grazing lands in both seasons. Heavy grazing would not allow the more palatable grasses to regrow during the growing period (Tukel, 1984). Dried forage yield was appreciably different in the ungrazed areas between the seasons. This difference may be explained on the basis that the enclosed site is dominated by shrubs and trees which provide high biomass during the wet seasons. In the dry season most of them are deciduous and hence shed off their foliage parts giving low biomass.

#### **4.7. Management implications**

This study shows that the influence of livestock on rangelands is expressed through their effect on vegetation. This is expressed through the reduction of above ground biomass and cover. The open site had less above ground biomass as compared to enclosed site. On the other hand livestock on the free grazing systems has a very important role in the maintenance of plant diversity. This is normally through the dispersal of readily germinating seeds in their manure. This is reflected in the species richness between the open and enclosed sites. Open site had high species diversity than the enclosed site and the livestock influences this. Again some plants of the arid lands also survive well through regular herbivory and hence livestock removal will have major consequences on them.

Grazing is apt to have a greater negative impact when the vegetation of an area is grazed continuously than when it is grazed only periodically. In the latter, the vegetation has an opportunity to rest and maintain its vigour. From the results grazing in adequate frequency and intensity play an important role in maintaining diversity of the rangelands. In the absence of grazing, shrubs gradually replace the grasses as evidenced in this study. The competitive effects of shrubs and trees on herbaceous plants are obvious. The canopies of woody plants shade and alter the productivity of understorey herbaceous species. Woody plants may have larger competitive effects than herbaceous species. This may simply be caused by the higher shoot mass of shrubs and hence greater reductions in light availability for under canopy layer.

Control of animal numbers is the most important rangeland management principle. As each animal grazes, it reduces available herbage both in quantity and quality, thereby changing the habitat for itself and altering future animal/habitat relations. Excessive forage utilization by either livestock or game animals reduces growth rates, weight gains and animal values (Heady and Child, 1994).

## **5. CONCLUSION AND RECOMMENDATIONS**

The rangelands of eastern Africa are characterized by a high biodiversity that is economically important both locally and nationally and their conservation is of paramount importance. This study area was found to be rich in plant species with diverse classes of plant life forms. High diversity of plant species as well as other living organisms is considered to be a desirable characteristic in any particular rangeland. They clearly indicate that rangeland ecosystems are vigorous and in good health and can sustain high forage productivity. In this case it means that livestock play a major role in the maintenance of biodiversity of the rangelands.

Although grazing is important for preserving species diversity in rangelands through the maintenance of species-rich grasslands, long-term effects must be considered in the formulation of future management plans. Species from the open site represent a significant component of the plant diversity of the rangeland and hence their survival depends on the amount of grazing pressure exerted in this rangeland. Moderate grazing pressure will not alter the species composition up to a certain degree but the carrying capacity of the site is also an important determinant of the number of the herbivores to be stocked in a certain area.

From the results it is evident that forage is not always available during the dry season and hence the farmers should look for alternative to supplement the little available forage. Planting forage species that thrive well in these rangelands is highly recommended. Again the farmers can introduce the systems of hay and silage whereby the grasses can be cut during the wet season and preserved for the unpredictable dry season. In doing so, the livestock will not always have available feeds.

The diet preferences and acceptance by goats and cattle that are kept in this rangeland are complementary rather than competitive as they favour different feed resources within the same area of rangeland and have adapted differently to seasonal changes in amount and quality of forage. Therefore, the use of mixed herds can considerably increase productivity in rangeland areas, minimize production risks and reduce environmental impact compared to single species production systems.

New strategies of resources utilization should be developed with the aim of making pastoralism more sustainable means of production. These strategies should take care of the stability of the ecosystems, means of sustainable use of the available resources i.e. vegetation, economically oriented and social acceptability. In the long run sustainable commercial use of the range vegetation, owing to its abundance, may be the most logical basis for any initiative that can lead to economic diversification. The multi-purpose use of the dominant vegetation type (woody species) may in fact help in its improved management and conservation. There are indeed a number of plants in the rangelands that are source of commercially exploitable products. For example *Acacia*

*senegal* is exploited sustainably for commercial gum Arabic production for international commerce (Doyo and Farah 1998).

Research should focus on the relationship between livelihood and rangeland biodiversity more especially in relation to harmonized pastoral and forage communities. Priorities for research should include; inventory and monitoring genetic, species, ecosystem and landscape diversity. Also analysing human impact on rangeland ecosystem and economic exploitation of biodiversity

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**Appendix 1. Raw data for environmental variables**

Parameter	pH	Avai P Me/L	N %	Ex K Me/L	Ex Ca Me/L	Ex Mg Me/L	Ex Na Me/L	TOM%	Particle Size assay			Textural class	Bd g/cm <sup>3</sup>	% M	colour code
Field ID									Sand %	Silt %	Clay %				
Open	6.6	9.4	0.27	0.6	3.6	1.1	0	1.9	80	7	13	Sandy loam	2.4	2.2	1
Open	6.9	25.7	0.47	0	0.5	0.02	8.5	1.5	85	2	13	Loamy Sand	1.9	1.8	2
Open	5.9	20.8	0.2	0.1	2	0.5	0.3	1.4	60	30	10	Sandy loam	1.5	1.3	3
Open	6.2	97.9	0.4	0.4	10.6	3.1	0	2.5	80	17	3	Loamy Sand	2.2	2.1	1
Open	6.1	10.4	0.23	0.2	3.3	0.9	0	1.2	65	27	8	Sandy loam	1.7	1.3	4
Open	6.7	48.9	0.23	0.3	10.3	3	0	1.1	36	44	20	Loam	1.9	2.9	1
Open	6.1	24.3	0.37	0.2	7.3	1.4	0	2.8	89	1	10	Loamy Sand	1.4	1.3	4
Open	6.6	16.8	0.6	0.3	4.4	1.8	0.01	2.4	90	0	10	Sand	1.5	1.4	4
Open	6	11.7	0.2	0.2	2.6	0.9	0.7	1.3	90	8	2	Sand	2.8	2.2	1
Open	6.1	17.7	0.3	0.2	6.7	1.8	0	1.9	79	8	13	Sandy loam	2.8	2.1	5
Open	6.3	14.7	0.3	0.2	9.2	2.3	0	1.5	90	2	8	Sand	3	2.1	2
Open	6.9	44.7	0.3	0.2	3.1	0.7	0	1.3	60	30	10	Sandy loam	1.5	3.8	1
Open	6	5	0.23	0.1	1.9	0.9	0	1.6	90	10	0	Sand	1.5	1.4	4
Open	6.7	5.6	0.17	1.4	5.3	1.8	0	2	49	46	5	Sandy loam	1.6	1.8	4
Open	6.6	9.8	0.2	0.5	3.7	1.5	0	1.4	29	58	13	Silt loam	1.4	2.4	4
Open	6.1	7.9	0.23	0.1	1.9	0.5	1	1.4	84	10	6	Loamy Sand	1.4	2.2	6
Open	6.2	7.3	0.17	0.3	2.7	1.5	0	1.5	87	5	8	Loamy Sand	1.4	1.3	1
Open	5.9	8.4	0.13	0.2	5.5	0.5	5.4	0.9	45	47	8	Sandy loam	1.6	0.8	4
Open	5.7	4	0.17	0.1	0.8	0.3	0.8	0.8	92	3	5	Sand	1.7	1	4
Open	6.6	11.1	0.3	0.5	9.7	2.4	0	1.9	75	5	20	Sandy loam	1.7	0.2	4
Open	6.3	4.1	0.2	0.4	2.6	0.9	0.3	1.3	82	13	5	Loamy Sand	1.6	1.7	4
Open	5.6	23.5	0.1	0.4	4.8	1.9	0	1.3	49	41	10	Loam	2.2	1	4
Open	6.7	9.1	0.17	0.5	3.9	2	0	1.7	82	5	13	Loamy Sand	1.6	2.6	6
Open	6.4	21	0.4	0.1	13.3	4.6	0	2.5	87	3	10	Loamy Sand	1.8	1.2	6
Open	6.5	17.9	0.23	0.6	2.1	1	1.1	1.4	85	12	3	Loamy Sand	1.7	0.9	4
Open	5.7	8.9	0.17	0.1	2.6	0.4	5.4	1	45	47	8	Loam	2.4	2	2
Open	5.7	6.4	0.2	0.2	4	1.3	0	1.4	87	5	8	Loamy Sand	1.5	1.2	4
Open	7	5.7	0.2	0.2	3.9	1	1.6	1.3	67	13	20	Sandy loam	1.6	1.2	1
Enclosed	6.1	13.7	0.25	0.1	2.8	0.4	0.4	1	92	3	5	Sand	1.3	5.7	6
Enclosed	6.4	12	0.43	0.4	11.3	1.5	0.8	2.3	77	9	14	Loamy Sand	1.4	2.8	4
Enclosed	5.9	15	0.37	0.7	5.5	1.3	1.6	2.1	69	18	13	Sandy loam	1.2	4.2	3
Enclosed	5.1	6.6	0.27	0.4	2.4	0.7	2.1	1	80	8	12	Loamy Sand	1.3	4.8	4
Enclosed	6.3	7.1	0.27	0.2	3.4	0.8	1.1	2.6	59	26	15	Sandy loam	1.5	5.1	2
Enclosed	6.1	7.2	0.4	0.3	3.4	0.8	0	1.5	87	3	10	Loamy Sand	1.4	3.8	4
Enclosed	5.7	7.1	0.23	0.2	2.8	0.8	2	1.4	87	3	10	Loamy Sand	1.2	3.9	3
Enclosed	5.9	6.8	0.3	0.2	2.1	0.7	1.3	2.5	90	5	5	Sand	1.3	2.8	1
Enclosed	6.1	8.5	0.23	0.3	2.9	0.8	0	1.4	85	7	8	Sandy loam	1.4	6.6	4
Enclosed	5.4	8.2	0.17	0.3	3.2	1.1	2.7	1.5	87	3	10	Loamy Sand	1.3	2.1	4
Enclosed	6.2	10.4	0.33	0.8	1.9	2	0	1.5	55	34	11	Sandy loam	1.4	3.5	4
Enclosed	6.2	10.1	0.2	0.8	4	1	0.8	1.5	63	29	8	Sandy loam	1.3	2.4	5
Enclosed	6.2	7.1	0.6	0.2	3.3	1	2.5	2	84	8	8	Loamy Sand	2.3	2.7	3
Enclosed	6.8	223.9	0.57	0.2	18.7	4	0	2.7	89	1	10	Loamy Sand	1.4	1.4	3
Parameter	pH	Avai P Me/L	N %	Ex K Me/L	Ex Ca Me/L	Ex Mg Me/L	Ex Na Me/L	TOM%	Particle Size assay			Textural class	Bd g/cm <sup>3</sup>	% M	colour code
Enclosed	6.9	39	0.4	0.5	18.2	3.8	0	2.1	67	14	19	Sandy loam	2.1	6.6	6
Enclosed	6.2	8	0.17	0.8	7.6	2	2.7	1.3	71	13	16	Sandy loam	2.1	2.9	5
Enclosed	6.4	16.1	0.33	0.5	9.9	3.1	0	2.8	65	14	21	SCL	1.4	3.7	4
Enclosed	5.7	8.5	0.23	0.1	3.9	1.9	0	2.2	50	37	13	Loam	1.3	4.6	4
Enclosed	4.7	67.3	0.27	0.2	2.1	0.8	1.4	1.5	74	3	23	SCL	1.3	3.1	5

**Key to Colour code**

1. Bright reddish brown 5YR 5/6
2. Greyish brown 5YR 4/2
3. Dull orange 5YR 6/4
4. Dull reddish brown 5YR 5/4
5. Reddish brown 5YR 4/6
6. Dark reddish brown 5YR 3/3