DIET SELECTION AND NUTRITION OF SHEEP (*Ovis aries* Linnaeus) AND GRANT'S GAZELLES (*Gazella granti* Brooke) ON KAPITI RANCH, KENYA

BY

JOSEPH M. KILONZO
(B.Sc in Wildlife Management)

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

RANGE MANAGEMENT

IN THE FACULTY OF AGRICULTURE OF

THE UNIVERSITY OF NAIROBI

2003

DECLARATION

I hereby declare that this thesis is my original work and has not been submitted for a degree in any other university

17 - 03 - 2004

Joseph M. Kilonzo

Date

This thesis has been submitted with our approval as university supervisors

17-03-2004

Dr. Wellington N. Ekaya
Department of Range Management
University of Nairobi.

Date

17 . 03 . 04

Dr. Robinson N. Kinuthia
Department of Range Management
University of Nairobi.

Date

DEDICATION

This thesis is dedicated to my parents, brothers and sisters, and all those who have encouraged me and contributed to my academic achievements since 1978

ACKNOWLEDGEMENTS

I gratefully acknowledge the Pastoral Information Network Programme (PINEP) for giving me a scholarship, which made it possible for me to embark on the Master of Science degree programme. My gratitude and deep appreciation goes to my supervisors, Dr. Wellington N. Ekaya and Dr. Robinson N. Kinuthia for their commitment, invaluable guidance, suggestions, comments and criticisms throughout the research period and in the preparation and completion of this thesis.

As for the research project, I am very thankful to the entire management of International Livestock Research Institute (ILRI) and Kapiti ranch for permitting me to reside and work within the ranch. My sincere appreciation also goes to Mr. Ngeno (Manager), Mr Muema (Assistant Manager), Musau (Clerk), Elias and the entire Kapiti ranch community for their continuous support during my field work i.e in providing me with accommodation, letting me use their computer facilities (with help of Mr. Musau) and transport whenever necessary.

I am also particularly grateful to Mr. Musembi, a technician from the Department of Range Management of the University of Nairobi, for his assistance in the microhistological work and identification of plant species in the field. Lots of thanks also go to my field assistants, Mr. Kyeva and Mr. Ndeti for their tolerance during the research work. Last but not the least, much appreciation goes to the Departments of Range Management and Animal Production both of the University of Nairobi for allowing me to use their laboratories and other facilities.

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ABSTRACT

A study was conducted to determine seasonal diet selection and nutritional characteristics of sheep and Grant's gazelles on Kapiti ranch in southeastern Kenya. The frequency and biomass production of herbaceous plants were determined in dry and wet season by using the plot method. Absolute and relative densities of woody plants on the site were determined using the point-centred quarter (PCQ) method. The dietary botanical composition of the study animal species was determined by using the microhistological technique. Relative density was used as an estimate of the dry weight composition of each forage species in the diets of each animal species. Plant species in the animal species' diets were categorized into grass, forb and browse forage classes. Shannon-Wiener and Morisita's similarity indices were used to express diet diversity and overlap respectively, between the two animal species. Diets were simulated based on microhistology results by weighting plant species corresponding to their relative densities in the diets to give 50 gm samples. These were then analysed for crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose, acid detergent lignin (ADL), and *in vitro* dry matter digestibility (IVDMD).

Diet analyses indicated that sheep were predominantly grazers during wet and dry season while Grant's gazelles were mixed feeders, with a higher preference for grasses during the wet season and an equal preference for both grasses and browse during the dry season. The forbs component was of little consequence for the two species.. Sheep mostly preferred *Themeda triandra*, *Digitaria macroblephara*, *Pennisetum meziamum*, *Pennisetum stramineum* and *Cynodon dactylon* during the wet and dry season. Grant's

gazelles showed high preference for *Balanites aegyptiaca*, *Hibiscus flavifolius*, *Acacia drepanolobium*, and *Themeda triandra* during the two seasons

Diet diversity based on forage-class revealed that the diets of Grant's gazelles were more diverse than those of sheep during the wet and dry season. This implies that Grant's gazelles can adopt their diets to change in vegetation at Athi Kapiti plains more than sheep. Degree of dietary overlap between the animal species was highest during the wet season when there were plenty of forage plants available for the two animal species. There was a positive correlation between the ranked orders of preference of shared plant species that constituted their diets during the two seasons, but it was strong only during the dry season.

There were significant differences ($P<0.05$) in dietary nutrient components between the animal species within seasons. IVDMD was significantly higher ($P<0.05$) for both animal species during the wet season. It was 67.9% for sheep and 82.6% for Grant's gazelles during the wet season while during the dry season it was 54.9% for sheep and 67.2% for Grant's gazelles. On the other hand, NDF, ADF, ADL and cellulose were significantly higher ($P<0.05$) during the dry season. The NDF, ADF, ADL values were 64.8%, 38.2% and 4.4% and 53.4%, 32.5% and 7.1% for Sheep and Grant's gazelles, respectively during the wet season. During the dry season the values were 74.5%, 47.5%, 6.7% and 61.6%, 37.4%, 9.6% for sheep and Grant's gazelles respectively. Sheep diets were significantly higher ($P<0.05$) in CP (5.8%) in the wet season, whereas it was significantly higher ($P<0.05$) in the diets of Grant's gazelles (8.1%) during the dry season. The nutrient components in the diets selected by the animal species showed that the sheep were dependent on grasses and that Grant's gazelles were mixed feeders, able to use both grasses and browse. The CP (4.2%) and IVDMD (54.9%) values were below the requirements for maintenance of sheep during the dry season. Protein supplementation in form of browse material and pods from *Acacia* species found in the ranch is thus recommended as a means of improving the diet quality and digestibility for sheep. This will in turn improve sheep production and efficient utilization of range forage.

Based on the findings of this study, it can be recommended that the two animal species be integrated on the same range because of the differences in diet selection and nutrition. The Grant's gazelles relied on a wide range of plant species selected from the three forage classes as compared to sheep which relied much on the grass species. On the basis of their browsing activities, they are able to suppress woody plants, resulting in an environment that favours establishment of the herb layer (grass and forbs), which is favourable for sheep. Therefore common use grazing involving these two ruminants is ecologically feasible. The integration of the two ruminants can therefore make unique and important contributions to food production and income generation opportunities in areas with similar vegetation to that of Athi Kapiti plains.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

In east Africa, arid and semi-arid lands make up to about 79% of the total land surface area (Pratt and Gwynne 1977). In Kenya, arid and semi-arid lands cover over 80% of the country's land surface area, and mainly support wildlife and extensive livestock production (Brown 1994). These areas are home to 25% of human population, 50% of the national cattle herd, 70% of the sheep and goats and 100% of the camels (GoK 1997). Further, Bernstein and Jacobs (1983) reported that over 90% of the wildlife populations are found in the arid and semi-arid lands in Kenya

The arid and semi-arid lands are generally of limited rainfall with annual means falling below 500 mm and characterised by erratic distribution within and between seasons Temperatures are high yearlong, fluctuating around 30°C and the potential evapotranspiration exceeds the annual rainfall resulting in low relative humidity, often less than 30% (Pratt and Gwynne 1977, Musembi 1986, Ekaya 1998, Ekaya *et al* 2001). Much of the vegetation in these areas is dominated by open tree savannah with varying understory of shrubs, forbs and grasses. This vegetation provides feed and habitat for livestock and wildlife.

Livestock and wildlife are two major rangeland resources, and each plays prominent roles in the lives of the people utilizing these lands. The pastoralists living in these areas rely upon flexibility and their diverse herds of livestock for food and other necessities.

Likewise, there are good moral, aesthetic (tourism), economic (production of goods and generation of revenue) and ecological (habitat creation, disease and vermin control) reasons for conserving wildlife. The integration of wildlife into livestock systems is necessary and is on increase. Research has shown that combining supplementary wildlife uses with livestock systems increases production and enhances financial viability (Collison 1979, Jarman and Sinclair 1979, Coppock *et al.* 1986, Child 1988, Cumming 1991, Barnes and Kalikawe 1992, Pauw and Peel 1993).

As a pre-requisite to integrating livestock and wildlife, it is desirable to evaluate the degree and extent of potential conflict, for example competition for scarce resources such as forage and habitat space. Wild herbivores and livestock may compete for scarce resources in arid and semi-arid rangelands (Voeten and Prins 1999). Range managers must therefore consider the optimal species-mix, stocking rates of the animals selected and harvest rates for the game animals when integrating wildlife into livestock production systems.

In the arid and semi-arid areas of east Africa, studies addressing the problem of competition and ecological separation between livestock and wildlife species remain few. The few published studies include those of Talbot (1962), Casebeer and Koss (1970), Field *et al.* (1973), Ng'ethe and Box (1976) and Ego (1996). Even fewer are studies involving the interaction between small domestic and wild ruminants.

The small ruminants are a major source of livelihood in many areas of Africa. They offer socio-economic advantages because of their minimal management requirements, low initial replacement and maintenance cost, production of meat and their ability to survive and produce in harsh environments (Campell 1978, Wilson 1991, Shafire 1992, Slippers *et al.* 1998). They can be important in increasing the productivity of smallholder agro-pastoralists in a continent desperately short of food for human consumption. There are many species of small wild ruminants in arid and semi-arid areas as well. These include gazelles and impalas These are hunted for food, sport and are a major tourist attraction in many African countries including Kenya. Ranches in Kenya's southern-eastern rangelands are inhabit by both wild and domesticated small ruminants.

The purpose of this study therefore was to gather information on forage preferences and dietary nutritional characteristics of free ranging sheep and Grant's gazelles on Kapiti ranch. No studies have considered the two species simultaneously. The findings from the study will give some vital information on the interaction of the two species, thus indicating some management implications of a small ruminant livestock-wildlife production system on Kapiti plains

1.2 Broad objective

To characterize livestock-wildlife interactions in the rangelands of south-eastern Kenya.

1.3 Specific objectives

a) To determine the dietary composition, overlap, and diversity of sheep and Grant's gazelles during wet and dry season

b) To determine the nutritional characteristics of simulated diets of the two animal species during the two seasons.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Wildlife/livestock grazing in east Africa's rangelands

There has always been a close and relatively harmonious association between the livestock and wildlife in east Africa (Berger 1993). Western (1976) reported that seasonal migration patterns and foraging strategies of the Maasai livestock and wildlife species are so similar that their niches are intermingled and inseparable. It has also been suggested that pastoralists have had a significant influence on the evolution of the ecology of their homelands and the type and distribution of wildlife species in the ecosystem (Western 1976). Although exclusive use of some rangelands by either wildlife or livestock exists in the form of national parks, game reserves or fenced ranches, wildlife is also found on private and communal grazing lands sharing resources with livestock.

Over the last century, numerous studies geared towards understanding of the foraging interactions between wildlife and livestock have been conducted. These interactions are usually analysed in terms of competition or niche separation. Talbot (1962) reported minimal competition between cattle (*Bos indicus*) and wild ungulates on the Loita plains of Narok district. Whereas cattle consumed mainly *Themeda triandra*, *Cynodon dactylon*, *Bothriochloa* spp, and *Chloris gayana*, the wild ungulates only consumed *T. triandra*. It was noted that *C. dactylon* was highly preferred by both cattle and wild species (Talbot 1962). Casebeer and Koss (1970) pointed out that the diet overlap in food utilization between cattle and wild herbivores on rangelands was considerable in southern Kenya. Differences existed, however in the use of small number of plants. All the animal species favoured *T. triandra* over *Pennisetum meziamim* and *Digitaria macroblephara*. Cattle selectivity did not vary, over the year, as much as that of the wild species. It was also not as varied as the available grass species. Cattle and zebra had the greatest similarity in diets. Each animal species had a wide spectrum of grasses in its diet. Wild animals had a greater inter-seasonal diet variation than cattle, with the diet of the later remaining much more consistent than that of the former the combination of available grasses

Field *et al.* (1973) conducted a comparative study of the grazing preferences of buffalo (*Syncerus caffer*) and Ankole cattle on three different pastures in Uganda. Cattle and buffalo were reported to have similar grazing preference, when grazing pastures similar in botanical composition. *Bracharia decumbensis, Chloris gayana, Cynodon dactylon, Digitaria melanochila* and *Setaria aequalis* were the most frequent grass species, which were highly preferred by both buffalo and cattle.

Field (1975) studied the food habits of buffalo, eland (*Taurotragus derbians*), oryx (*Oryx beisa*) and cattle in the Galana ranch, Kenya. With regard to the specific food habits of these herbivores, buffalo consumed mostly *Bothriochloa* spp, *Enneapogon* spp. and *Cymbogon* spp. during or shortly after the rain season. Eland consumed very little of the four grasses. Oryx, however, concentrated mostly on *Enneapogon* and *Chloris* spp. except during the wet when annuals such as *B. deflexa* became abundant and constituted a significant proportion of oryx diets. Cattle consumed mostly the *Brachiaria* and *Schoenfeldia* spp.

Ego (1996) studied the seasonal diet and habitat preference of cattle, kongoni (*Alphcelaphus buselaphus*), and wildebeest (*Connochaetus taurinus*) grazing on a common range. *Themeda triandra*, *Digitaria macroblephara* and *P. mezianum* were the three most abundant grass species in the diets of the three animals. Diet overlaps were lower between cattle and wild herbivores than between the wild herbivores themselves.

The principle objective of the above studies has been to understand the basis of coexistence of various species of herbivores It would be expected that in order for two or more species to co-exist there should be differential niche occupancy and little competition for key resources. On the basis of studies conducted in Tanzania, Lamprey (1963) suggested that this separation is accomplished in different ways Species can, (i) select different types of food, (ii) separate topographically on seasonal basis, (iii) select the same area but at different seasons, (iv) select different feeding levels in the vegetation, and (v) separate on a vegetation basis according to season of food stress

Studies on African grasslands have shown that grazing by one species of herbivore can alter the sward structure in a way, which is beneficial to the nutrient intake of another species. For example wildebeests and Thomson gazelles (*Gazella thomsoni*) appear to benefit from the grazing behaviour of the Burchell's zebra (Bell 1970, McNaughton 1976). The zebra, which have high intake rates and can cope with plant materials with low digestibility (Duncan *et al.* 1990), graze upon the tall stemmy grasslands exposing the leaves at the base of the plants and allowing greater access for wildebeest, which need a higher proportion of leaf in their diets. Wildebeest then remove the majority of the tall grass, leaving a short sward for Thomson gazelles. Bell (1970) explained the grazing succession in terms of feeding preferences.

2.2 Range forage nutrient characteristics

Range forages are generally composed of grasses, forbs and browse. The importance of the forage plants to the domestic and wild animals is determined by their availability, palatability and nutritive value (Lusigi *et al.* 1984). Their quality may be looked at in terms of the concentration of digestible nutrients and concentration of compounds that limit digestibility such as fibre, lignin, silica and tannins (Hansen *et al.* 1973, Provenza and Malechek 1984). The quality of the range forage is also affected by factors of climate and soil conditions (Semenye 1987), plant species and part (Hart *et al.* 1983) and stage of maturity of the plants (Maglad *et al.* 1986). Climatic and soil conditions are prime determinants of the adaptations of herbage species to any area, and climatic variations in form of seasons largely determine herbage quality. Climatic conditions such as precipitation may have a more direct effect by leaching nutrients from plants. Laycock and Price (1970) reported that protein, phosphorus, ash and carotene are often leached from dry mature plants, leaving the indigestible crude fibre or lignin. It was also reported that temperature is important in determining rate of development, phenology and total yield of many plants, thus indirectly influencing chemical composition.

Soil characteristics such as texture and richness influences the availability of minerals to the plants. An abundance of available plant nutrients in soil is reflected in the chemical

The nutritive value derived from forage consumed by the herbivores largely depends on the availability of the various nutrients to the animal's body. This is affected by the concentration of secondary compounds like tannins, insoluble phenolics and sapponins (Provenza and Malechek 1984). Lignin and cutin are other compounds associated with cell walls of plant cells and are almost indigestible (Hansen *et al.* 1973). These compounds physically inhibit the digestion of the enclosed cell nutrients (Stobbs and Minson 1979).

2.3 Herbivore food selection frame work

Generally, if an animal is faced with a variety of possible food items, it will prefer to consume some and avoid others. Not all forages are acceptable, and even those that are acceptable at one stage of growth are not favoured at other times (Hanley and Henley 1982). The following are some of the reasons that are necessary for the understanding of forage needs of range animals and the underlying basis of competitive interaction among them (Hanley 1982).

2.3.1 Roles of sight, taste, smell and touch in forage selection

All the above senses are involved in diet selection (Bell 1959, Arnold 1966a,b, Krueger *et al.* 1974). Sight is most important in orienting the animal with respect to other animals and its environment. Sheep do recognise conspicuous food plants by sight but do not use sight to help them graze selectivity (Arnold 1966b). Smell reinforces the sense of taste, and therefore, smell may be regarded as taste projected to a distance (Bell 1959). Marked changes in the relative palatability of forage species may occur when taste and smell are

(1986) attributed this to contamination of acid detergent lignin with cutin, which occurs in high levels in browse plants.

The leaf to stem ratio has been reported to affect the quality of herbage consumed by grazing animals (Milford and Minson 1965, Wallace *et al* 1972). More leaves in the diet implies better quality since leaves are more nutritious and of higher digestibility than stems (Milford and Minson 1965), although in a few cases no relationship could be found between the leaf to stem ratio and nutritive value of rangeland grasses. Furthermore, reduced herbage availability resulting from intense forage use leads to selection of diets low in digestibility and crude protein in the diets (Heady 1964, Hodgeson *et al.* 1977).

Genetically, different plant species have varying capability for extraction of soil nutrients and also accumulation of dry matter. Studies comparing quality of different plant species include those of Karue (1974) and Hart *et al.* (1983). Preference for particular plant species, parts of plants and for living versus dead herbage have been described for many herbivores (Bell 1970, Nge'the and Box 1976, Wangoi 1984, Kinyamario and Muthuri 1986, Ekaya 1991). Plant parts though influenced by plants species defer qualitatively. Leaves are usually more nutritious and of higher degradability than stems. More newly produced leaves are often of higher nutritional value to animals than old ones (Coppock *et al.* 1987).

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surgically impaired in sheep (Arnold 1966b). It was found that when sheep were kept in an atmosphere of a specific odour, the power to detect the odour was rapidly lost. Arnold (1966b) found that inability to taste had the effect of improving the acceptability of more forage species than did the inability to smell or to feel them

Touch and thermal receptors aid taste and smell in animal responses to food (Bell 1959, Arnold 1966a). It was reported that selective removal of alfalfa leaves by sheep is achieved by the sense of touch, involving leaf plucking with the lips and that they remove the leaves while running the stems through their lips leaving an intact mass of bare stems. Arnold and Dudzinski (1978) indicated that chemical signals influence food selection. These signals are received at receptors for taste and smell. Stimuli are transmitted to the brain and the animal respond behaviourally or physiologically to the messages they contain (Krueger *et al.* 1974). The animal then responds by integrating these messages with others, telling the current nutritional state of the animal. The desire to consume may then result in lowering either tastes or smells thresholds of rejection (Goatcher and Church 1970, Arnold and Dudzinski 1978).

The role of special senses in the selection of plants with anti-nutritive factors should not be overlooked. Many of the browse species produce secondary compounds, which may be bitter, tasty, poisonous, or have an offensive odour or have anti-nutritional effects to herbivores. Arnold and Dudzinski (1978) indicated that chemical signals from such plants influence their selection by the browsing animal. These are received at receptors for taste and smell. The stimuli are transmitted to the brain and the animal respond behaviourally or physiologically to the messages they contain (Krueger *et al.* 1974) The animal then integrates these messages with others, "telling" the current nutritional status of the animal. The desire to consume may then result in lowering of either taste or smell thresholds of rejection or acceptance (Arnold and Dudzinski 1978). High levels of tannins, insoluble phenolics and sapponins in the animal diets interferes with digestion mechanisms in the animals due to their toxic effects or through enzyme inhibition and substrate binding in their digestive tracts (Mahamadou and Huss 1982, Van Soest 1982, Amrik and Menke 1986, Reed 1986). It is possible then, that these animals showed less preference for many browse species during the wet season, when they may contain higher quantities of these compounds.

2.3.2 Morphological parameters

These parameters include body size, type of digestive system (cecal or ruminant), rumino-reticular volume to body-weight ratio and mouth size as outlined by Hanley (1982). The review of these parameters is important in understanding the nutritional basis for food selection by ungulates.

(i) Body size. This determines the overall time-energy constraints within which the ungulates may forage selectively (Hanley 1982). Due to the increasing costs of maintenance and production, the food requirements of mammals increase with increasing body weight (Hanley 1982). A larger animal requiring a greater absolute quantity of nutrients per day, has less time per nutrient unit to spend foraging selectivity than does a smaller mammal with a lower absolute requirement, and therefore can meet its nutritional needs with relatively lower quality forage (Hanley, 1982). It is in this context that Bell (1970, 1971), generalised that where forage quantity is limiting, small body size is advantageous, and where forage quality is limiting, large body size is advantageous

(ii) Type of digestive system. Ungulates have evolved a variety of digestive systems enabling them to efficiently utilize fibrous forage resources, heterogeneous with regard to plant cell wall thickness and extent of lignifications. The ungulates have developed the ruminant and cecal digestive systems to enable them digest cell walls by anaerobic fermentation and so subsist on relatively higher fibre diets (Janis 1976). In cecal digestive system microbial fermentation occurs after the food has passed through the stomach and very little microbial protein can be recycled. The ruminant is a more selective forager than the cecal, but being a more efficient digester, it requires a lower absolute quantity of forage to meet its requirements it has been generalised that where forage quantity is limiting, a ruminant digestive is advantageous, whereas where forage quality is limiting, cecal system is advantageous (Bell 1970, 1971, Janis 1976)

(iii) The rumino-reticular volume to body weight ratio of a ruminant determines the type of food the ruminant is most efficient in processing (Hanley 1982). High rumino-reticular volume to body weight ratio is an adaptation to high cellulose content diet, typically of grasses. Low rumino-reticular volume to body weight ratio is an adaptation to a high cellular content, typically a diet consisting of young grasses, forbs and browse (Nagy *et al.* 1969). Large rumen volume ruminants select a diet high in cell walls while small rumen volume ruminants select a diet low in cell walls (Schwartz *et al.* 1977, Wallmo *et* *al*. 1977). Within the ruminants, large body size and large rumen volume are adaptations to exploitation of high cellulose diets. Small body size and small rumen volume, on the other hand, are adaptations to exploitation of high cell soluble and lignin diets.

(iv) Mouth size. The degree of selectivity that an animal may exhibit is determined by largely by mouth size (Hanley 1982). Animals with small mouthparts have been reported to be more selective of plant parts than animals with large mouth (1957, Wangoi 1984). Data from fistulated animals show that sheep, obtain a higher quality diet than do cattle by selecting higher quality plant parts when animals have access to the same forage (Church 1975).

The knowledge of the four morphological parameters involved in the food selection by ungulates will therefore help in understanding of the reasons why they select the kinds of foods that will yield predictive insight into problems involving competition and food resource partitioning in ungulate communities. One should be able to predict not only the types of foods that will be selected by the members of a given array of ungulates species but also the rank of each species along a gradient reflecting the differences in degree of selectivity and types of foods selected.

2.4 Diet selection by sheep

Several studies involving comparison of diets selected by sheep when grazing alone or with other herbivores have been reported across the tropical rangelands. Ghosh *et al.* (1986) arrived at the general conclusion that sheep are mainly grazers. Pfisher and

Malechek (1986) also observed that sheep and goats in the semi-arid parts of Brazil selected similar diets during the dry seasons. The main dietary components for both species were grasses and browse. In the wet season, sheep selected mainly grasses and forbs. The degree of dietary overlap between sheep and goats was greatest in the dry seasons. Wangoi (1984) observed that more than 50% of the sheep diet consisted of grasses in all but, one season, with the browse component increasing during the very dry season. Severson and May (1965) in their study of food preference of pronghorn antelope (*Antilocapra americana*) and domestic sheep in Wyoming Red Desert, found out that there was little competition between the two kinds of animals. It was concluded that the degree of competition between the two herbivores varied greatly, and appeared to depend on the geographical area, season, and vegetative types available.

In Wyoming, Stoddart *et al* (1975) reported that sheep diets contained a greater proportion of forbs than grasses during early in the grazing season i.e. 73% in July, 52% in August, and 40% in September. Sheep also discriminate between grass species. For example, *Festuca vulva* and *Poa* species were preferred to *Agrostis* and *Holcus* species (Jewell *et al*. 1974). Coppock *et al* (1986) found the composition of sheep diets for total herbaceous (grass and forbs), dwarf shrub, and all other browses (including seeds and seedpods), were 67%, 28% and 5%, respectively. The sheep were thus mixed feeders and tended to have more varied diets during wet and early dry periods than during mid- or late-dry intervals. Elsewhere, Ekaya (1991) found that sheep were mixed feeders during the dry season. The three most preferred plant species in this study were *Balanites aegyptiaca*, *Grewia* species and *Chloris roxyburghiana*, constituting 77% of the diet.

During the growing season they shifted their preference towards grasses *D. macroblephara*, *C. roxyburghiana* and *Grewia* species were the three most preferred plant species making up to 90% of the diet.

On the nutritional requirement of sheep, the nitrogen content of the sheep diets declines as the forbs content decreases (Stoddart *et al* 1975). Sheep select leaf in preference to stem and the green material in preferred over dry or old (Crawley 1983). Compared to the forage as a whole, the selected material by the grazing animal is usually higher in nitrogen, phosphorus, sugars and gross energy, and lower in fibres (Crawley 1983). Topps (1967) reported that sheep in Rhodesia maintained on herbage with an average crude protein content of 2.2% ingested diets with an average crude protein content of 10.7%. After rains, sheep consume succulent grasses, but during a dry season they are forced to eat less palatable species, pods and stems (Weston and Moir 1969). Zeeman *et al.* (1983) reported that during the dry season, dorper and Marino sheep selected diets with higher digestibility than goats and cattle. It has also been reported that sheep obtain a diet of lower digestibility than the pasture because the sward is so diluted by dead grass that they are unable to select between the different types of green material (Hamilton *et al.* 1973).

2.5 Diet selection by Grant's gazelles

Little research has been done on this species, especially on the chemical composition of its diet. Grant's gazelles inhabit the bush savannah of eastern Africa and arid zones with very low rainfall and desert vegetation (Hoffman 1973). It is wide spread throughout

Kenya except for densely populated highlands and coastal region (Stewart and Stewart 1963). It has been found that this species feeds on grass and browse. Its diet is flexible varying according to season and area. However, in semi-arid conditions of sparse grass cover, the species is considered to be primarily a browser (Spinage *et al.* 1980). Stewart and Stewart (1972) also found that dicotyledonous material figured abundantly in faecal samples and considered that the dicotylendons were the major source of food at the end of the rains and the dry seasons, but grasses important at the beginning of the rain. Lamprey (1963) concluded, however, from direct observation that 91% of its preferred food was grass. Elsewhere Grant's gazelle has been described as a seasonally adapted intermediate feeder preferring herbs and shrub foliage (Hoffman 1973).

The stomach contents of Grant's gazelles have been primarily analysed in different areas of Kenya and Tanzania (Table 1). There is also one report of faeces analysis (Stewart and Stewart 1970) and several accounts of feeding observations. From these results, the conclusion is that a Grant's gazelle is a mixed feeder, feeding on both browse and grass. However the browse-grass ratio is not constant but varies considerably with season and area. Gwynne (1971) working in northern Tanzania found that the grass-browse ratio does not change with rains. Hofmann and Stewart (1972) classified Grant's gazelle as an intermediate feeder preferring dicotyledon material and having a rumen similar in structure to steenbok and eland.

Table 1: Percentage composition of grass and browse in the diet of Grant's gazelle

Area	Grass %	Browse %	Method	Author(s)
Maasai and Serengeti	40	60	Stomach analysis	Talbot and Talbot 1962
Tanzania	91	9	Observation	Lamprey 1963
Tanzania	42	58	Stomach analysis	Gwynne 1973
Turkana	18	82	"	"
Serengeti	45	55	"	"
R. Valley	48	52	"	Field 1973

Seasonality in the diet of the Grant's gazelle has yet to be studied extensively. Stewart and Stewart (1971) working in the Rift valley, Kenya, observed that Grant's gazelles eat mainly grass at the start of the rains but mainly browse by the late rains and in the dry season. During the early-wet season Grant's gazelles include grasses in their diet, principally short species such as *C. dactylon* and *Herpachne schimperi*. The fresh shoots of *Hyparrhenia* and *Themeda* species are avoided at a later stage in their growth. Once the grasses are longer they mainly browse from shrubs and short herbs such as *Solanum incanum*, *Indigofera* and *Sida* species. Fruits of *Balanites*, *Solanum* and *Calotropis* species have also been recorded in their diet (Talbot and Talbot 1962).

Bell (1971) through stomach content analysis found that Grant's gazelle select the green parts of plants. These parts offer high protein, digestible carbohydrates, thin cell walls and low fibre. Jerman (1974) also reported that browse plants produce leaves in succession as opposed to grasses and herbs that have short specific bursts of growth. Hence in the dry season browse can offer high quality food long after the grasses and herbs have dried.

2.6 Some methods of determining foods habits of herbivores

Several methods are currently available to researchers interested in herbivore diet composition. The following is a brief review of some of these methods

2.6.1 Utilization techniques

Martin (1970) give reviews of the various utilization techniques used in estimating diets of grazing animals. Approaches to utilization are many and vary. Clipping plots with a pasture before and after grazing to determine use by calculating the difference is one of them. It requires hours of labour in clipping, weighing and estimating biomass Estimation of eaten forage by the use of paired plots can be done by fencing off an area of range from grazing allowing natural growth patterns to occur. These areas are then compared to adjacent grazed lands to determine the amounts and types of vegetation removed. This procedure offers difficulties in assigning removed materials to specific consumers. The advantages of utilization techniques include speed and the fact that it provides information on where and to what degree, a range is being used. Serious limitations with the utilisation techniques are generally unsuitable when plants are actively growing and more than one herbivore is using the area under study (Holechek *et al.*, 1982).

2.6.2 Direct observation

Information on this procedure is reviewed by Bjugstad *et al.* (1970), Theurer *et al.* (1976). Quantitative information from direct observation has been obtained from the cafeteria, feeding-minute and bite-counts approaches. The reliability of some of these approaches depends on the accuracy of the observer trained in botany. It is limited to either tame or easily observed animals, and can be difficult in a "two dimensional" landscapes such as in short grass pastures. Wide-mouthed consumers such as cattle can consume several species of plants in one bite, which may be obscured from the viewer. Difficult in species identification and quantification of how much of a plant was consumed are also important problems associated with the method (Holechek *et al.* 1982). Direct observation is not applicable in studies involving feeding habits of grazers. This is because grasses generally grow low and close to the ground.

2.6.3 Stomach and rumen content analysis

It is a common method used by wildlife researchers' (Chippendale 1962, Talbot and Talbot 1962, Chamrad and Box 1964, Korschger 1966, Chamrad and Box 1968, Smith and Shandruk 1979). The method requires the sacrificing of animals and their stomach and rumen contents examined.

The method has limits in that it requires the destruction of the animal subject. It may not be possible to sacrifice animals solely for food habits studies because of limited animal populations. A researcher would therefore encounter difficulties using this method to investigate less populous species. Stomach contents from road and hunter kills may not provide reliable estimates of diet because of various deficiencies in the method of sample collection. Data can only be obtained covering the short period just prior to collection. Differential digestibility of different plant species could also be a source of error (Hill 1946, Anderson *et al.* 1965, Leslie *et al.* 1983). The method was later modified by the use of tranquilization to avoid the problem of animal sacrifice when stomach analysis is used to sample large ruminant diets with trocar sampling (Wilson *et al.* 1977). Layering of rumen contents and infections by parasites are problems associated with this technique. Thus, the technique should not be used on rare or endangered species.

2.6.4 Esophageal and rumen fistulation

This is another method of direct diet analysis that does not require the sacrificing of animals, but involves the cannulation of animals. Holechek *et al.* (1982) have reviewed fistula esophageal and rumen techniques in general. Fistulation of big animals is a delicate and expensive procedure. It requires a tame animal, a veterinarian who is intimately familiar with the cannulation procedure, and a crew of dedicated and experienced persons to provide daily care and medication to the cannulated animals. There is some concern that the fistulation may alter foraging habits, particularly if coupled with fasting procedure.

2.6.5 Microhistology technique

Faecal analysis has received greater use for evaluating herbivore food habits than any other procedure with the increased use of micrihistological techniques (Sparks and Malechek 1968). Epidermal characteristics of plants consumed remain intact through the digestion process, thereby making identification possible for a trained technician (Holechek *et al.* 1982). It has been recently used to estimate the diets of at least 16 large mammals, 20 small mammals, four birds, and a few insects in North America (Hansen and Lucich 1978). Numerous studies have also been conducted in Africa, Australia, and New Zealand using the technique.

Microhistological process can be applied on fistulated rumen and oesophageal, stomach and faecal samples and clipped plant samples. However, microhistological analysis using faecal samples has several unique advantages, which account for its popularity as a research tool (Ward 1970, Antony and Smith 1974), and which is the method of choice in the present study. These are:

- It does not interfere with the normal habits of the animals.
- It permits practically unlimited sampling.
- It has particular value where animals range over mixed communities.
- It is the only one feasible where animals range over mixed communities.
- Can be used to compare the diets of two or more animals at the same time.
- Actual sampling requires very little equipment.
- And last and not the least, generates a physical and durable record in the preserved slides so that any queries or further research can be objectively addressed.

The microfecal method is based on a number of assumptions; (1) fragments of every ingested plant species and plant parts pass through the gastro intestinal tract (GIT) of herbivores without being disturbed and can be recognized in the faeces; (2) recovery and identification of these fragments are consistently proportional to ingestion rates (Dearden *et al.* 1975); (3) a predictable relationship exists between the frequency of occurrence of dietary items in faecal samples and their weight or density (Sparks and Malechek, 1968);

and (4) the method is repeatable among technicians with similar training (Holechek and Gross 1982, Holecheck 1982).

Microhistology is thus still a leader in diet determination. It's accuracy in estimating diet composition of grazing animals has shown to be well over 94% when comparisons were made with the actual species composition in forage mixtures (Holecheck *et al.* 1982, Martin 1982, Tadingar 1986). It's limits, when understood, are reasonable and can be addressed by the researcher and comprehensively factored into a study Until another method can stand more uncontested than those currently available, microhistology provides a detailed window into herbaceous diets

It is apparent from the above review that some studies have been undertaken in evaluating the degree and extent of potential conflict for scarce resources such as forage and habitat use, between livestock and wildlife on the same range. However, due to differences in the animal species studied, methods used, shortcomings associated with the methods, difference in body morphologies, and differences in study area, the reported results show some variations in forage preferences and nutritional requirements of those herbivores. Thus there is need to do more research on the subject especially on small ruminant livestock-wildlife production systems in arid and semi arid rangelands. A sound understanding of the diet selection and nutritional requirements is necessary if small ruminants livestock-wildlife production systems are to be managed in a way that provides adequate food production, employment and income generation opportunities for present population while maintaining management options for future generations.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The study was conducted on the Kapiti ranch, located in northwestern part of Machakos district, along the Nairobi-Mombasa highway (Figure 1). The ranch is owned by the International Livestock Research Institute, and covers an area of about 13, 279 ha. Kapiti ranch falls under ecological zone IV (Pratt and Gwynne 1977).

3.1.1 Climatic characteristics

The study area is characterised by low and erratic rainfall with bimodal distribution pattern. The long rains are between March and May followed by a cool, cloudy and dry season from June to September. The short rainy season extents from October to December and is followed by a hot and sunny dry period, which continues, to the middle of March. Long-term data (1991 to 2000) from the ranch was used in the characterisation of rainfall. The long term mean annual rainfall was 422 mm. Two rainfall peaks are conspicuous (Figure 2). These are in April and November with 55 mm and 109 mm respectively. The two peaks are expected due to the influence of the Inter-tropical Convergence Zone, resulting in the long and short rains respectively. Coefficient of variation (Figure 2) was lowest for the November peak and highest for the April peak, indicating less variation in the amount of rainfall recorded during the months of November, compared to that of months of April. During the study period the usual long rainy season was expected with highest rainfall received on April. March to May and June to September were considered wet and dry seasons respectively in this study.

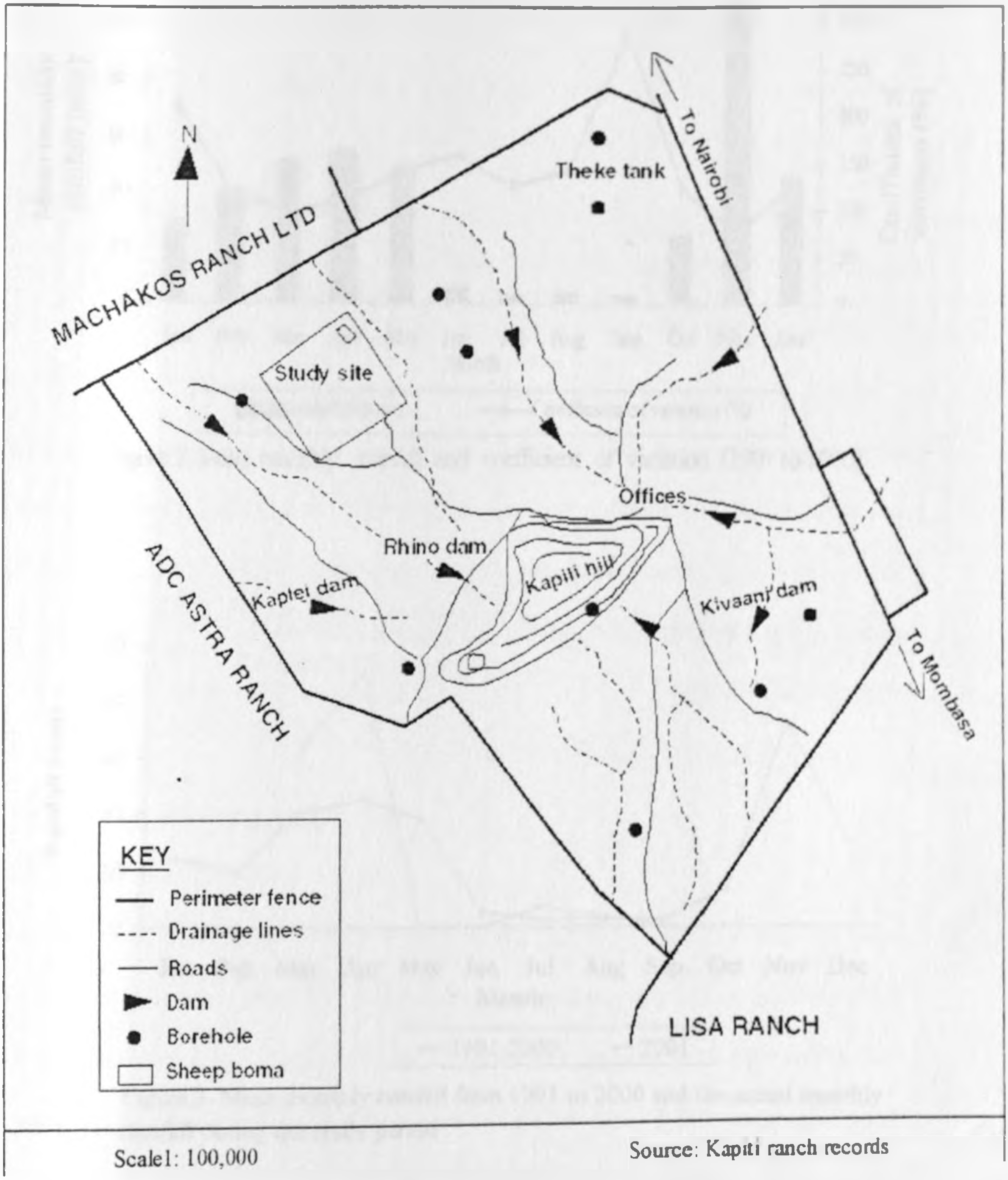

Figure 1. Map showing the study area and site

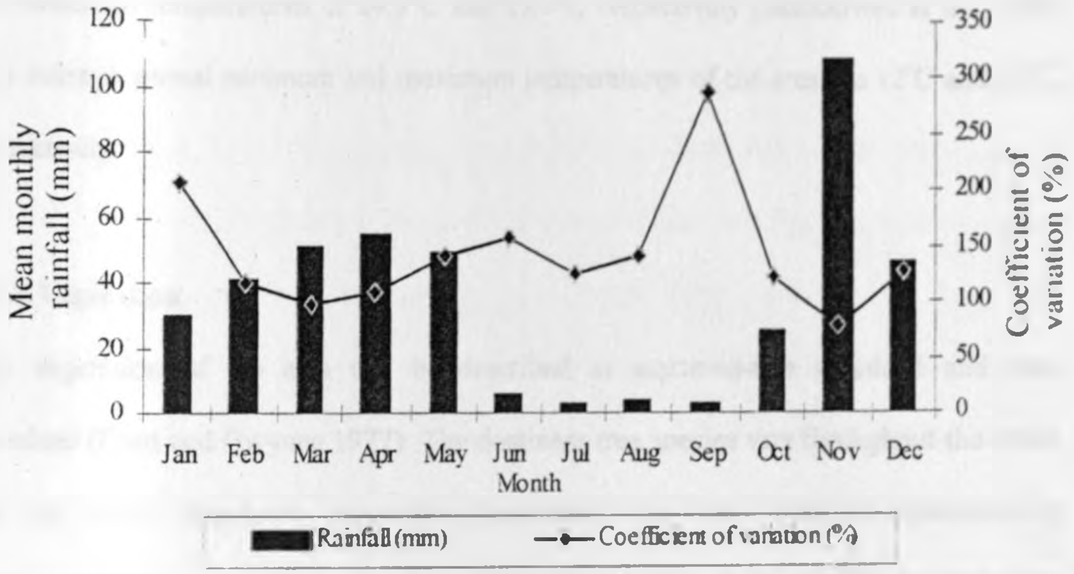

Figure 2. Mean monthly rainfall and coefficient of variation (1991 to 2000)

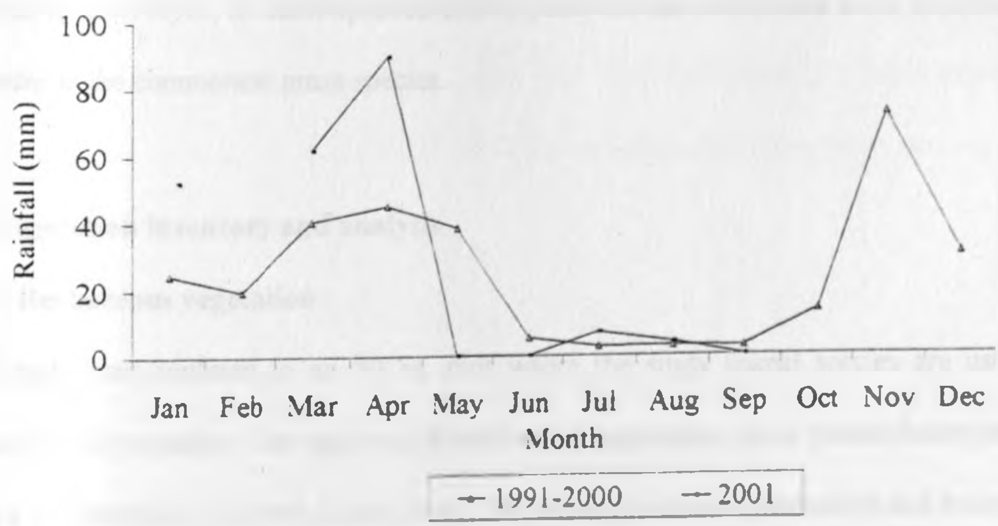

Figure 3. Mean monthly rainfall from 1991 to 2000 and the actual monthly rainfall during the study period

Temperature in the area is characterised by warm days and cool nights, with maximum and minimum temperatures of 24.9°C and 13.7°C respectively (MacDowell *et al.* 1988). The average annual minimum and maximum temperatures of the area are 12°C and 24°C, respectively.

3.1.2 Vegetation

The vegetation of the area can be described as scattered-tree grassland and open grassland (Pratt and Gwynne 1977). The dominant tree species vary throughout the ranch. On the plains, *Balanites aegyptiaca* dominates. The herb layer is dominated by gramineae, particularly *Themeda triandra* and *Pennisetum mezianum*. The grass expanse is interspersed by *Aspilia mossambicensis* and *Hibiscus flavifolius.* On the valleys and drainage lines, bushland vegetation occurs and is mainly dominated by trees of the genus *Acacia*. *Acacia seyal*, *A. xanthophloea* and *A. paoli* are the commonest trees, whereas *T. triandra* is the commonest grass species.

3.2 Vegetation inventory and analysis

3.2.1 Herbaceous vegetation

The study was confined to an 80 ha. plot where the study animal species are usually found grazing together. The plot was dominated by herbaceous plant species interspersed with a *H. flavifolius* and few *Acacia* trees. The herbage biomass production and botanical composition of the herbaceous layer was sampled twice, once in wet season and once in the dry season. During the wet season sampling period, the herbaceous vegetation was at the vegetative stage and still green while in the second sampling period it was at the seed set stage.

Six line transects, each 100 m long were marked out randomly in the study plot by throwing a peg and the direction faced by the pointed end was used to locate the next transect (Tadingar 1986). Five quadrats were systematically marked out along each transect at 20 m intervals to give a total of 30 quadrats. The sampling of aboveground plant material was carried out using a 1 m^2 quadrat frame. Grass and forb species present in each quadrat were recorded and frequency determined. The individual plant species within each quadrat were then clipped at ground level, and bagged separately in paper bags with the corresponding quadrat reference numbers. The packed material was transported to the laboratory at the Department of Range Management of the University of Nairobi, where it was oven-dried to constant weight at 80° C and the dry weight determined. Dry matter yield for each species was then determined. To avoid repeated clipping of the same plots in the next season's sampling, the plots were sequentially shifted forward by one metre.

3.2.2 Woody vegetation

Woody species density was determined using point-centred quarter method (PCQ) (Mueller-Dombois and Ellenberg 1974). The sampling was done at the start of the experiment. On the six 100 m line transects marked out, five points were systematically marked out along each line transect at intervals of 20 m making a total of 30 sampling points. Four quadrants were marked around each sampling point. In each quarter the distance between the nearest woody plant and the sampling point was measured and recorded together with the name of the species. In addition, the height of the plant was recorded. Density was then calculated from mean distance and area using the following formulae (Mueller-Dombois and Ellenberg 1974):

$$\text{Mean distance (d)} = \frac{\text{Total distance}}{\text{Total number of all plants recorded}}$$

$$\text{(i) Total density (N/ha)} = \frac{10,000}{d^2}, \text{ where "} d^2 \text{" is the mean area per plant.}$$

$$\text{(ii) Relative density (\%)} = \frac{\text{Density of i}^{th} \text{ species}}{\text{Total density}} \times 100$$

3.3 Diet determination

3.3.1 Faecal sampling

The botanical composition of the diets of sheep and Grant's gazelles was determined using the microhistological technique (Sparks and Malecheck 1968, Ward 1970, Hansen and Dearden 1975). A total of 150 sheep and 42 Grant's gazelles were used in the sampling of the animals' diets. The number of Grant's gazelles however decreased to 30 during the dry season. There were 3 sampling periods each consisting of nine days during each season.

On the morning of each sampling day, two pellets were collected from each sheep's rectum, and from randomly selected Grant's gazelles' fresh droppings at the study site.

The faecal samples collected on each sampling day from each animal species were air-dried for three days and later oven dried at 60° C for 24 hours. Faecal samples collected for each period were later thoroughly mixed to make one composite sample.

3.3.2 Preparation of plant reference slides

Reference slides were prepared from herbaceous and woody plants identified from the study site during initial vegetation inventory. Samples were collected from the plants by clipping leaves and non-lignified stems and storing them in labelled paper bags. The plant samples were then transported to the laboratory where they were oven-dried at 60°C for 48 hours and ground in a Willey mill through a 1 mm sieve to reduce all fragments to uniform size. Slides were prepared from the materials following the procedures described by Cavender and Hansen (1970). A 5-10 g sub-sample of the reference material was bleached in a test tube using Jik detergent for 15 minutes. Following this treatment, the bleached samples were then washed with running tap water over a 212 µm sieve for 3 minutes to remove smaller plant fragments, bleaching agent and any dirt. A spatula and 1 mm thick metal template with 6 mm diameter openings was used to transfer equal drops of the bleached plant fragments onto glass microscope slides. Hoyer's solution (Cavender and Hansen 1970) was added in small quantities so as to cover the sample. A teasing needle was used to mix the sample material with the solution. The mixture was then spread evenly over an area large enough to be covered by a 22 x 22 mm glass cover slip. The cover slip was affixed and the slide was slowly heated over an alcohol burner till the solution started to bubble. The bottom part of the slide was immediately pressed onto a wet cloth material to drive out air bubbles. The cover was gently sealed to the slide using few drops of Hoyer's solution. The prepared slides were then placed in a rack and dried at 60°C for 48 hours and stored. These were later studied under microscope and drawings were prepared, showing the histological features of each plant species

3.3.3 Preparation of slides from faecal material

The compounded samples of faecal material were ground in a Willey mill having a 1 mm sieve. Five microscopic slides were prepared from composite sample following the procedure described by Cavender and Hansen (1970) as described in section 3.3.1 above.

3.3.4 Slide quantification

Faecal slides were quantified as described by Hansen *et al.* (1984) and Foppe (1984). The slides were examined under a binocular microscope at a magnification of 100x. On each slide, twenty fields of view were systematically selected and inspected for identifiable plant fragments. Each fragment encountered in a field of the microscope was identified if its observed characteristics matched those on the reference slide. Analysis was based on comparisons with the plants identified from the study site. Histological features such as size and shape of epidermal hairs, presence or absence of hairs, cell shapes, druses, and crystals included in epidermal cells provided diagnostic characteristics for identification of forb species. The occurrence and position of epidermal cells, micro hairs, silica cells, silico-suberose couples, size and shape of the guard and subsidiary cells of the stomata provided diagnostic characteristics for identification of grasses.

The average percent frequency of a forage species in a faecal sample was calculated by dividing the number of fields in which it occurred by the total number of fields in all five slides. The density of the species per field was then determined from the percentage frequency by the formula (Hansen 1984):

$$Y = 0.09\,X - 0.01$$

Where;

Y = density, and

X = percent frequency.

For a given percentage frequency, a mean density of discerned fragment for a species per microscopic field was determined. The mean density was then converted to a relative density using the formula given below (Hansen *et al.* 1984);

$$\text{Relative Density (\%)} = \frac{\sum \text{Density of discerned fragments for a species}}{\text{Sum of densites of discerned fragments for all species}} \times 100$$

The percent relative density was used as an estimate of the dry weight composition of each forage species in the diet, assuming that the relationship between the two is highly correlated (Sparks and Malechek 1968, Hansen *et al.* 1984).

3.4 Nutritional characteristics of animal diets

Diet composition results from microhistology were used to simulate diets for each of the animal species during the dry and wet season. Simulation of the diets was based on the relative densities with which the selected plants appeared in the respective diets. The grass samples consisted of stems, leaves and seeds depending on the time of plucking while woody plant samples consisted of leaves and their petioles The plant samples were oven-dried at 60°C for 48 hours and ground in a Willey mill having a 1 mm sieve. The weighting of the ground samples for nutritional analysis was based on their relative densities in the diets to give 50 gm sample diets. These samples were then analysed for crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), cellulose and *in vitro* dry matter digestibility (IVDMD). CP was determined by the Kjeldahl method (A.O.A.C. 1980). The fibre fractions were determined by procedures described by Goering and Van Soest (1970) IVDMD was determined according to the procedures of Tilley and Terry (1963) in the laboratory of the Department of Animal Production. University of Nairobi Rumen liquor was obtained from rumen fistulated steer maintained on grass hay dominated by two grass species, *Themeda triandra* and *Chloris gayana*, at Upper Kabete College of Agriculture and Veterinary Sciences. It was assumed that the steer inoculum provided reasonable values of actual digestibility dynamics in the field (Coppock 1985).

3.5 Data analysis

3.5.1 Diet composition

The composition of the diets of the animal species for each season were determined according to their corresponding relative densities. For each animal species and for each season the dietary components at species level were tabulated together with their mean relative densities. The diet composition of the two animal species for each season was then quantified into grasses, forbs and browse forage classes. Data was subjected to analysis of variance and means separated by least significant of difference (Steel and Torrie 1980).

3.5.2 Diet diversity

Diet diversity was calculated on a forage-class basis for animal species for each season using the Shannon-Wiener index (Shannon 1948, Hurtubia 1973):

$$H' = -\sum_{i=1}^{n} (p_i \times \log p_i),$$

where:

H' = diet diversity index,

n = no. of forage classes,

P_i = proportion of the i^{th} forage class in a given diet

The index gives the variety and evenness of the components in the diet. The index in this study primarily indicated the evenness of the three diet components in the diets of sheep and Grant's gazelles. A high diet diversity index indicated that an animal species was able to feed evenly on the available food categories.

3.5.3 Diet overlap

Diet overlap between the two animal species during the wet and dry season was calculated using Morisita's similarity index (1959) as modified by Horn (1966):

$$C_\lambda = \frac{2\sum_{i=1}^{s} X_i Y_i}{\sum_{i=1}^{s} X_i^2 + \sum_{i=1}^{s} Y_i^2}$$

where;

C_λ = overlap coefficient

S = total number of plant species,

X_i and Y_i = proportion of the total diet of herbivore X and Y taken from i^{th} plant species.

The overlap coefficient C_λ ranges from 0.0 for completely distinct diets to 1.0 for complete similarity.

Spearman's rank order correlation coefficients (R_n) (Snedecor and Cochran 1967) were computed to determine the correlation between the animal species' dietary overlaps within seasons:

$$R_n = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)},$$

where,

R_n = Spearman's rank correlation coefficient (lies between -1 and +1),

d_i = differences in rank for i^{th} pair of observation,

n = number of pairs.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Vegetation characteristics

The frequency and biomass production of herbaceous plant species in the study site are presented in Table 2. A total of 30 wet and 23 dry season herbaceous plant species were

Table 2. Frequency and biomass production of herbaceous plant species during wet and dry season

Plant species	Frequency		Biomass production (gm⁻²)	
Grasses	Wet season	Dry season	Wet season	Dry season
Andropogon dummeri	13.3	0	24.4	0
Aristida keniensis	10.0	26.7	8.0	2.3
Dichanthium insculpta	20.0	26.7	14.9	11.7
Brachiaria eruciformis	3.3	0	1.5	0
Brachiaria leersiodes	6.7	3.3	0.1	0.1
Brachiaria semiundulata	40.0	36.7	14.6	4.3
Cynodon dactylon	16.7	6.7	10.2	30.0
Digitaria macroblephara	86.7	90.0	40.3	50.2
Eragrostis cilianensis	10.0	6.7	1.4	1.1
Eustachys paspaloides	43.3	36.7	24.7	5.0
Harpachne schimperi	3.3	3.3	0.1	0.1
Heteropogon contortus	3.3	0	0.5	0
Hyparrhenia lintonii	3.3	3.3	2.7	0.1
Ischaemun afrum	16.7	56.7	15.6	40.1
Lintonia nutans	10.0	23.3	1.5	3.7
Panicum coloratum	6.7	0	0.5	0
Pennisetum mezianum	86.7	83.3	64.1	35.1
Pennisetum stramineum	26.7	36.7	26.2	34.0
Setaria verticillata	3.3	0	2.7	0
Sporobolus discosporus	13.3	13.3	1.7	1.3
Themeda triandra	90.0	76.7	65.7	78.5
Forbs				
Aspilia mossambicensis	36.7	23.3	16.4	5.0
Barlaria acanthoides	3.3	3.3	0.1	0.1
Commelina benghalensis	26.7	13.3	11.3	0.2
Crotalaria pycnostachys	26.7	13.3	10.4	5.0
Hermania alhiensis	6.7	6.7	0.3	6.3
Indigofera schimperi	10.0	6.7	0.8	0.6
Ipomoea mombassana	13.3	10.0	10.4	4.0
Rhynchosia minima	3.3	0	0.1	0
Solanum incanum	6.7	0	0.3	0
Total			371.5	318.8

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Aristida keniensis	10.0	26.7	8.0	2.3
Dichanthium insculpta	20.0	26.7	14.9	11.7
Brachiaria eruciformis	3.3	0	1.5	0
Brachiaria leersiodes	6.7	3.3	0.1	0.1
Brachiaria semiundulata	40.0	36.7	14.6	4.3
Cynodon dactylon	16.7	6.7	10.2	30.0
Digitaria macroblephara	86.7	90.0	40.3	50.2
Eragrostis cilianensis	10.0	6.7	1.4	1.1
Eustachys paspaloides	43.3	36.7	24.7	5.0
Harpachne schimperi	3.3	3.3	0.1	0.1
Heteropogon contortus	3.3	0	0.5	0
Hyparrhenia lintonii	3.3	3.3	2.7	0.1
Ischaemun afrum	16.7	56.7	15.6	40.1
Lintonia nutans	10.0	23.3	1.5	3.7
Panicum coloratum	6.7	0	0.5	0
Pennisetum mezianum	86.7	83.3	64.1	35.1
Pennisetum stramineum	26.7	36.7	26.2	34.0
Setaria verticillata	3.3	0	2.7	0
Sporobolus discosporus	13.3	13.3	1.7	1.3
Themeda triandra	90.0	76.7	65.7	78.5
Forbs				
Aspilia mossambicensis	36.7	23.3	16.4	5.0
Barlaria acanthoides	3.3	3.3	0.1	0.1
Commelina benghalensis	26.7	13.3	11.3	0.2
Crotalaria pycnostachys	26.7	13.3	10.4	5.0
Hermania alhiensis	6.7	6.7	0.3	6.3
Indigofera schimperi	10.0	6.7	0.8	0.6
Ipomoea mombassana	13.3	10.0	10.4	4.0
Rhynchosia minima	3.3	0	0.1	0
Solanum incanum	6.7	0	0.3	0
Total			371.5	318.8

The biomass production values of this study were significantly different to those reported in other studies in Kenya (Ekaya 1991, Kirui 1995 and Ego 1996). Ekaya (1991) working at Kiboko reported biomass production values of 358 gm^{-2} and 319 gm^{-2} for the wet and dry season, respectively. Kirui (1995) reported 1,053 gm^{-2} and 841 gm^{-2} in the wet and dry season respectively, while Ego (1996) reported values of 789 gm^{-2} and 495 gm^{-2} for the two seasons respectively.

The total density of trees and shrubs encountered in the study area was 107 plants /hactares) (Table 3). Eight woody plant species were recorded within the study site. Of these, two were trees and four were shrubs.

Table 3. Absolute and relative densities of woody plant species at the study site

Plant species	Absolute density (ha^{-1})	Relative density (%)
Acacia drepanolobium (S)	57.0	53.3
Hibiscus flavifolius (S)	21.4	20.0
Acacia seyal (T)	13.4	12.6
Balanites aegyptiaca (T)	12.4	11.6
Acacia mellifera (S)	1.8	1.7
Acacia paoli (S)	0.9	0.8
Total	106.9	100

S: Shrub T: Tree

The density of shrubs (81.1 shrubs/ha) was more than that of trees (25.8 trees/ha). *Acacia drepanolobium* had the highest density, followed by *H. flavifolius* and *A. seyal*.

4.2 Diet composition

Table 4 presents the average relative densities of plant species in the diets of sheep and Grant's gazelles during the wet and dry season.

4.2.1 Wet season diet composition

A total of 33 plant species were identified in the diets of sheep during this season. The most preferred plant species were *T. triandra, D. macroblephara, P. mezianum, E. cilianesis, C. dactylon, P. stramineum, S. discosporus* and *B. semiundulata* in that order. These plants constituted about 58% of the total diet of the sheep. A total of 28 plant species were identified in the diets of Grant's gazelles. Of these plants, the most preferred were *A. drepanalobium, T. triandra, H. flavifolius, P. mezianum, D. macroblephara, B. aegyptiaca, S. discosporus and P. stramineum*, in that order. They constituted about 69% of the total diet. These plants were highly selected possibly because of their high relative abundance on the ground.

The proportions of grass and browse in the diets were significantly different ($P<0.05$) within and between the animal species (Table 5). The ratio of grass to browse was approximately 44:1, for sheep, during the wet season while that of Grant's gazelles was 2:1.

Table 4. Mean relative densities of forage plants in the diets of sheep and Grant's gazelles during wet and dry season

Plant species	Wet season		Dry season	
	Sheep	Grant's gazelles	Sheep	Grant's gazelles
Grasses				
Themeda triandra	16.8	11.1	18.9	8.3
Digitaria macroblephara	11.8	7.6	11.7	2.6
Pennisetum mezianum	10.3	7.8	11.8	4.7
Eragrostis cilianensis	7.1	2.2	4.7	4.0
Cynodon dactylon	4.6	T	5.1	2.4
Pennisetum stramineum	6.8	5.4	5.2	1.7
Brachiaria semiundulata	5.5	3.1	1.9	T
Dichanthium insculpta	3.8	1.7	4.2	T
Eustyachys paspaloides	3.7	5.0	5.4	8.0
Sporobolus discosporus	5.6	6.8	7.5	1.9
Ischaemun afrum	2.5	1.8	1.6	1.8
Aristida keniensis	1.3	2.2	1.2	1.7
Heteropogon contortus	T	T	T	T
Lintonia nutans	2.9	T	4.7	2.4
Brachiaria leersiodes	T	1.8	T	T
Harpachne schimperi	1.9	1.2	1.2	1.8
Brachiaria eruciformis	T	-	-	-
Hyparrhenia lintonii	T	1.3	T	-
Andropogon dummeri	T	-	T	-
Setaria verticillata	T	-	T	-
Panicum coloratum	T	T	T	-
Brachiaria reptans	-	-	T	-
Denebra retroflexa	-	-	T	-
Forbs				
Indigofera schimperi	2.4	-	T	T
Aspillia mossambicensis	1.7	1.5	1.1	1.4
Crotalaria pycnostachys	T	-	-	-
Barlaria acanthoides	2.6	1.2	2.9	2.4
Hermania alhiensis	1.1	0.6	2.6	1.2
Rhynchosia minima	T	T	T	-
Ipomoea mombassana	T	1.8	T	T
Commelina benghalensis	T	T	1.0	T
Solanum incanum	T	2.6	2.0	7.7
Browse				
Acacia drepanolobium	T	12.3	1.2	8.2
Balanites aegyptiaca	T	6.9	-	21.5
Hibiscus flavifolius	1.5	11.0	1.5	9.4
Acacia paoli	-	-	-	T
A. mellifera	-	-	-	T
A. seyal	-	-	-	2.3

T: trace amounts (<1%) -: Not observed in the diet

Sheep selected a significantly higher (P<0.05) percentage of grass compared to Grant's gazelles. Grant's gazelles' diets on the other hand comprised higher (P<0.05) percentage of browse and significantly less (P<0.05) grass than sheep in this season. The higher preference of grass by sheep and Grant's gazelles can be attributed to; (i) the high abundance and high variety of grass species in the study area, which gave the animal species opportunities to select more, grass than forbs and browse. (ii) the phenology of the grasses during the sampling period.

Table 5. Percent grass, forb, and browse in the diets of sheep and Grant's gazelles during the wet season

Forage class	Sheep	Grant's gazelles
Grasses	87.8 ± 3.4^{a1}	61.2 ± 4.5^{b1}
Forbs	10.3 ± 2.1^{a2}	8.7 ± 1.7^{a2}
Browse	2.0 ± 0.9^{a3}	30.1 ± 5.4^{b3}

Row and column means with different letter and numerical superscripts, respectively, are significantly different (P < 0.05)

4.2.2 Dry season diet composition

Thirty-two plant species were identified in the diets of the sheep while a total of 29 were identified in the diets of Grant's gazelles. The most preferred grass species by sheep were *T. triandra, D. macroblephara, S. discosporus, P. mezianum, C. dactylon, E. paspaloides,* and *P. stramineum*, in that order. These plants made up about 66% of the total diets. Their relative abundance in the diets reflected their relative abundance on the ground. For the Grant's gazelles, *B. aegyptiaca, H. flavifolius, T. triandra, A. drepanolobium, E. paspaloides* and *S. incanum* were the most preferred species constituting about 63% of their total diet. Besides being the most frequent plants, *B. aegyptiaca, H. flavifolius* and

A. drepanolobium, were the most preferred woody plants for Grant's gazelles a phenomenon, which was attributed to their relative greenness and accessible heights

In the dry season, the proportion of grass in the sheep diets was significantly higher ($P < 0.05$) than that in the diets of Grant's gazelles (Table 6). The reverse was true for the browse component. During the season the ratio of grass to browse was 21:1 and that of Grant's gazelles 1:1.

Table 6. Percent grass, forb, and browse (%) in diets of sheep and Grant's gazelles during the dry season

Forage class	Sheep	Grant's gazelles
Grasses	84.8 ± 2.2^{a1}	42.9 ± 5.4^{b1}
Forbs	10.9 ± 3.4^{a2}	14.2 ± 1.6^{a2}
Browse	4.3 ± 1.2^{a3}	42.9 ± 2.3^{b1}

Row and column means with different letter and numerical superscripts, respectively, are significantly different ($P < 0.05$)

There was no significant difference ($P<0.05$) in the amounts of grass and browse consumed by Grant's gazelles, although the two components were higher than the forbs. Grant's gazelles are able to assume a bipedal stance while feeding and can consume browse potentially available to them. This partly explains why the amount of browse in their diets increased during the dry season.

The proportions of the three forage classes in the diets of sheep were not significantly different ($P<0.05$) between the two seasons. Grant's gazelles showed a significant ($P<0.05$) change in the proportion of grass and browse in their diets between the two seasons. In the wet season, Grant's gazelles selected significantly higher percentage of grass compared to dry season. The reverse was true for browse component. The forbs is little consequence for the two animal species. Although forbs made up a relatively small component of the two animal species diets, their presence indicated the ability of the animal species to consume a wide variety of plants. Browse was selected mainly during the dry season when the herbaceous layer was mature and hence less succulent, less digestible and less palatable, (Karue 1975, Van Soest 1982, Ekaya 2001).

The results of this study are consistent with others in that sheep are grazers in both seasons. They will maintain a high proportion of grass in their diets in both seasons. The results agree with those of (Pratt and Qwynne 1977, Field 1979, Schwartz and Ellis 1981, Squares 1982, Mugambi 1982, Wangoi 1984, Ghosh *et al.* 1986) who reported that sheep are grazers. However, Field (1972), Coppock (1985) and Ekaya (1991) working in different study areas classified sheep as intermediate feeders. The forb and browse made up relatively small proportions of the sheep diets. Though poorly represented in the diets, presence of some of the forbs could be due to their high nutritious value. Jensen *et al* (1972) found that forbs were important components of sheep diets at all times. Wangoi (1984), Ekaya (1991) and Pfisher and Malechek (1986) reported that browse component in sheep diets increased during the dry season, while in the wet season, sheep selected mainly grasses and forbs. The seasonal consistency of sheep in terms of preferred plant species agreed with findings of Mugambi (1982), Coppock (1985), Wangoi (1984) and Ekaya (1991) working in Kenya who recorded *T. triandra*, *Pennisetum* spp., *Hyparrhenia* spp., *Eragrostis* spp. and *D. macroblephara* as the preferred species.

Grant's gazelles were mixed feeders throughout the study period. These results are in agreement with those of Lamprey (1963), Schenkel (1966), Hoffman (1973), GOK (1979), and Sommerate and Hopcraft (1994), who also classified Grant's gazelles as mixed feeders. However, Talbot and Talbot (1962), Maloiy (1963) and Spinage *et al* (1980) reported that the Grant's gazelles were primarily browsers. The current study reported *B. aegyptiaca, A. drepanolobium* and *H. flavifolius* as the major woody plant species in both seasons. The three woody plant species especially *B. aegyptiaca*, remain green and retain their succulent leaves during the dry season. *T. triandra* was recorded as a major grass species in the diets of Grant's gazelles. The most likely explanation for the preference of *T. triandra* by Grant's gazelle is its high relative frequency in the study area. Grant's gazelles have finer muzzles which allows them to select the high-nutritious dry season browse species, such as *Acacia, Balanites, Solanum* and *Calatropis* spp., and young leaves between the thorns of *Acacia* bushes (Talbot and Talbot 1962).

Some hypothesized aspects of diet selection in relation to rumino-reticular volume to body weight advanced by Henley (1982) may also apply in this study. The high rumino-reticular volume to body weight ratio, as in sheep is an adaptation to high cellulose content diet, typically a diet consisting primarily of grass. On the other hand, low rumino-reticular volume to body weight ratio as for Grant's gazelles is an adaptation to a diet, composed primarily of grasses, forbs and browse (mixed feeder) (Hoffman and Stewart 1972).

4.3 Diet diversity and overlap

In the wet season, the mean diet diversity index was greater for Grant's gazelles' (0.39) and less for sheep (0.18). There was significant difference (χ^2, $P < 0.05$) in diet diversity between the two animal species within each season. This implies that Grant's gazelles tended to have a wide variety of plant species in their diets, selected from the three forage classes as compared to sheep. The same trend was also observed in the dry season during which Grant's gazelle had a diet diversity index of 0.42, whereas sheep had an index of 0.20. Although there was slight increase in the diet diversity index for both animal species during the dry season, this was not significantly different (χ^2, $P>0.05$). However, the slight increase in the diet diversity may be attributable to the seasonal change in forage-class quantity. For instance, there was an increase in the proportion of forbs and browse material consumed by the two animal species. Grant's gazelles had the most variable diets than sheep, which confirmed their reputation as mixed feeders.

Mean diet similarity indices based on the 28 and 25 plant species commonly selected by the two animal species during the wet and dry seasons respectively, indicated that the diets overlapped more in the wet season (0.72) than in the dry season (0.04). This was attributable to the similarity in food habits exhibited by the two animal species in the wet season. Similarity was highest during the wet season when the two animal species consumed considerable amounts of grass. The degree of overlap decreased as the dry season approached with the Grant's gazelles reducing their grass consumption and increasing browse utilization. Elsewhere, logistic model for Grant's gazelle indicated complementarity with kongoni and competitive with oryx (Kinyua and Njoka 2001).

These results were consistent with the feeding behaviour of these species. Grant's gazelle and oryx are mixed feeders while kongoni is a grazer that prefers short grasses (Schenkel 1966). However, herbivores with overlapping food preferences do not necessary indicate competition unless the resources being shared are limiting (Colwel and Futuyma 1971). Feeding on different plant parts at different growth stages (Gwynne and Bell 1968) may ecologically separate the two animal species. Ecological separation of the two animal species may also be achieved by spatial separation (Talbot and Talbot 1962). The two animal species were therefore ecologically separated by feeding on different variety of plant species from different vegetation strata (Lamprey 1963). This demonstrates the feeding complementarity of these two species and suggests that a combination of the two animal species provide a more efficient utilization of forage at Athi Kapiti plains.

There was a positive correlation between the ranked orders of preference of shared plant species in the averaged seasonal diets. The Spearman's rank-order correlation coefficient (R_n= 0.32) between the diets of the two animal species in the wet season indicates that the order in which they selected similar plant species was not significantly different ($P>0.05$). This was possibly due to the high preference for the actively growing grass species by the animal species in the wet season. There could also be some notable differences in plant-part selection. In the dry season however, the order of preference (R_n=0.57) for the plant species selected in common was significantly different ($P < 0.05$) i.e. there was a strong correlation for the order in which the two animals species selected the same plant species that constituted their diets. There was a potential for competition by the two kinds of animals for these plant species.

4.4 Nutrient composition of animal diets

The nutritional characteristics of diets selected by the sheep and Grant's gazelles during the wet and dry season are presented in Tables 7 and 8.

Table 7. Nutritional characteristics (mean ± SE) of diets of sheep and Grant's gazelles during the wet season

Nutritional variable	Sheep	Grant's gazelles
Crude protein	5.8 ± 0.01[a]	6.8 ± 0.14[b]
Neutral detergent fibre	64.8 ± 1.95[a]	53.4 ± 1.26[b]
Acid detergent fibre	38.2 ± 0.55[a]	32.5 ± 0.57[b]
Acid detergent lignin	4.4 ± 0.25[a]	7.1 ± 0.04[b]
Cellulose	30.4 ± 0.33[a]	25.4 ± 0.69[b]
In vitro dry matter digestibility	67.9 ± 1.05[a]	82.6 ± 0.53[b]

Row means with different letter superscripts differ significantly ($P < 0.05$)

4.4.1 Wet season

The sheep diets were higher ($P< 0.05$) in NDF, ADF and cellulose, but less in IVDMD, CP and ADL than those of Grant's gazelles (Table 7). The observed differences in the nutrient components of the diets selected by the two animal species in this season were a reflection of their forage preferences. The higher fibre content in the diets of sheep can be explained by the high proportion of the grass components in their diets as compared to those of Grant's gazelles. The high and low preferences of browse and grass respectively, by the Grant's gazelles explain why their diets contained higher CP and IVDMD than those of sheep. It has been reported that browse from young growing woody plants have high CP (Otsyina and McKell 1985). Elsewhere, it has been shown that grasses contain high levels of NDF and this poses a problem during digestion (Reed 1986). The high preference for browse by Grant's gazelles as compared to sheep explains why their diets were higher in ADL. However, it has been reported (Van Soest 1982) that young growing browse plants contain high levels of secondary compounds e.g tannins, which may interfere with the digestion processes in the animals (Mould and Robbins 1981). It is possible then, that these compounds affected the digestibility of the browse consumed by the animal species.

4.4.2 Dry season

During this season, Grant's gazelles' diets were higher ($P < 0.05$) in CP and IVDMD values but lower in NDF, ADF and cellulose than those of sheep (Table 8). The high fibrous fractions and low protein content in the sheep diets can be attributed to the high and low proportions of grasses and browse in their diets, respectively. Due to high preference for browse during this season, Grant's gazelles' diets exhibited higher ADL than those of sheep.

Table 8. Nutritional characteristics (mean ± SE) of diets of sheep and Grant's gazelles during the dry season

Nutritional variable	Sheep	Grant's gazelles
Crude protein	4.2 ± 0.01^{a}	8.1 ± 0.05^{b}
Neutral detergent fibre	74.5 ± 0.19^{a}	61.6 ± 0.42^{b}
Acid detergent fibre	47.5 ± 0.74^{a}	37.4 ± 0.76^{b}
Acid detergent lignin	6.7 ± 0.19^{a}	9.6 ± 0.25^{b}
Cellulose	37.0 ± 0.54^{a}	29.8 ± 0.20^{b}
In vitro dry matter digestibility	54.9 ± 0.47^{a}	67.2 ± 0.13^{b}

Row means with different letter superscripts differ significantly ($P < 0.05$)

Influence of season on the nutrient components of both animal species was observed. In general, dietary IVDMD were significantly higher ($P < 0.05$) in the wet season than in the dry season. NDF, ADF, ADL and cellulose were significantly higher ($P < 0.05$) during the dry season. Dietary CP was higher for sheep and Grant's gazelles in wet and dry season repectively. The higher IVDMD exhibited by the animal specie's diets can be attributed to the higher availability of green herbage during the wet season as compared to the dry season. The animal species are able to select more leaves and the new growth, which are more digestible

Significant variations in nutritional components in the diets were also observed within animal species between seasons ($P < 0.05$) The sheep diets were higher ($P<0.05$) in CP and IVDMD in the wet season and in fibrous fractions in the dry season. Diets of Grant's gazelles on the other hand, had significantly higher CP, and ADL ($P<0.05$) during the dry season than in the wet season. Dietary CP, IVDMD and ADL on the other hand, were significantly higher ($P<0.05$) in Grant's gazelles than in that of sheep in both seasons However, the diet of Grant's gazelles despite having a higher content of lignin than those of sheep, had higher ($P < 0.05$) dry matter digestibility. It seems that the lower NDF and higher CP compensated the digestibility depressing effect of lignin in the diets

The observed differences in the nutritional characteristics of the animals' diets were due to the nutrient dynamics of the forages preferred by each animal species over the two seasons. High diet quality values occurred during the wet season, which was a period of active plant growth when the grazing animals would have been actively selecting for leafy, green plant materials (Mnene 1985, Tessema 1986). Periods of advanced plant maturity have been documented as periods of low CP and IVDMD (Smith *et al.* 1971, Haggar *et al.* 1971). The observed differences in the nutritional characteristics of the diets selected by the two animal species during the two seasons are a reflection of different food habits exhibited by the two animal species. Sheep diets, which were dominated by grasses in both seasons, had higher total fibre content. The dependence on grass by sheep is thus a great disadvantage in the dry season during which time mature range grasses have low CP content and high fibre content. This accounts for the much lower CP and IVDMD and higher NDF, ADF and ADL of sheep diets in the dry season. According to McDowell (1985) animals in tropics need a diet containing 7% CP to maintain their weight. Thus the CP value in the diets during the two seasons seems to fall below the requirements for maintenance of sheep. Various authors (Van Soest 1982, Wangoi 1984, Milford and Minson 1986) reported dietary CP of 7-8% as the critical minimum for efficient microbial activity including maintenance of positive nitrogen balance, below which digestibility decline. This indicates that during the dry season, protein content in grasses can be potentially limiting to the utilization of rangelands by sheep, and protein content supplementation being sometimes necessary. Leng (1990) reported that 65% DMD indicates a good quality diet and high digestibility. This indicates that because of the reported high DMD values during the wet season, the animal species selected good quality and highly digestible diets. But in the dry season, sheep selected poor quality and lowly digestibility diets than the Grant's gazelles. Grant's gazelles depended more on browse species, which contain higher CP and cell solubles, which are more digestible and show a slower decline in quality with advancing maturity than grass species, and they were therefore able to ingest diets of better nutritional quality than sheep during the dry season.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

The findings of this study revealed some important differences between the feeding behaviour of sheep and Grant's gazelles. The data on diet composition at species level showed that *Themeda triandra*, *D. macroblephara*, *P. mezianum*, *P. stramineum* and *C. dactylon* were the most preferred plant species by the sheep during the wet and dry season. Grant's gazelles showed high preference for *B. aegyptiaca*, *H. flavifolius*, *A. drepanolobium*, and *T. triandra* during the two seasons. The results on the proportion of grass, forbs and browse in the diets of the two kinds of animals showed that the three components were significantly different within and between the animal species during the two seasons. Sheep showed a higher preference for grass followed by forbs and browse. Grant's gazelles on the other hand showed higher preference for grass than browse and forbs. Grant's gazelles are mixed feeders with high preference for grasses in the wet season and equal preference for both grasses and browse during the dry season. Sheep are grazers with highest preference for grasses during the two seasons. Sheep and Grant's gazelles feeding together should therefore be complementary.

Data on diet diversity based on the grass, forbs and browse contents, revealed that Grant's gazelles were better able to adopt their diets to change in vegetation at Athi Kapiti plains than sheep. The Grant's gazelles utilized different plant species selected from the three forage classes. The results on dietary overlaps unveiled that the two animal species overlapped more in the wet season than in the dry season. This might have management implications on the vegetation composition and therefore suitability of the range to the animals in the long run. As the animals compete for the relatively nutritious herbaceous plants, they continuously reduce the photosynthetic tissues of these plants, in effect reducing the plant capacity to manufacture both storage and structural materials. These plants will lose vigour and their recovery following the stressful periods would be hindered. Therefore optimum stocking and harvesting rates as well as timing of grazing should be considered during the wet season.

Data on diet quality showed that Grant's gazelles selected nutritionally superior diets with higher crude protein and lower fibre content than sheep. This was largely because of the tendency of Grant's gazelles to consume both browse and grasses available in the ranch. This inclination could confer a great survival advantage to Grant's gazelles relative to sheep especially during the dry season. The dependence on grass by sheep is a great disadvantage in the dry season, during which mature range grasses have low protein content and less digestible. Hence management strategies aiming at improving the production of the animals should develop optimal programs for grazing and over-sowing the ranch with legumes. Plant foliages and pods from *Acacia* species, normally fed dried or fresh will be recommended as a means of improving the diet quality and digestibility for sheep. Supplying deficient protein may also increase the digestibility of other nutrients. Consequently efficient utilization of range forage and sheep production will be improved.

This study was carried out over two seasons within a year, and further research work needs to be done to cover at least two wet and dry seasons and probably for a number of years in order to have a thorough study on the subject. The study should also include habitat use and productivity of the two animal species. In future studies it would be desirable to simultaneously quantify food habits, food distribution, herbage production, and herbivore populations by seasons. There is lack of knowledge on the carrying capacity of land in Kenya's southeastern rangelands. Scientific census and regular checking of animal numbers in the ranches are necessary for determining the carrying capacity of the ranches.

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7.0 APPENDICES

Appendix I. Botanical names of plant species identified at the study site

1. *Andropogon dummeri* Staff
2. *Aristida keniensis* Henr.
3. *Asystacia schimperi* T. Anders
4. *Dichathium insculpta* (A. Rich) A. Camus
5. *Brachiaria eruciformis* Griseb
6. *Brachiaria leersioides* (Hochst) Forsk
7. *Brachiaria reptans* Staff
8. *Brachiaria semiundulata* (A. Rich) Staff
9. *Cynodon dactylon* (L.) Pers.
10. *Digitaria macroblephara* (Hack) Staff
11. *Dinebra retroflexa* (Vahl) Panzeor
12. *Eragrostis cilianesis* (All.) Lutati
13. *Eustachys paspaloides* (Vahn) Lanza & Mattei
14. *Harpachne schimperi* A. Rich
15. *Heteropogon contortus* (L.) Roem & Schuut
16. *Ischaemum afrum* (J. F. Gmel) Dandy
17. *Hyparrhenia lintonii* Staff
18. *Lintonia nutans* Staff
19. *Microchloa kunthii* Desv.
20. *Panicum coloratum* L.
21. *Pennisetum mezianum* Leek
22. *Pennisetum stramineum* Peter
23. *Setaria verticillata* (L) Beauv
24. *Sporobolus discosporus* Nees
25. *Themeda triandra* Forsk
26. *Tragus berteronianus* Schult
27. *Ageratum conyzoides* (L)
28. *Aspilia mossambincensis* (Oliv) Willd.
29. *Barlaria acanthoides* Vahl
30. *Bidens ugandensis* Sherff
31. *Blepharis hildebrandtii* Lindau
32. *Cassia mimosoides* (L)
33. *Commelina benghalensis* (L)
34. *Conyiza schimperi* Sch. B. P
35. *Corchorus olitorus* (L)
36. *Crotolaria pycnostachya* Benth
37. *Elvolvulus alsinoides* (L)
38. *Erlangea calycinum* S. Moore
39. *Euphorbia heterochroma* Pax
40. *Hermania alhiensis* K. Schum
41. *Hirpicium diffussa* O. Hoffm
42. *Hypoxis obtusa* Burch
43. *Indigofera schimperi* Jaub & Spach
44. *Ipomoea mombassana* Vatke
45. *Leucas calostachys* Oliv
46. *Monsonia angustifolia* A. Rich

47. *Oxygonum sinuatum* (Meisn) Dammer
48. *Pentanisia ouranogyne* S. Moore
49. *Phyllanthus maderaspatensis* L
50. *Priva curtisiae* Kobuski
51. *Rhynchosia minima* L.D C
52. *Rubia cordifolia* L.
53. *Sida cuneifolia* Roxb
54. *Solanum incanum* L.
55. *Tephrosia pumila* (Lam) Pers.
56. *Acacia drepanolobium* Herms ex Sjostedt
57. *Acacia mellifera* (Vahl) Benth
58. *Acacia paoli* Chiov
59. *Acacia seyal* Del
60. *Balanites aegyptiaca* (L.) Del.
61. *Hibiscus flavifolius* Ulbr.

Appendix II Heights of the woody plants within the study site

Plant species	Height (m)
A. drepanolobium	0 85
H. flavifolius	0 60
A. seyal	1.20
B. aegyptiaca	2.29
A. mellifera	0.77
A. paoli	0.75

Appendix III Monthly rainfall (mm) received since 1991 to 2000 and during the study period (March to September 2001)

Year	Months											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991	1.71	1.06	1.2	2.04	2.57	1.18	0.1	0.45	0	3.62	2.85	5.19
1992	0	0.04	0	7.87	1.26	0	0.08	0	0.08	1.95	2.34	2.69
1993	22.6	75	23.5	3.5	19	0	0	0	0	12.5	115.5	16.5
1994	0	121.5	41	37.5	51	0	3	3.5	0.5	84	167.5	106.5
1995	17	84.5	126	42	33.5	0	0	5	0	58.5	35.5	26
1996	29	37	90.5	48	42.5	22.5	0	0	27.5	0	124	0
1997	2	0	38	197	62.5	11	10	4.5	0	61	248.5	190
1998	200.5	93	40.5	111.5	239	23	10	2	0	0	86	13.5
1999	11.5	0	134.5	57	5	0	3.5	18	0	10	229	54
2000	10	0	14.5	38.5	40	2	5.5	5	2	20	80	53
2001			62	90	0	0	7	4	0			