THE ECOLOGY OF LARGE HERBIVORES IN HELL'S GATE NATIONAL PARK - NAIVASHA - KENYA

A thesis submitted for the degree of Doctor of Philosophy
at the University of Leicester

by

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PARK MANAGEMENT

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ABSTRACT

This study sought to determine the population size, density, distribution, habitat utilization and biomass of large herbivores in Hell's Gate National Park and two neighbouring ranches, Kedong and Kongoni. The study further determined primary production and wildlife grazing in the Park grassland, the effects of wildlife on the vegetation around the Park's artificial water troughs and the effects of Maasai livestock and geothermal prospecting on the Park vegetation.

Herbivore counts were carried out in Hell's Gate National Park and the two neighbouring ranches between February 1990 and April 1992. Kongoni, zebra and Thomson's gazelle were found to be the most abundant species. The distribution pattern exhibited by the ungulates in the three areas was neither random or regular, and appeared to be influenced by both topography and vegetation type. Dry and wet season distribution patterns of the wildlife were similar. In the three study areas, most of the herbivores were found to prefer the grassland followed by relatively open shrubland. Areas of dense vegetation and rugged terrain were not preferred.

Kongoni, zebra, eland and buffalo contributed the highest proportion of the herbivore biomass. They contributed 82% of the total herbivore biomass in the Park, 85% in Kedong Ranch and 82% in Kongoni Ranch. The herbivore biomass fluctuated monthly depending on population fluctuations, such that when there was a high count of the herbivores in a given month, there was a corresponding high biomass.

Above-ground primary production and herbivore grazing were estimated in the Park grassland which was the main grazing area for most of the ungulates. There were two peaks of primary production which coincided with the occurence of the long and short rains, such that there was a significant linear regression between net primary production and rainfall. The monthly amount of dead and live grass biomass fluctuated in response to seasonal rainfall, such that during the dry season the amount of dead biomass increased while that of the live biomass decreased and *vice versa* during the wet season. There was a significant linear regression of live grass biomass on rainfall, but there was no significant correlation between rainfall and dead grass biomass. The annual productivity of the grassland was 720g/m^2/yr, and the total annual offtake of the grass forage by the herbivores was 12.7%. Therefore, most of the grass forage dried up to form dead biomass which was probably of little food value to the wildlife.

The effect of both wildlife trampling on the vegetation around three artificial water troughs and illegal livestock grazing on the Park vegetation (in the Narasha area) were studied between April 1990 and April 1992. Overall, vegetation cover between the trampled and

untrampled areas of the water troughs did not show any significant difference. Trampling also did not lead to any overall difference in plant species composition, diversity and abundance between the trampled and untrampled areas.

Livestock grazing at Narasha did not lead to a significant difference in percentage vegetation cover and mean species diversity between the grazed and ungrazed areas. Although some plant species were only found in either the grazed or ungrazed areas, overall, grazing appeared not to lead to a significant difference in plant species composition and abundance between the two areas. It was therefore concluded that livestock grazing was not altering the Park vegetation in any significant way.

The long term future of the Hell's Gate ecosystem (the Park together with the surrounding ranches) as a self sustaining unit requires that its current ecological integrity be maintained. The human activities that are taking place within it, especially expansion of agriculture, will determine its future, and if not controlled will lead to loss of wildlife habitats and a decline in the population size of the various herbivore species found within it.

CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Conservation of wildlife has become a global issue and has raised great concern in different countries. Most African countries have already realised the economic and potential value of wildlife (Ajayi *et al.*, 1981). In East Africa, it forms the backbone of the tourist industry, generating foreign exchange (Eltringham, 1984; Lamprey, 1962). Apart from its tourist value, wildlife is a potential source of food (Eltringham, 1984; Ramade, 1984) with about 75% of Africa's population depending on it as a source of protein (Asibey, 1974). In Botswana for example, 60% of the annual meat consumption comes from wildlife (Von Richter, 1970), while in Senegal about 3.7 $x10^5$ metric tons of game meat are consumed annually (Cremoux, 1963).

The rate at which Africa's wildlife (especially East Africa's) is being depleted has also raised a global concern (Eltringham, 1984; Ramade, 1984). The two main causes of this decline is illegal poaching and habitat destruction (Asibey, 1974; Myers, 1975, Osemeobo, 1988). Calls have been made for a global collective responsibility to save wildlife and the habitats upon which they depend. The most affected species are the african elephant *Loxodonta africana*, the black rhino *Diceros bicornis* and the white rhino *Ceratotherium simum*. In Uganda for example, poaching reduced elephant population of Ruwenzori and Kabalega National Parks to 5% of their original numbers (Malpas, 1981), while in Kenya between 1973 and 1980 they were reduced by two thirds (Anon, 1980). In Africa as a whole, poaching had reduced the elephant population from about 1.3 million in 1979 (Douglas-Hamilton, 1979) to approximately 625,000 by 1989, while the black rhino population was reduced to 9,000 by 1984 from an estimated 14,000 in between 1980 and 1984 (Western and Vigne, 1985).

Apart from poaching, the other threat to Africa's wildlife is an increasing human population which has led to large areas previously occupied by wildlife being converted into agricultural land, leaving small and marginal areas for wildlife. Large populations of livestock kept by pastoralists as a sign of wealth are also a great threat as they compete with wildlife for the same grazing areas (Mordi, 1989).

Having realised the economic importance of wildlife, and in order to save it from extinction, different countries have set aside land in the form of parks and reserves in which wildlife is preserved. In Kenya, the government has set aside large areas as National Parks and Game Reserves (parks occupy 29,500 km^2 and reserves occupy 15,550 km^2, which is 5% and 2.7% of the total land area respectively). National Parks are under Kenya Wildlife Service (K. W. S) and any revenue generated from them goes to this parastatal, whereas in the case of Game Reserves, these are managed by local councils or government and any revenue generated from them goes to the councils. For example, Masai-Mara and

Samburu Game Reserves are managed by the Narok and Samburu County Councils respectively. No human activites like cattle grazing are allowed in National Parks, but in Game Reserves these activities are allowed, for instance in Masai-Mara Game Reserve, grazing and watering of local Masai livestock is allowed especially during the dry season.

The problem with these conservation areas is that they are remnants of the large habitats that were previously occupied by wildlife and for some species like elephants they have proved to be insufficient in meeting habitat and food requirements. Man therefore, has to manage them in order to retain their ecological integrity. Areas adjacent to them which formerly acted as buffer zones or important dispersal areas are increasingly being encroached by settlement, leaving the wildlife to concentrate in small areas which do not fully meet their home range and habitat requirements. The encroachment has meant that the animals cannot migrate annually to new areas as they did before man interfered with their habitats, thus making them unable to cope up with natural climatic changes such as drought.

Although the Kenya government generates considerable revenue from tourism, serious ecological problems face conservation areas upon which it depends and these might deteriorate unless management strategies are formulated and properly implemented. With the country's current population growth rate, human pressure is mounting in and around the conservation areas as people look for more land to settle and cultivate. In certain of the conservation areas like Amboseli, Nairobi and Nakuru National Parks, tourists too have already interfered with their ecology through overuse (Anon, 1973; Henry, 1977), and this calls for a management strategy to prevent further damage to these parks. Therefore if wildlife conservation in Kenya (and in East Africa) is going to be a leading foreign currency earner, then management for existing conservation areas is vital. The existing management plans for these areas need to be reviewed frequently to evaluate their effectiveness and be modified as the situation demands. Detailed scientific studies should be encouraged and their findings and recommendations put into practical use.

Kenya Wildlife Service has come up with a new management policy where construction of facilities such as hotels, lodges and Park houses in all Parks is to be concentrated in future at the entrance gates whereas previously such infra-structures were constructed inside the Parks. For instance, in Nakuru National Park, the Park facilities are being transfered to the provincial headquaters in Nakuru town (Ruhiu pers. comm.). In order to enhance wildlife conservation in both Parks and Game Reserves and their environs, Kenya Wildlife Service has introduced a policy where the revenue generated from these areas is being shared between the government and the local people. Part of the revenue is therefore being used to construct schools, hospitals, dispenseries, cattle dips and provide pumped water, and these facilities are shared between the local people and the Park or Game Reserve administration. It is hoped that the local people will in turn support wildlife conservation effort in these conservation areas and their environs. Such an arrangement is already taking place in both Amboseli National Park and the Masai-Mara Game Reserve.

A particular current problem of many Parks is vegetation damage by tourist vehicles. For instance, off-road driving is quite common in Amboseli National Park and the Masai-Mara Game Reserve and this leads to loss of vegetation cover. To reduce this problem, the management has come up with a strategy where any drivers from tour operating companies caught off-road driving will not be allowed to take their tourists to these areas in future. The other strategy is that any off-road tracks are closed for use by tourist vehicles and by so doing allow their vegetation to recover.

Hell's Gate National Park is a relatively new conservation area, established in 1984. A management plan was produced in 1985 (W. C. M. D, 1985) which was revised in 1992 to guide the management of the Park for the period 1991-1996 (K. W. S - Planning Department, 1992). The overall goal of the Park is the preservation and protection of the Park's geomorphological features, fauna and flora. To achieve this goal, several management objectives have been proposed and in summary they include:

(a) Conservation of unique scenic features such as the cliffs, Central and Fischer's towers, caves and steam vents.

(b) Conservation of fauna and flora, mainly the *Tarchonanthus* shrubland.

(c) Provision of educational and research opportunities.

(d) Soil conservation.

To aid in achieving these objectives, various management procedures have been proposed :

(a) Participation of the Park warden on the District Development Committe to represent the interests of Kenya Wildlife Service.

(b) Provision of water for the local people especially the Masai and their livestock. It is hoped that when this is done, it will eliminate the problem of Masai grazing and watering their animals in the Park.

(c) Revenue sharing. This will involve funding of community based projects like construction of cattle dips, schools, health centres and supply of pumped water using some of the revenue generated by the Park.

(d) Prevention of Park encroachment by the Masai. This will help prevent illegal Masai squatters living and grazing in the Park.

However, there is little scientific basis for the Park management plans of 1985 and 1991-1996, and this led me to carry out my study.

Like most Parks of East Africa, Hell's Gate National Park is already facing encroachment by man. Adjacent areas to the Park such as the Sulmac and Oserian Development Companies (floricultural enterprises); Kedong, Kongoni and Akira Ranches have already been or are gradually being settled by man, and have been or are being converted into agricultural land for both crop growing and livestock keeping. All these areas used to be occupied by wildlife and therefore their settlement by man has displaced the wildlife which is being forced to occupy a smaller area than it used to.

Livestock keeping in the region is on the increase, and in Kedong, Kongoni, Akira Ranches and at the Narasha area of the Park, cattle graze in the same areas with wildlife. Another threat to the viability of the Park is the Olkaria geothermal power station which operates within the Park. This station, the only one in Africa, produces electricity using underground steam and is gradually expanding to meet the demands of electricity for both domestic and industrial use. Its existence and planned expansion has ecological implications considering that the Park has been established not only as a tourist attraction, but also to conserve the fauna and flora of the region. In view of these human activities that are taking place in the ecosystem, there is a need to study the wildlife populations of the region, and from this provide data on their status.

The objectives of this study were therefore:

(a) To determine the population size, density, biomass, habitat utilization and distribution of the large herbivores.

(b) To determine primary production and wildlife grazing in the Park grassland.

(c) To investigate the effects of wildlife on the vegetation around the Park's artificial water troughs.

(d) To investigate the effects of Maasai livestock on the vegetation.

(e) To investigate the effects of geothermal prospecting on the vegetation.

1.2 THE STUDY AREA

The study was carried out in Hell's Gate National Park (area 68.25km^2) between February 1990 and April 1992. The Park is situated in the Eastern Rift Valley (Nakuru District) approximately 100km N.W of Nairobi and 19km South of Naivasha town (Figure 1.1). To the West are the Mau escarpment and Eburru Mountains, while the Nyandarua Ranges (Aberdares) and Kinangop Plateau are to the North east. Lake Naivasha and Mount Longonot are to the North and South east respectively (Figure 1.2). The Park lies between longitude 34^0 23' East and 36^0 30' East and between latitudes 0^0 30' South and 1^0 00' South. The region where it is located is semi-arid, and is in ecological zone IV of Pratt *et al.* (1966), where *Tarchonanthus* - *Acacia* shrubland dominates.

The Njorowa Gorge, once an outlet of Lake Naivasha during the Holocene period (Gaudet and Melack, 1981), dissects the Park into two unequal parts (Figure 1.3). The Hell's Gate area is one of the Rift Valley regions which is still volcanically active. Hot springs, steam vents and fumaroles are common especially on the western part of the Park.

Figure 1.1: Hell's Gate National Park: National Setting

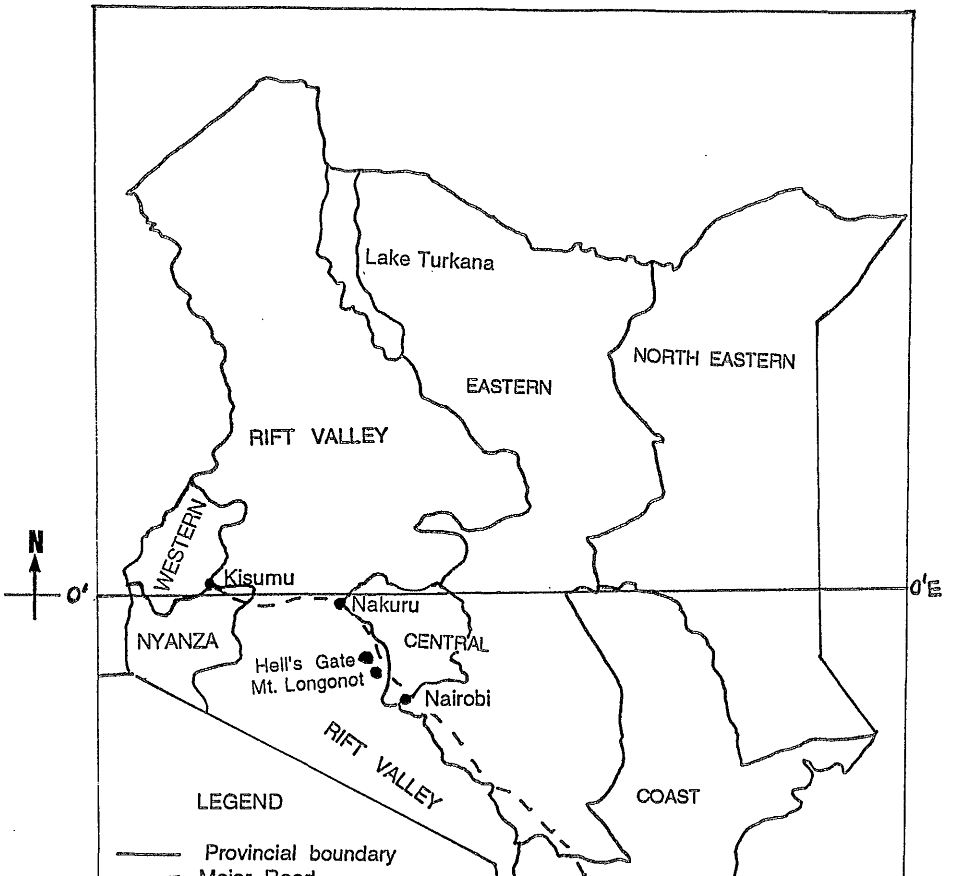


Figure 1.2: Naivasha drainage basin (Modified from Gaudet and Melack, 1981). N - Lake Naivasha, Ol - Lake Oloidien, G - Gilgil River, M - Malewa River.

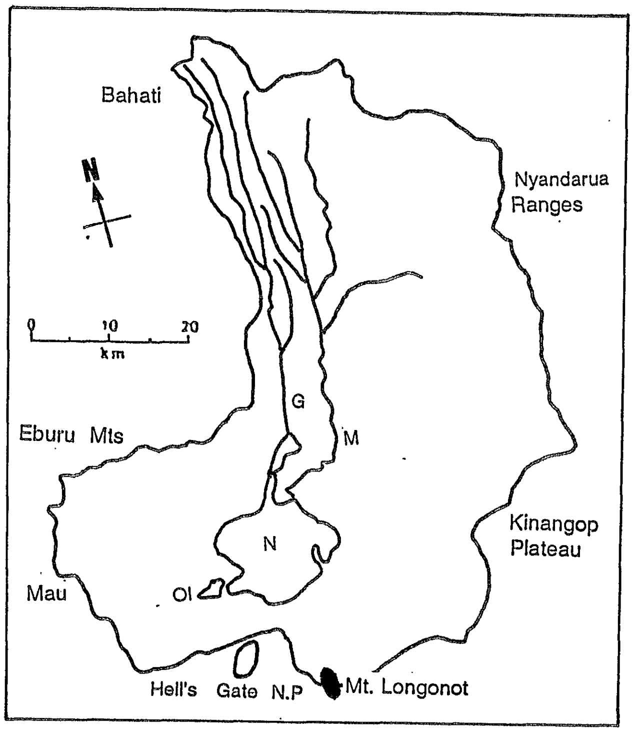
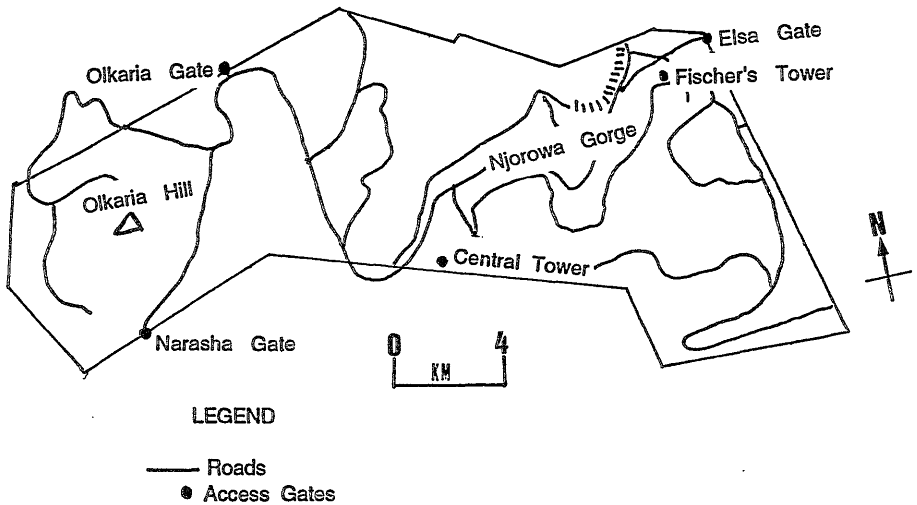


Figure 1.3: Hell's Gate National Park: Njorowa Gorge and Roads



1.3 CLIMATE

The climate of the area is warm and dry with a mean annual rainfall of about 550mm (W.C.M.D, 1985). Rainfall is bimodal in nature, and is both unreliable and unpredictable. Long rains normally occur from April to May and the short rains from late September [or sometimes early October] to November. In July and August, weather conditions are relatively cool with some occasional rain, while December to late March are dry and hot months. Temperatures range from about 5 ^{o}C to 33 ^{o}C. Mean rainfall and temperature data for the region (1980-90) are presented in figure 1.4 and 1.5.

The adjacent highlands such as Kinangop plateau receive more rain than the Park which is on the leeward side of the plateau. Although it is adjacent to the Lake Naivasha catchment area (Figure1.2), there are no permanent drainage streams passing through the Park. The main rivers from the catchment - the Malewa and Gilgil end up in the lake. This has necessitated water to be pumped from the lake to the Park for drinking by wildlife.

1.4 GEOLOGY AND SOILS

The geology of the area is quite diverse. The region within and around the Park is mainly covered by sediments which accumulated during the Pleistocene period. Rocks are mostly under-saturated tephrites and acid rocks like rhyolites and sodic rhyolites. The Njorowa Gorge has commendite sediments with underlying grey and pumicious ashes. Tephrites, trachytes, basalts, tuffs, phonolites and agglomerates are the major volcanic rocks found in this region. Obsidian, rhyolite and commendite are also common. Being a volcanic area, soils are mostly porous volcanic ash derived from volcanic rocks, and are easily eroded. Depending on their origin or parent material they can be categorised into:

(a) Those derived from lacustrine lake deposits
(b) Those derived from lava and
(c) Those derived from pyroclastic rocks.

The Park soils are poor in exchangeable cations (Na^{+}, Mg^{2+} and Ca^{2+}), percentage carbon and nitrogen; and have a low cation exchange capacity (C.E.C) (Kiringe, 1990). Over 50 per cent of the soil is sand and the rest is made up of clay and silt. This high amount of sand make the soils very porous reducing their water holding capacity.

1.5 FLORA

The Park can be divided into three major vegetation types (Kiringe, 1990) making up thirteen vegetation communities (Figure 1.6). The major vegetation types are:

(a) *Cynodon /Digitaria* grassland and *Digitaria /Acacia* dwarf shrub grassland

Figure 1.4: Mean +/-S.E rainfall for Hell's Gate area 1980 - 90 (Data source: Sulmac Dev. Comp.)

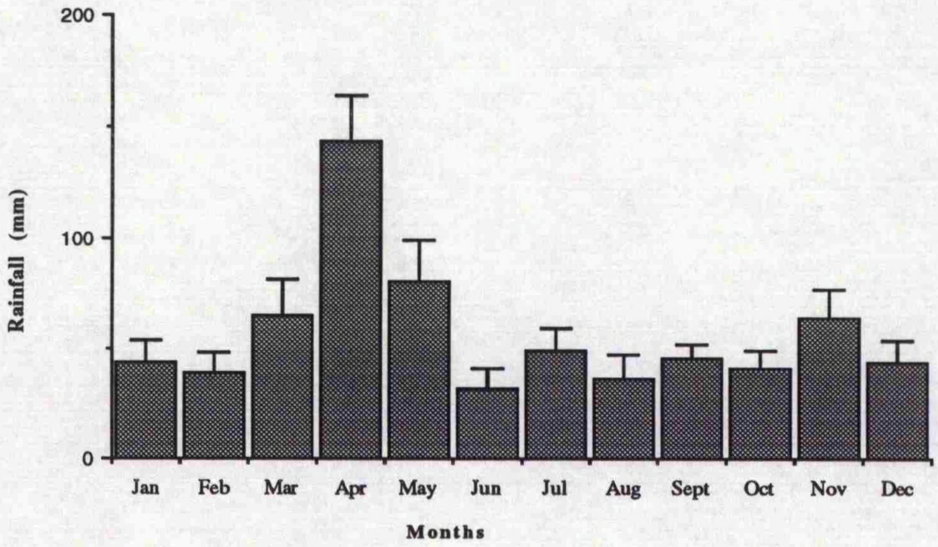


Figure 1.5: Temperature for Hell's Gate area (Data source: Sulmac Dev. Comp.)

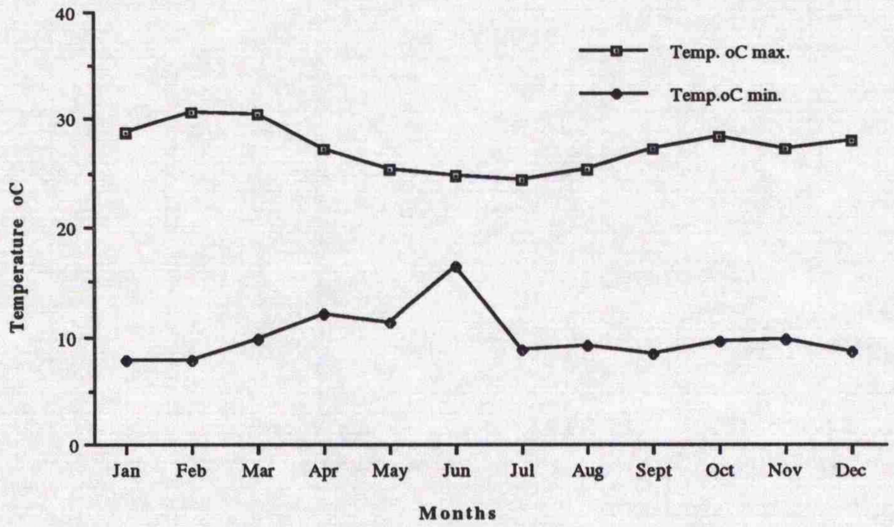
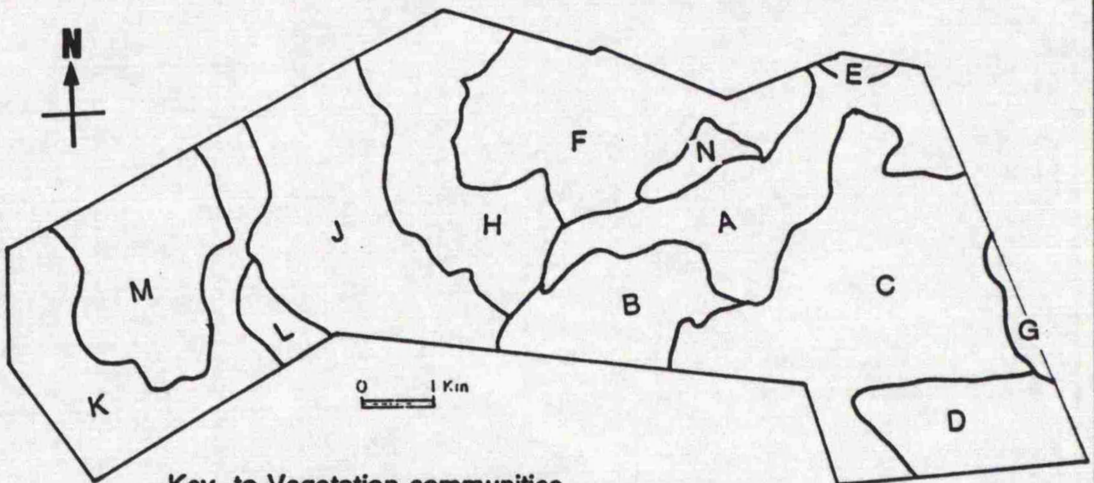


Figure 1.6: Hell's Gate National Park: Vegetation Communities - 1988/89



Key to Vegetation communities

A-*Cynodon* / *Digitaria* grassland

B-*Hyparrhenia* / *Digitaria* / *Tarchonanthus* / *Acacia shrubland*

C-*Themeda* / *Tarchonanthus* / *Acacia* dwarf shrubland

D-*Themeda* / *Digitaria* / *Tarchonanthus* / *Acacia* shrubland

E-*Digitaria* / *Hyparrhenia* / *Tarchonanthus* / *Dodonea* shrubland

F-*Digitaria* / *Tarchonanthus* / *Acacia* dwarf shrubland

G-*Digitaria* / *Acacia* dwarf shrub grassland

H-*Themeda* / *Digitaria* / *Tarchonanthus* / *Acacia* shrubland

J-*Hyparrhenia* / *Acacia* / *Tarchonanthus* dwarf shrubland

K-*Hyparrhenia* / *Tarchonanthus* / *Acacia* shrubland

L-Sparsely vegetated rocky zone

M-*Digitaria* / *Themeda* / *Tarchonanthus* / Acacia dwarf shrubland

N-*Digitaria* / *Tarchonanthus* / *Acacia* dwarf shrubland

(community A and G)

(b) Open *Tarchonanthus camphoratus* / *Acacia drepanolobium* shrubland (community C, F, J and M)

(c) Dense *T. camphoratus* / *A. drepanolobium* shrubland (community B, D, H, E, K and N).

Open and dense *T. camphoratus* / *A. drepanolobium* vegetation types cover the largest part of the Park (about 82 %), while the grassland covers about 18%. Most of the vegetation communities have similar species composition, and their distribution is influenced by both topography and geology. The dominant grass species are *Themeda triandra*, *Cymbopogon caesius*, *Digitaria milanjiana* and *D. scalarum*. Other common species include *Felicia muricata*, *Cynodon dactylon* and *Hyparrhenia* sp. Steam vents which are mostly found on the western part of the Park have unique plant species like *Dissotis senegambiensis*, *Ophioglossum vulgatum* and *Lycopodium cernum*. Three hundred and sixty six plant species belonging to seventy three families have so far been identified (Kiringe, 1990). *T. camphoratus* and *A. drepanolobium* are the dominant woody species of the Hell's Gate region. However, this shrubland is disappearing elsewhere in the Rift Valley due to agricultural expansion.

1.6 FAUNA

Wildlife species in the Park and adjacent areas are predominantly plains species. Zebra *Equus burchelli*, kongoni *Alcephalus buselaphus* and Thomson's gazelle *Gazella thomsonii* are the most common, and in areas like Kedong Ranch they occur in large numbers. Other herbivore species include buffalo *Syncerus caffer*, Grant's gazelle *Gazella granti*, Masai giraffe *Giraffa camelopardalis*, warthog *Phacochoerus aethiopicus*, klipspringer *Oreotragus oreotragus*, steinbuck *Raphicerus campestris*, dikdik *Rhynchotragus kirkii*, defassa waterbuck *Kobus defassa* and bohor reedbuck *Redunca redunca*. Various carnivore species are present in low numbers although figures are not available to show their population sizes; lion *Panthera leo*, cheetah *Acinonyx jubatus*, leopard *Panthera pardus*, hyena *Crocuta crocuta* and silver backed jackal *Canis mesomelas* have been occasionally recorded. A list of carnivores and herbivores is provided (Appendix 1).

The Park avifauna is quite diverse, and the gorge and cliffs serve as breeding sites for several raptor species such as Auger buzzard *Buteo rufofuscus*, Egyptian vulture *Nephron perenopterus*, Ruppell's vulture *Gyps ruppelli*, peregrine falcon *Falco peregrinus*, Verreaux's eagle *Aquila vereauxis* and lanner falcon *Falco biarmicus*. Appendix 2 shows some of the bird species that have so far been identified in the Park.

1.7 LAND USE WITHIN AND OUTSIDE THE PARK

The main development activity in the Park is geothermal power production by the OlKaria geothermal station, using underground steam. This station has been in existence since the 1980's even before the Park was gazetted in February 1984. The future strategies of the project include:

(a) Construction of two more power stations at both Olkaria east and west, after the geothermal potential and output has been establised

(b) Exploring the possibility of geothermal production from the domes of Eburru, Suswa and Mount Longonot.

Although power generation is of great importance to the development of the country, it should not be forgotten that the Park has been created for tourism development. The present and proposed power station expansion has and will have some effects on the well-being of the Park, both from an ecological and tourism development point of view. The project thus poses a threat to the future of the Park in ways such as wildlife diplacement, gaseous emissions, noise and water pollution, existence of an exploration village, soil erosion, waste water disposal, landscape and flora distabilisation. An enviromental impact study has already been done to establish how the geothermal project and its future expansion will affect the viability of the Park. The results of this study are still private, and have not yet been released to either the Kenya Wildlife Service or the Warden of Hell's Gate.

Outside the Park, the main actvities include farming (mostly floriculture and horticulture) and livestock keeping. This is done in areas like Kongoni, Kedong, Akira Ranches, Oserian and Sulmac Development Companies and other smaller farms around Lake Naivasha.

CHAPTER 2

POPULATION ESTIMATES, DENSITIES, DISTRIBUTION, HABITAT UTILIZATION AND BIOMASS OF LARGE HERBIVORES

2.1 INTRODUCTION

For effective wildlife management, it is important to know the numbers of each species and how they are changing with respect to time (Ayieko, 1976; Bull, 1981; Norton-Griffiths, 1978). Apart from enabling predictions to be made on the dynamics of each species, the data collected on numbers and densities can be useful in formulating a cropping policy for some of the wildlife if it is found neccesary. Population estimates of herbivores in East Africa have been made using a number of methods. These are: (1) aerial counts, (2) total counts and (3) sample counts on the ground (Barnes and Douglas-Hamilton, 1982; Cobb, 1976; Kahurananga, 1981; Jarman, 1972; Western, 1973). All these studies are aimed at understanding the ecology of the herbivores and the population dynamics of the species.

The increase of human population has resulted in a demand for more agricultural land, settlement, urban areas, infra-structure and industry at the expense of wildlife (Asibey,1974; Laws, 1970; Osemeobo, 1988). This has led to habitat loss for wildlife which has been forced to concentrate in smaller areas. In order to conserve wildlife, conservationists have advocated the creation of National Parks and Game Reserves. These areas act as confinements and often do not meet home range requirements for many animals. The confinement of large animals, especially herbivores curtails their migration behaviour to other feeding areas, and populations increase in these limited spaces. Confinement also limits the animals' ability to cope with any climatic or seasonal variations in their habitat. This situation has made conservation and management of herbivores difficult, and many national parks in East Africa are presently undergoing habitat alterations through changes in their vegetation (Western, 1973). To prevent these habitat changes, further management has become necessary.

Hell's Gate National Park is situated in an area of intensive agriculture especially to its northern boundaries. Adjoining areas like Kedong, Akira and Kongoni Ranches at present have plenty of wildlife which may move between them and the Park.There is no fencing between the Park and the two ranches. The Park is an important wildlife conservation component of the Hell's Gate ecosystem, and the fact that adjacent areas are under intensive agriculture whose expansion threatens future wildlife conservation makes knowledge of the herbivore populations that inhabit the Park important. Currently the only available data on the herbivores is from Kiringe (1990). This study over nine months (October 1988 to June 1989) was only a preliminary classification of the vegetation of the National Park and census of the main herbivore species. The present study was therefore undertaken to obtain more accurate knowledge of the population sizes and densities of the Park herbivores in order to further undertand their ecology and dynamics, and also contribute to the development of the management plan for the Park.

2.1.1 Method

Population sizes of wildlife can be estimated either by making a total or sample count. The method used will depend on a number of factors such as cost involved, the behaviour of the species to be studied, availability of resources, objectives of the study, the size, terrain and vegetation type of the study area (Norton-Griffiths, 1978).

Total counts involve searching the whole of the study area for any wildlife and determining the numbers of each species. The disadvantages of this method are: it is expensive and time consuming; it is not suitable for large areas (over 100 km^2) and where vegetation and topography hinder accessibility and visibility making it difficult to locate some of the animals; it is not suitable where the species to be counted occurs in large herds (e.g a migratory herd of wildebeest) and where a species has a cryptic behaviour which makes it difficult to locate. In spite of these short comings, the method may give accurate population estimates for areas less than 100km^2 (Norton-Griffiths, 1978). The method has been found to give reliable wildlife estimates by various authors for example Blankenship and Field (1972) in Akira Ranch (Naivasha), Kutilek (1974) in Lake Nakuru National Park and Duggan (1978) in Nairobi National Park. However, these authors did not calculate confidence limits of the herbivore counts they made in their study areas.

The sample count method uses selected representative areas of the overall study area where the animals in them are counted. The data obtained are then used to estimate the population size of the species in the whole area. This method has advantages over the total count method and is therefore frequently used in making population estimates. It allows large areas to be covered quickly, saves time, is cheaper depending on availability of resources and is suitable where topography and vegetation of the study area hinder accessibility and visibility. This method has been used to estimate herbivore counts by authors such as Lamprey (1964) in Tarangire Game Reserve, Watson and Graham (1969) in Loliondo area, Northern Tanzania and Watson *et al.* (1969) in Mkomazi region of Northern Tanzania. These authors did not calculate the percentage counting errors of the herbivores they counted nor did they indicate the advantage or reliability of sample count method over the total count method. However the decision to make either a total or sample count is not really choosing the "best" method but rather to avoid the "worst" (Norton-Griffiths, 1978).

For this study, I carried out ground counts to estimate the population sizes of the different large herbivore species. The terrain and vegetation of the study areas did not hinder visibility enough to make the herbivores difficult to locate. Availability of funds did not allow aerial counts to be made since it is too expensive. Road transect counts were not used since in my 1988-89 herbivore counts in the Park the method was found to over-estimate the population sizes of the herbivores compared with ground counts. Apart from making herbivore counts in this study, I also wanted to establish their habitat utilization and distribution, and this could best be done by carrying out ground counts.

The following assumptions are usually made when using the total count method:

(a) All individuals of a given species are located and accurately counted.

(b) The census area is fully searched and all animals located.

(c) Animals do not move before detection and none are counted twice or more.

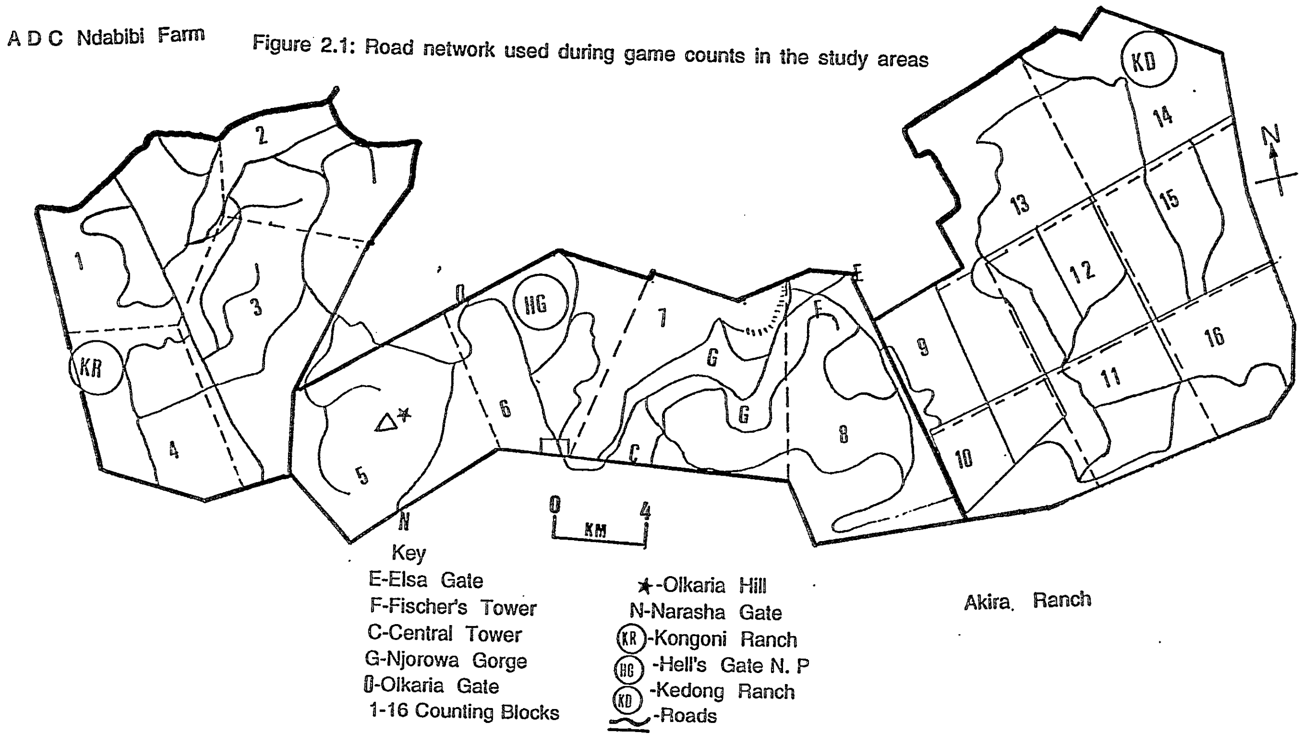
(d) Sequential sampling is done in uniform habitats and weather conditions, and all the animals are uniformly conspicuous to the observer.

In this study, although total counts were attempted, it must be admitted that all the above assumptions could not be met. This was principally because some parts of the study areas were not accessible by road and therefore an unknown proportion of the areas was not searched for large herbivores during counting. Initially I believed that these areas had few or no large herbivores associated with them, but the results I obtained indicate that this was fallacious. A further disadvantage of any total count is that no confidence limits can be made unless counts are repeated within a very short time. I was unable to carry out such duplicate counts because of lack of funds.

When counting, not all individuals of a species can be counted and some are missed. It was not possible to assess how many individuals of each species were not counted although counting was done to the best of the observer's ability. The accessible parts were thoroughly searched for any animals and counting done carefully. The animals were not used to the vehicle and fled once approached, but counting was completed before they were out of sight. The timing of census was such that counting was done as early as possible in the morning before the animals dispersed into the bushes. Their mobility was less during this time and therefore animals that were counted rarely crossed to an area where no counting had been done. This reduced the possibility of double counting. Species like warthog, mountain reedbuck, dikdik, steinbuck and klipspringer were less conspicuous to the observer than kongoni, zebra, Grant's gazelle and Thomson's gazelle. The body colour of klipspringer matched with that of their rocky habitat making it difficult to locate them. The study areas lie in a semi-arid zone and therefore weather conditions did not change appreciably to have any effect on the census success.

Each month from February 1990 to April 1992, counts of large herbivores were carried through out in the Park, Kedong and Kongoni Ranches using a vehicle and the existing road network (Figure 2.1). The study areas were sub-divided into blocks (based on the nature of the vegetation and terrain - Park - 4 blocks, Kedong Ranch - 8 blocks and Kongoni Ranch - 4 blocks) in which counting was done separately (Figure 2.1). Counting started after dawn at about 0730hrs when most of the herbivores were active, feeding and

Figure 2.1: Road network used during game counts in the study areas



had not retreated into the bushes due to the day's heat. In each block, when a herd of herbivores was sighted, the vehicle was stopped. The observer then stood on top of the vehicle and using a pair of binoculars counted all the herbivores that were sighted within an estimated radius of 300m. The following information was recorded: species name and number, number of adults, sub-adults and juveniles and position on a grid reference map. The vehicle then moved to a new site within the block and the same procedure was repeated. When counting in one block was finished, the observer drove to a new one and counting as already described carried out until all the blocks had been visited. Bushes suspected to have any animals in them in any block were thoroughly searched on foot with minimal disturbance, and any animals seen counted.

Observation of the results of monthly herbivore counts in the three study areas showed that they varied from month to month. To demonstrate the variation in total herbivore counts in each block, counts of February 1990 (a dry month), April 1990 (a wet month), January 1991 (a dry month) and June 1991 (a wet month) were summarised. The choice of these months for further herbivore count data analysis had nothing to do with the uniqueness of their data; other months could have been choosen.

In the Park, herbivore counts in each block varied monthly. To demonstrate how the block counts varied, data were analysed for the month of June 1991. In each block, the number of individuals of each species were summed to obtain a total herbivore count. As previously mentioned, there was no uniqueness in the data obtained for this month, and any other month could have been choosen for data analysis.

For each study area, the number of individuals of each species counted in each block were summed to make a single count of the unit (Park, Kedong or Kongoni Ranches) per month. These data were then divided by the area (of each study unit) to give monthly densities of each species. The monthly counts of zebra, kongoni, Thomson's gazelle, Grant's gazelle, impala and eland in the three study areas combined as one were summed for each species separately and line graphs drawn to show their monthly changes. Line graphs for the same species and buffalo were also drawn separately for each study area to see whether for individual area monthly changes differed.

Each month, the percentage of adults, sub-adults and juveniles of kongoni, zebra, Thomson's gazelle, Grant's gazelle, eland and impala in each of the study areas was calculated and line graphs drawn. The monthly percentage of adults for each of these species was summed and a mean and standard error calculated.

It took 6-7hrs to count game in Kedong Ranch due to its size (80km^2) compared with the Park (68.25km^2) and Kongoni Ranch (54.63km^2) which took $3^1/_2$-$4^1/_2$ hrs and 4-$4^1/_2$hrs respectively. Large scale movements of animals were unusual and this helped to reduce the probability of double counting. Not all sections of the study areas were accessible by road. About 36% in the Park, 13% in Kedong Ranch and 18% in Kongoni Ranch were not accessible. These sections had thick vegetation and rugged terrain, and from preliminary casual observations, they were not important wildlife concentration areas. These were then not included in the total census area, but continued observations during the study suggested that this did not substantially affect the herbivore counts obtained.

The counting technique did not record group size separately, but it was apparent that most of the herbivores did not occur in large herds. This made it easier to obtain an accurate count and reduce error due to some of them being missed during counting. However, Thomson's gazelle in Kedong Ranch were the only species which did occur in large herds of between 50-200 individuals such that during counting it was not possible to count all the individuals in a herd, especially at the upper size range. In such herds, some individuals were therefore missed during counting as they continued moving, making it difficult to tell which individuals were counted or not. If aerial counts of the large herds had been made, it would have been possible to correct the counting error by counting individuals from such photographs and compare them with the actual ground counts and therefore increase the accuracy of the counts, but this was not done. Eland is a browser (Hofmann and Stewart, 1972), and therefore during counting many of them may have been in bushes, and this may have affected the accuracy of their monthly counts.

2.1.2 Results

Some of the herbivore counts obtained (in each block) for the three study areas are shown in table 2.1. There was variation in total number of herbivores counted in each block. In the Park, block 7 and 8 had the highest total herbivore counts, while block 5 and 6 had the lowest (Table 2.2).

The monthly herbivore counts and densities (numbers/km^2) for the Park, Kedong and Kongoni Ranches from February 1990 - April 1992 are shown in tables 2.3 - 2.5 and 2.6 - 2.8 respectively. Monthly counts of kongoni, zebra, buffalo, eland, Thomson's gazelle, Grant's gazelle and impala for each of the study areas and the study areas combined are shown in figures 2.2 - 2.8 and 2.9 - 2.14 respectively.

The summed counts of kongoni, zebra and Thomson's gazelle for the combined study areas showed an increase and decrease in their numbers. Between February 1990 and May 1990 there was a steady increase of kongoni population size with a monthly increment of 263 individuals per month (Figure 2.9). A decrease in numbers occured between June 1990 and April 1991 at 149 kongoni per month; then between May 1991 and June 1991 there was

Table 2.1: Herbivore counts in blocks of the three study areas

	February 1990	April 1990	January 1991	June 1991
Block	Count	Count	Count	Count
1	370	619	255	626
2	90	73	68	138
3	132	218	199	265
4	289	352	225	103
5	16	17	9	10
6	27	27	24	12
7	252	317	428	409
8	305	485	420	427
9	180	458	227	442
10	245	548	280	575
11	351	622	368	651
12	168	388	514	854
13	80	112	62	120
14	72	92	66	117
15	25	109	56	123
16	75	179	78	254

Table 2.2: Herbivore counts in blocks of the Park - June 1991

Species	Block 8 Count	Block 7 Count	Block 6 Count	Block 5 Count
Kongoni	160	108	3	-
Zebra	86	103	9	10
Buffalo	80	84	-	-
Eland	35	44	-	-
Thomson's gazelle	23	24	-	-
Grant's gazelle	24	12	-	-
Warthog	8	25	-	-
Steinbuck	3	2	-	-
Masai giraffe	3	2	-	-
Dik dik	5	5	-	-
Total	427	409	12	10

Table 2.3: Monthly herbivore counts in the Park

Species	Feb.'90	Mar.'90	Apr.'90	May '90	Jun.'90	Jul.'90	Aug.'90	Sept.'90	Oct.'90	Nov.'90	Dec.'90	Jan.'91	Feb.'91	Mar.'91
Kongoni	258	267	264	347	305	285	357	291	380	438	227	439	261	482
Zebra	83	198	159	224	400	290	222	205	200	215	103	123	109	136
Buffalo	95	100	98	120	100	100	90	190	240	250	200	192	181	150
Eland	36	116	186	33	145	78	55	27	76	176	20	6	35	35
Thomson's gazelle	30	34	46	38	64	40	67	34	48	55	46	35	35	26
Grant's gazelle	14	26	27	21	14	50	46	54	48	49	46	28	47	23
Warthog	20	22	20	22	20	22	20	24	25	20	26	26	24	27
Klipspringer	13	6	9	8	18	10	12	10	10	8	-	8	8	-
Mountain reedbuck	20	13	8	-	12	-	10	-	8	8	10	-	8	7
Steinbuck	10	11	6	5	6	7	10	5	14	13	10	10	4	5
Masai giraffe	5	6	9	22	9	6	5	7	6	7	12	7	-	9
Reticulated giraffe	6	5	5	2	7	5	5	4	-	-	-	1	-	1
Dik dik	10	9	9	6	8	-	5	8	10	-	11	6	-	12
Impala	-	-	-	-	-	-	-	-	-	-	-	-	-	14
Defassa waterbuck	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.3: Monthly herbivore counts in the Park (continued)

Species	Apr.'91	May '91	Jun.'91	Jul.'91	Aug.'91	Sept.'91	Oct.'91	Nov.'91	Dec.'91	Jan.'92	Feb.'92	Mar.'92	Apr.'92
Kongoni	300	397	271	427	311	203	298	390	515	277	389	228	328
Zebra	150	137	208	241	305	241	135	230	269	169	210	171	233
Buffalo	140	150	164	180	189	180	195	200	210	200	215	240	220
Eland	86	80	79	30	45	50	111	30	26	20	21	11	330
Thomson's gazelle	48	34	47	34	39	23	62	60	40	39	57	36	41
Grant's gazelle	31	40	36	42	38	36	66	64	77	70	70	36	48
Warthog	25	27	33	29	27	28	30	32	33	34	64	62	70
Klipspringer	-	-	-	10	9	8	-	-	10	10	10	10	10
Mountain reedbuck	-	8	-	-	10	-	-	-	10	10	8	12	20
Steinbuck	7	11	5	6	6	9	8	8	6	8	10	8	8
Masai giraffe	5	11	5	19	7	3	2	8	15	15	12	5	15
Reticulated giraffe	1	-	-	-	-	-	-	-	-	5	-	-	-
Dik dik	-	-	10	8	-	-	-	10	6	8	6	8	10
Impala	-	4	-	11	12	59	20	26	44	50	16	-	-
Defassa waterbuck	-	-	-	-	-	-	-	-	-	-	-	-	10

Table 2.4: Monthly herbivore counts in Kedong Ranch

Species	Feb.'90	Mar.'90	Apr.'90	May '90	Jun.'90	Jul.'90	Aug.'90	Sept.'90	Oct.'90	Nov.'90	Dec.'90	Jan.'91	Feb.'91	Mar.'91	Apr.'91	May '91
Kongoni	333	597	850	1200	999	780	726	457	606	756	532	492	255	311	201	412
Zebra	129	662	571	520	592	480	475	249	403	556	461	299	318	194	172	339
Thomson's gazelle	1101	687	801	1324	1348	1060	1112	795	825	1138	917	591	348	273	1089	1370
Grant's gazelle	73	49	73	67	102	60	70	27	33	71	57	48	42	28	44	59
Eland	137	134	308	285	340	210	189	211	256	340	230	30	29	32	20	64
Warthog	3	3	6	7	-	8	7	11	-	18	13	23	19	30	23	14
Steinbuck	7	2	1	5	4	2	8	3	-	9	9	7	6	11	4	9
Wildebeest	1	1	1	1	1	-	1	1	-	1	-	-	-	1	1	1
Impala	118	169	177	213	160	150	142	130	121	106	130	147	110	148	114	96
Masai giraffe	14	4	7	10	10	8	9	14	-	9	16	8	13	22	11	5
Reticulated giraffe	5	-	4	6	4	5	7	-	-	6	-	-	-	-	-	-
Dik dik	6	3	-	2	4	4	-	3	-	6	12	6	-	4	-	5

Table 2.4: Monthly herbivore counts in Kedong Ranch (continued)

Species	Jun.'91	Jul.'91	Aug.'91	Sept.'91	Oct.'91	Nov.'91	Dec.'91	Jan.'92	Feb.'92	Mar.'92	Apr.'92
Kongoni	880	574	362	750	712	700	712	429	825	552	1441
Zebra	601	355	349	310	257	310	453	429	405	279	781
Thomson's gazelle	1301	593	775	734	920	989	1089	729	1067	1062	1645
Grant's gazelle	61	77	36	82	47	88	111	61	93	81	121
Eland	118	18	115	18	51	60	57	59	53	50	325
Warthog	17	14	16	-	9	14	12	9	16	36	27
Steinbuck	8	6	7	6	5	5	6	4	6	7	8
Wildebeest	1	1	-	1	-	1	1	-	-	1	-
Impala	127	111	116	106	108	110	201	180	150	180	245
Masai giraffe	14	15	28	16	21	17	18	23	41	14	14
Reticulated giraffe	-	-	-	-	-	-	-	1	-	-	-
Dik dik	7	5	4	6	-	8	6	8	6	6	8

Table 2.5: Monthly herbivore counts in Kongoni Ranch

Species	Feb.'90	Mar.'90	Apr.'90	May '90	Jun.'90	Jul.'90	Aug.'90	Sept.'90	Oct.'90	Nov.'90	Dec.'90	Jan.'91	Feb.'91	Mar.'91
Kongoni	143	213	221	240	289	300	464	227	203	128	111	94	93	150
Zebra	274	268	567	420	535	490	437	384	290	197	288	309	280	286
Thomson's gazelle	30	36	53	35	45	37	40	62	50	52	32	40	33	28
Grant's gazelle	156	123	152	151	157	150	156	164	139	129	88	97	37	81
Eland	110	98	64	101	61	40	25	7	25	40	35	54	70	65
Warthog	7	7	9	8	6	10	-	12	-	6	-	-	7	-
Steinbuck	4	3	2	6	5	6	-	3	-	6	-	6	5	-
Defassa waterbuck	-	-	9	-	5	-	-	-	-	-	4	25	-	-
Masai giraffe	6	15	6	-	2	7	-	8	-	13	24	12	17	7
Impala	147	150	175	205	219	190	80	44	195	227	215	106	139	96
Dik dik	-	-	-	-	-	-	-	-	-	6	-	4	5	-
Reticulated giraffe	4	8	4	-	6	5	-	4	-	-	-		-	-

Table 2.5: Monthly herbivore counts in Kongoni Ranch (continued)

Species	Apr.'91	May '91	Jun.'91	Jul.'91	Aug.'91	Sept.'91	Oct.'91	Nov.'91	Dec.'91	Jan.'92	Feb.'92	Mar.'92	Apr.'92
Kongoni	145	147	217	225	250	228	181	155	177	184	184	98	103
Zebra	237	242	431	465	264	275	375	371	174	166	419	189	385
Thomson's gazelle	66	62	58	40	63	83	74	118	57	65	85	63	84
Grant's gazelle	95	120	139	111	92	123	158	117	186	180	140	150	111
Eland	60	40	35	27	62	52	43	53	50	40	27	22	75
Warthog	-	-	-	8	-	-	-	5	4	13	-	12	26
Steinbuck	6	-	-	-	-	8	6	-	5	5	-	-	-
Defassa waterbuck	-	-	-	-	-	-	-	-	-	-	-	-	-
Masai giraffe	17	10	8	4	10	10	7	15	34	34	20	7	16
Impala	209	215	244	145	130	99	231	187	141	151	192	134	172
Dik dik	4	-	-	-	4	-	-	-	5	4	6	4	10
Reticulated giraffe	-	-	-	-	-	-	-	-	-		-	-	-

Table 2.6: Monthly herbivore densities (numbers/km2) in the Park

Species	Feb.'90	Mar.'90	Apr.'90	May '90	Jun.'90	Jul.'90	Aug.'90	Sept.'90	Oct.'90	Nov.'90	Dec.'90	Jan.'91	Feb.'91	Mar.'91
Kongoni	3.78	3.91	3.87	5.08	4.47	4.18	5.23	4.26	5.57	6.42	3.33	6.43	3.82	7.06
Zebra	1.22	2.9	2.33	3.28	5.86	4.25	3.25	3	2.93	3.15	1.51	1.8	1.6	1.99
Buffalo	1.39	1.47	1.44	0	1.47	1.47	1.31	0	3.52	3.66	2.93	0	0	2.2
Eland	0.53	1.7	2.73	0.48	2.12	1.14	0	0.4	1.11	2.58	0.29	0.09	0.51	0.51
Thomson's gazelle	0.44	0.5	0.67	0.56	0.94	0.59	0.98	0.5	0.7	6.81	0.67	0.51	0.51	0.38
Grant's gazelle	0.21	0.38	0.4	0.31	0.21	0.73	0.67	0.79	0.78	0.72	0.67	0.41	0.69	0.34
Warthog	0.29	0.32	0.29	0.32	0.29	0.32	0.29	0.35	0.37	0.29	0.38	0.38	0.35	0.4
Klipspringer	0.19	0.09	0.13	0.12	0.26	0.15	0.18	0.15	0.15	0.12	0	0.12	0.12	0
Mountain reedbuck	0.29	0.19	0.12	0	0.18	0	0.15	0	0.12	0.12	0.15	0	0.12	0.1
Steinbuck	0.15	0.16	0.09	0.07	0.09	0.1	0.15	0.07	0.21	0.19	0.15	0.15	0.06	0.07
Masai giraffe	0.07	0.09	0.13	0.32	0.13	0.09	0.07	0.1	0.09	0.1	0.18	0.1	0	0.13
Reticulated giraffe	0.09	0.07	0.07	0.03	0.1	0.07	0.07	0.06	0	0	0	0.01	0	0.01
Dikdik	0.15	0.13	0.13	0.09	0.12	0	0.07	0.12	0.15	0	0.16	0.09	0	0.18
Impala	0	0	0	0	0	0	0	0	0	0	0	0	0	0.21
Defassa waterbuck	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.6: Monthly herbivore densities (numbers/km2) in the Park (continued)

Species	Apr.'91	May '91	Jun.'91	Jul.'91	Aug.'91	Sept.'91	Oct.'91	Nov.'91	Dec.'91	Jan.'92	Feb.'92	Mar.'92	Apr.'92
Kongoni	4.4	5.82	3.97	6.26	4.56	2.97	4.37	5.71	7.55	4.06	5.7	3.34	4.81
Zebra	2.2	2.01	3.05	3.53	4.47	3.53	1.98	3.37	3.94	2.48	3.08	2.51	3.41
Buffalo	2.05	2.2	0	2.64	2.77	2.64	0	2.93	3.08	2.93	3.15	3.52	3.22
Eland	1.26	1.17	1.16	0.44	0	0	1.63	0.44	0.38	0	0.31	0.16	4.84
Thomson's gazelle	0.7	0.5	0.69	0.5	0.57	0.34	0.91	0.88	0.59	0.57	0.84	0.53	0.6
Grant's gazelle	0.45	0.59	0.53	0.62	0.56	0.53	0.97	0.94	1.13	1.03	1.03	0.53	0.7
Warthog	0.37	0.4	0.48	0.42	0.4	0.41	0.44	0.47	0.48	0.5	0.94	0.91	1.03
Klipspringer	0	0	0	0.15	0.13	0.12	0	0	0.15	0.15	0.15	0.15	0.15
Mountain reedbuck	0	0.12	0	0	0.15	0	0	0	0.15	0.15	0.12	0.18	0.29
Steinbuck	0.1	0.16	0.07	0.09	0.09	0.13	0.12	0.12	0.09	0.12	0.15	0.12	0.12
Masai giraffe	0.07	0.16	0.07	0.28	0.1	0.04	0.03	0.12	0.22	0.22	0.18	0.07	0.22
Reticulated giraffe	0.01	0	0	0	0	0	0	0	0	0.07	0	0	0
Dikdik	0	0	0.15	0.12	0	0	0	0.15	0.09	0.12	0.09	0.12	0.15
Impala	0	0.06	0	0.16	0.18	0.86	0.29	0.38	0.64	0.73	0.23	0	0
Defassa waterbuck	0	0	0	0	0	0	0	0	0	0	0	0	0.15

Table 2.7: Monthly herbivore densities (numbers/km2) in Kedong Ranch

Species	Feb.'90	Mar.'90	Apr.'90	May '90	Jun.'90	Jul.'90	Aug.'90	Sept.'90	Oct.'90	Nov.'90	Dec.'90	Jan.'91	Feb.'91	Mar.'91
Kongoni	4.16	7.46	10.63	15	12.49	9.75	9.08	5.71	7.58	9.45	6.65	6.15	3.19	3.89
Zebra	1.61	8.28	7.14	6.5	7.4	6	5.94	3.11	5.04	6.95	5.76	3.74	3.98	2.43
Thomson's gazelle	13.76	8.59	10.01	16.55	16.85	13.25	13.9	9.94	10.31	14.22	11.46	7.39	4.35	3.41
Grant's gazelle	0.91	0.61	0.91	0.84	1.28	0.75	0.88	0.34	0.41	0.89	0.71	0.6	0.53	0.35
Eland	1.71	1.68	3.85	3.56	4.25	2.63	2.36	2.64	3.2	4.25	2.88	0.38	0	0.4
Warthog	0.04	0.04	0.08	0.09	0	0.1	0.09	0.14	0	0.23	0.16	0.29	0.24	0.38
Steinbuck	0.09	0.03	0.01	0.06	0.05	0.03	0.1	0.04	0	0.11	0.11	0.09	0.08	0.14
Wildebeest	0.01	0.01	0.01	0.01	0.01	0	0.01	0.01	0	0.01	0	0	0	0.01
Impala	1.48	2.11	2.21	2.66	2	1.88	1.78	1.63	1.51	1.33	1.63	1.84	1.38	1.85
Masai giraffe	0.18	0.05	0.09	0.13	0.13	0.1	0.11	0.18	0	0.11	0.2	0.1	0.16	0.28
Reticulated giraffe	0.06	0	0.05	0.08	0.05	0.06	0.09	0	0	0.08	0	0	0	0
Dikdik	0.08	0.04	0	0.03	0.05	0.05	0	0.04	0	0.08	0.15	0.08	0	0.05

Table 2.7: Monthly herbivore densities (numbers/km2) in Kedong Ranch (continued)

Species	Apr.'91	May '91	Jun.'91	Jul.'91	Aug.'91	Sept.'91	Oct.'91	Nov.'91	Dec.'91	Jan.'92	Feb.'92	Mar.'92	Apr.'92
Kongoni	2.51	5.15	11	7.18	4.53	9.38	8.9	8.75	8.9	5.36	10.31	6.9	18.01
Zebra	2.15	4.24	7.51	4.44	4.36	3.88	3.21	3.88	5.66	5.36	5.06	3.49	9.76
Thomson's gazelle	13.61	17.13	16.21	7.41	9.69	9.18	11.5	12.36	13.61	9.11	13.34	13.28	20.56
Grant's gazelle	0.55	0.74	0.76	0.96	0.45	1.03	0.59	1.1	1.39	0.76	1.16	1.01	1.51
Eland	0.25	0.8	1.48	0.23	1.44	0.23	0.64	0.75	0.71	0.74	0.66	0.63	4.06
Warthog	0.29	0.18	0.21	0.18	0.2	0	0.11	0.18	0.15	0.11	0.2	0.45	0.38
Steinbuck	0.05	0.11	0.1	0.08	0.09	0.08	0.06	0.06	0.08	0.05	0.08	0.09	0.1
Wildebeest	0.01	0.01	0.01	0.01	0	0.01	0	0.01	0.01	0	0	0.01	0
Impala	1.43	1.2	1.59	1.39	1.45	1.33	1.35	1.38	2.51	2.25	1.88	2.25	3.06
Masai giraffe	0.14	0.06	0.18	0.19	0.35	0.2	0.26	0.21	0.23	0.29	0.51	0.18	0.18
Reticulated giraffe	0	0	0	0	0	0	0	0	0	0.01	0	0	0
Dikdik	0	0.06	0.09	0.06	0.05	0.08	0	0.1	0.08	0.1	0.08	0.08	0.1

Table 2.8: Monthly herbivore densities (numbers/km2) in Kongoni Ranch

Species	Feb.'90	Mar.'90	Apr.'90	May '90	Jun.'90	Jul.'90	Aug.'90	Sept.'90	Oct.'90	Nov.'90	Dec.'90	Jan.'91	Feb.'91	Mar.'91
Kongoni	2.62	3.9	4.05	4.39	5.29	5.49	8.49	4.16	3.72	2.34	2.03	1.72	1.7	2.75
Zebra	5.02	4.91	10.38	7.69	9.79	8.97	8	7.03	5.31	3.61	5.27	5.66	5.13	5.24
Thomson's gazelle	0.55	0.66	0.97	0.64	0.82	0.68	0.73	1.13	0.92	0.95	0.59	0.73	0.6	0.51
Grant's gazelle	2.86	2.45	2.78	2.76	2.87	2.75	2.86	3	2.54	2.36	1.61	1.78	0.68	1.48
Eland	2.01	1.79	1.17	1.85	1.12	0.73	0.46	0.13	0.46	0.73	0.64	0.99	1.28	1.19
Warthog	0.13	0.13	0.16	0.15	0.11	0.18	0	0.22	0	0.11	0	0	0.13	0
Steinbuck	0.07	0.05	0.04	0.11	0.09	0.11	0	0.05	0	0.11	0	0.11	0.09	0
Defassa waterbuck	0	0	0.16	0	0.09	0	0	0	0	0	0.07	0.46	0	0
Masai giraffe	0.11	0.27	0.11	0	0.04	0.13	0	0.15	0	0.24	0.44	0.22	0.31	0.13
Impala	2.69	2.75	3.2	3.75	4.01	3.48	1.46	0.81	3.57	4.16	3.94	1.94	2.54	1.76
Dikdik	0	0	0	0	0	0	0	0	0	0.11	0	0.07	0.09	0
Reticulated giraffe	0.07	0.15	0.07	0	0.11	0.09	0	0.07	0	0	0	0	0	0

Table 2.8: Monthly herbivore densities (numbers/km2) in Kongoni Ranch (continued)

Species	Apr.'91	May '91	Jun.'91	Jul.'91	Aug.'91	Sept.'91	Oct.'91	Nov.'91	Dec.'91	Jan.'92	Feb.'92	Mar.'92	Apr.'92
Kongoni	2.65	2.69	3.97	4.12	4.58	4.17	3.31	2.84	3.24	3.37	3.37	1.79	1.89
Zebra	4.34	4.43	7.89	8.51	4.83	5.03	6.86	6.79	3.19	3.04	7.67	3.46	7.05
Thomson's gazelle	1.21	1.13	1.06	0.73	1.15	1.52	1.35	2.16	1.04	1.19	1.56	1.15	1.54
Grant's gazelle	1.74	2.2	2.54	2.03	1.68	2.25	2.89	2.14	3.4	3.29	2.56	2.75	2.03
Eland	1.1	0.73	0.64	0.49	1.13	0	0.79	0.97	0.92	0.73	0.49	0.4	1.37
Warthog	0	0	0	0.15	0	0	0	0.09	0.07	0.24	0	0.22	0.48
Steinbuck	0.11	0	0	0	0	0.15	0.11	0	0.09	0.09	0	0	0
Defassa waterbuck	0	0	0	0	0	0	0	0	0	0	0	0	0
Masai giraffe	0.31	0.18	0.15	0.07	0.18	0.18	0.13	0.27	0.62	0.62	0.37	0.13	0.29
Impala	3.83	3.94	4.47	2.65	2.38	1.81	4.23	3.42	2.58	2.76	3.51	2.45	3.15
Dikdik	0.07	0	0	0	0.07	0	0	0	0.09	0.07	0.11	0.07	0.18
Reticulated giraffe	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 2.2: Monthly counts of Kongoni - February 1990 - April 1992

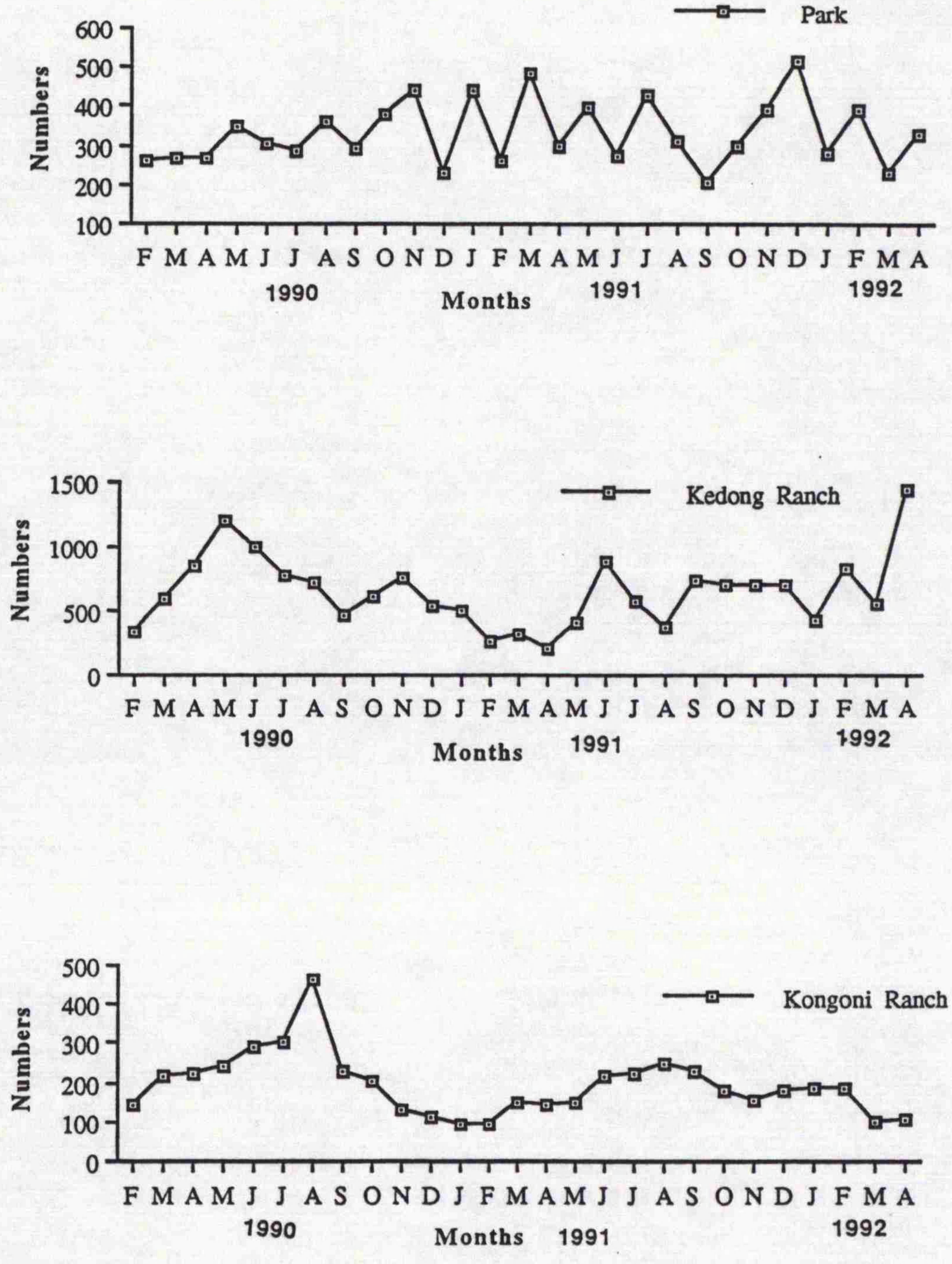
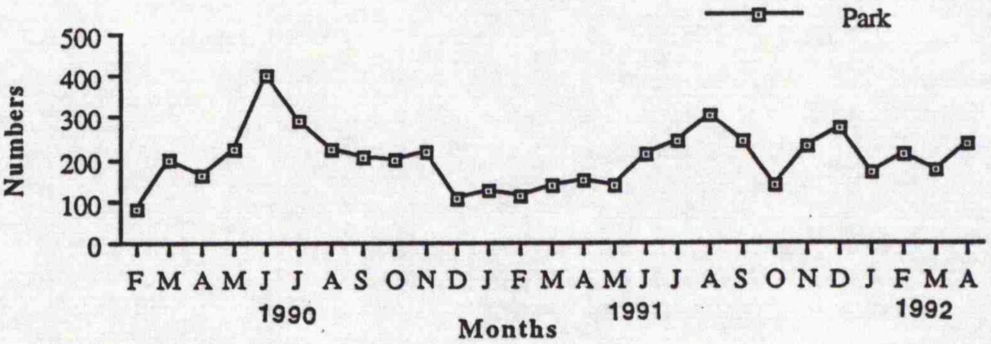
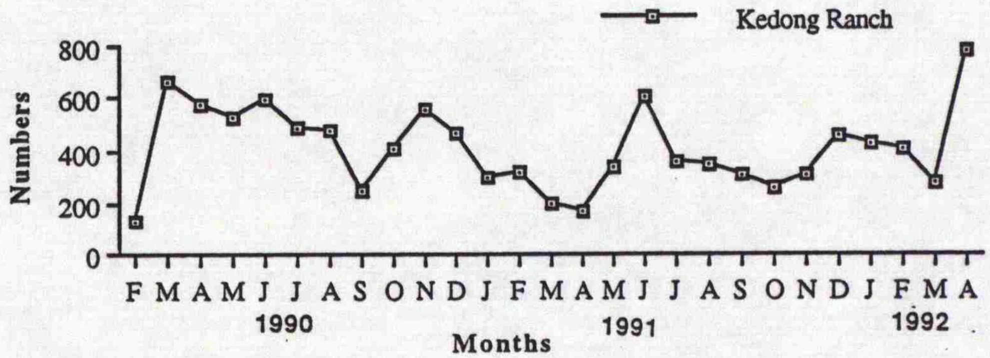


Figure 2.3: Monthly counts of Zebra - February 1990 - April 1992





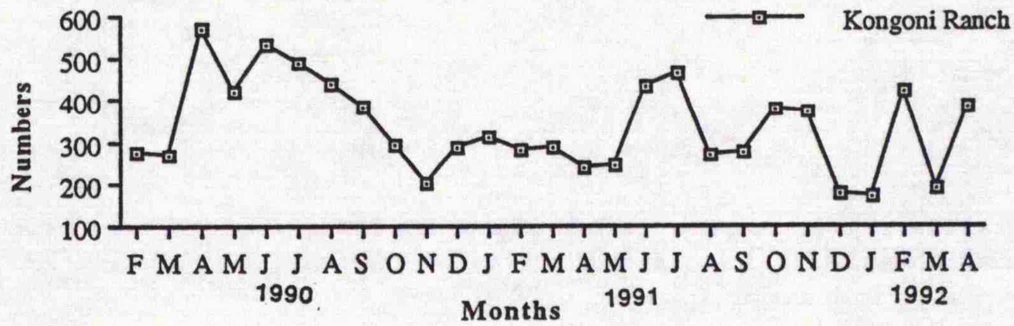


Figure 2.4: Monthly counts of Buffalo - February 1990 - April 1992

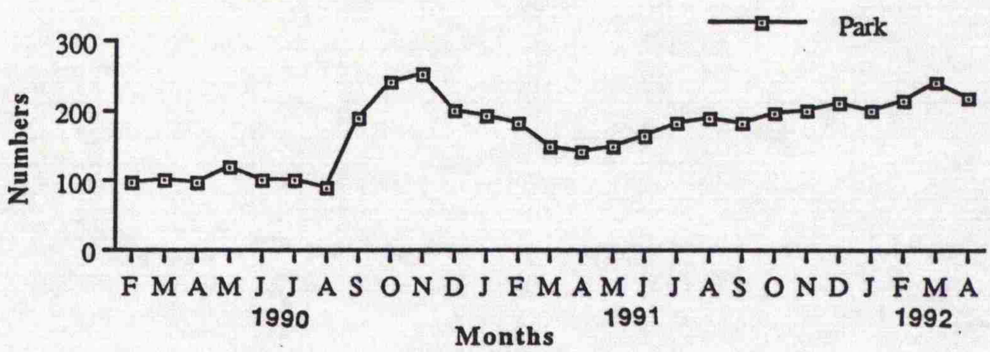


Figure 2.5: Monthly counts of Eland - February 1990 - April 1992

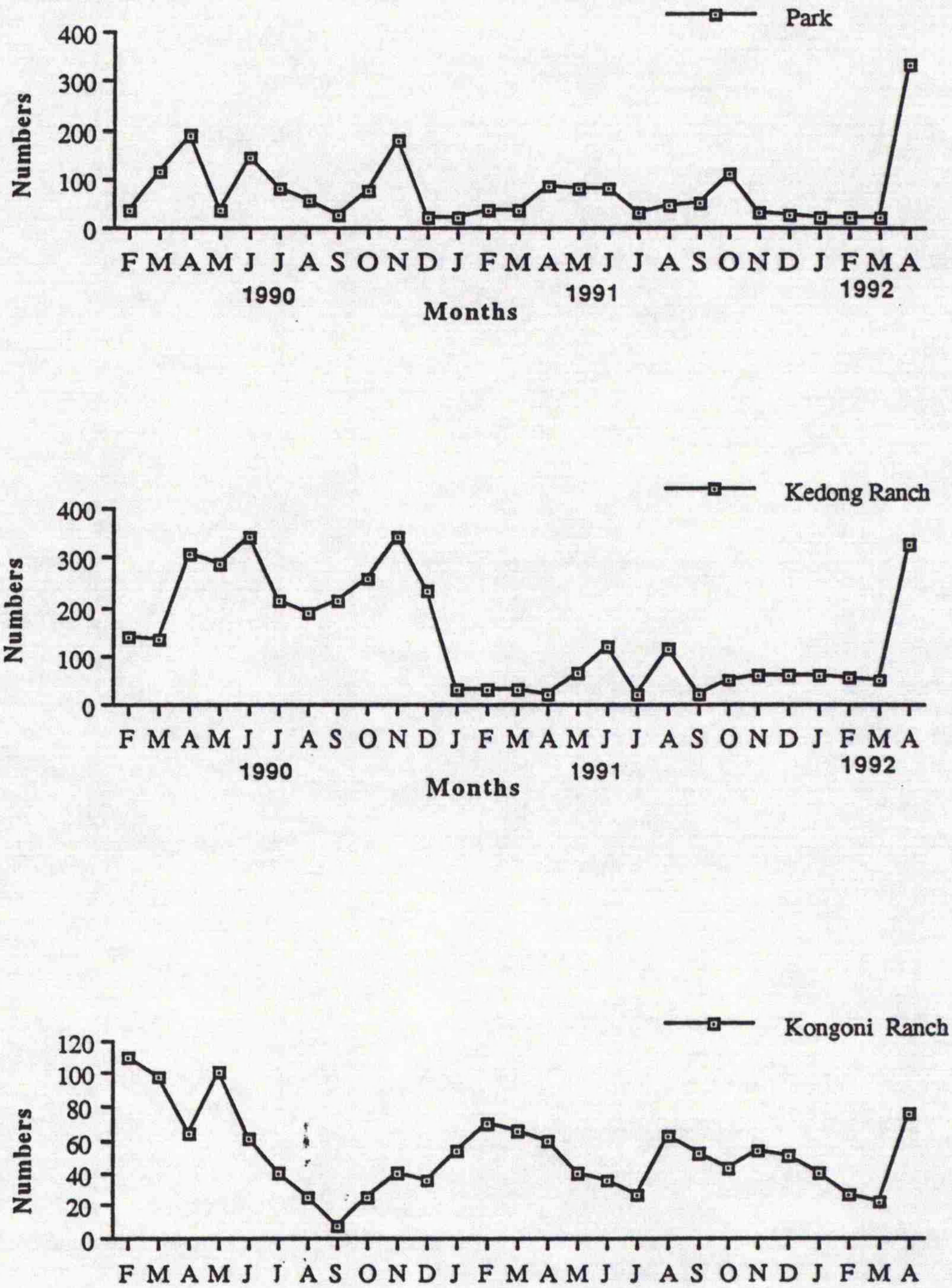


Figure 2.6: Monthly counts Thomson's gaz. - Feb.1990 - April 1992

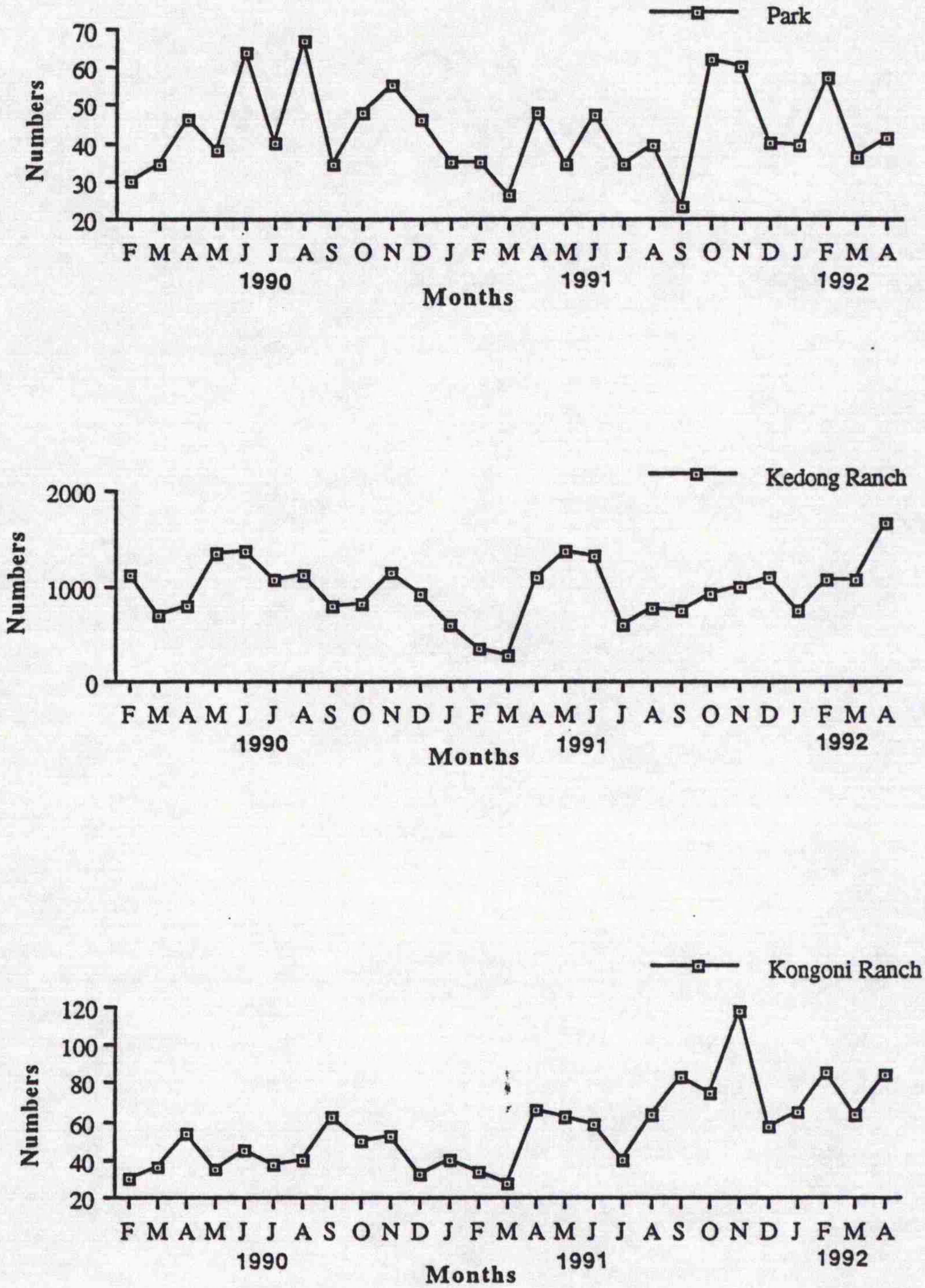


Figure 2.7: Monthly counts of Grant's gazelle - Feb.1990 - April 1992

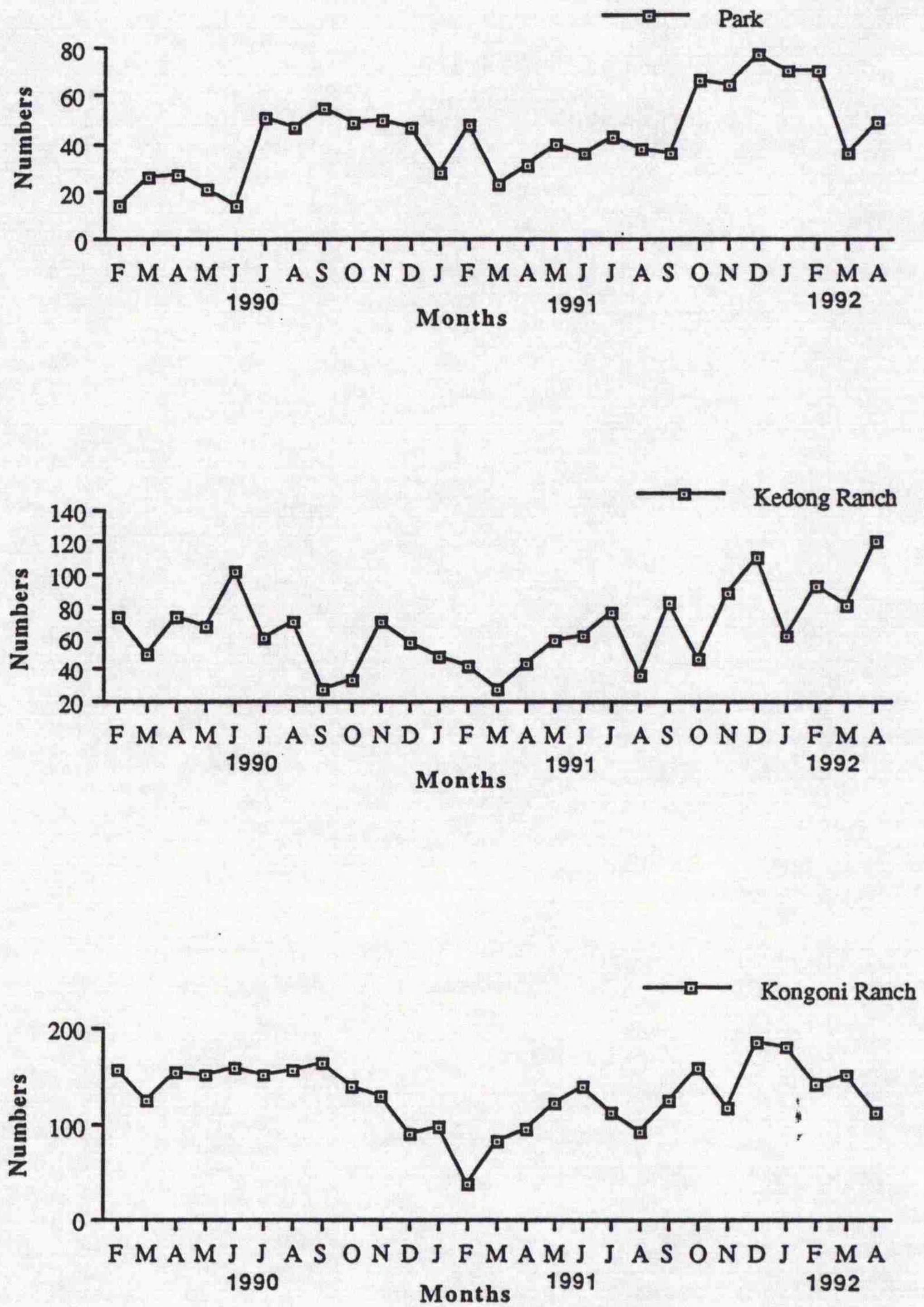


Figure 2.8: Monthly counts of Impala - February 1990 - April 1992

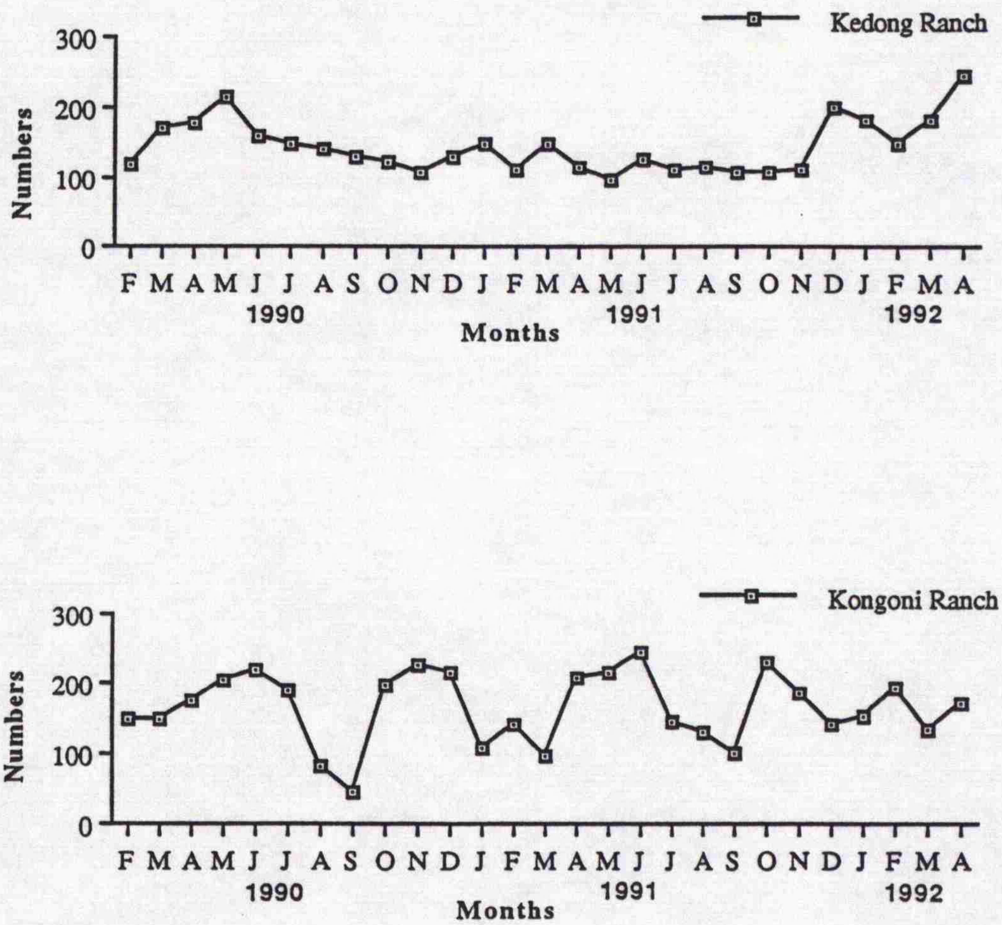


Figure 2.9: Summed monthly counts of Kongoni - February - 1990 - April 1992

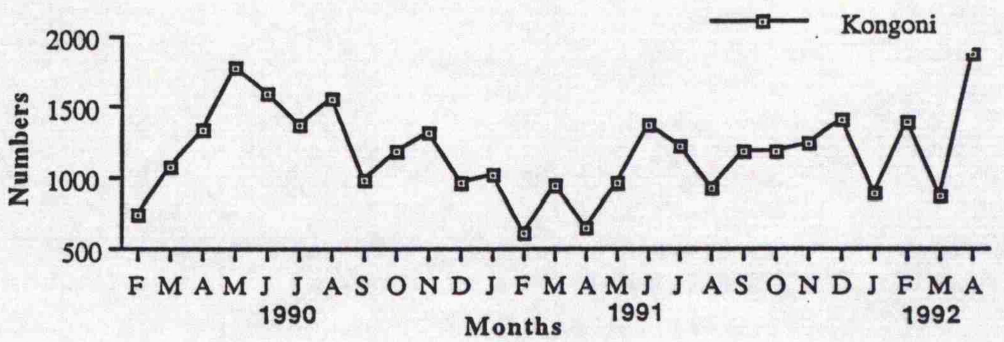


Figure 2.10: Summed monthly counts of Zebra - February 1990 - April 1992

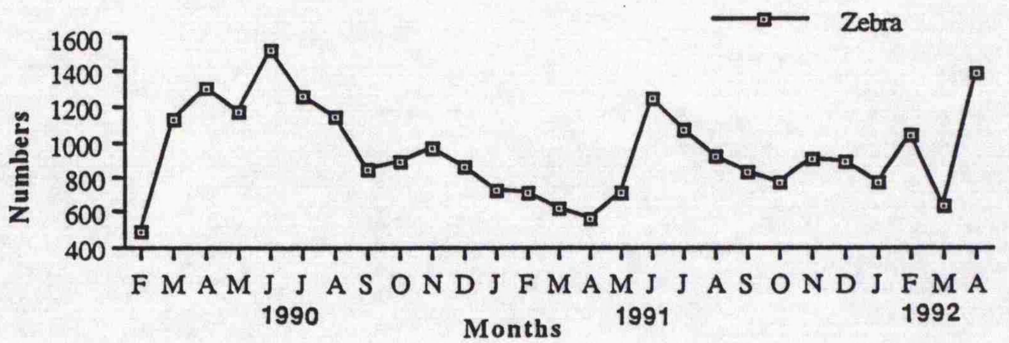


Figure 2.11: Summed monthly counts of Thomson's gaz. - February 1990 - April 1992

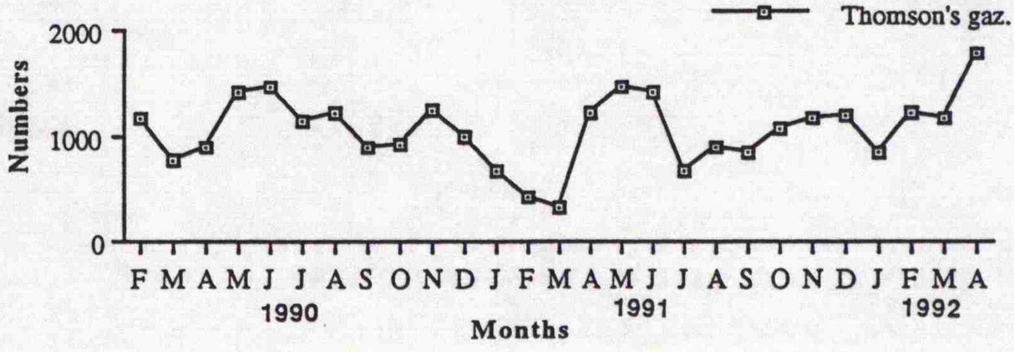


Figure 2.12: Summed monthly counts of Grant's gaz. - February 1990 - April 1992

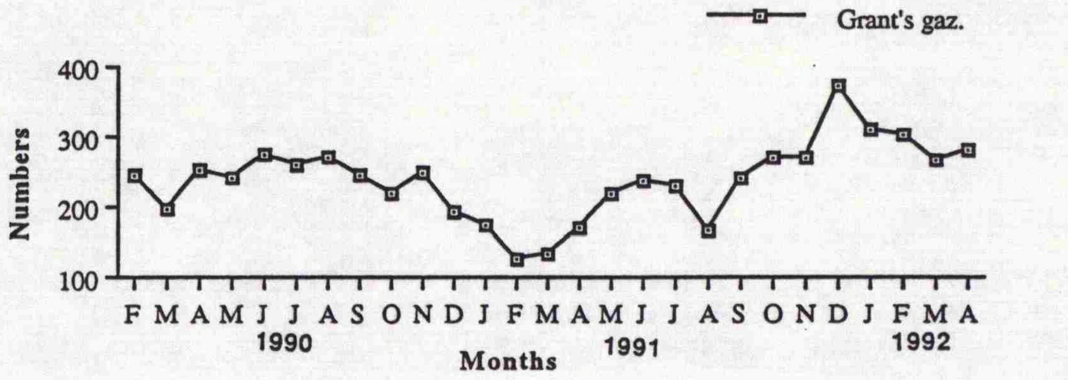


Figure 2.13: Summed monthly counts of Impala - February 1990 - April 1992

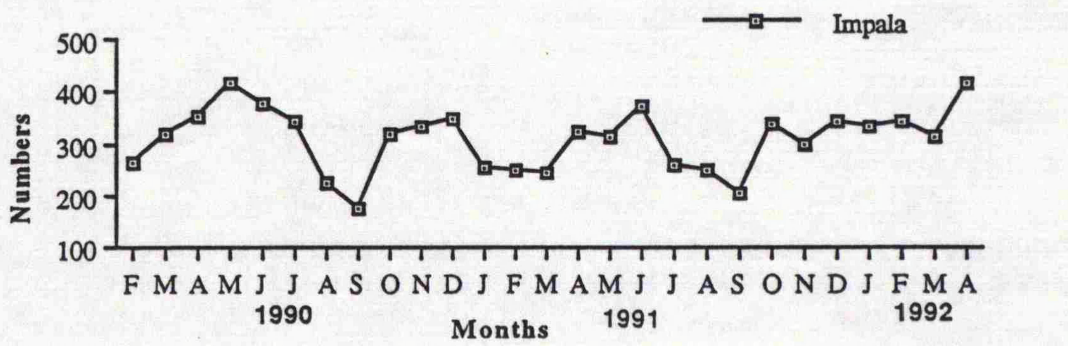
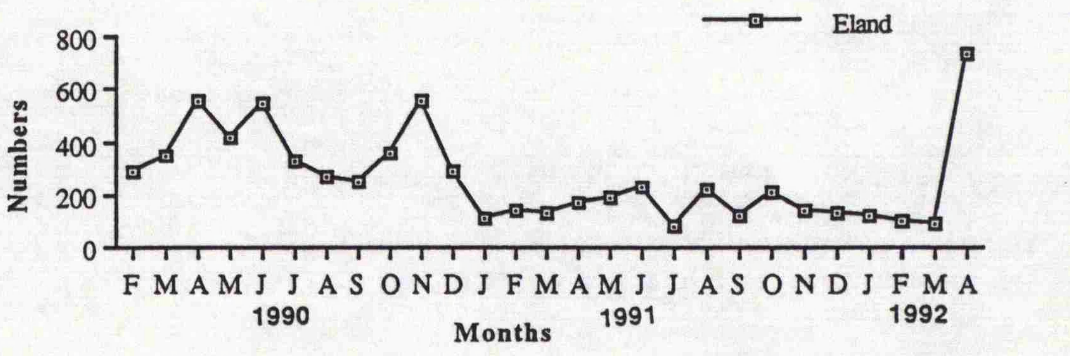


Figure 2.14: Summed monthly counts of Eland - February 1990 - April 1992



a rise in total numbers at a rate of 241individuals per month. July 1991 to March 1992 there was a decrease in the population size at a rate of 54 kongoni per month, and then in April 1992 the population size rose to 1872 kongoni from a total of 878 in March 1992.

Zebra (summed for all the study areas) also showed an increase and decrease pattern in its population size throughout the study, such that between February 1990 and June 1990, there was a population increase at a rate of 208 zebra per month (Figure 2.10). Between July 1990 and April 1991 there was a gradual decrease in numbers at a rate of 97 zebra per month, and then between May 1991 and June 1991 there was a gradual increase in the population size at a rate of 227 zebra per month. Between July 1991 and March 1992 the population size decreased at a rate of 68 zebra per month, and then it rose from a total of 639 zebra in March 1992 to 1399 zebra by April 1992.

Thomson's gazelle (summed for all the study areas) also showed a decrease and increase pattern in its population size during the study period. Between March 1990 and June 1990 the population increased at a rate of 175 individuals per month (Figure 2.11). From July 1990 to March 1991 there was a decrease in population size at a rate of 90 individuals per month. From April 1991 to May 1991 there was an increase of 380 individuals per month; this was followed by a decrease of 72 per month. In April 1992 the population size was 1770 having increased from 833 in January 1992 at a rate of 234 individuals per month.

Between February 1990 and November 1990 the population of Grant's gazelle (summed for all the study areas) remained fairly stable and monthly fluctuations in numbers may have been caused by birth, death and some of them being missed during counting (Figure 2.12). In December 1990 to February 1991 there was a decrease in population size at the rate of 41 individuals per month. This monthly decrease was too high to be due to a sudden increase in death rate since carcasses were not found during census. From March 1991 to April 1992 there was a gradual rise in the population size at a rate of 11 Grant's per month and this could have been due to an increased birth rate and counting inaccuracies.

The population size of eland (summed for all the study areas) remained stable between February 1990 and November 1990 (Figure 2.14) and the observed monthly fluctuations in numbers may have been due to death, birth and some of them being missed during counting. The population size then dropped from December 1990 and remained low, but stable up to March 1992.

Throughout the study, the population of buffalo remained fairly stable, but with a gradual increase in numbers except between August 1990 and November 1990 (Figure 2.4) when there was a sudden increase in numbers probably due to an increased birth rate compared with other months. Overall, monthly fluctuations were not great and this could have been due to both death, birth and some of the buffalo being missed during counting.

From the graphs showing the monthly trend in the counts of zebra, kongoni, eland, impala, buffalo, Thomson's gazelle and Grant's gazelle for each of the study areas, there is no clear indication that these species used to move between the study areas. If there was any movement between them, then a decrease in monthly counts say of zebra or kongoni in the Park could have been followed by an increase in these species in either Kongoni or Kedong Ranches or both and vice versa, but this was not the case from the graphs.

Klipspringer, mountain reedbuck, dikdik, and steinbuck showed variability in their numbers. The chance of missing them was high due to their cryptic nature and their variability was caused by not seeing all the individuals of each species during census. Warthog counts also showed monthly variability. This was due to some individuals going underground during the day, particularly during bad weather. They also lie under open bushes during the heat of the day. Therefore some of them were missed during counting. Defassa waterbuck were mostly sighted in Kongoni Ranch. Their population size was thought to be greater than found in this study (Rogers - ranch manager pers. comm.). They were associated with bushes, and were therefore not easy to locate; and as such most of them were missed during counting.

In the Park, kongoni had the highest population size and density followed by zebra and buffalo. Thomson's gazelle had the highest population size and density in Kedong Ranch, followed by kongoni and zebra respectively, while in Kongoni Ranch, zebra had the highest population size and density followed by kongoni, impala and Grant's gazelle in that order.

Kongoni constituted 38% of the total herbivore population of the Park followed by zebra (23%) and buffalo (15%). The rest was shared among the other species. In Kedong Ranch, Thomson's gazelle constituted 40% of the herbivore population followed by kongoni (27%) and zebra (17%); while in Kongoni Ranch zebra constituted 35% of the herbivore population followed by kongoni (19%), impala (18%) and Grant's gazelle (14%).

The percentage population structure of kongoni, zebra, Thomson's gazelle, Grant's gazelle, eland and impala in the three study areas is shown in figure 2.15 - 2.20. For each species, the monthly percentage of adults was greater than that of either sub-adults or juveniles. The mean ± S.E percentage of adults for each species is shown in table 2.9. Except for eland and Grant's gazelle (in the Park and Kedong Ranch), the other species showed a gradual monthly increment in the percentage of adults, sub-adults and juveniles. From my own judgement and the results obtained, the herbivore population structures appeared to be "healthy", although they were not characterised by high birth rates.

Fig. 2.15: Percentage population structure of kongoni - Feb. 1990 - April 1992

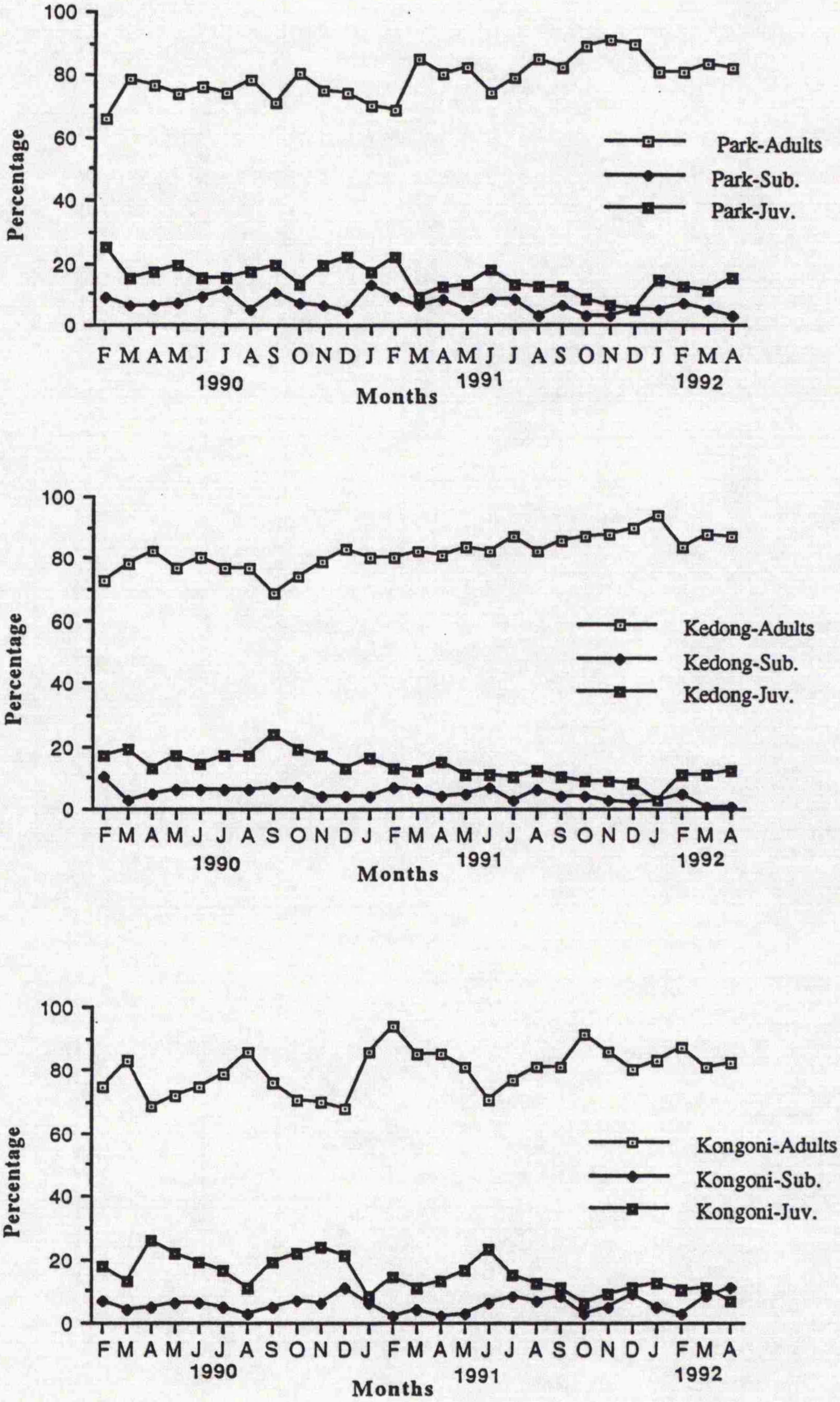


Fig. 2.16: Percentage population structure of zebra - Feb. 1990 - April 1992

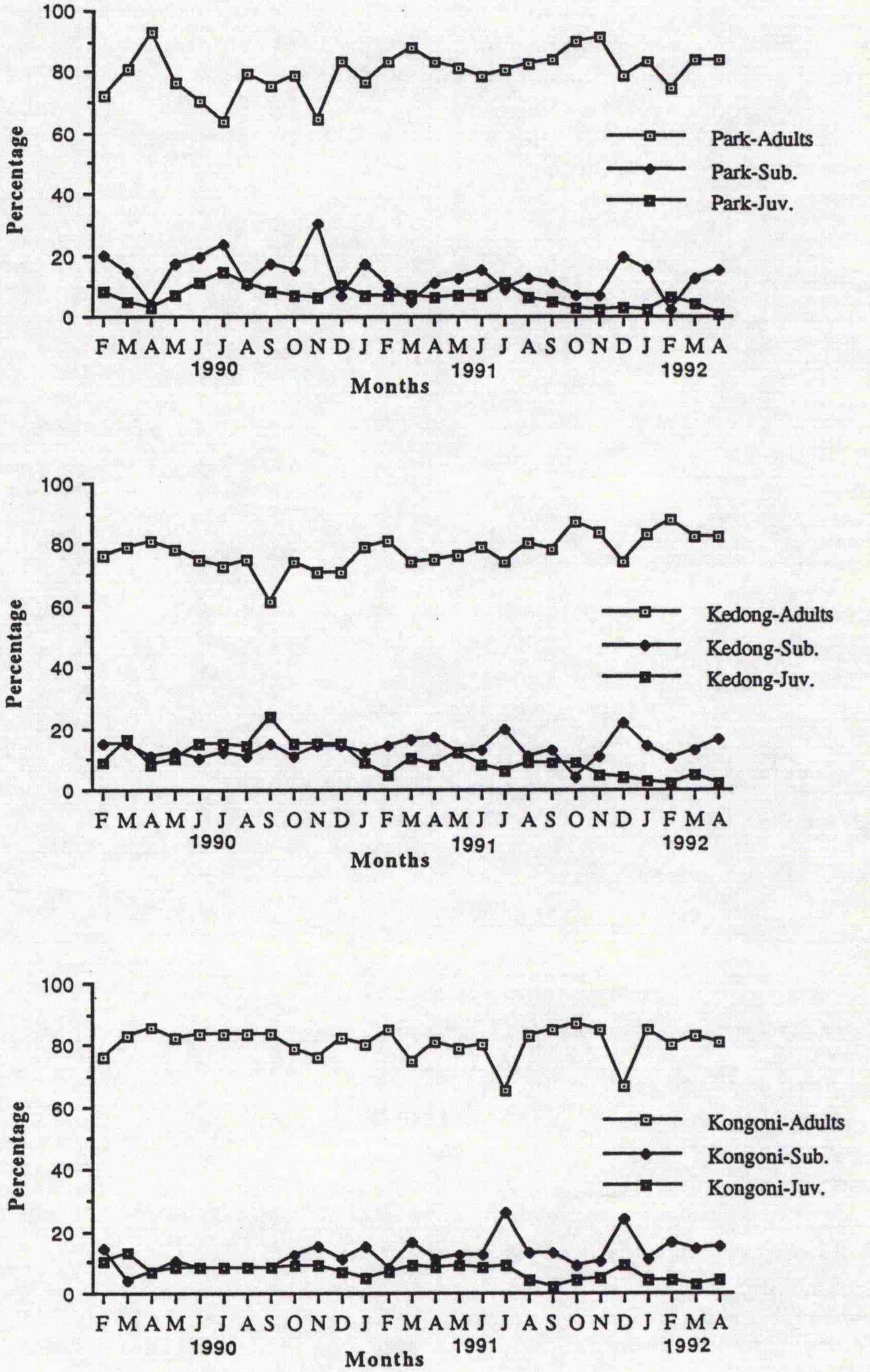


Fig. 2.17: Percentage population structure of Thomson's gaz.- Feb.1990-April 1992

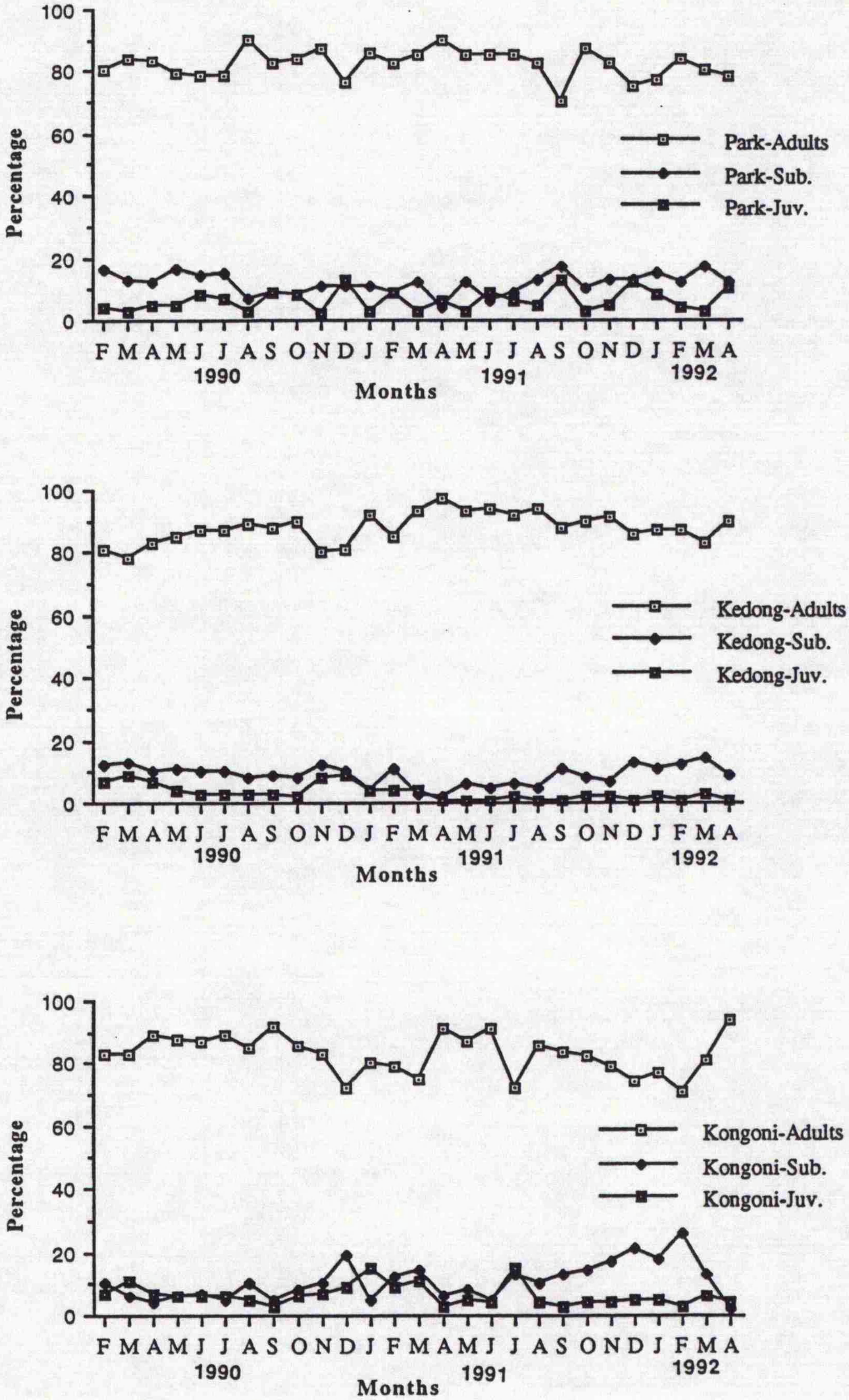


Fig. 2.18: Percentage population structure of Grant's gaz - Feb. 1990 - April 1992

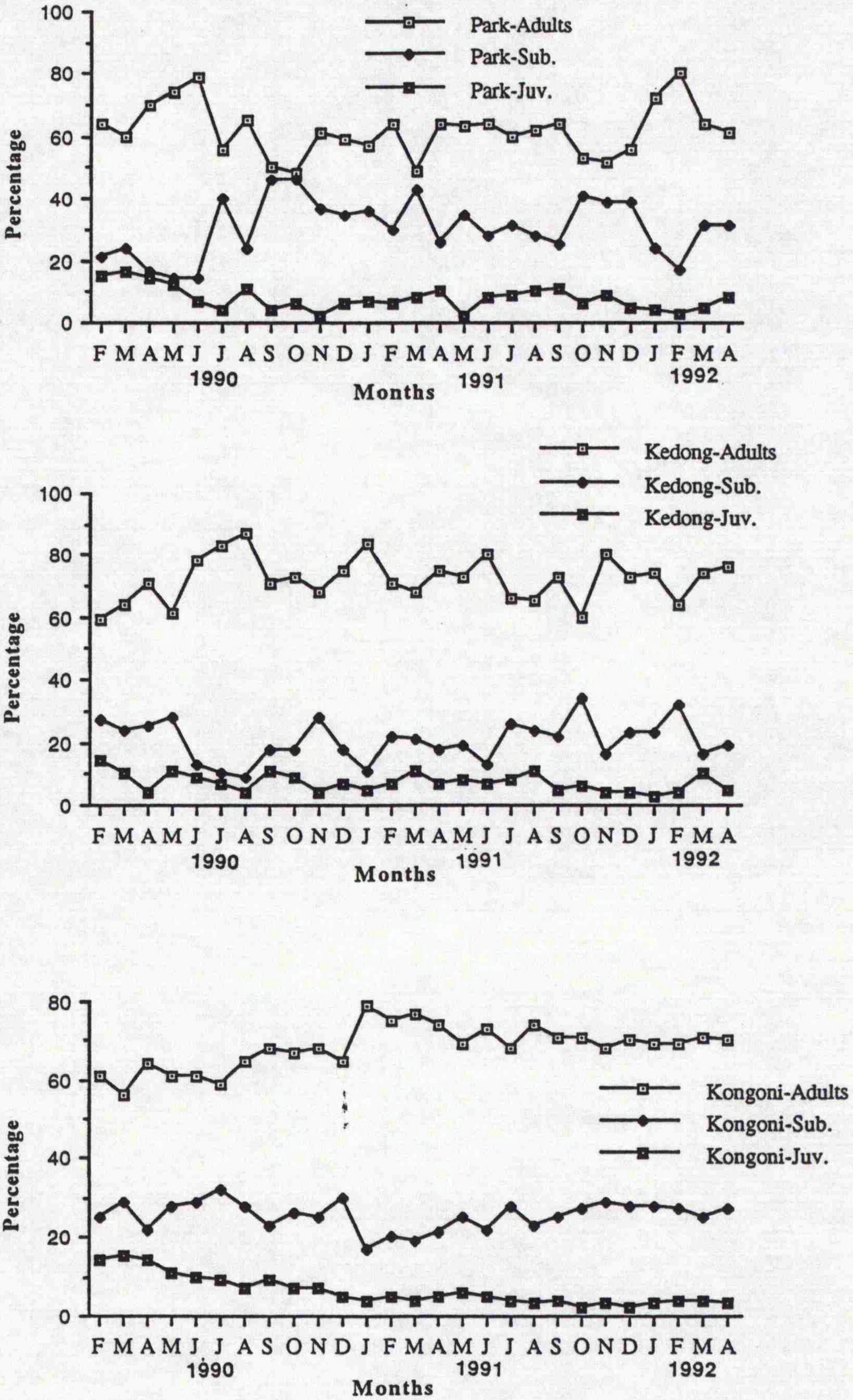


Fig. 2.19: Percentage population structure of eland - Feb. 1990 - April 1992

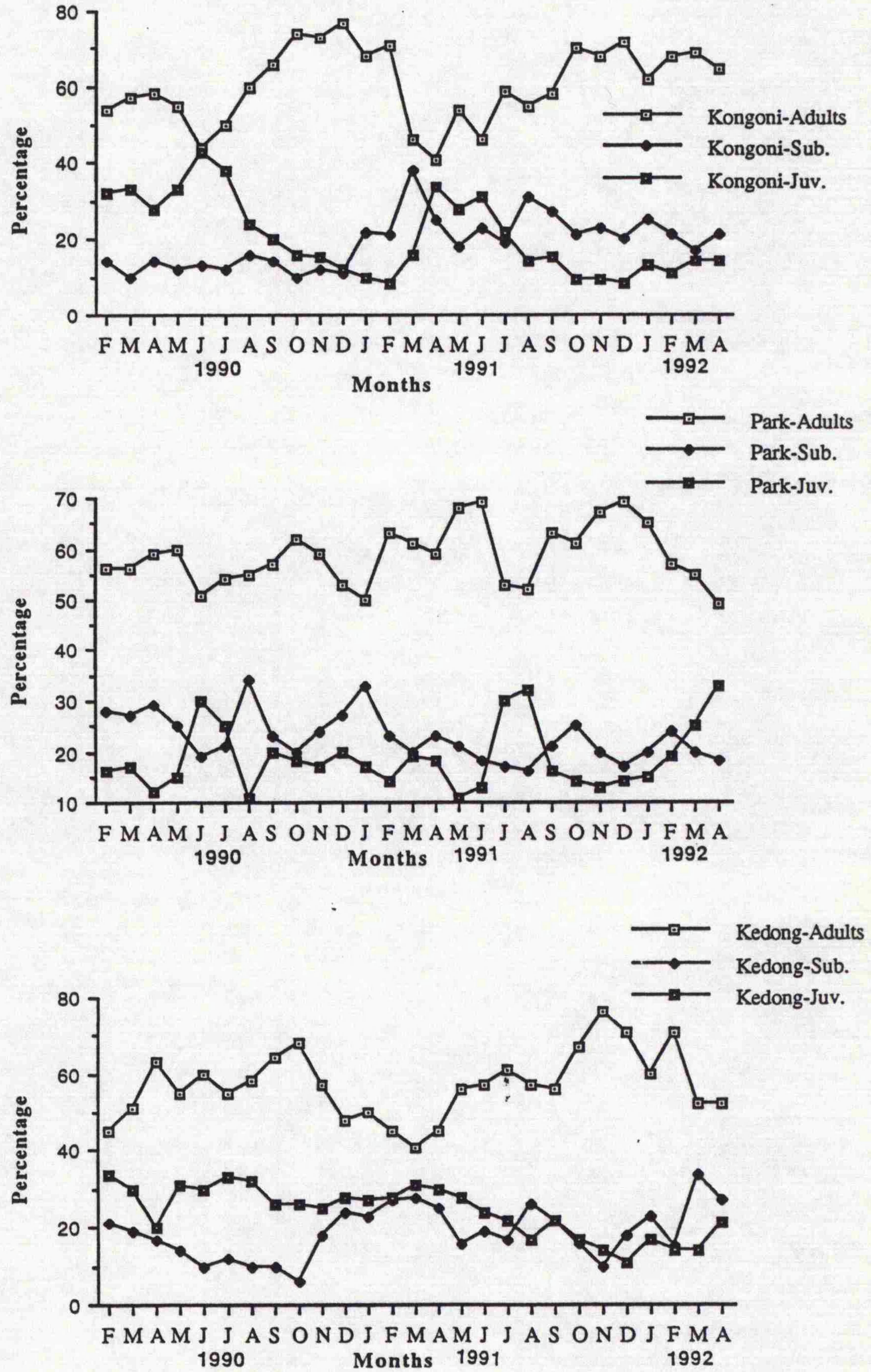
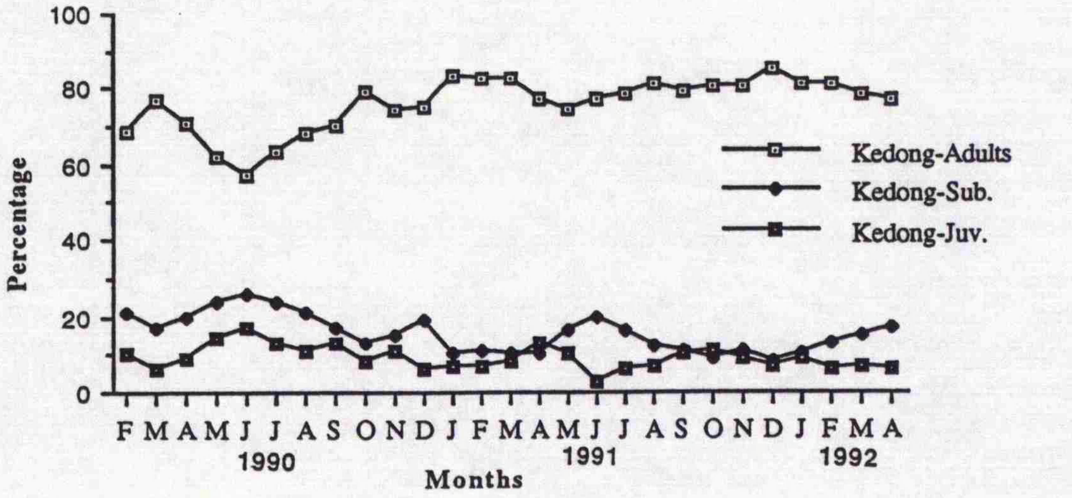


Fig. 2.20: Percentage population structure of impala - Feb. 1990 - April 1992



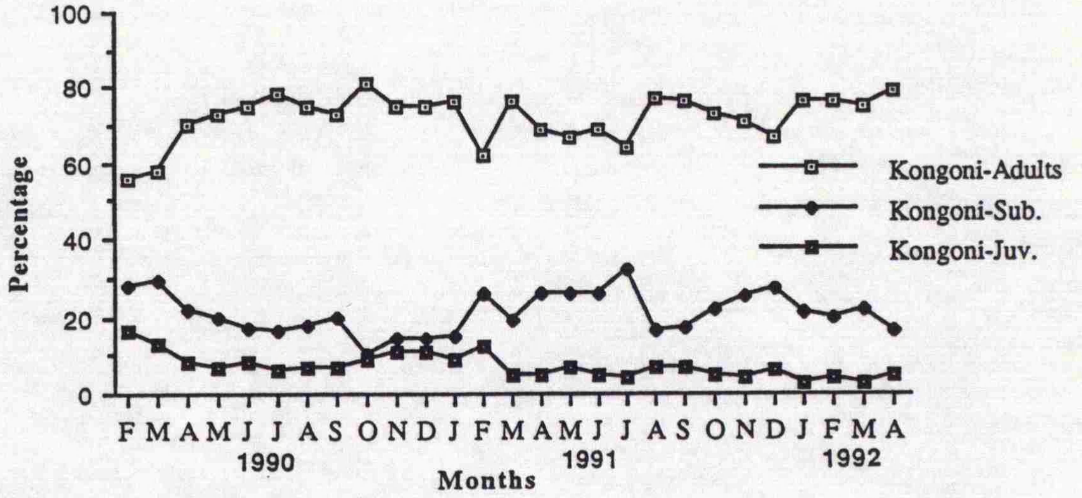


Table 2.9: Mean percentages of adults for the main herbivore species

	Park	Kedong Ranch	Kongoni Ranch
Species	Mean +/- S.E	Mean +/- S.E	Mean +/- S.E
Kongoni	79+/-6	82+/-6	80+/-7
Zebra	80+/-7	77+/-6	81+/-5
Thomson's gazelle	82+/-5	88+/-5	83+/-6
Grant's gazelle	62+/-8	72+/-7	68+/-6
Eland	59+/-6	57+/-9	61+/-10
Impala	-	76+/-7	72+/-6

This study did not look at the population dynamics of the mentioned species and therefore further analysis of the obtained data on the percentage of adults, sub-adults and juveniles is limited. A study looking at the population dynamics in order to see how the proportion of adults, sub-adults and juveniles change with time would require a longer study duration and that a single species be studied.

2.1.3 Discussion

The population and density estimates in this study have given an indication of the herbivore abundance in Hell's Gate National Park and its environs with kongoni and zebra and to an extent Thomson's gazelle being the most abundant species. The summed monthly counts (for all the study areas) of zebra, kongoni, Grant's gazelle, Thomson's gazelle, eland and impala showed variation, and this was most likely due to most of them being missed during counting than death and birth.

The overall herbivore community in the study areas was characterised by low numbers and densities in contrast to similar species (i.e. zebra, warthog, impala, kongoni, Grant's gazelle, Thomson's gazelle, defassa waterbuck, eland, giraffe and buffalo) in other areas of East Africa, such as Masai-Mara Game Reserve (Stewart and Talbot, 1962), Akira Ranch, Naivasha (Blankenship and Field, 1972), Tsavo National Park (Cobb, 1976), Ruaha-Rungwa area of Southern Tanzania (Barnes and Douglas-Hamilton, 1982) and Ramade (1984) in Serengeti National Park. Compared to other parts of East Africa, the zebra densities in this study were lower than of Ngorongoro Crater, Tanzania, estimated to be 18.0/km^2 (Kruuk, 1970). Kahurananga (1981) reported an average density for zebra to be 10.96/km^2, eland 6.10/km^2, Thomson's gazelle 15.62/km^2, giraffe 5.64/km^2 and impala 4.89/km^2 during the rains in 1971 and 1972 in Simanjiro Plains, Tanzania; while Skoog (1970) studying the population ecology of zebra in the Serengeti reported their density to be 13.79/km^2. Estes and Small (1981) working in Ngorongoro Crater, Tanzania reported herbivore densities of various species to be, Thomson's gazelle 11.79/km^2, eland 1.07/km^2, kongoni 6.63/km^2, buffalo 4.42/km^2, Grant's gzelle 5.14/km^2 and zebra 13.67/km^2. The herbivore densities reported by these workers are higher than those I found in my study. Eltringham and Woodford (1973) studying buffalo population dynamics in Ruwenzori National Park, Uganda reported a buffalo density of 11.16/km^2 and 11.89/km^2 in 1968 and 1969 respectively, which far exceed my buffalo density estimate in Hell's Gate. Similarly, Watson and Turner (1965) also studying the population ecology of buffalo in Lake Manyara National Park, Tanzania estimated their density to be 3.90/km^2, which is within the range of that of Hell's Gate. Unlike the Hell's Gate region, the above mentioned areas are characterised by high rainfall which results in high primary production and therefore enables them to support high herbivore numbers and densities.

The observed population density of the herbivores in this study is an indication of how much the primary production of the ecosystem can support. It has been found that food resources whose availability and amount are determined by rainfall (Walter, 1954; Whittaker, 1970) limits the density of large herbivore communities (Lack,1954; Hairston *et al.*, 1960; Wynne-Edwards, 1962; Sinclair, 1974a). Only five grass species *Cynodon dactylon, Digitaria milanjiana, D. scalarum, Themeda triandra* and *Chloris gayana* (whose primary production was determined by rainfall) were found to be the major source of food for the herbivores (Chapter 3). Their densities may have therefore been food limited. Although the population size of predators in the study areas is not known, their numbers appeared to be too low to have any influence (through predation) on the population sizes of the large herbivores.

Studies done in East Africa have shown that whenever cattle and wildlife occur together, they often feed on the same grass species, and this to an extent may bring about competition for food among them. For instance, Casebeer and Koss (1970) studying the food habits of wildebeest, zebra, hartebeest and cattle in the Athi-Kapiti Plains, Kenya found that all these species ate the same grass species mainly *Themeda triandra, Cynodon dactylon, Pennisetum mezianum* and *Digitaria macroblephara*. In a similar study in Uganda looking at the grazing preferences of buffalo and Ankole cattle *Bos indicus* on three different pastures, Field *et al.* (1973) found that they ate the same grass species mostly *Chloris gayana* and *Cynodon dactylon* among other grass species like *Digitaria melanochila, Setaria aequalis* and *Brachiara decumbens. Themeda triandra* was also eaten by both species although buffalo showed less preference for this grass species than did cattle.

In this study (Chapter 3), wildlife in the Park were found to feed on *Cynodon dactylon, Chloris gayana, Themeda triandra, Digitaria milanjiana* and *Digitaria scalarum*. Since these grass species were the most abundant in both Kedong and Kongoni Ranches (pers. obser.), cattle in these ranches were probably feeding on them (the grass species) together with the wildlife. In Kedong and Kongoni Ranches, there were about 6,000 and 3,000 head of cattle respectively. These grazed in the same areas with the wildlife and a certain degree of food overlap may have occured, which might have introduced competition for food and therefore limit the population size of the wildlife. Competition for food between cattle and wildlife was established by Kahurananga (1981) in Simanjiro plains, Tanzania. He found that the density of zebra and wildebeest in the plains was limited by food supply due to competition between them and cattle. The wildebeest was the most affected and faced more competition for food from cattle than did zebra. However, he did not state by how much the density of zebra and wildebeest was limited by food supply as a result of competition between them and cattle, nor did he indicate by how much food competition between cattle and wildebeest affected the latter in relation to zebra. In another study in Loliondo, Tanzania, Watson *et al.* (1969) found that there was an overlap between the food requirements of cattle and wildebeest. This competition lowered the population growth of the latter by 2.6 per cent due to lack of food. In Nairobi National Park, Kenya, the exclusion of cattle from the Park resulted in an increase of 5.6 per cent of wildebeest population a year later due to reduced competition between the two species (McLaughlin, 1970).

The history of the Hell's Gate area may have had an influence on the herbivore populations. A few decades ago hunting was prevalent (Stephenson pers. comm.) and species like bushbuck, bushduicker and wildebeest were present. Hunting may have reduced the population of these species together with impala, steinbuck, mountain reedbuck and bohor reedbuck. From mid-seventies, the Hell's Gate ecosystem has been experiencing a high rate of human settlement especially around Mai-Mahiu, Longonot and Nyamathi. This has converted areas previously occupied by wildlife into agricultural land thus compressing their habitat and food resources which may have led to the decline in population size of the species already mentioned including zebra, Thomson's gazelle, Grant's gazelle, buffalo and kongoni.

2.2 DISTRIBUTION AND HABITAT UTILIZATION

Animals exhibit a distribution pattern which varies from species to species. Contiguous or clumped distribution is the most common due to the spatial heterogeneity of the enviroment. Regular and random distributions are rare in nature. Enviromental factors such as topography, vegetation condition and water availability have been shown to affect the distribution and movements of ungulates (Field and Laws, 1970; Jarman, 1972; Leuthold and Sale, 1973; Stelfox, 1985; Western and Lindsay, 1984). Rogers (1980) studying the herbivore community of the miombo woodlands of South East Tanzania observed that the herbivores' distribution and movement within the woodlands was determined by water availability and burning of the vegetation. Burnt areas and places with permanent water attracted large numbers of herbivores. Eltringham and Woodford (1973) working in Ruwenzori National Park, Uganda found that water availability determined the distribution of the buffalo population. During the dry season, the crater areas of the Park were devoid of permanent fresh water and therefore the buffalo were rarely sighted there, but during the rains there were numerous temporary water pools which provided an adequate supply of drinking water.

Habitat preference is a common phenomenon among the grazing herbivores of East African grasslands (Bell, 1969; Lamprey, 1963; Leuthold,1971; Owaga, 1975). This results in the optimal use of food quantity and quality from the habitat. Western (1973) working in

Amboseli National Park established the habitat preferences of members of the herbivore community. He found that the eland was the most habitat specific, concentrating mostly in the denser woodlands. Wildebeest, zebra and Grant's gazelle used all the available habitats such as grassland and open bushes, with zebra and Grant's gazelle being the least selective. Leuthold and Leuthold (1972) studying the giraffe in Tsavo National Park found that they had a preference for woody habitats from which they obtained browse material. During the dry season, riverine areas were preferred, but as the wet season set in, they dispersed into the woodlands.

Knowledge of habitat utilization and distribution of animals in relation to their environment is essential for effective wildlife management and range utilization (Afolayan, 1972; Laws and Parker, 1968). Strategies such as burning in order to improve savanna food quality and prevent bush encroachment depend on these kinds of data. Studies aimed at finding out the range condition, supply of water for wildlife use and road construction for better game viewing also depend on distribution data.

Habitat utilization and distribution of wildlife in Hell's Gate National Park has previously been studied; Kiringe (1990) showed that most of the herbivores - kongoni, zebra, Thomson's gazelle, warthog and Grant's gazelle - occupied the grassland vegetation type which covers the Njorowa Gorge. Dikdik, steinbuck, klipspringer and mountain reedbuck preferred open bushland. The herbivores showed a clumped distribution pattern and for most of the year they were concentrated in the Gorge. Their distribution pattern was influenced by the topography, nature of the vegetation and the spatial variation in food resources. There was a preference for flat areas and rugged terrain was avoided. Except for buffalo, most of the animals avoided thick bushes.

Hell's Gate is a relatively new Park and thus needs to frequently review its management plan in order to effectively meet its objectives as a wildlife conservation area. Information on habitat preference and distribution of the wildlife will be useful. The data can be used in planning how the present road network can be expanded in order to ensure that all areas of wildlife concentration can be visited by tourists. Currently three water troughs have been constructed to supply water to wildlife. More may be constructed in other areas of the Park in order to avoid overuse of the existing ones. The decision on where to construct them will depend on knowledge of the habitat preference and distribution of the wildlife. The present study was therefore undertaken with an objective of providing more knowledge on the habitat preference and distribution of the Park ungulates and by so doing provide information to be used in modifying the existing management plan for the Park.

2.2.1 Method

During census, the approximate position of the herbivores was located on a 1km by 1km grid reference topographical map of the study areas. Observation of the data obtained on the monthly distribution maps of the three study areas showed that the distribution of the wildlife was the same during the wet and dry season. There was therefore no need to draw maps showing the monthly distribution pattern of the herbivores, and so a single map showing the general distribution pattern of the wildlife in all the three study areas was drawn. To show in detail the monthly distribution pattern exhibited by the Park wildlife, a map for June 1991 was drawn (any other month could have been choosen since observation of the monthly wildlife distribution maps showed that the distribution was similar for all the months)

2.2.2 Results

The distribution pattern exhibited by the Park wildlife in June 1991 is shown in figure 2.21 which clearly shows that some areas had higher wildlife concentration than others. Figure 2.22 shows the distribution of the herbivores in the three study areas. The shaded parts represent areas where most of the wildlife was concentrated. The overall distribution pattern exhibited by the herbivores in the three study areas was neither random or regular. Dry and wet season distribution pattern of the ungulates was similar. Most of the species were found in open flat areas and avoided areas of rugged terrain and thick vegetation. Therefore, their distribution appeared to be influenced by both topography and vegetation type.

My observations suggested that there was more movement of wildlife between Kedong Ranch and the Park than between Kongoni Ranch and the Park, although this could not be quantified.

2.3 HABITAT UTILIZATION

2.3.1 Method

For the Park, a map showing different vegetation types (Figure 1.6) had previously been prepared Kiringe (1990). In Kedong and Kongoni Ranches such a detailed vegetation map was not prepared. Their vegetation was visually categorized into three major vegetation types or communities referred to as habitats: grassland (1), open *Tarchonanthus camphoratus* / *Acacia drepanolobium* shrubland (2) and dense *T. camphoratus* / *A. drepanolobium* shrubland (3). During census, the vegetation type in which a species occured was recorded. The total number of months a species occured in a given habitat out of all the months for the study were converted into percentage time occupancy as:

Figure 2.21: Hell's Gate National Park: Showing grids and wildlife distribution pattern - June 1991

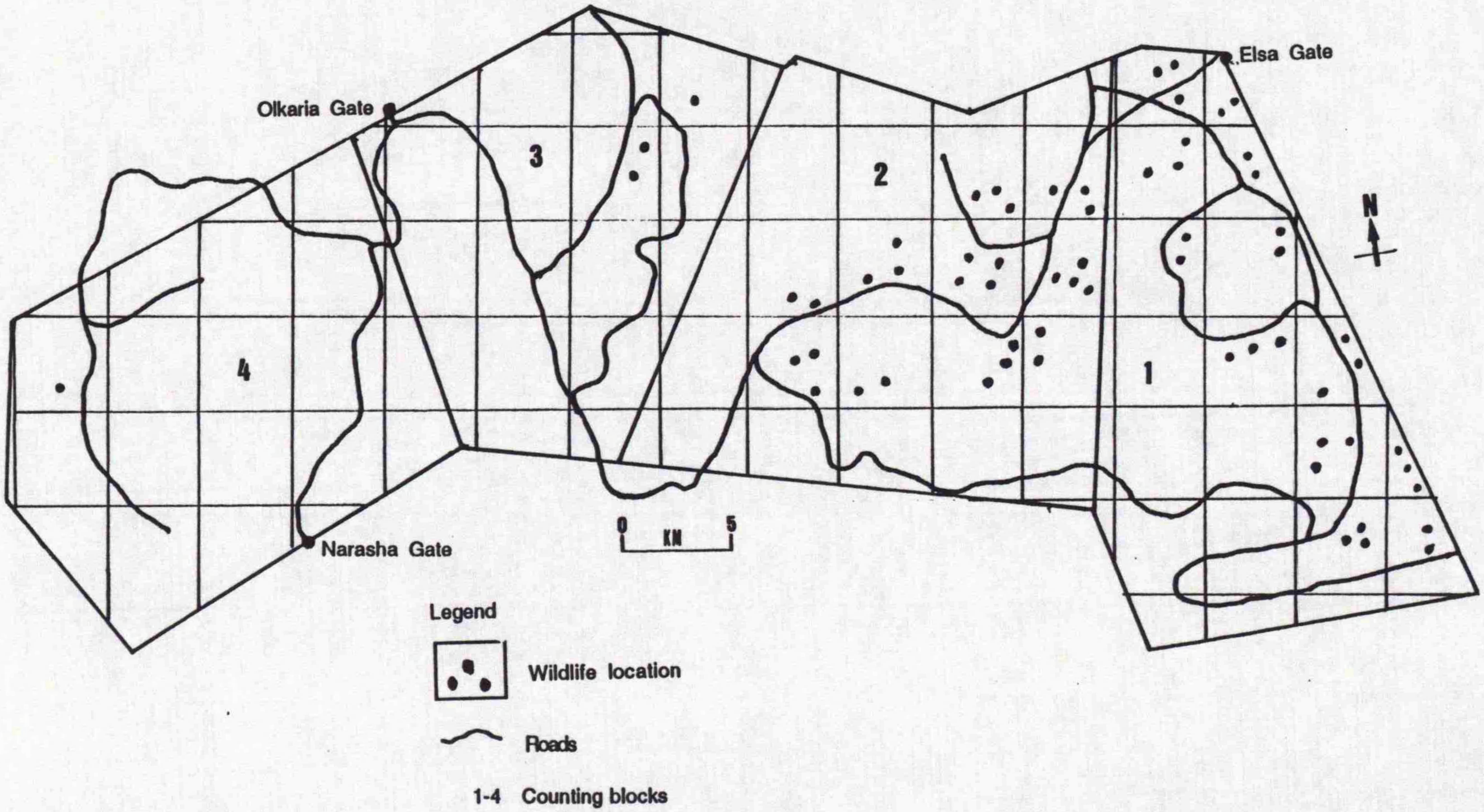
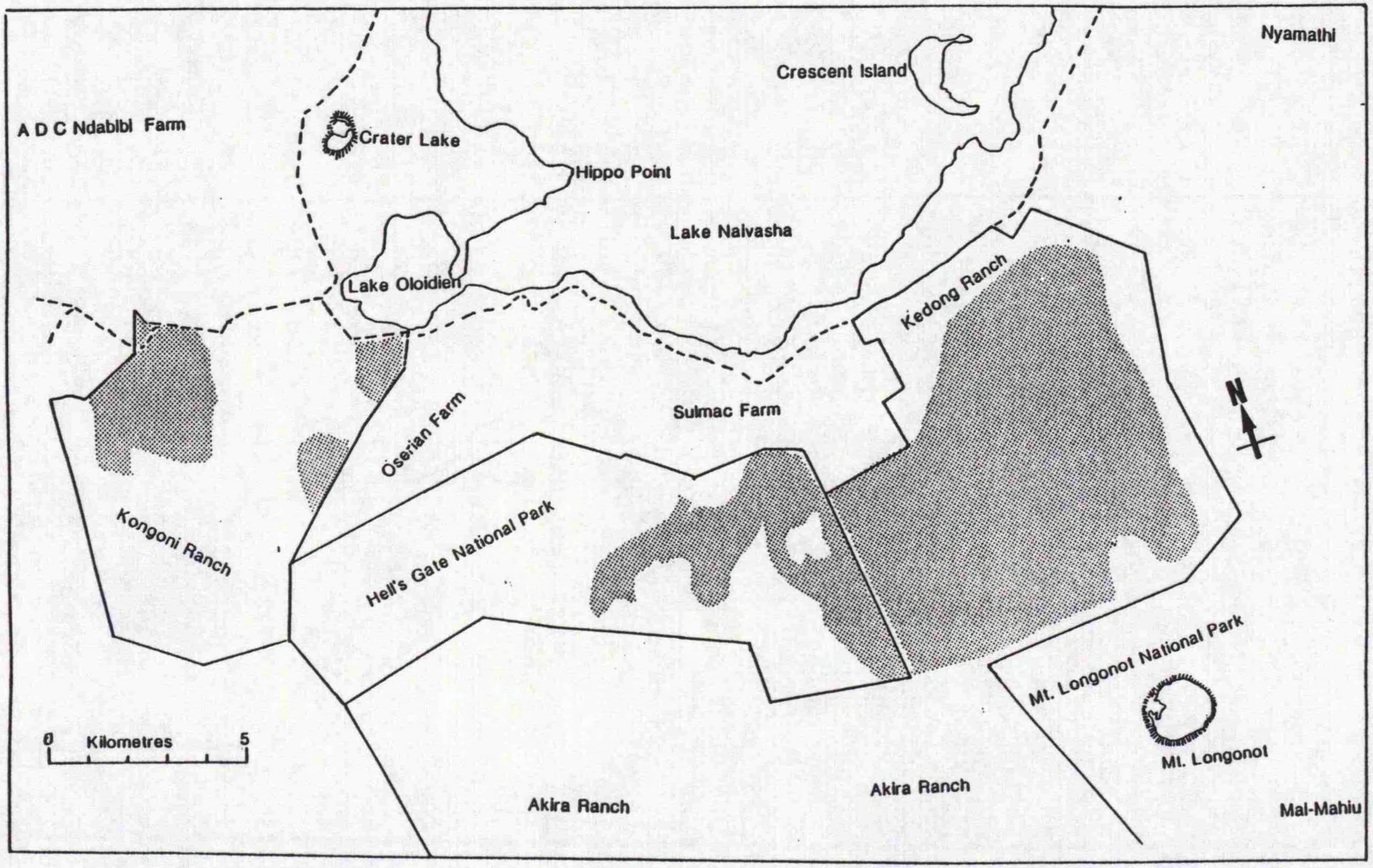


Figure 2.22: Wildlife distribution pattern in Hell's Gate, Kedong and Kongoni Ranches



The shaded parts represent areas where most of the wildlife was concentrated

$$\% \text{ time occupancy} = \frac{\text{total number of individuals of a species in a habitat for the study duration}}{\text{total number of individuals of a given species in all habitats for the study duration}} \times 100$$

These data were then summarised to show the percentage time occupancy of each herbivore species in a given habitat, and hence which habitat (s) was / were preferred.

Casual observations were made on whether the animals were grazing in short or tall grass areas, and how they seasonally moved from the grassland to the bushes, but this was not presented in the form of data.

2.3.2 Results

Table 2.30 - 2.32 show the percentage time a habitat was occupied and which habitat(s) was / were preferred by the herbivores in the Park, Kedong and Kongoni Ranches respectively. In the Park, vegetation community A (grassland) was the most preferred habitat by most of the herbivores. This was followed by community C, G and to a certain extent community B, while the rest of the communities were less preferred habitats. In Kedong and Kongoni Ranches, vegetation community I was the most preferred habitat followed by community 2 and community 3 was the least preferred.

Zebra, kongoni, Thomson's gazelle, Grant's gazelle and warthog were seen to select short grass areas during the wet season. During the dry season, warthog, zebra and kongoni were seen to select areas of tall grass. Dikdik, impala, klipspringer, mountain reedbuck and steinbuck preferred open bushes from which they obtained browse material. Giraffe were seen to prefer open bushes with a high concentration of *Acacia drepanolobium*, their preferred food. Buffalo were mostly found both in dense and open bushes. Warthog, Thomson's gazelle and Grant's gazelle were not seen in bushes even during the dry season when most of the grass forage in the grassland was dead and dry.

As the dry conditions set in, eland, zebra and kongoni were visually observed to retreat into the bushes in search of forage. Eland was the first to retreat, while zebra and kongoni followed much later. Thomson's gazelle, Grant's gazelle and warthog did not follow this pattern, and remained in the grassland during the wet or dry seasons.

2.4 DISCUSSION

2.4.1 Distribution

From my observations, there seemed to be no spatial variation in rainfall distribution in the whole area, such that if it was wet or dry in the Hell's Gate region, then it was wet or dry

Table 2.30: Habitat utilization by herbivores in the Park

	Percentage time a habitat was occupied											
Species	A	B	C	D	E	F	G	H	J	K	N	Preferred habitat
Kongoni	38	5	24	4	2	-	20	-	-	-	27	A, C, G
Zebra	30	5	20	2	3	2	26	4	-	-	8	A, C, G
Thomson's gazelle	72	-	-	-	-	-	28	-	-	-	-	A
Eland	26	-	57	-	5	5	7	-	-	-	-	C
Buffalo	-	40	60	-	-	-	-	-	-	-	-	B, C
Grant's gazelle	54	-	9	-	-	-	37	-	-	-	-	A, G
Klipspringer	14	-	-	-	86	-	-	-	-	-	-	E
Impala	-	-	-	-	-	-	-	-	44	56	-	J, K
Giraffe	26	-	30	15	-	-	15	10	4	-	-	A, C, D, G, H
Warthog	40	24	6	-	-	-	-	-	-	-	30	A, N
Mountain reedbuck	-	-	-	-	-	-	-	-	100	-	-	J
Steinbuck	58	-	42	-	-	-	-	-	-	-	-	A, C
Dikdik	-	82	18	-	-	-	-	-	-	-	-	B

Key to habitats

A-*Cynodon* / *Digitaria* grassland
B-*Hyparrhenia* / *Digitaria* / *Tarchonanthus* / *Acacia shrubland*
C-*Themeda* / *Tarchonanthus* / *Acacia* dwarf shrubland
D-*Themeda* / *Digitaria* / *Tarchonanthus* / *Acacia* shrubland
E-*Digitaria* / *Hyparrhenia* / *Tarchonanthus* / *Dodonea* shrubland
F-*Digitaria* / *Tarchonanthus* / *Acacia* dwarf shrubland
G-*Digitaria* / *Acacia* dwarf shrub grassland
H-*Themeda* / *Digitaria* / *Tarchonanthus* / *Acacia* shrubland
J-*Hyparrhenia* / *Acacia* / *Tarchonanthus* dwarf shrubland
K-*Hyparrhenia* / *Tarchonanthus* / *Acacia* shrubland
L-Sparsely vegetated rocky zone
M-*Digitaria* / *Themeda* / *Tarchonanthus* / Acacia dwarf shrubland
N-*Digitaria* / *Tarchonanthus* / *Acacia* dwarf shrubland

Table 2.31: Habitat utilization by herbivores in Kedong Ranch

	Percentage time a habitat was occupied			
Species	1	2	3	Preferred habitat
Kongoni	70	25	5	1
Zebra	65	30	5	1and 2
Thomson's gazelle	90	10	-	1
Grant's gazelle	90	10	-	1
Eland	16	80	4	2
Warthog	92	8	-	1
Steinbuck	89	11	-	1
Dikdik	-	92	8	2
Giraffe	5	70	25	2
Impala	20	72	8	2

Key to habitats

1: Grassland

2: Open *T. camphoratus / A. drepanolobium* shrubland

3: Dense *T. camphoratus / A. drepanolobium* shrubland

Table 2.32: Habitat utilization by herbivores in Kongoni Ranch

	Percentage time a habitat was occupied			
Species	1	2	3	Preferred habitat
Kongoni	55	38	7	1
Zebra	58	36	6	1 and 2
Thomson's gazelle	95	5	-	1
Grant's gazelle	88	12	-	1
Eland	30	62	8	2
Warthog	94	6	-	1
Steinbuck	89	11	-	1
Dikdik	-	92	8	2
Giraffe	26	68	6	2
Impala	10	82	8	2

Key to habitats

1: Grassland

2: Open *T. camphoratus / A. drepanolobium* shrubland

3: Dense *T. camphoratus / A. drepanolobium* shrubland in the Park, Kedong and Kongoni Ranches. Therefore, the distribution pattern of the animals during the dry and wet seasons was similar and appeared to be influenced by topography and vegetation type. Animal harassment (hunting) was almost absent and predators were few, so it is unlikely that either influenced the distribution of the ungulates. In the Park, water for wildlife use was provided in three water troughs, but no such troughs provided water in Kedong and Kongoni Ranches. However, from my personal observations, water was probably not an important factor in influencing the distribution of the animals. Had it been, there could have been a high concentration of wildlife in the Park water troughs (especially during the dry season when most of the herbivores need to drink frequently) which had water throughout the year, but this was observed not to be the case.

The results of this study compare with those of Blankenship and Fields (1972) in neighbouring Akira Ranch, Naivasha, where they found that vegetation condition was the major factor affecting the distribution of the herbivore community. Burnt areas attracted large numbers of Thomson's gazelle. In general burning of grass improves its palatability and nutritional status. They were also attracted to areas of short grass like cattle bomas, water troughs and over-grazed areas. In such areas, the short grass was continously growing, is more palatable and nutritious than tall grass that has ceased to grow.

Other studies in East Africa have shown that topography, predation, habitat quality and water resources influence the distribution of ungulates. For example in Queen Elizabeth National Park, Uganda, Field and Laws (1970) found that the spatial distribution of herbivores was influenced by water, predators, man, fire and vegetation conditions. However, further analysis was not done to determine which of these factors were more important in influencing the distribution of the animals. Western (1973) working in Amboseli National Park, Kenya found out that for most of the ungulate species he studied, the distribution pattern changed seasonally depending on water and food availability. During the dry season, they used the Amboseli basin for water and forage and later dispersed into the surrounding areas of Maasai land during the wet season. This seasonal change in their distribution was as a response to water and food requirements. Ayieko (1976) studying the herbivore community of Lambwe Valley, Kenya, found that the animals exihibited a contiguous or clumped distribution pattern influenced by a number of factors which included range condition, topography, water availability and spatial and temporal variation of food resources. Their respective importance in influencing the distribution pattern of the herbivores was not determined.

Climatically determined movements of ungulates are wide spread in African savannas and are related to the rainfall pattern which influence the spatial and temporal availability of both water and food resources (Dora and Balakrishnan, 1991; Eltringham and Woodford, 1973; Kahurananga, 1981). Rainfall induced ungulate movements occur between Nairobi National

Park and the Athi-Kapiti Plains (Foster and Coe, 1968; Keiyoro, 1982; Gichohi per. comm.), in Tarangire National Park, Tanzania (Lamprey, 1964), Loliondo area of Tanzania (Watson *et al.,* 1969) and between Serengeti and Masai-Mara Game Reserve (Sinclair, 1979).

In the Hell's Gate ecosystem, massive migration of the herbivore community did not take place as happens in some other areas of East Africa. However localised small scale movements did occur between the Park and its environs (especially Kedong Ranch) on a daily basis, but was not related to rainfall pattern or seasonality (pers. obs.). There was more herbivore movement between the Park and Kedong Ranch than Kongoni Ranch, but this did not appear to be induced by the rainfall pattern of the area (pers. obs.). One aim of the monthly herbivore counts that I carried out was to find out whether there was any seasonal movement of the ungulates between the Park, Kedong and Kongoni Ranches, but the results obtained showed that this was not the case.

2.4.2 Habitat Utilization

An animal will select a habitat in which it can maximise its fitness, food quantity and quality (Rogers, 1980). Habitats which do not meet these requirements will be rarely chosen or will be avoided totally. The observed habitat preferences mean that the species selected the habitat(s) that best suited them in terms of supplying food resources. Those vegetation communities that were less selected as habitats were either steep or had thick vegetation or both and therefore did not offer good habitats for the animals.

Most of the species were grazers and selected the grassland where there was plenty of grass forage for most of the year compared with the other habitats. Eland, being more of a browser than a grazer (Hofmann and Stewart, 1972), were more sensitive to the dry range conditions than zebra and kongoni hence they retreated early into the bushes where they sought browse forage. Zebra and kongoni were more resistant to the dry range conditions, and could survive on hard dry grass material during the dry season and hence were the last to retreat. The other species like warthog, Thomson's gazelle and Grant's gazelle remained in the grassland even when most of the forage was dead and dry. Klipspringer, mountain reedbuck, steinbuck and dikdik due to their small size require highly nutritious food to maintain their body physiological processes (Hofmann and Stewart, 1972) and that is why they preferred open bush areas from where they could obtain browse forage.

The selection for short grass areas (short due to continuous grazing) by Thomson's gazelle, Grant's gazelle and warthog during the wet season, and selection for tall grass areas during the dry season by zebra and kongoni ensured that they maximised intake of green forage. Similar behaviour among grazers has been observed in the Serengeti Plains, Tanzania (Bell, 1969), Athi-Kapiti Plains, Kenya (Owaga, 1975), Kidepo Valley National Park, Uganda (Ross *et al.*, 1965) and in Mweya Peninsula, Ruwenzori National Park (Eltringham, 1974). Bell (1969) working in the Serengeti showed that wildebeest *Connochaetes taurinus* preferred short grass areas in all seasons and only grazed in tall grass areas following their grazing by zebra and buffalo. Zebra showed a preference for short grass during the rains, but during the dry season, they grazed both in tall and short grass areas.

In other studies, Bradley (1968) working in Nairobi National, Kenya, found that warthog *Phacochoerus aethiopicus* preferred short grass areas, but at the end of the dry season, long grass areas were chosen in preference to short dead grass areas. During this time, the long grass had more green leaves compared with the short grass and therefore was better in providing high quality forage (although the nutrient status of the grass forage was not determined), hence its selection. A similar phenomenon was observed in topi *Damaliscus lunatus* by Duncan (1975) in the Serengeti National Park, Tanzania. Rogers (1980) working in the miombo woodlands of South East Tanzania observed that the herbivore species he studied changed their habitat depending on the enviromental changes of the area. Wildebeest, impala and warthog showed selection for the short grass, whilst the hartebeest selected the woodland types. Although he did not measure the nutrient status of the forage consumed, he concluded that these habitats were chosen because they provided high quality food during the dry season when the other areas were dry with less and non-nutritious forage.

2.5 HERBIVORE BIOMASS

The "carrying capacity" or the amount of animal life that an area can support without deteroriating is of value in planning the correct management of the land concerned (Stewart and Zaphiro,1963). This is commonly expressed in two ways : (1) numbers or densities (2) biomass (Lamprey,1964; Stewart and Zaphiro, 1963). Population size is a good indicator of the abundance of different herbivores in a particular area but does not give an accurate comparative biological parameter because it does not take animal biomass into consideration. Biomass density on the other hand gives such a comparative factor when the animals are converted into the same units (Kahurananga, 1981).

When converting number or density of animals in a given area into biomass, one encounters the problem of finding a suitable average weight to represent all the individuals in a population of a given species (Foster and Coe, 1968). Ideally this figure should take into account the number of young and sub-adults in the population, but much work would be needed to determine this variable. Unit weight of a given species may vary depending on the age structure (i.e. the proportion of adults, sub-adults and juveniles), nutritional status and the location and or altitude where mean weight may differ in different parts of a species range (Leuthold and Leuthold, 1976). Some of the herbivore weights given in literature refer to trophies (Meinertzhagen,1938), and are not suitable for determining an average adult weight, while others do not seem to adjust sufficiently for the young and sub-adults in the population.

When determining the unit mass to be used to calculate the biomass of a given species, there has been a bias to weigh only adults and not including both sub-adults and juveniles, therefore equating the adult weight to be similar to that of juveniles and sub-adults. Depending on the proportion of these in a population, there can be an over-or under-estimate of the biomass. It is therefore imperative that unit mass be indicated whenever biomass figures are presented (Leuthold and Leuthold, 1976).

Comparison of herbivore biomass in different areas is sometimes difficult due to three main reasons (Leuthold and Leuthold, 1976; Stewart and Zaphiro, 1963):

(a) Biomass calculations have been based on single counts of herbivores in a given area. If such an area is subject to periodic animal movement in and out, then a single count is not a representative of the actual population status of the area being studied, and therefore the biomass calculated from such a single count may be an over-or under-estimate and not a representative of the true value of the animal biomass.

(b) Counts have been made of arbitrary defined areas, parts of which are not used significantly, or at all by the animals concerned. The inclusion of such parts in the calculation of biomass is an under-estimate of the remainder of the area.

(c) Different authors have used different unit masses when calculating animal biomass therefore making direct comparison difficult.

Herbivore biomass estimates of different species in East African savanna has been made by several authors; for example Lamprey (1964) in Tarangire Game Reserve (now an National Park), Leuthold and Leuthold (1976) in Tsavo East National Park, Kenya, Kutilek (1974) in Nakuru National Park, Kenya, Field and Laws (1970) in Ruwenzori National Park, Uganda and Kahurananga (1981) in Simanjiro Plains, Tanzania. These studies have demonstrated that the East African savanna does support a high herbivore biomass compared to other grassland areas of the world. This is due to their high primary productivity (which leads to high secondary production) and diversified herbivore species composition (Bourliere, 1963; Bourliere and Hadley, 1970). The diversified herbivore populations are ecologically separated such that they are capable of making maximum use of the available food resources and habitats, thus enabling different species of varying feeding habits and sizes to co-exist in the same area.

Coe *et al.* (1976) has given a summary of herbivore biomass density of different parks of East Africa (Table 2.33). The biomass varies from Park to Park depending on the rainfall amount which determines primary production and consequently the level of secondary production. The vegetation type which provides food and habitat for the herbivores will also determine the species variety and population size found in a Park (e.g. some Parks like Tsavo, Amboseli and Ruwenzori have elephants unlike Parks such as Lake Nakuru and Hell's Gate) and the associated biomass. In certain situations, rainfall alone cannot fully explain the herbivore biomass differences among the Parks, and other factors like herbivore species composition are equally important. Wildlife species differ in their body weights. Therefore a herbivore community dominated by Thomson's gazelle or Grant's gazelle will have a different biomass density compared with another one which is dominated by wildebeest or kongoni whose body weights are greater. Amboseli and Nairobi National Parks have almost a similar herbivore biomass density yet the former has a far much lower rainfall amount than the latter (Table 2.33). One would have expected Nairobi Park to have a higher biomass density due to its high rainfall amount, but this is not the case. The reason for this is due to the fact that although the two Parks have an almost similar herbivore species composition composed mainly of zebra, wildebeest, kongoni, eland, Thomson's gazelle, Grant's gazelle and buffalo, Amboseli National Park has swamps which provide drinking water and year round food supplies for the wildlife in the ecosystem especially during the dry season when adjacent Masailand is dry. The Park therefore serves as a dry season concentration area for the regional wildlife populations which during this time move from adjacent areas to the Park where they are assured of permanent water supply (Western, 1973, 1975). This leads to a high wildlife concentration in the Park and consequently the herbivore biomass per unit area. For Nairobi National Park, most of the herbivores move to neighbouring Athi-Kapiti Plains where they are resident for most of the year (Keiyoro, 1982, Gichohi pers. comm.), such that the overall population size of the wildlife in the Park is low for most of the year leading to a low biomass density. Amboseli National Park also contains migratory elephants which contribute significantly to the herbivore biomass due to their high body weight.

Considering that National Parks and Game Reserves in East Africa do not represent the full habitat requirements for most of the animals particularly herbivores, management by man has become necessary. Determination of the carrying capacity or the animal biomass that these areas can effectively support without deteroriation of the range is important so that any negative trend of the range can be prevented by management such as cropping some of the animals. This study was undertaken to provide information on the current herbivore biomass of Hell's Gate National Park leading to an estimate of its carrying capacity. The data will serve as a baseline against which to evaluate future trends of the herbivore biomass and also aid in the management of the Park especially its ability to support wildlife.

Table 2.33: Herbivore biomass in some East Africa National Park

Park	Annual rainfall (mm)	Herbivore biomass (kg/km2)
Ruwenzori National Park-Uganda	1010	19928
Lake Manyara National Park-Tanzania	915	19189
Ngorongoro Crater-Tanzania	893	7561
Lake Nakuru National Park-Kenya	878	6688
Amboseli National Park-Kenya	350	4848
Nairobi National Park-Kenya	844	4824
Tsavo National Park(East) North of Voi River Kenya	553	4033
Tsavo National Park(East) South of Voi River Kenya	553	4388
Serengeti National Park-Tanzania	803	8352
Ruaha National Park-Tanzania	625	3909

Source: Coe et al.(1976)

2.5.1 Method

The difficulty of calculating accurate herbivore biomass from population counts especially choosing an appropriate unit mass to represent all the individuals of a species has previously been discussed. Ideally I should have determined the mean weight of the species studied in order to calculate their biomass, but the Kenya government prohibits shooting of any game. I therefore used unit mass of each species from available literature; the weights given by Western (1973) which were derieved from Foster and Coe (1968), (appendix 3). For a better determination of the herbivore biomass, biomass of adults, sub-adults and juveniles should have been calculated separately because each of these categories vary in their weight. From literature, only the weight of adults was available and was therefore used in the calculation of the biomass. This may not have caused any over-estimation of the herbivore biomass since for all species adults dominated the population structure (Kiringe, 1990, this study). Weight of reedbuck, steinbuck, dikdik, klipspringer and mountain reedbuck was not available from literature and therefore their biomass was not calculated. Their low population sizes may not have led to a significant under-estimation of the total herbivore biomass.

Monthly biomass of each species was calculated by multiplying the monthly counts with the mean weight of each species. Mean $\pm$ S.E biomass of each species was then calculated by summing the monthly biomass and dividing it with the number of months a species was counted. When herbivore biomass density is calculated using the total area of a given area, it indicates the biomass that can be supported per unit area assuming that all the available area is utilised by the animals. However, in reality this is not the case, and in most cases only certain areas are utilised by the animals and therefore to have a better idea of how much animal biomass that can be supported by a given area, then one has to consider the area which is actually put into use. In this study, herbivore biomass density was calculated by dividing the mean biomass of each species with the total area of each of the study areas and also the approximate areas actually occupied or utilised by the wildlife. Since most studies that have estimated herbivore biomass have calculated their biomass density using total area of their study areas, this has been used to compare my results of herbivore biomass density with other studies.

The monthly biomass of kongoni, zebra, eland, Thomson's gazelle, Grant's gazelle, impala and buffalo in each of the study areas was presented in the form of line graphs in order to obtain an idea of how it fluctuated monthly. For each month, the monthly biomass of each of these species in all the study areas was summed and presented in the form of line graphs to show its monthly trend. Percentage contribution to the total herbivore biomass of the most dominant species, kongoni, zebra, eland and buffalo was calculated by dividing their total biomass for all the months by the total biomass of all the species.

2.5.2 Results

The monthly biomass of each species in the study areas is given in table 2.34 - 2.42. Monthly biomass of kongoni, zebra, Thomson's gazelle, eland, Grant's gazelle, impala and buffalo in each of the study areas is presented in figure 2.23 - 2.29. Summed monthly biomass of the same species for all the study areas is presented on figure 2.30 - 2.35. The herbivore biomass fluctuated monthly depending on the monthly population fluctuations such that when there was a high count of the herbivores in a given month, there was a corresponding high biomass and vice versa when the monthly herbivore counts were low. Zebra, kongoni, eland and buffalo contributed the highest proportion of the overall herbivore biomass. They contributed 82% of the total herbivore biomass in the Park (kongoni=21%, zebra=22%, buffalo=39%), 85% in Kedong Ranch (kongoni=32%, zebra=35%, eland=18%) and 82% in Kongoni Ranch (kongoni=17%, zebra=53%, eland=12%).

The total mean biomass (kg) ±S.E and biomass density for the herbivores in the Park, Kedong Ranch and Kongoni Ranch was 219,670±16,900kg (3,218kg/km^2), 279,397±26,010kg (3,492kg/km^2) and 154,810±12,297kg (2,886kg/km^2) respectively.

2.5.3 Discussion

This study has estimated the ungulate biomass of Hell's Gate and its environs. The monthly herbivore biomass varied from count to count and this variation could have been caused by:

(a) Wildlife movement between the study areas and their environs like ADC Ndabibi Farm and Akira Ranch.

(b) Birth and death.

(c) Some of the animals being missed during counting.

Wildlife movement between the study areas and adjacent areas like Akira Ranch and ADC Ndabibi farm was probably the main factor that led to the monthly herbivore biomass variation and therefore any variation in biomass as a result of death and birth may have been insignificant. Zebra, kongoni, eland and buffalo contributed the highest percentage of the herbivore biomass compared with the other species.

Except for Kedong Ranch, the herbivore biomass density calculated using the approximate area occupied by the wildlife in Kongoni Ranch and Hell's Gate is high compared with herbivore biomass density reported elsewhere in East Africa. However, the herbivore biomass density obtained using the total area of each of the study areas is low in relation to herbivore biomass that has been established in other areas of East Africa. For example,

Table 2.34: Herbivore biomass (kg) in the Park - 1990

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Kongoni	35088	36312	35904	47192	41480	38760	48552	39576	51680	59568	30872
Zebra	19754	47124	37842	53312	95200	69020	52836	48790	47600	51170	24514
Thomson's gazelle	600	680	920	760	1280	800	1340	680	960	1100	920
Warthog	1180	1298	1180	1298	1180	1298	1180	1416	1475	1180	1534
Eland	13068	42108	67518	11979	52635	28314	19965	9801	27588	63888	7260
Mountain Reedbuck	820	533	328	-	492	-	410	-	328	328	410
Grant's gazelle	700	1300	1350	1050	700	2500	2300	2700	2400	2450	2300
Masai giraffe	3860	4632	6948	16984	6948	4632	3860	5404	4632	5404	9264
Reticulated giraffe	4632	3860	3860	1544	5404	3860	3860	3088	-	-	-
Buffalo	47500	50000	49000	60000	50000	50000	45000	95000	120000	125000	100000

Table 2.35: Herbivore biomass (kg) in the Park - 1991

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Kongoni	59704	35496	65552	40800	53992	36856	58072	42296	27608	40528	53040	70040
Zebra	29274	25942	32368	35700	32606	49504	57358	72590	57358	32130	54740	64022
Thomson's gazelle	700	700	520	960	680	940	680	780	460	1240	1200	800
Buffalo	96000	90500	75000	70000	75000	82000	90000	94500	90000	97500	100000	105000
Masai giraffe	5404	-	6948	3860	8492	3860	14668	5404	2316	1544	6176	11580
Grant's gazelle	1400	2350	1150	1550	2000	1800	2100	1900	1800	3300	3200	3850
Mountain Reedbuck	-	328	287	-	328	-	-	410	-	-	-	410
Eland	2178	12705	12705	31218	29040	28677	10890	16335	18150	40293	10890	9438
Warthog	1534	1416	1593	1475	1593	1947	1711	1593	1652	1770	1888	1947
Reticulated giraffe	772	-	772	772	-	-	-	-	-	-	-	-
Impala	-	-	630	-	180	-	495	540	2655	900	1170	1980

Table 2.36: Herbivore biomass (kg) in the Park - 1992

Species	January	February	March	April	Mean Biomass [kg]	S.E	n	Biomass kg/km2 as total Park area	Biomass kg/km2 as utilised area
Kongoni	37672	52904	31008	44608	45006	2137	27	659	3600
Zebra	40222	49980	40698	55454	47300	3189	27	693	3784
Grant's gazelle	3500	3500	1800	2400	2124	164	27	31	170
Thomson's gazelle	780	1140	720	820	858	45	27	13	69
Eland	7260	7623	3993	119790	26123	4943	27	383	2090
Warthog	2006	3776	3658	4130	1774	152	27	26	142
Masai giraffe	11580	9264	3860	11580	6889	746	26	101	551
Buffalo	100000	107500	120000	110000	84981	4747	27	1245	6798
Moutain Reedbuck	410	328	492	820	439	39	17	6	35
Impala	2250	720	-	-	1152	267	10	17	92
Reticulated giraffe	3860	-	-	-	3024	471	12	44	242
n=Number of months a species was counted							Total	3218 km2	17573 km2

Table 2.37: Herbivore biomass (kg) in Kedong Ranch - 1990

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Kongoni	45288	81192	115600	163200	135864	106080	98736	62152	82416	102816	72352
Zebra	30702	157556	135898	123760	140896	114240	113050	59262	95914	132328	109718
Eland	49731	48642	111804	103455	123420	76230	68607	76593	92928	123420	83490
Thomson's gazelle	22020	13740	16020	26480	26940	21200	22240	15900	16500	22760	18340
Grant's gazelle	3650	2450	3650	3350	5100	3000	3500	1350	1650	3550	2850
Warthog	177	177	354	413	-	472	413	649	-	1062	767
Wildbeest	166	166	166	166	166	-	166	166	-	166	-
Impala	5310	7605	7965	9585	7200	6750	6390	5850	5445	4770	5850
Reticulated giraffe	3860	-	3088	4632	3088	3860	5404	-	-	4632	-
Masai giraffe	10808	3088	5404	7720	7720	6176	6948	10808	-	6948	12352

Table 2.38: Herbivore biomass (kg) in Kedong Ranch - 1991

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Kongoni	66912	34680	42296	27336	56032	119680	78064	49232	102000	96832	95200	96832
Zebra	71162	75684	46172	40936	80682	143038	84490	83062	73780	61166	73780	107814
Thomson's gazelle	11820	6960	5460	21780	27400	26020	11860	15500	14680	18400	19780	21780
Grant's gazelle	2400	2100	1400	2200	2950	3050	3850	1800	4100	2350	4400	5550
Eland	10890	10527	11616	7260	23232	42834	6534	41745	6534	18513	21780	20691
Warthog	1357	1121	1770	1357	836	1003	836	944	-	581	836	708
Wildbeest	-	-	166	166	166	166	166	-	166	-	166	166
Impala	6615	4950	6660	5130	4320	5715	4995	5220	4770	4860	4950	9045
Masai giraffe	6176	10036	16984	8492	3860	10808	11580	21616	12352	16212	13124	13896

Table 2.39: Herbivore biomass (kg) in Kedong Ranch - 1992

Species	Jan	Feb	Mar	Apr	Mean Biomass [kg]	S.E	n	Biomass kg/km2	Biomass kg/km2
Kongoni	58344	112200	75072	195976	87866	7406	27	1098	1489
Zebra	102102	96390	66402	185878	96513	7208	27	1206	1636
Thomson's gazelle	14580	21340	21240	32900	19024	1211	27	238	322
Grant's gazelle	3050	4650	4050	6050	3261	235	27	41	55
Eland	21417	19239	18150	117975	50269	7840	27	628	852
Warthog	531	944	2124	1593	876	101	24	11	15
Wilbeest	-	-	166	-	166	0	18	2	3
Impala	8100	6750	8100	11025	6442	323	27	81	109
Masai giraffe	17756	31652	10808	10808	11313	1186	26	141	192
Reticulated giraffe	772	-	-	-	3667	500	8	46	62
n=Number of months a species was counted							Total	3492kg/km2	4735kg/km2

Table 2.40: Herbivore biomass (kg) in Kongoni Ranch - 1990

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Kongoni	19448	28968	30056	32640	39304	40800	63104	30872	27608	17408	15096
Zebra	65212	63784	134946	99960	127330	116620	104006	91392	69020	46886	68544
Eland	39930	35574	23232	36663	22143	14520	9075	2541	9075	14520	12705
Grant's gazelle	7800	6150	7600	7550	7850	7500	7800	8200	6950	6450	4400
Impala	6615	6750	7875	9225	9855	8550	3600	1980	8775	10215	9675
Thomson's gazelle	600	720	1060	700	900	740	800	1240	1000	1040	640
Warthog	413	413	531	472	354	590	-	708	-	354	-
Defassa waterbuck	-	-	1350	-	750	-	-	-	-	-	600
Masai giraffe	4632	11580	4632	-	1544	5404	-	6176	-	10036	9675
Reticulated giraffe	3088	6176	3088	-	4632	3860	-	3088	-	-	-

Table 2.41: Herbivore biomass (kg) in Kongoni Ranch - 1991

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Kongoni	12784	12648	20400	19720	19992	29512	30600	34000	31008	24616	21080	24072
Zebra	73542	66640	68068	56406	57596	102578	110670	62832	65450	89250	88298	41412
Thomson's gazelle	800	660	560	1320	1240	1160	800	1260	1660	1480	2360	1140
Grant's gazelle	4850	1850	4050	4750	6000	6950	5550	4600	6150	7900	5850	9300
Eland	19602	25410	23595	21780	14520	12705	9801	22506	18876	15609	19239	18150
Warthog	-	413	-	-	-	-	472	-	-	-	295	236
Masai giraffe	9264	13124	5404	13124	7720	6176	3088	7720	7720	5404	11580	26248
Impala	4770	6255	4320	9405	9675	10980	6525	5850	4455	10395	8415	6345
Defassa waterbuck	3750	-	-	-	-	-	-	-	-	-	-	-

Table 2.42: Herbivore biomass (kg) in Kongoni Ranch - 1992

Species	Jan	Feb	Mar	Apr	Mean Biomass [kg]	S.E	n	Biomass kg/km2 as total area	Biomass kg/km2 as utilised area
Kongoni	25024	25024	13328	14008	26041	2073	27	486	2170
Zebra	39508	99722	44982	91630	79492	5051	27	1482	6624
Thomson's gazelle	1300	1700	1260	1680	1104	81	27	21	92
Grant's gazelle	9000	7000	7500	5550	6485	323	27	121	540
Eland	14520	9801	7986	27225	18567	1740	27	346	1547
Warthog	767	-	708	1534	551	81	15	10	46
Masai giraffe	26248	15440	5404	12352	9571	1270	24	178	798
Impala	6795	8640	6030	7740	7397	442	27	138	616
Reticulated giraffe	-	-	-	-	3989	505	6	74	332
Defassa waterbuck	-	-	-	-	1613	731	4	30	134
n=Number of months a species was counted							Total	2886 kg/km2	12899 kg/km2

Figure 2.23: Monthly kongoni biomass - Feb. 1990 - April 1992

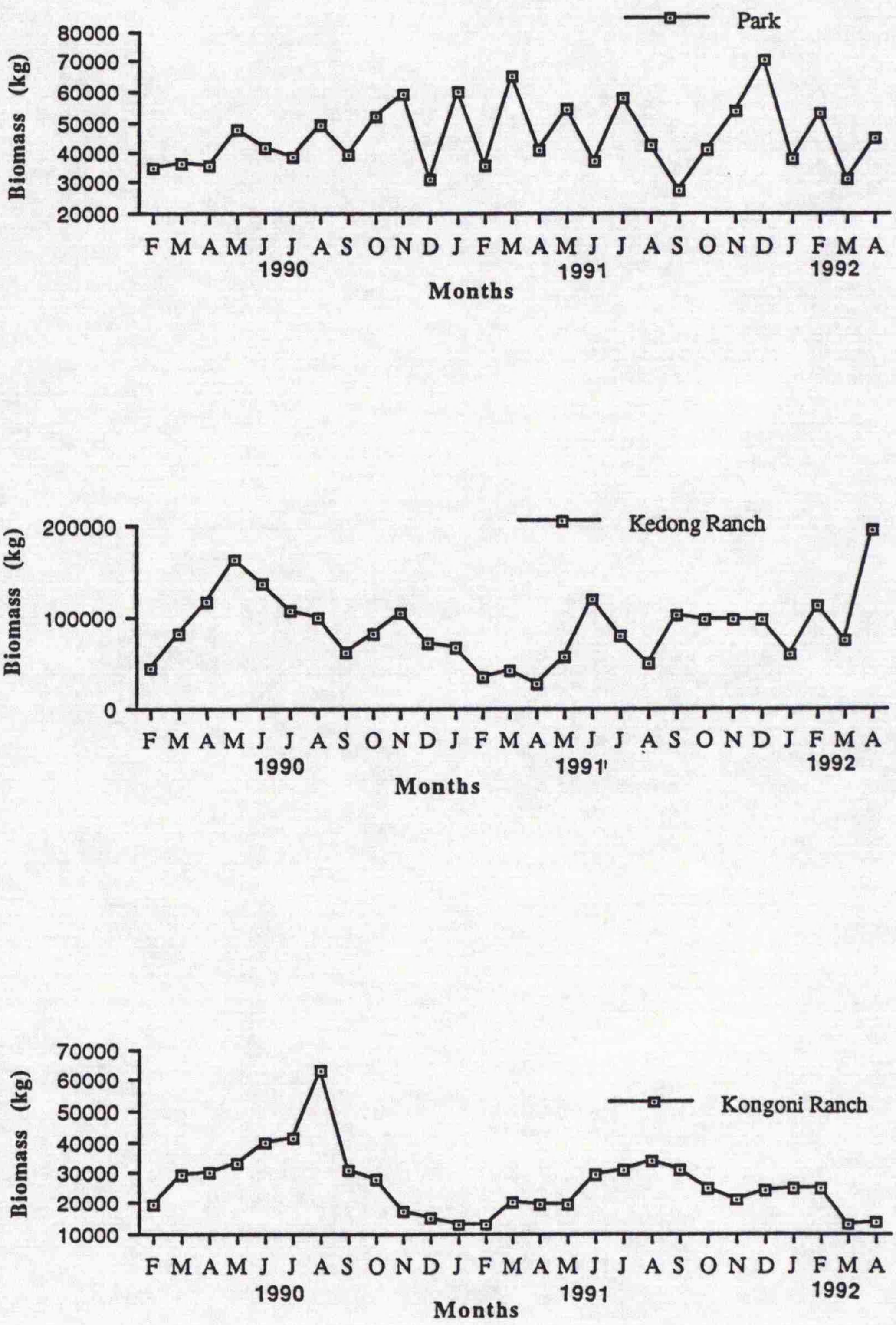


Figure 2.24: Monthly zebra biomass - Feb. 1990 - April 1992

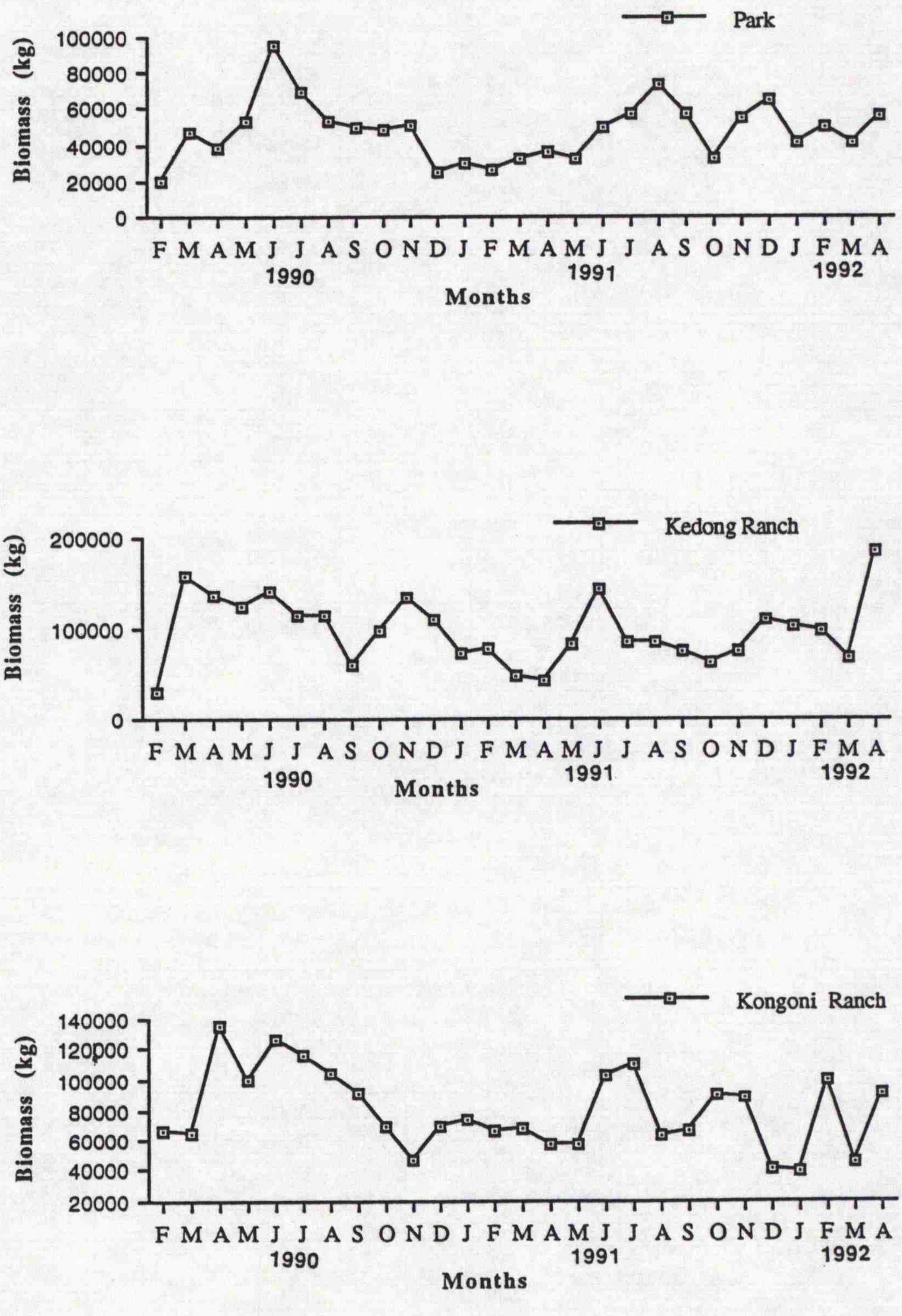


Figure 2.25: Monthly Thomson's gazelle biomass - Feb. 1990 - April 1992

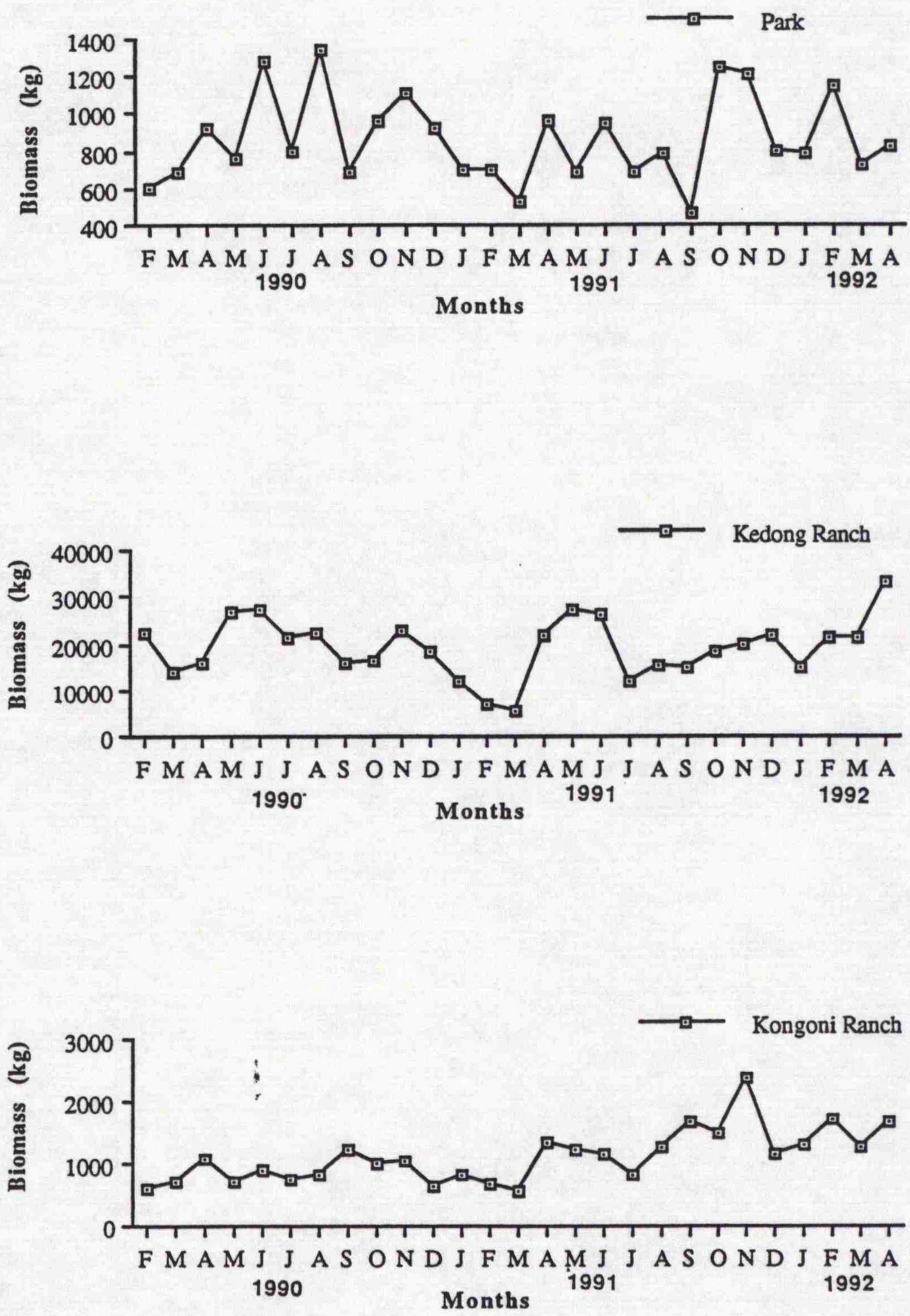
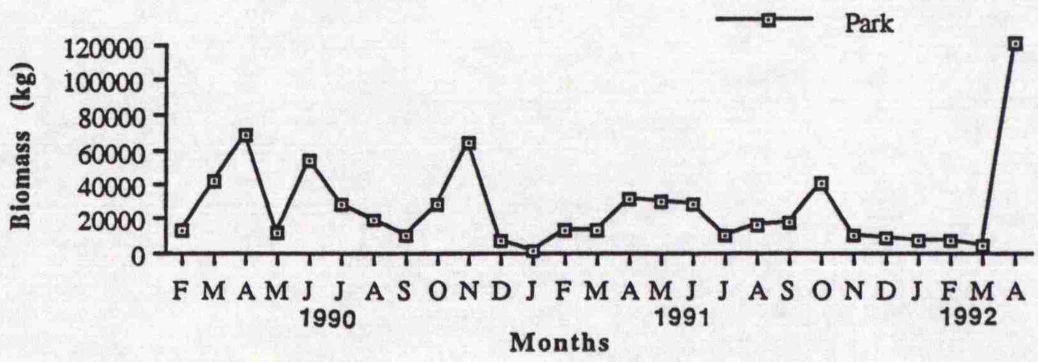
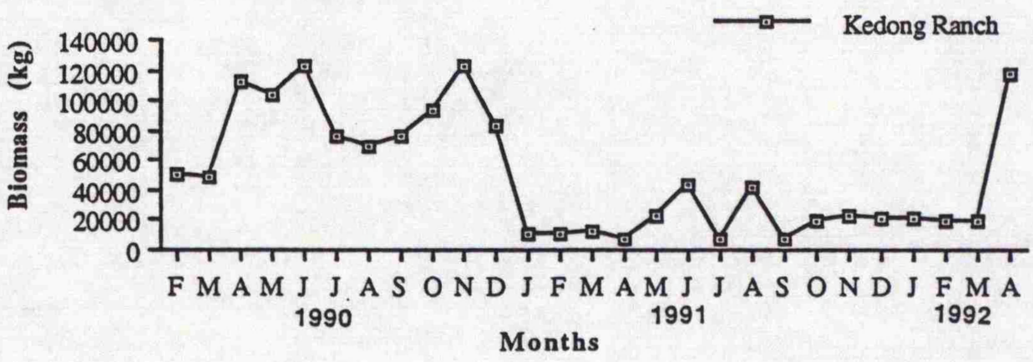


Figure 2.26: Monthly eland biomass - Feb. 1990 - April 1992





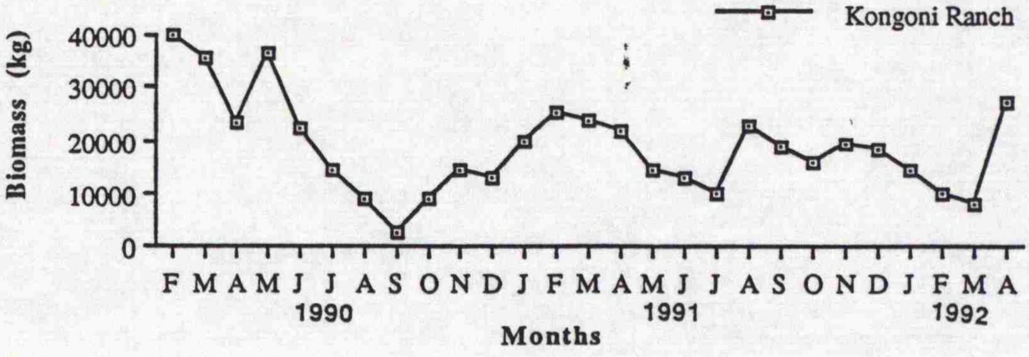


Figure 2.27: Monthly Grant's gazelle biomass - Feb. 1990 - April 1992

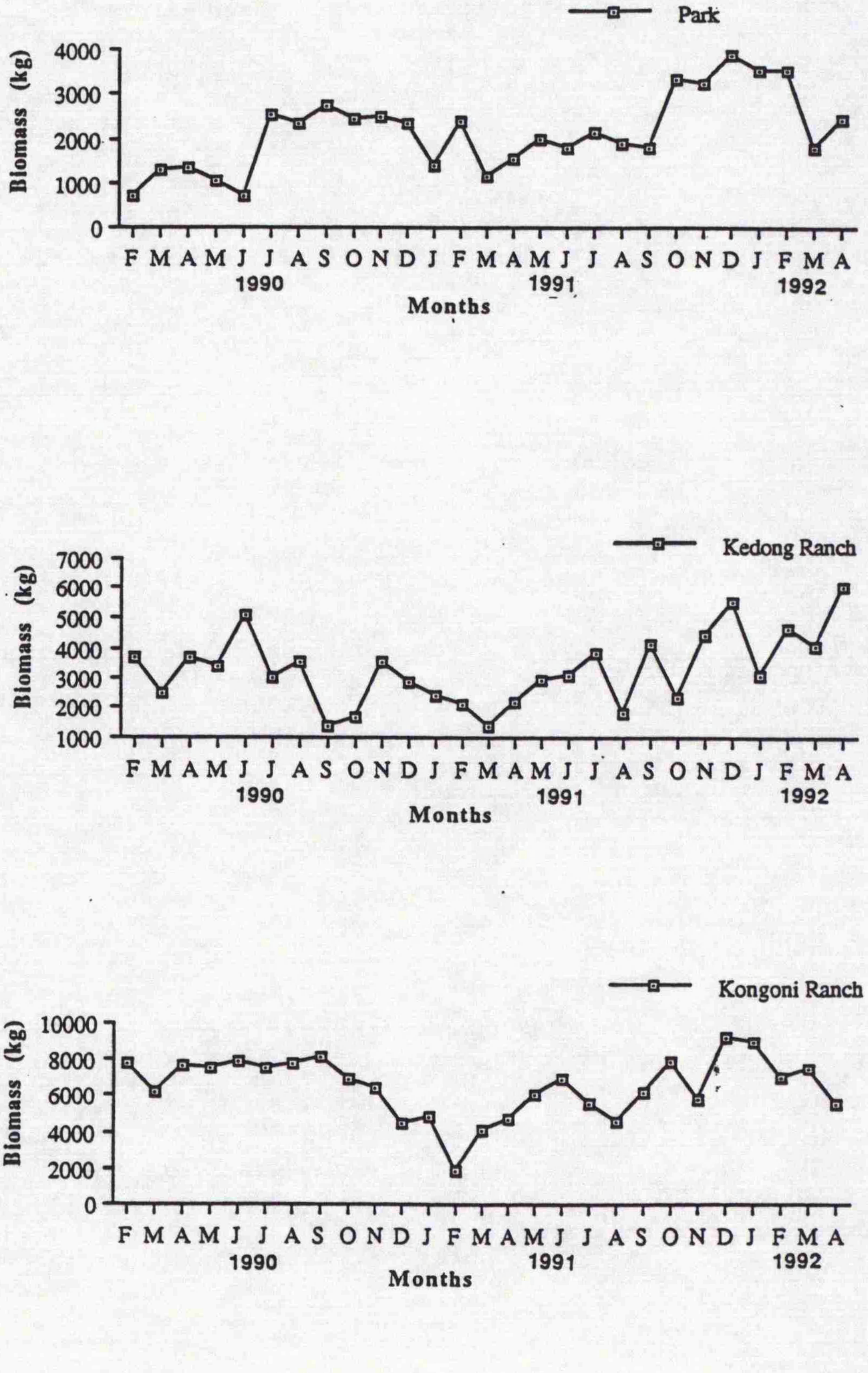


Figure 2.28: Monthly impala biomass - Feb. 1990 - April 1992

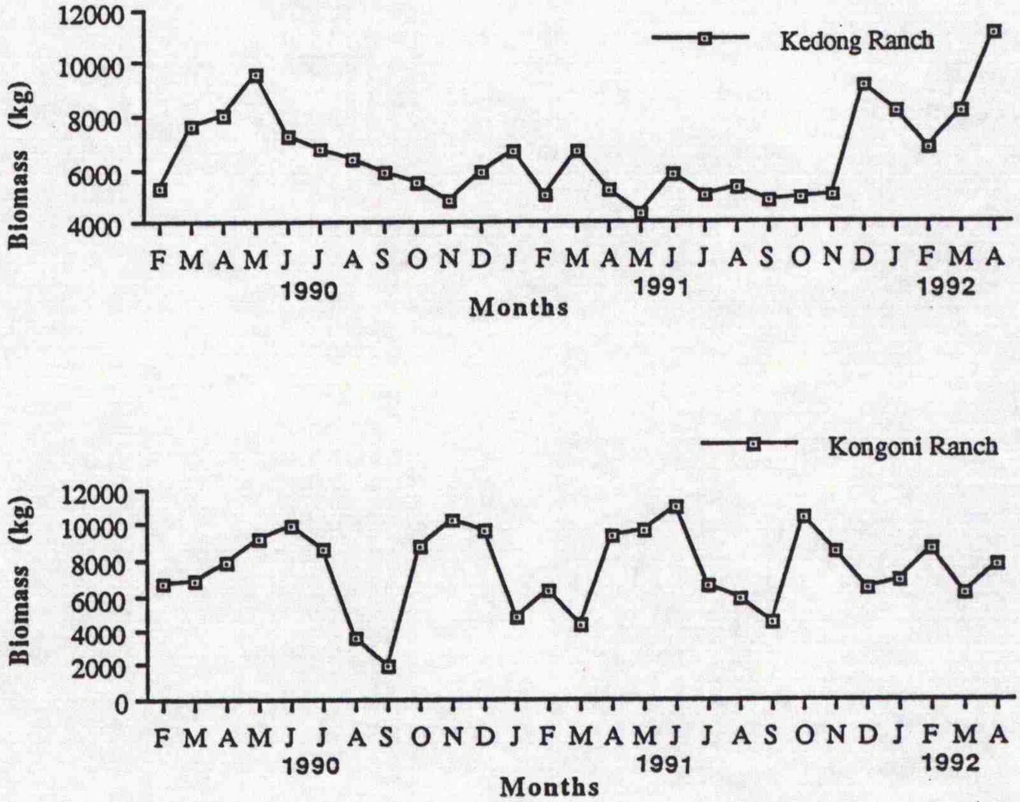


Figure 2.29: Monthly buffalo biomass - Feb. 1990 - April 1992

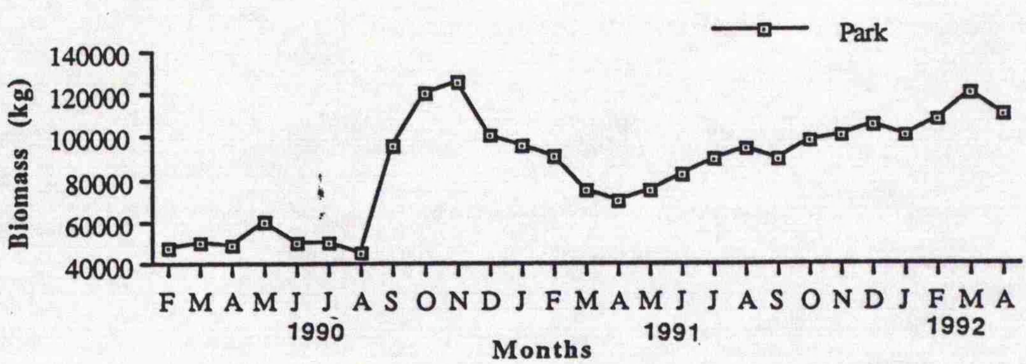


Figure 2.30: Monthly summed kongoni biomass - Feb. 1990 - April 1992

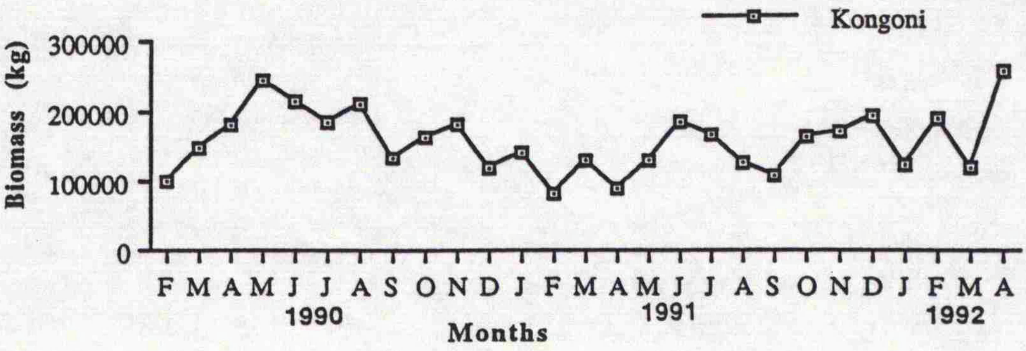


Figure 2.31: Monthly summed zebra biomass - Feb. 1990 - April 1992

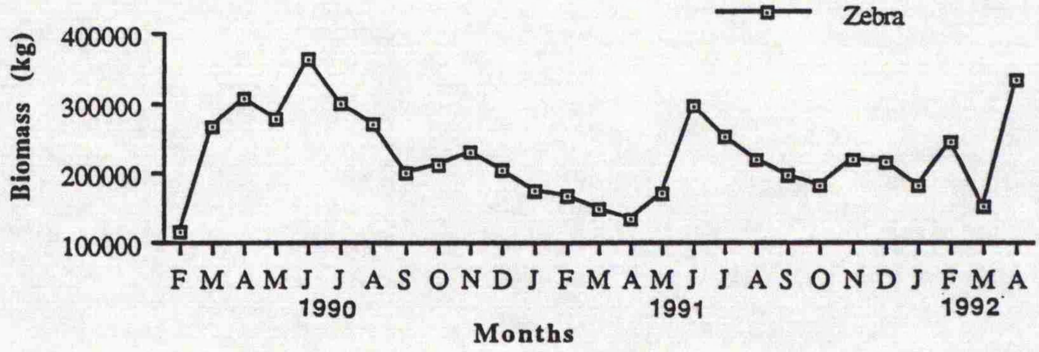


Figure 2.32: Monthly summed Thomson's gazelle biomass - Feb. 1990 - April 1992

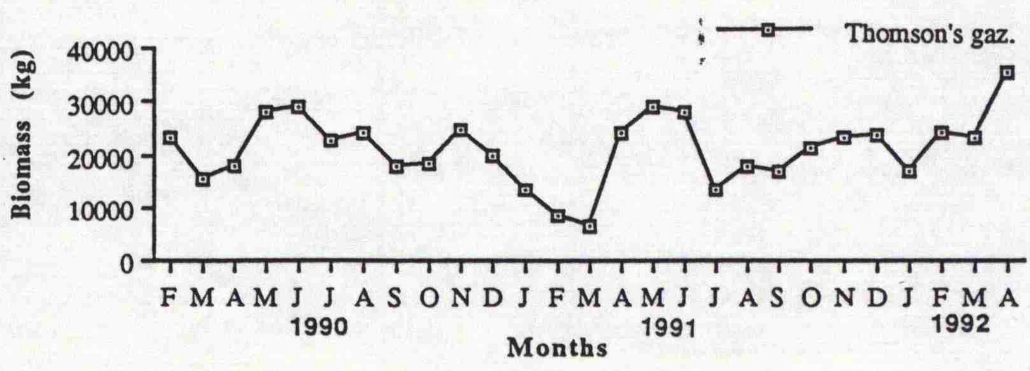


Figure 2.33: Monthly summed Grant's gazelle biomass - Feb. 1990 - April 1992

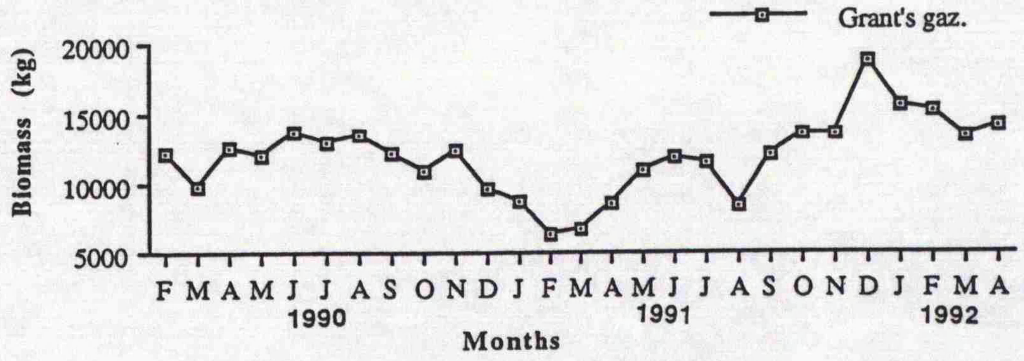


Figure 2.34: Monthly summed impala biomass - Feb. 1990 - April 1992

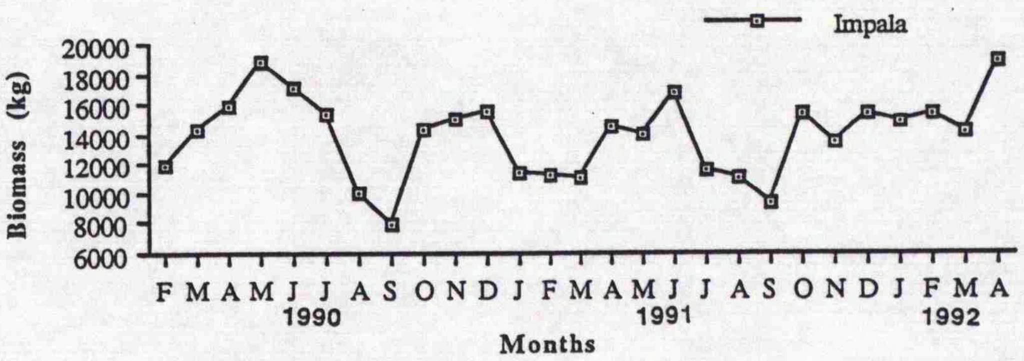
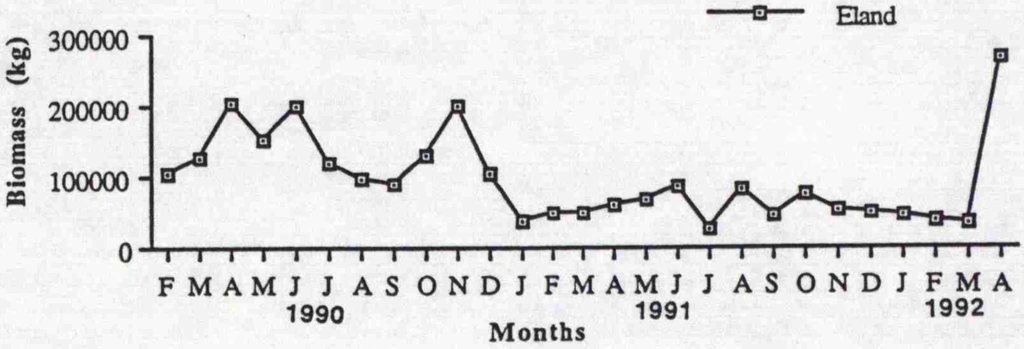


Figure 2.35: monthly summed eland biomass - Feb. 1990 - April 1992



Foster and Coe (1968) obtained a mean herbivore biomass density of 5,686kg/km^2 in Nairobi National Park. In Simanjiro Plains, Tanzania, Kahurananga (1981) obtained a mean herbivore biomass density for all species of 7,337kg/km^2 in 1971 and 8,450kg/km^2 in 1972. Other established mean herbivore biomass densities include that of Ngorongoro Crater, Tanzania of 6,255kg/km^2 (Lamprey 1964), Nakuru National Park, Kenya of 6,298kg/km^2 (Kutilek, 1974) and 6,300kg/km^2 for Serengeti Plains, Tanzania (Stewart and Talbot, 1962). These areas had such high herbivore biomass densities because they had more rainfall and therefore higher primary production which allowed them to have a higher secondary production than the Hell's Gate region.

The herbivore biomass in this study is an indication of how much ungulate biomass is currently supported by the primary production of the study areas. Only five grass species *Cynodon dactylon, Digitaria milanjiana, Digitaria scalarum, Themeda triandra* and *Chloris gayana* were found to be the main food source for the herbivores (Chapter 3). Their primary production was found to be rainfall dependent (Chapter 3) and this may have caused food shortage for the animals especially during the dry season when most of the grass biomass dried up, and therefore put a limit to how much herbivore biomass the range can support. Large herbivore communities have been found to be limited by their food resources which are limited by rainfall through its effect on primary production (Sinclair, 1974a; Lack, 1954; Hairston *et al.*, 1960; Wynne-Edwards, 1962). It has also been demonstrated that primary production which depends on rainfall determines how much herbivore biomass can be supported by a given area (Coe *et al.*, 1976).

Kedong and Kongoni Ranches had 6,000 and 3,000 head of cattle which was feeding in the same areas with wildlife. It has been shown that there is some degree of food resources overlap between livestock and wildlife which could lead to competition (Casebeer and Koss, 1970, Field *et al.* 1973), (this is discussed more fully under population estimates and densities). Therefore in the two ranches there could have been some degree of food resources overlap between livestock and wildlife leading to competition. This may have limited food availability to the wildlife and ultimately affect their population sizes and therefore the actual biomass that could have been supported by the rangeland if there was no livestock.

The current potential free movement of wildlife in the Hell's Gate system prevents any overuse of the rangelands. This might however change in future depending on the human activites that are taking place. In Kongoni Ranch a large portion of land (>3000 acres) which used to be an important feeding area for species like zebra, kongoni, Thomson's gazelle, Grant's gazelle, impala, warthog, eland and giraffe was ploughed in April 1991 and put under wheat growing. This left the wildlife to concentrate in a smaller area (about 12km^2)

which was shared between them and cattle, while some moved to ADC Ndabibi Farm, close to Eburru mountains (Figure 1.2). If the number of cattle in the ranch increases in future, this will probably increase food competition between the wildlife and cattle, such that its carrying capacity might be surpassed. The situation in Kedong Ranch was different since no farming activity was taking place. Wildlife and cattle used the same feeding areas, but if the population of either one of these or both increases in future, then competition for food will set in and the carrying capacity might also be surpassed. In future, if arable farming starts as has already happened in Kongoni Ranch, both cattle and wildlife will loose their feeding grounds and this will reduce the carrying capacity of the ranch. The wildlife in the Park will have lost an important dispersal area, and fencing might have to be considered to prevent any conflict between wildlife and crop growing in the ranch. Considering that about $12.5 km^2$ of the Park is the most important habitat for most of the wildlife, fencing will mean that this area will be forced to support a greater herbivore biomass than it can, leading to its gradual deteroriation.

CHAPTER 3

ABOVE GROUND PRIMARY PRODUCTION AND HERBIVORE GRAZING

3.1 INTRODUCTION

Grasslands can be floristically defined as plant communities in which grasses (family Poaceae) are the dominant plants, with shrubs and trees absent or present (Milner and Hughes, 1968). They contain many other kinds of herbaceous plants such as sedges, rushes and legumes. Their animal life is quite diverse ranging from different species of invertebrates to vertebrates like the ungulates of Central and East Africa and marsupials of Australia. Rodents, birds, snakes, amphibians, lizards and predators of the cat and dog family are also dependent on them.

About 24×10^6 km^2 (16%) of the earth's surface is covered by grasslands (Whittaker, 1975). Their origin is not fully understood, but it is thought they evolved during the Miocene (25 million years ago to 5 million years ago) (Moore, 1966). During this time, there was a decrease in rainfall and consequent diminuation of forest cover leaving grasses and other low growing plants occupying the plains in both the old and new world, which finally developed into present world grasslands.

Grasslands consist mainly of savanna, prairie and steppe, and can be classified into two broad climatic types, tropical and temperate grasslands. Tropical grasslands are the most extensive and cover approximately 15×10^6 km^2 of Africa, South America, Asia and Australia. They are characterised by a continous herbaceous stratum which is dominated by grasses and various herb species, frequent fires, unreliable rainfall with an alternating dry and wet season (Menault *et al.*, 1984). Temperate grasslands on the other hand are mostly found in Central North America, Eastern Europe and in the middle latitudes of Asia and in Northern Argentina (Coupland, 1979).

Grasslands (both natural and those secondarily derived from woodland clearance) are a major contributor to world animal production. They supply at least 50 per cent of subsistence food for most farm animals in Europe (Semple, 1972). In Greece for example, pastures occupy 57 per cent of agricultural land and provide 81 per cent of the feed for livestock. In Uruguay (South America), nearly 90 per cent of the total land is natural grasslands which support 8 million beef cattle and 28 million sheep. Similarly, the wool exports of Australia and South Africa are derived mainly from natural grasslands. The grasslands of East Africa form an important ecosystem for grazing herbivores and are known for their high ungulate species diversity (Pratt *et al.*, 1966). In Kenya, they cover 80 per cent of the land area (49,000 km^2) which supports 60 per cent of the country's head of cattle, 70 per cent of sheep and goats and nearly all the ungulate populations (Ayuko, 1978; Talbot and Stewart, 1964; Sinclair, 1975; McNaughton, 1979a).

3.2 PRIMARY PRODUCTION AND GRAZING

A starting point for the understanding of community performance and function is knowledge of the dynamics and production of autotrophs (Bourliere and Hadley, 1970; Thomas *et al.*, 1988). In terrestrial ecosystems, this involves the determination of primary production of producers upon which secondary production is based.

Primary production and the factors which influence it have extensively been studied in a number of tropical grasslands, for example Deshmukh (1986) in Nairobi National Park, Kenya, Owaga (1980) in the Athi-Kaputei Plains, Kenya, Singh and Yadava (1974) in Kurukshetra, India, Strugnell and Pigott (1978) in Ruwenzori National Park, Uganda, Thomas *et al.* (1988) in Nairobi National Park and Masai-Mara Game Reserve, Kenya and Kevin (1990) in Mana Pools National Park, Zimbabwe. These and other studies have shown that tropical grassland primary production is water dependent, and rainfall is the major cause of variation in primary production from region to region (Bourliere and Hadley, 1970). During the dry season, the vegetation becomes so short of water such that growth effectively ceases. On the other hand, growth takes place during the wet season as soil moisture increases. Macharia (1981) working in four different grasslands of Kenya–in Masai-Mara Game Reserve, Amboseli, Nairobi and Aberdares National Parks-showed that they had different annual grass biomass depending on their rainfall regime. Annual production ranged from 66g/m^2 for Amboseli to 811g/m^2 for Masai-Mara. In temperate grasslands by contrast, seasonal plant biomass dynamics are generally controlled by both temperature and rainfall, and plant growth is limited by temperature for most of the year (Thomas *et al.*, 1988).

The grassland plains of Africa and in particular those of East Africa support an outstanding assemblage of ungulates whose biomass is often higher than that found in other habitats throughout the world (Stewart, 1966). These ungulates can exert a major impact on the vegetation especially where movement is restricted. For example, it is estimated that in the Serengeti, Tanzania, herbivores which include species like zebra, buffalo, Thomson's gazelle, Grant's gazelle, wildebeest and hartebeest consume 40 per cent of the annual grass biomass (Braun,1973). Stelfox *et al.* (1980) found that in the Masai-Mara Game Reserve, Kenya, ungulates which included zebra, wildebeest, Thomson's gazelle, Grant's gazelle and elephant consumed at least 30 per cent of the annual above ground net primary production. During the annual migration of wildebeest, 80-90 per cent of the plant biomass was consumed within a few weeks.

Considering the value attached to wildlife conservation in Africa particularly in East Africa, there is a need to understand the dynamics of the plant biomass especially its seasonal production and utilization by herbivores in the conservation areas in order to understand how it influences the feeding ecology of the ungulates. Therefore, for effective wildlife conservation, it is important to know the feeding habits and herbage utilization (that is how much of the available herbage is consumed) of the animals being conserved (Wyatt, 1969). Cropping of some of the animals will depend on this kind of information especially where it is found that some of the animals are dying due to food shortage since their numbers have increased beyond the food supply capacity of the habitat. The aim of this study was therefore to determine the primary production and grazing of the grasses that were found to be commonly used as a source of food by the herbivores of Hell's Gate, and therefore understand their dynamics and utilization in relation to seasonal variation in rainfall.

3.3 REVIEW OF METHODS FOR ESTIMATING PRIMARY PRODUCTION AND HERBIVORY

3.3.1 Principles

The analysis of terrestrial ecosystem structure and function normally involves determination of primary production (Bradbury and Hofstra, 1976). To do this, the common method involves harvesting vegetation at regular intervals and summing the maximum biomass values obtained for each species. A limitation of this approach is that it does not take into account the mortality and disappearance of the vegetation (by herbivory and decomposition) between harvesting dates leading to an under-estimation of net primary production (Bradbury and Hofstra, 1976; Deshmukh and Baig, 1983; Deshmukh, 1986).

In temperate grasslands, it has been shown that the harvest method, by failure to account for mortality, under-estimates primary production (Deshmukh and Baig, 1983). The extent of under-estimation ranges from 30 per cent (Deshmukh, 1979) to more than 100 per cent (Bradbury and Hofstra, 1976). Wiegert and Evans (1964) solved this problem indirectly by using a paired plot method to estimate the rate of vegetation decomposition. This method assumes that the change in the amount of dead vegetation and litter during an interval of time is a function of two processes; vegetation death and decomposition. Therefore, estimation of change in dry weight of the dead material and decomposition of vegetation on a plot during a period of time will provide an estimate of vegetation death during the same period. To determine the disappearance rate of dead vegetation during a given time period, the dead vegetation and litter are collected from one paired plot at time zero and from the second plot at time one. Also at time zero all live plant material is removed from the second plot so that the change in dry weight of dead vegetation and litter can be attributed to decomposition.

Lomnicki *et al.* (1968) proposed a modification of the Wiegert and Evans (1964) method for determining vegetation death which does not require estimation of either the disappearance rate or the change in biomass of dead vegetation and litter. In addition, the modified method eliminates the assumption of the original Wiegert and Evans method which is that the decomposition rate of dead vegetation and litter is unaffected by the removal of living vegetation. The modified approach also utilizes paired plots, but at time zero dead material and litter is collected from one plot without disturbing the living material, and after a given time period, the amount of dead vegetation present on the plot is considered to represent vegetation death.

Although the Wiegert and Evans (1964) method of determining plant biomass decomposition is recommended for use by IBP (Milner and Hughes, 1968), not many studies on primary production have considered the decomposition rate of the plants under study. Those which have determined decomposition rate include that of Ohiagu and Wood (1979) in Guinea savanna, Nigeria; Menaut and Cesar (1979) in the Lamto savanna of Ivory Coast; Grunow *et al.* (1980) in Nylsvley, South Africa; Deshmukh and Baig (1983); Deshmukh (1986) and Kinyamario (1987) all in Nairobi National Park, Kenya. Other studies such as Strugnell and Pigott (1978) in Ruwenzori National Park, Uganda and Owaga (1980) in the Athi-Kaputei Plains, Kenya only determined herbivory (grazing amount) and not plant decomposition rate in their primary production determination, thus under-estimating primary production. It is therefore likely that the lack of determination of decomposition rate and herbivory in terrestrial primary production studies, especially where both occur, will have led to under-estimation of primary production. Both of these factors should therefore be included if a better estimate of primary production is to be achieved.

Above ground primary production can be determined using either destructive or non destructive methods (Milner and Hughes, 1968, Odum, 1971). These include: the harvest method, chlorophyll method, carbon dioxide method and the radioactive method.

3.3.2 The harvest method

This depends on clipping the vegetation in a determined quadrat size using for example a pair of scissors or hand shears either to the ground level or a certain level above the ground. The plant material is then sorted into live and dead components, dried and weighed. This method is the most commonly used to determine above ground primary production due to its easy applicability (Malone, 1968, Odum, 1960). It has been used to estimate primary production by authors such as Deshmukh (1986) in Nairobi National Park, Kenya; Macharia (1981) in Masai-Mara Game Reserve, Aberdares, Amboseli and Nairobi National Parks, Kenya; Kinyamario (1987) in Nairobi National Park and Strugnell and Pigott (1978) in Queen Elizabeth National Park, Uganda (now Ruwenzori National Park). Its main disadvantage is that sorting of the clipped plant biomass is laborious and therefore limits the number of quadrats that can be cut and sorted. Where the plants under study are annuals, single harvesting of the biomass can be used to estimate net primary production, but where plants are perennials, the best way to estimate net production is by successive harvesting of

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the biomass in order to make a better interpretation of loss and gains of plant biomass (Coupland, 1979).

3.3.3 Chlorophyll method

This involves extracting chlorophyll from a known weight of leaves by solvents such as acetone or methanol and then measuring its concentration with a spectrophotometer. Conversion factors may then be used to relate productivity to biomass under prevailing enviromental conditions, or chlorophyll is treated as an indicator of biomass.

3.3.4 Carbon dioxide method

One of the raw materials for photosynthesis is carbon dioxide. Its uptake by plants during the process of photosynthesis can be measured and used to estimate primary production of single plants species or communities. A plastic transparent chamber or bell shaped jar is placed over the plant or the community under study. Air is then drawn through the enclosure and carbon dioxide concentration in the incoming or out going air is measured with an infrared gas analyzer. The problem with this method is that the chamber used to cover the plants acts as a green house, which quickly heats up unless a flow of air is maintained. Another disadvantage of the method is that the size of many terrestrial communities make them difficult to enclose. The enclosed plants or communities may differ in their rates of photosynthesis thus affecting the primary production estimate. Where a single plant species to be studied is growing together with others, the method will not be applicable since the carbon dioxide uptake measured will be for multiple species and not for a single species. The sophisticated instrumentation required for this method is such that it can only be used where resources are available.

3.3.5 Radioactive tracer technique

This method can be used to measure both net and gross primary production. It involves the use of radioactive $C^{14}O_2$ where its rate of incorporation during the process of photosynthesis is measured using equipment that will detect the radioactive emissions of the carbon dioxide. The method is however more applicable in aquatic than terrestrial ecosystems to measure primary production for the reasons stated in (3.3.4).

3.3.6 Decomposition of dead grass

The rate of decomposition of dead material is a function of the type of material, type of decomposers and climatic factors (mostly temperature and rainfall). In tropical grasslands, including those of East Africa, rainfall (moisture) is the limiting factor for the process of decomposition, particularly during the dry season (Ohiagu and Wood, 1979; Swift *et al.*, 1979). High humidity coupled with high temperature are optimal for microbial activity which leads to high rates of decomposition. There is little temperature variation in the tropics, so temperature probably never limits the process of decomposition in East African grasslands (Kinyamario, 1987).

In most grass species, especially those which are perennials, mortality of the older parts such as leaves occurs after they have matured. The dead parts start to decay almost immediately they die and later fall as litter. To determine this decomposition rate, litter bags have often been used for example, Abougundia and Whitman (1979), Kinyamario (1987), Macharia (1981), Wiegert and Evans (1964). When using litter bags, a known amount of dead plant material is put in the bags, returned to the field from where it was collected, and left for a certain duration before it is retrieved and the material remaining at the end is weighed after drying. Experiments using litter bags are however subject to errors since plant material fragments are easily lost when handling and during the process of decomposition, while foreign plant material and soil particles may enter (Edwards, 1977). The mesh size used is also critical since it can allow or limit entry of macro-invertebrates which may play an important role in the process of decomposition.

3.4 FOOD HABITS AND GRAZING IN HERBIVORES

Different methods can be used to study the food habits of herbivores. These include direct observation, oesophageal fistulation, analysis of rumen or stomach content and faecal analysis.

3.4.1 Direct observation

This is the commonest method of determining the food habits of herbivores. The observer uses a pair of binoculars to observe feeding animals under study and from this compiles a list of different plant species being fed on. The method has successfully been used by various workers to determine the food habits of different herbivore species. For example, Leuthold and Leuthold (1972) used this method to study the food habits of giraffe in Tsavo National Park, Kenya. A total of sixty six plant species were found to be eaten by the giraffe, most of them being trees and shrubs, with a few creepers and vines. There was a seasonal difference in their diet with deciduous trees, shrubs and vines being the dominant during the wet season with evergreen plant species being utilised during the dry season. Goddard (1970) studying the food habits of the black rhinoceroes *Diceros bicornis* in Tsavo National Park using the observation method found that they fed on one hundred and two plant species from thirty two families. The rhinos were found to be very selective for herbs and shrubs, and showed a preference for legumes. Other workers who have used this method include Field (1976), Leuthold (1970, 1971), Talbot (1962) and Wyatt (1969).

One shortcoming of the method is that it does not allow the observer to approach the study animals close enough in order to ascertain the plants being fed on, and therefore to a certain extent, it does not give a true picture of the plants being eaten as food. It does not allow the quantification of food intake from the enviroment and the estimation of the proportion of different plant parts (leaves, stem and sheath) in the diet.

3.4.2 Analysis of rumen or stomach content

The method involves shooting a determined number of the animal to be studied and then observing their rumen or stomach content under a microscope to determine the food items and proportions that have been fed on. Casebeer and Koss (1970) used this method to study the food habits of wildebeest, zebra, hartebeest and cattle in Maasai land, Kenya. Their results showed that grasses in particular *Themeda triandra*, *Pennisetum mezianum* and *Digitaria macroblephara* were the major food sources for the herbivores. Owaga (1975) also used this method to study the food habits of wildebeest and zebra in the Athi-Kaputei Plains, Kenya. She found that for both species, *T. triandra* was the main source of food with species like *Pennisetum stramineium*, *Eragrostis tenuifolia* and *Hyparrhenia* spp. constituting a low percentage of the diet. Other authors who have used this method include Field (1972) in Queen Elizabeth National Park, Uganda and Irby (1977) on Chanler's mountain reedbuck *Redunca fulvorufula* in Arthur Coe Ranch near Gilgil, Kenya.

Like direct observation, the method does not allow quantification of how much food is taken. It can only quantify the relative proportion of food items taken (leaves, sheath and stem), but to a certain extent it exaggerates their relative proportion in the diet due to fragmentation of the food items during ingestion and rumination. It is not suitable where the ungulates to be studied are not allowed to be shot, and fistulation is not possible. In such a situation, faecal analysis becomes important.

3.4.3 Faecal analysis

Faecal analysis as a method of determining food habits in herbivores relies on the fact that upon ingestion, especially for grasses, the leaf epidermis to a certain degree retains its characteristic features which can be used to identify plants to species level. Before faecal analysis can be done, field observations are made to determine the different grass species that are potentially available as food for the herbivores under study. Once they are identified, their leaf epidermis are processed and microphotographs prepared with full descriptions of the characteristics that can be used as an aid to their identification. Prepared faecal samples are then observed under a microscope and the different grass species in the faeces identified using the already prepared epidermis microphotographs.

The method allows quantification of the proportion of plant parts e.g. leaves, stem and sheath that have been taken by an animal, but it does not allow quantification of how much food is ingested. One shortcoming of the method is that preferred succulent grasses or herbs making up the bulk of the animals' diet may be completely digested to an extent that their identification in the faeces is difficult, while an occasional coarse plant of a species that is rarely eaten may pass through the digestive tract in a readily identifiable form (Talbot, 1962) and its importance exaggerated. Fragmentation of the epidermis is another problem that may lead to certain important plant species which form the bulk of the diet of an animal be under represented while rare species not important as food sources may have their importance exaggerated. Simple anaysis of faeces might therefore give an erroneous picture of the food habits of an animal, and only with a considerable background research can the method yield an accurate picture of the food habits. Inspite of these shortcomings, the method has successfully been used to determine the food habits of ungulates. Talbot (1962) using this method studied the food habits of wildebeest, Thomson's gazelle, impala and Grant's gazelle. He found that *Cynodon dactylon* was the most preferred species, and was therefore an important food source. Stewart and Stewart (1970) studying the food habits of Grant's gazelle, Thomson's gazelle, zebra and wildebeest using faecal analysis established that they feed on ten grass species available in the pasture and among these *C . dactylon* and *Themeda triandra* were the most important as food sources.

3.4.4 Oesophageal fistulation

Oesophageal fistulation is a technique that has often been used in studies of diets and nutrition of domestic ruminants (Duncan,1975). It is a surgical operation in which the epidermis of the oesophagus is sutured to and heals onto the skin of the neck, leaving a hole lined by oesophageal epidermis which connects the oesophagus to the outside of the muscle and the connective tissue of the neck. Normally, the hole is kept closed by a plug which may be of various designs. Its function is to maintain the size of the hole and to prevent loss of saliva and ingested food. When it is necessary to conduct a grazing experiment, the plug is removed and owing to the failure of peristalsis at the fistula, ingested food passes out of the fistula and is collected in a bag placed around the animals' neck. Depending on the size of the fistula in relation to the oesophagus, all or some of the ingested food is collected.

Assuming that the fistula is of such a size that all the food passes out, then this method will give accurate information on the diet of an animal. There are however difficulties in extrapolating dietary habits obtained using this method from fistulated animals to the wild population, since the operation may affect their grazing behaviour. The most obvious way the operation can affect the grazing of the animals is through discomfort at the fistula, causing the animal to select a softer diet than it would otherwise do (Duncan, 1975). The neccessity to handle the study animals dictates that captive individuals be used. This is a problem since only a few can be kept for the study and they may not therefore represent the different age and sex classes in the population, and the number may be insufficient to study the individual differences in the diet. Further, the captive animals will usually not live in a normal social enviroment in which the time occupied in social and anti-predator behaviour may cause the wild animals to feed differently from the captive ones (Duncan, 1975; Talbot, 1962). However, the advantage of the method is that it allows the collection of food samples before they are subjected to rumination and digestion and therefore gives a good picture of the diet of the animal under study. Duncan (1975) used this method to study the food habits of the topi *Damariscus lunatus* in the Serengeti, Tanzania. He found that they were mainly grazers and selected grass leaves during their feeding.

3.4.5 Estimating grazing by herbivores

The difference method, where live grass biomass is determined in grazed and ungrazed plots, and the difference in their biomass is the amount consumed by herbivores is the simplest and most widely method of estimating grazing amount by herbivores (Walter and Evans, 1979). Using this technique, grazing harvest by herbivores over a certain time interval is estimated as the difference in forage biomass in grazed and ungrazed plots. Linehan *et al.* (1952) showed that this method often over-estimates the true harvest by herbivores, and suggested a procedure in which the change in forage biomass from the initial value on grazed and ungrazed plots over a given interval is adjusted by a ratio of differences in logarithms of the various biomasses.

Using the difference method, weldmesh cages have widely been used to estimate the amount of forage biomass consumed by herbivores, e.g. Kevin (1990) in Mana Pool National Park, Zimbabwe; Strugnell and Pigott (1978) in Ruwenzori National Park, Uganda; Owaga (1980) in the Athi-Kaputei Plains, Kenya; Cox and Waithaka (1989) in Nairobi National Park, Kenya and Onyeanusi (1983) in Masai-Mara Game Reserve, Kenya.

3.4.6 Selection of methods

Although the chlorophyll, carbon dioxide and radioactive tracer methods can be used to estimate terrestrial primary production, they are quite complicated in their application and will involve the use of complicated equipments which in certain situations like in my study might not be available. Where one is interested in measuring how much of the net primary production is consumed by herbivores, these methods can not be used. The alternative means of estimating net primary production is to use the harvest method, which involves successive harvesting of plant biomass for a specified time interval in quadrats of known size. This is the method I chose to study the primary production of the grass species that were mostly fed on by the Hell's Gate herbivores. The method enabled me to estimate not only the primary production of the grasses, but also the proportion of the net primary production that was being consumed by the Park herbivores.

Both the paired plot method and the litter bag technique as described by Wiegert and Evans (1964) and Lomnicki *et al.* (1968) can be used to estimate the rate of decomposition of dead grass material. However, when using the paired plot method to determine the rate of decomposition of dead grass biomass, there is likelihood that dead material in the experimental plots might be increased or decreased by wind action and this may lead to either under-or overestimation of decomposition rate. This does not happen when litter bags are used to estimate decomposition rate of dead material. The bags prevent the enclosed dead material from being blown away by the wind, while addition of dead biomass into the bags from the surroundings is less likely. This makes the method to be the most preferred in studies aimed at estimating decomposition rate of dead plant material and is the one I used to determine the rate of decomposition of the dead grass material in this study.

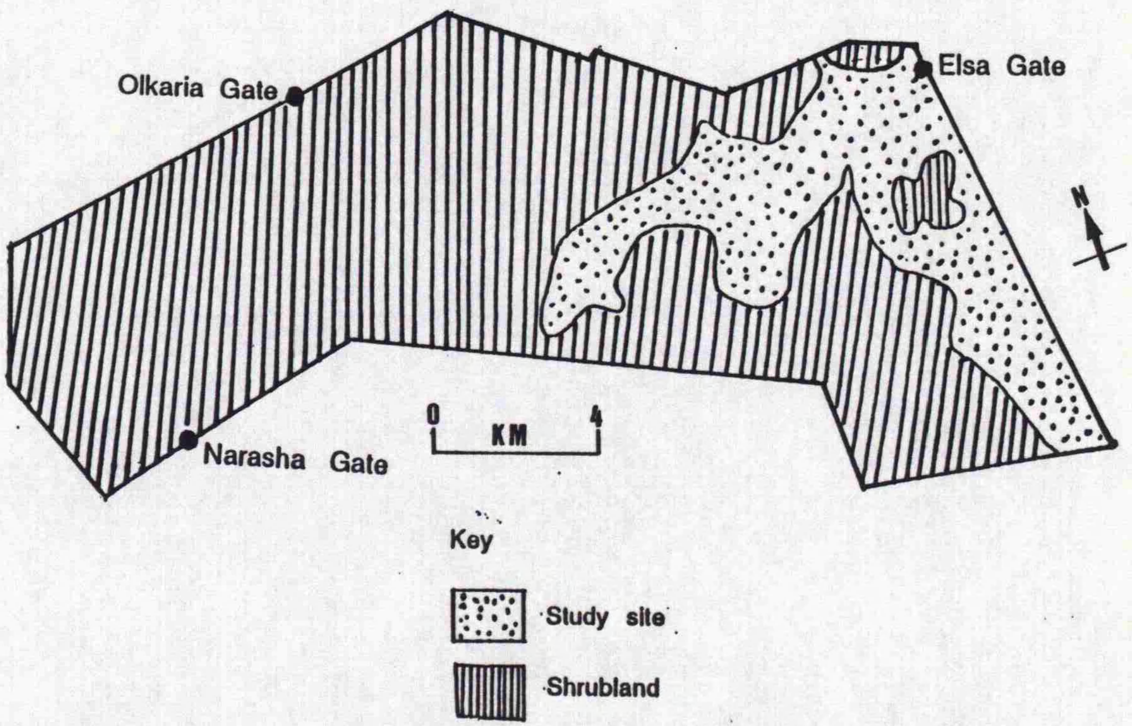
A review of methods that can be used to study food habits in herbivores has already been described. Shooting of wildlife in Kenya is prohibited by the government and therefore I could not use analysis of rumen or stomach content as a method of determining food habits of the herbivores, since this could have involved shooting some of them. Since this study aimed at determining primary production and herbivory of the grass species that were commonly grazed by the Park herbivore community, it was not practical to carry out a faecal analysis of individual herbivore species in order to determine which grass species they were feeding on. Even if such a study was attempted, it could have been too laborious and could have consumed most of the time allocated for the whole study. Oesophageal fistulation as a method of studying food habits in herbivores requires that domesticated animals be used as opposed to free ranging wildlife species. It was not practical to domesticate a few individuals of each species in order to study their food habits.

In view of the inapplicability of these methods as a means of studying food habits of the Hell's Gate herbivores, I chose the direct observation method to determine the grass species that were commonly used as a source of forage by most of the wildlife.

3.5 STUDY SITE

The study site was a grassland with an area of about 12.5km^2 (Figure 3.1). A large portion of it occupied the Njorowa Gorge, an outlet of Lake Naivasha during the Holocene (Gaudet and Melack, 1981) which divides the Park into two unequal parts. The grassland vegetation

Figure 3.1: Showing the primary production study site



was studied in a separate study by Kiringe (1990). The dominant species were *Cynodon dactylon, Felicia muricata, Digitaria milanjiana* and to an extent *D. scalarum.* Other common species included *Themeda triandra, Indigofera tanganyikensis, I. ambalensis, Harpachne schimperi, Eragrostis tenuifolia, Chloris gayana* and *Euphorbia inaequilatera. Tarchonanthus camphoratus* and *Acacia drepanolobium* were the main woody species, and were sparsely distributed. The grassland was observed to have the highest concentration of game animals mainly kongoni, zebra, Thomson's gazelle, Grant's gazelle and warthog (Kiringe,1990; this study). Observations made during the study on the seasonal changes of the grassland vegetation showed that during the dry season most of the grass and various herb species dried up, but as the long and short rains started, growth started almost immediately, and the grassland turned green with much forage for the herbivores. This seasonal change in the vegetation subjects the herbivores to times when there is plenty of forage, and times when forage is reduced.

3.6 METHODS

3.6.1 Above ground primary production and grazing

Before primary production determination started in March 1990, a preliminary study was done for two weeks to establish which particular grass species were being utilised by the ungulates. Observations on feeding herbivores started at 0730hrs when most of them were actively feeding. These observations were made in the grassland where the production study was to be done, and was the same area which had the highest herbivore concentration compared with the rest of the Park.

When a herd of feeding herbivores was encountered, a pair of binoculars was used to observe what they were feeding on. For every observation made, the plant species being fed on were recorded. Occasionally I waited for the animals to move to a new site, then walk to where they were grazing and make observations on which plants they were feeding on by visual evidence of freshly bitten leaves and shoots. From these observations, seven grass species, *Cynodon dactylon, Digitaria milanjiana, D. scalarum, Eragrostis tenuifolia, Harpachne schimperi, Themeda triandra* and *Chloris gayana* were found to be the most frequently fed on.

From March - December 1990 primary production and decomposition rate were determined for all the grass species (with *D. milanjiana* and *D. scalarum* being considered together because they were difficult to distiguish in the field). However, in January 1991, it was noted that the abundance of *E. tenuifolia* and *H. schimperi* had declined, and they did not constitute an important food source for the herbivores. Their production determination was therefore stopped, but studies on decomposition continued.

Monthly above ground primary production was estimated for twenty six months using the harvest method. Each month, ten quadrats each of $0.25m^2$ were randomly selected using grids drawn on a map of the study site. In each of these, individual grass species were harvested by cutting using a pair of scissors up to the ground level. The material (both dead and live) was then put in polythene bags and taken to the laboratory where it was sorted into dead and live components. This material was then dried at a temperature of 45-52 ^oC for three weeks prior to weighing (all weights were in grams). New sampling sites were randomly selected each month and the same procedure repeated.

Grazing by herbivores was estimated using ten weld mesh cages (width 0.5m by 0.5m by 0.75m high) with a mesh size of 5cm by 5cm. Ten of these were used to correspond to each of the ten "cut" quadrats. After cutting all the grass biomass in the quadrats as already described, a cage was placed next to each of the "cut" areas and pegged to the ground using metal pegs to prevent dislodgement by moving animals. The cages were left until the next harvesting time during which their grass biomass was clipped to the ground level using a pair of scissors. The material was then sorted in the laboratory into dead and live components, dried at 45-52 ^oC for three weeks and weighed. Monthly percentage offtake by herbivores of each grass species was then calculated as:

$$\%\text{offtake} = \frac{\text{mean live biomass inside cages - mean live biomass outside cage}}{\text{mean live biomass inside cages}} \times 100$$

The monthly %offtake of each grass species was then summed for the entire study period and a monthly mean %offtake calculated.

When using this method to estimate herbivory, some assumptions were made:

(a) The species composition in the cages and adjacent "cut" quadrats was the same.

(b) the amount of live and dead grass biomass at time zero was the same in the cages and the "cut" quadrats.

(c) conditions in the cages did not change significantly to have any effect on plant growth.

Species composition, amount of live and dead biomass in the cages and adjacent "cut" quadrats were not always similar. This could have been due to spatial variation in soil properties such as moisture, nutrients and texture from site to site within the study area. The cages which acted as exclosures to prevent herbivory were set for one month, which from my own judgement I considered to be a short duration for any significant changes in vegetation growth and species composition to occur due to exclusion of the herbivores.

3.6.2 Decomposition of dead grass

Decomposition or rate of disappearance of dead grass of the species under study were estimated using litter bags. Each month, fresh attached dead grass was clipped in fifteen random chosen quadrats from the study site and dried at 45-52 ^oC. Ten grams of each species were then weighed and put in nylon mesh bags, 20cm wide and 30cm long with a mesh size of 5mm by 5mm. Five samples of each species were taken back to the field where they were placed on the ground and pegged using metal hooks to prevent dislodgement by moving animals. They were retrieved after one month and the remaining material dried and weighed after removing soil particles. The decomposition rate (r) or rate of disappearance of the dead grass was then calculated using the formula:

$$r = \frac{\ln W_o/W_1}{t_1 - t_o}$$

Where:

W_o = Initial weight (g) of dead grass at t_o

W_1= Mean weight (g) of dead grass at t_1

r= Rate of decomposition in mg/g/day

t_1-t_0= time interval in days

Using the data collected on monthly plant biomass and decomposition of the grass species understudy, their above ground primary production was estimated using the basic equations of Wiegert and Evans (1964) and Milner and Hughes (1968) which defines primary production in grasslands as: $P_n = \Delta B + L + G$

Where:

ΔB= Change in plant biomass, which is usually estimated using successive harvesting techniques

L= Loss of plant biomass due to mortality

G = amount of plant biomass consumed by herbivores

Let (after Wiegert and Evans, 1964):

t_1-t_0 = time interval

a_0= dead grass material (g) at t_0

a_1= dead grass (g) material at t_1

b_0= live biomass material (g) at t_0 (outside exclosure)

b_1= live biomass material (g) at t_1 (outside exclosure)

B = ungrazed live biomass material (g) at t_1 (inside exclosure)

X= amount of dead material disappearing during the time interval t_1-t_0
then:

(a) $\Delta b = b_1 - b_0$

(b) $\Delta a = a_1 - a_0$

(c) $X = \frac{a_1 + a_0}{2r(t_1 - t_0)}$

(d) $G = B - b_0$

Since Δa is the change in dead grass material during the time interval t_1-t_0, then, Δa+X, is the amount of dead material added to the dead standing biomass during the time interval t_1-t_0. Mortality of live material (d) is, $d=\Delta a+X$, which is equivalent to L. Plant growth (y) during the time interval is, $y=\Delta b+d$, which is equal to $\Delta B+L$.

3.7 FATE OF NET PRIMARY PRODUCTION

In order to obtain an idea of the fate of the net primary production of the four main grass species (*C. dactylon, D. milanjiana / scalarum, C. gayana* and *T. triandra*) that were mostly fed on by the large herbivores, their total above ground live biomass, net production, amount of net production that was consumed by large mammals, amount of dead grass biomass and the proportion of net production that decomposed were calculated and a flow diagram drawn. Above ground live biomass was estimated by calculating the mean above ground live biomass of each species using the monthly data obtained for live biomass. These were then summed to give an overall amount of above ground live biomass. Annual net primary production of each species was obtained by multiplying the mean monthly production by 12, which was then summed to give total net primary production for all the grass species. The amount of net primary production of each grass species consumed by the large herbivores was obtained by dividing the annual net production with the estimated percentage offtake (for each grass species). These were then summed to obtain the total amount of the net primary production that was consumed by the large mammals. The mean amount of dead biomass for each grass species was calculated using the obtained monthly dead biomass weights. These were then summed to obtain the overall amount of dead biomass for all the species. The amount of net primary production that decomposed for each species was determined by multiplying the net production with the proportion that decomposed annually. The amounts were then summed to obtain an overall amount of the net production that decomposed annually.

Secondary production of the Park herbivores was estimated in three different ways.

(a) Using the estimated herbivore offtake (of all the studied grass species), and assuming that assimilation efficiency (A/C) is half herbivore offtake and production

efficiency (P/C) is 2% (0.02) of the assimilation efficiency (Deshmukh, 1986).
(b) Using herbivore biomass supported by the grassland per unit area, and assuming a P/B ratio of 0.1 (Banse and Mosher, 1980; Deshmukh, 1986), where P = secondary production and B = herbivore biomass.
(c) Using estimated net primary production (of all the studied grass species) of the grassland, and assuming that herbivore production is 10% of the net primary production (Deshmukh, 1986). This represents the probable maximum secondary production that can be achieved by the grassland.

3.8 RAINFALL

I collected monthly amount of rainfall data using a rain gauge kept at the main gate (Elsa Gate) of the Park. The data were to be used to determine whether primary production and amount of dead, live biomass and decomposition of the grasses correlated with rainfall or not.

3.9 RESULTS

3.9.1 Above ground primary production and grazing

Monthly above ground net primary production of the grasses is shown in figure 3.2 - 3.4. The production varied from month to month ranging from 2.1 ± 1.01 g/m^2/month to 30.2 ± 4.96g/m^2/month, and the mean ± S.E monthly net primary production for each species was:

C. dactylon	14.8±3.62 g/m^2/month
D. milanjiana /scalarum	10.6±1.82 g/m^2/month
T. triandra	12.3±3.05 g/m2/month
C. gayana	11.1±2.86 g/m^2/month
H. schimperi	3.89±1.11 g/m^2/month
E. tenuifolia	7.4±1.78 g/m^2/month

This gave a total net primary production of about 60 g/m2/month for all the species. There were two peaks of high primary production coinciding with the occurence of the long and short rains. There was however a time lag between time of rainfall and when maximum net primary production was attained. Except for *H. schimperi* (r=0.442, d.f=5, P> 0.05) and *E. tenuifolia* (r=0.618, d.f=6, P> 0.05), the other species showed a significant linear regression between net primary production and rainfall (Figure 3.5 - 3.10), *C. dactylon* (r=0.509, d.f=22), *D. milanjiana / scalarum* (r=0.402, d.f=23), *T. triandra* (r=0.467, d.f=22) and *C. gayana* (r=0.598, d.f=23), with P< 0.05 in all cases. Lack of significant regression between net primary production and rainfall for *H. schimperi* and *E. tenuifolia*

Figure 3.2: Above ground primary production g/m2/month Mar.1990 - April 1992

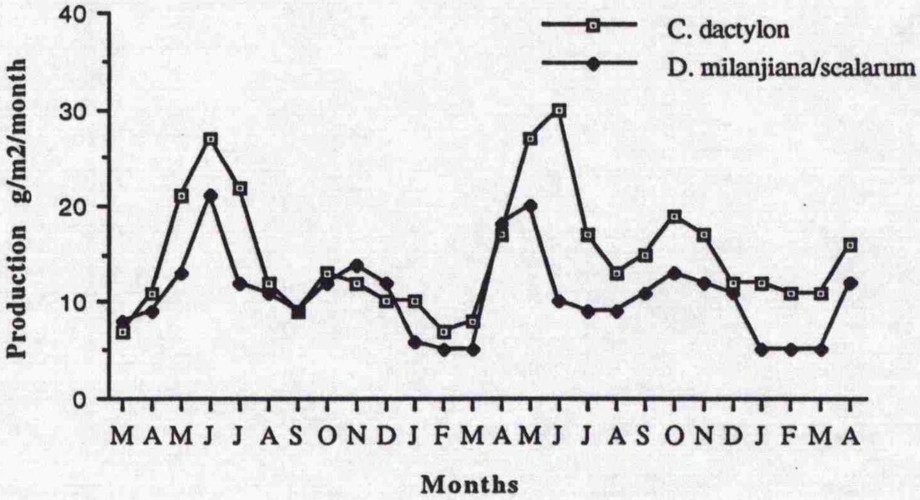


Figure 3.3: Above ground primary production g/m2/month Mar.1990 - April 1992

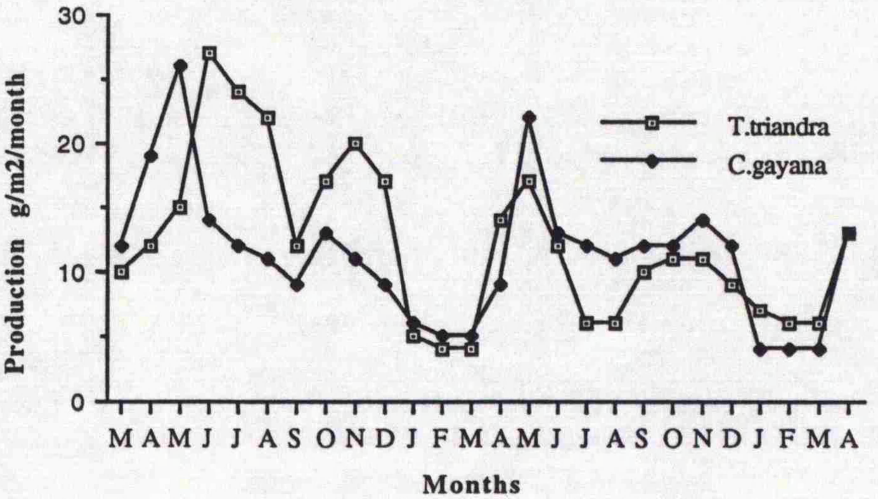


Figure 3.4: Above ground primary production g/m2/month Mar.1990 - Dec. 1990

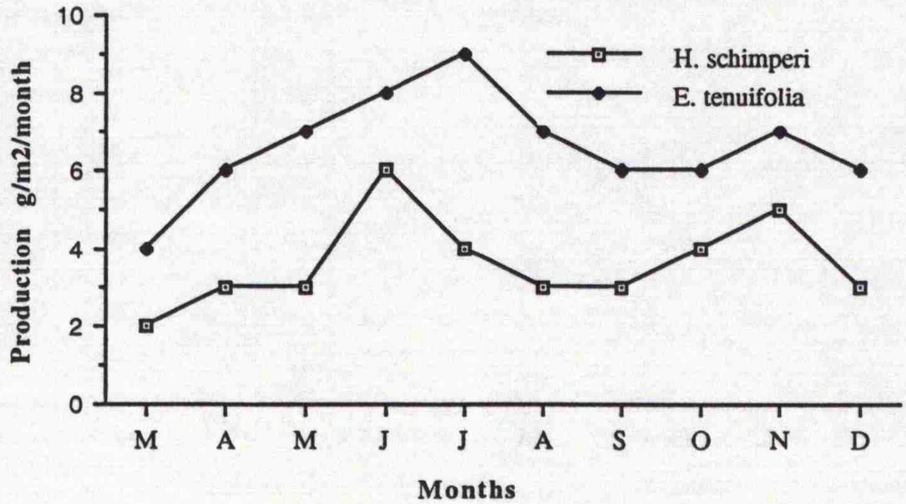


Figure 3.5: Regression of primary production on rainfall

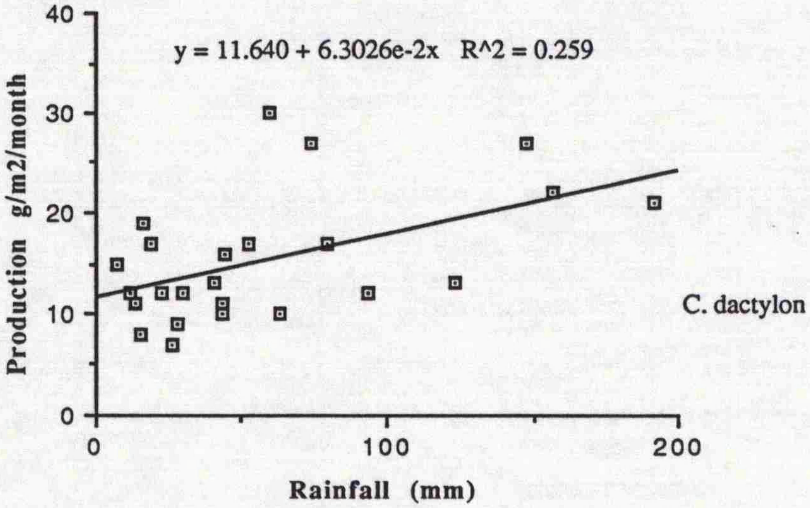


Figure 3.6: Regression of primary production on rainfall

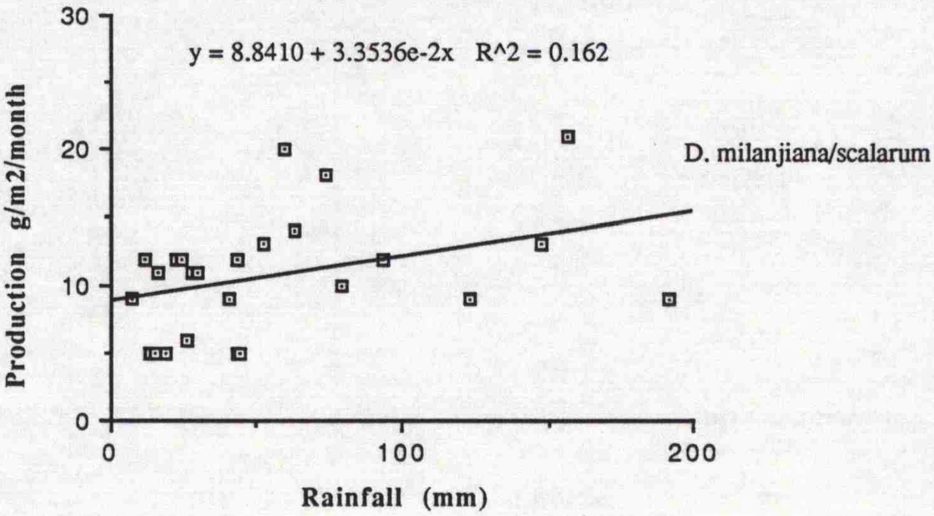


Figure 3.7: Regression of primary production on rainfall

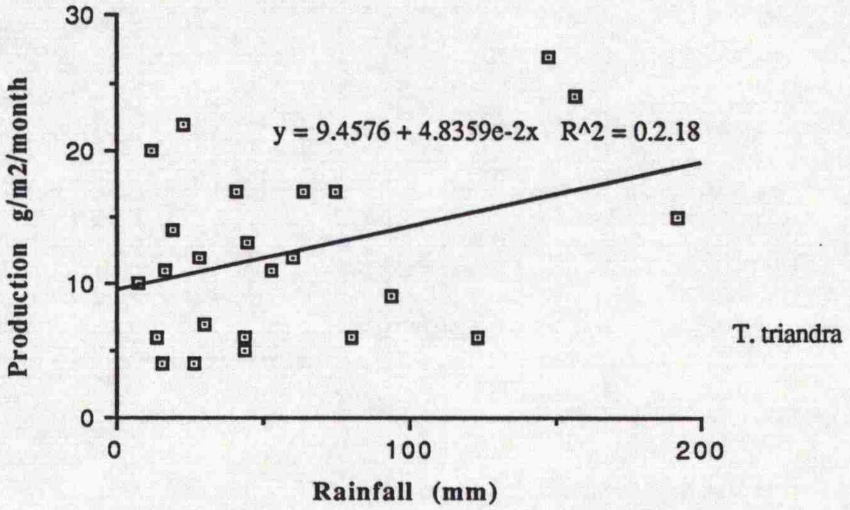


Figure 3.8: Regression of primary production on rainfall

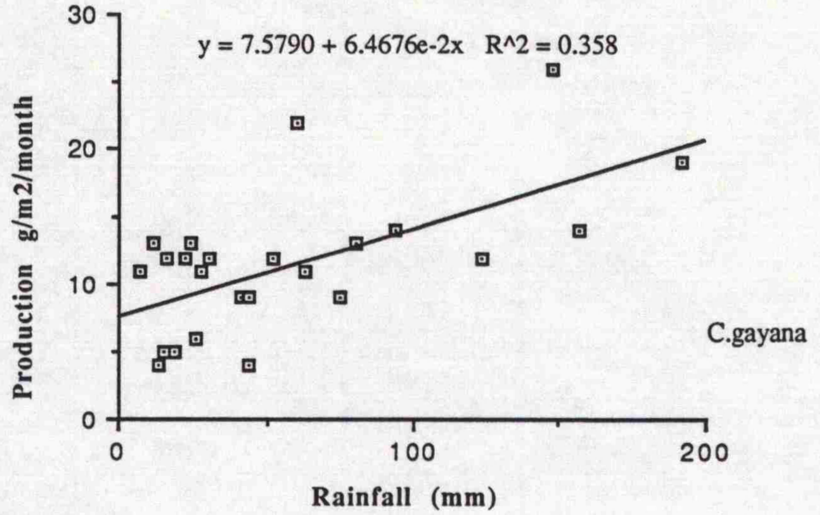


Figure 3.9: Regression of primary production on rainfall

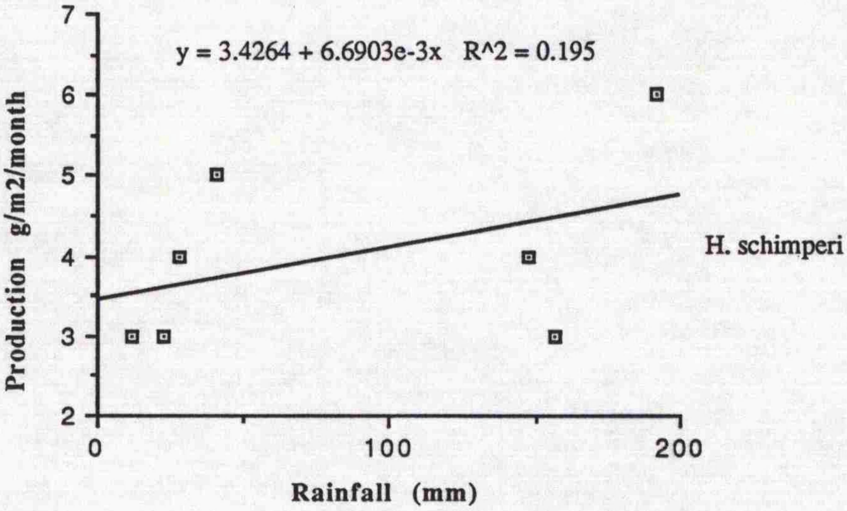
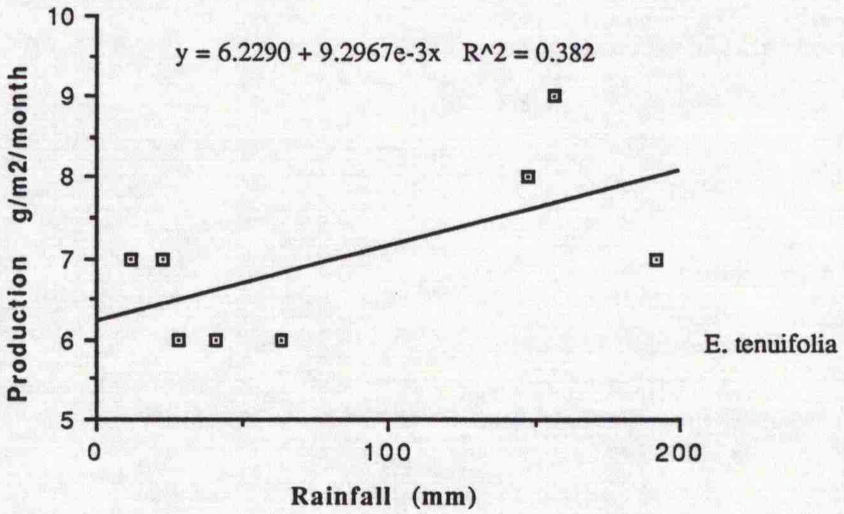


Figure 3.10: Regression of primary productio on rainfall



could have been due to few samples, since their primary production was done for only ten months (March - December 1990), while the other species had their primary production determined for a longer period, from March 1990 - April 1992.

The monthly amounts of dead and live biomass of each species are shown in figures 3.11 - 3.14. Dead biomass ranged from 16.2±4.01 g/m^2 to 308.1±21.87 g/m^2, while live biomass ranged from 3.4±1.12 g/m^2 to 165.4±7.94 g/m^2. The biomass fluctuated in response to the seasonal availability of rainfall, such that during the dry season the amount of dead biomass increased while that of live biomass decreased and vice versa during the wet season. The mean ±S.E dead and live biomass values of each species were: *C.dactylon*, dead biomass 200.3±9.86g/m^2/month, live biomass 113.8±6.06g/m^2/month, *D. milanjiana /scalarum*, dead biomass 108.9±11.65g/m^2/month, live biomass 44.7±5.05g/m^2/month, *T. triandra*, dead biomass 160.4±8.98g/m^2/month, live biomass 34.3±4.02g/m^2/month and *C.gayana*, dead biomass 94.9±7.06g/m^2/month and live biomass 41.3±1.96g/m^2/month. High values of dead and live material occured during the dry and wet season respectively. There was a significant linear regression between rainfall and the amount of live biomass, *C. dactylon* (r=0.561, d.f=22), *D. milinjiana / scalarum* (r=0.711, d.f=22), *T. triandra* (r=0.502, d.f=22) and *C. gayana* (r=0.432, d.f=23), with $P < 0.05$ in all cases, figures 3.15 - 3.18, but there was no significant linear regression between rainfall and amount of dead biomass, *C. dactylon* (r=0.032, d.f=24), *D. milanjiana / scalarum* (r=0.152, d.f=24), *T. triandra* (r=0.077, d.f=24) and *C. gayana* (r=0.145, d.f=24), with $P > 0.05$ in all cases, figures 3.15 - 3.18. The latter was due to the fact that the rate of decomposition of the dead grass material was low, leading to detritus accumulation from season to season, and from year to year, such that the overall monthly amount of the dead biomass was higher than that of the live biomass.

Productivity varied from species to species with *C. dactylon* having the highest productivity of 180g/m^2/yr. This was followed by *T. triandra* with a productivity of 144g/m^2/yr, *C. gayana* 132g/m2/yr, *D. milanjiana / scalarum* 132g/m^2/yr, *E. tenuifolia* 84g/m^2/yr and *H. schimperi* 48g/m^2/yr, making a total annual productivity of 720 g/m^2/yr for the grassland.

Annual percentage offtake of grass forage by herbivores was: *Cynodon dactylon* 1.4±0.2%, *Digitaria milanjiana / scalarum* 2.5±0.6%, *Themeda triandra* 2.8±0.3%, *Chloris gayana* 1.8±0.2%, *Eragrostis tenuifolia* 2.3±0.5% and *Harpachne schimperi* 1.9±0.2%, making a total percentage herbivory of 12.7% of the grass material.

Figure 3.11: Mean +/-S.E dead and live biomass for C. dactylon - Mar. 1990 - April 1992

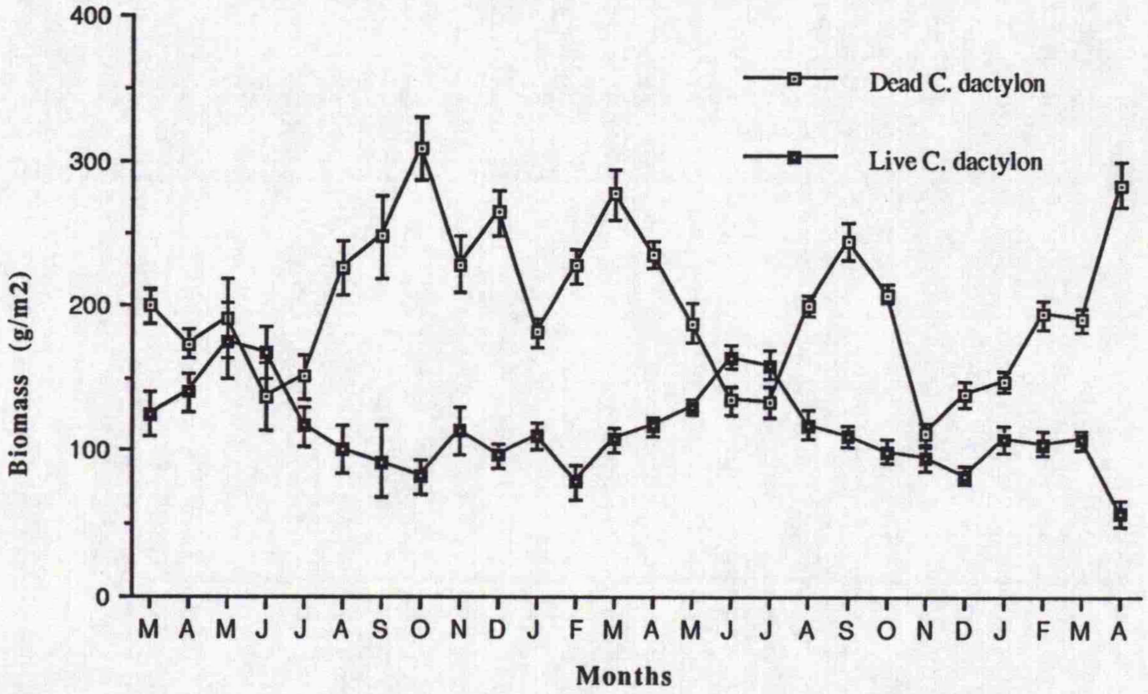


Figure 3.12: Mean +/-S.E dead and live biomass of D. milanjiana/scalarum - Mar.1990 - April 1992

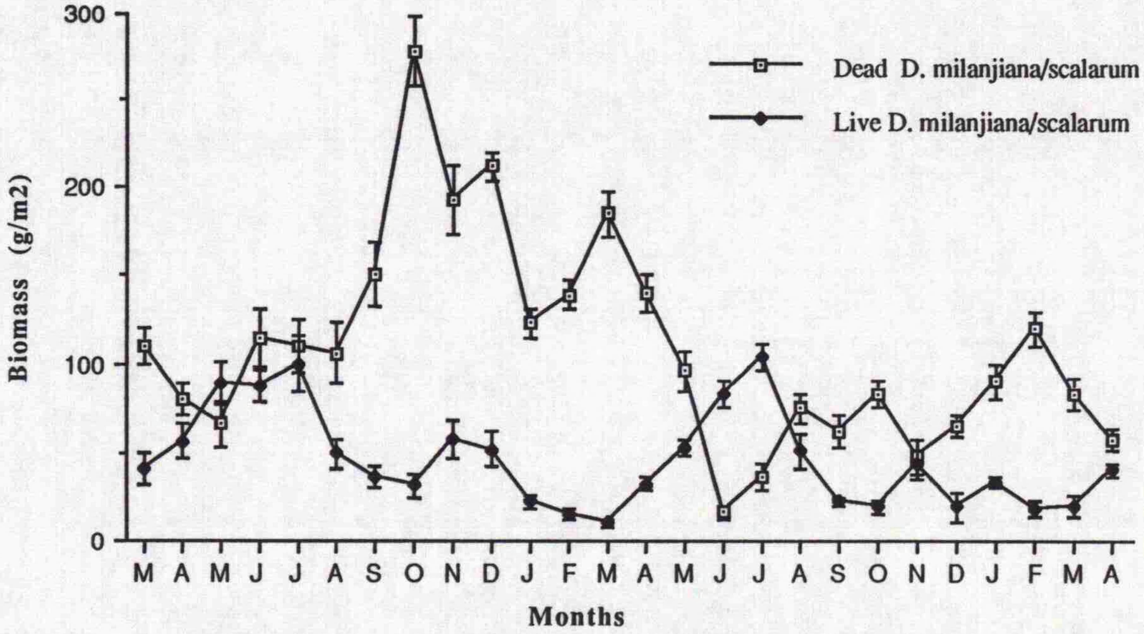


Figure 3.13: Mean +/-S.E dead and live biomass for T. triandra - Mar.1990 - April 1992

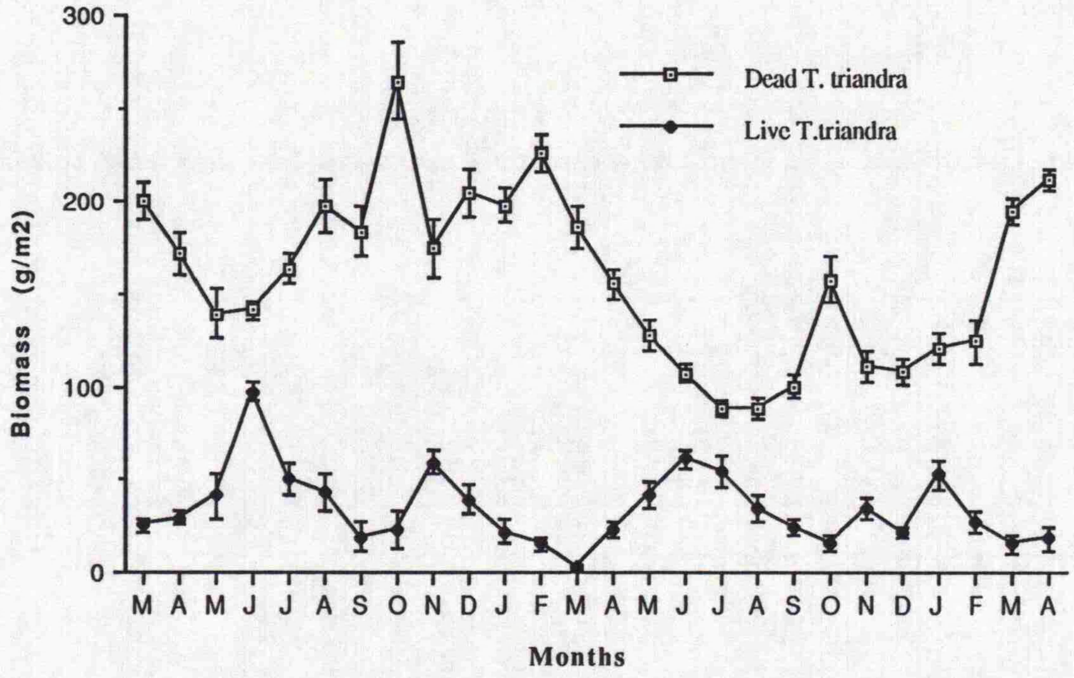


Figure 3.14: Mean +/-S.E dead and live biomass for C. gayana Mar. 1990 - April 1992

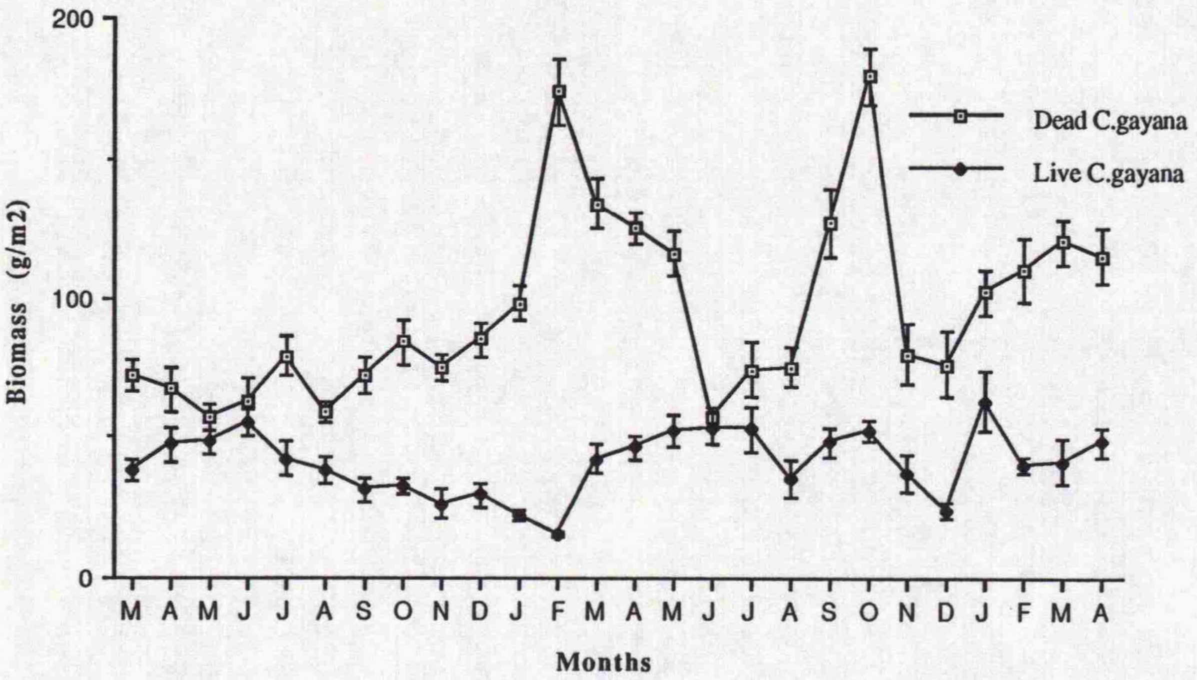
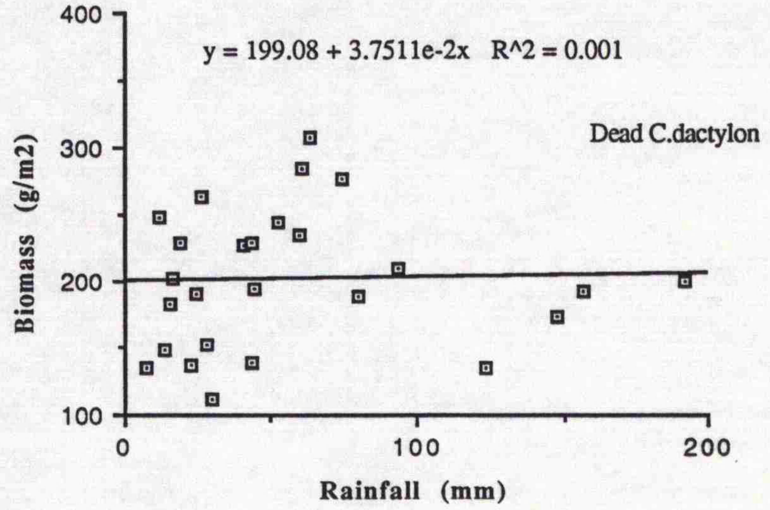


Figure 3.15: Regression of dead and live C. dactylon biomass on rainfall



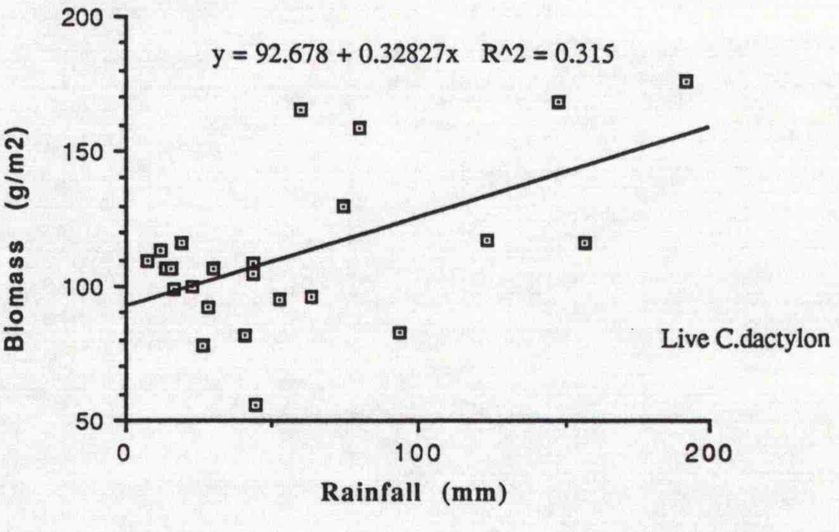
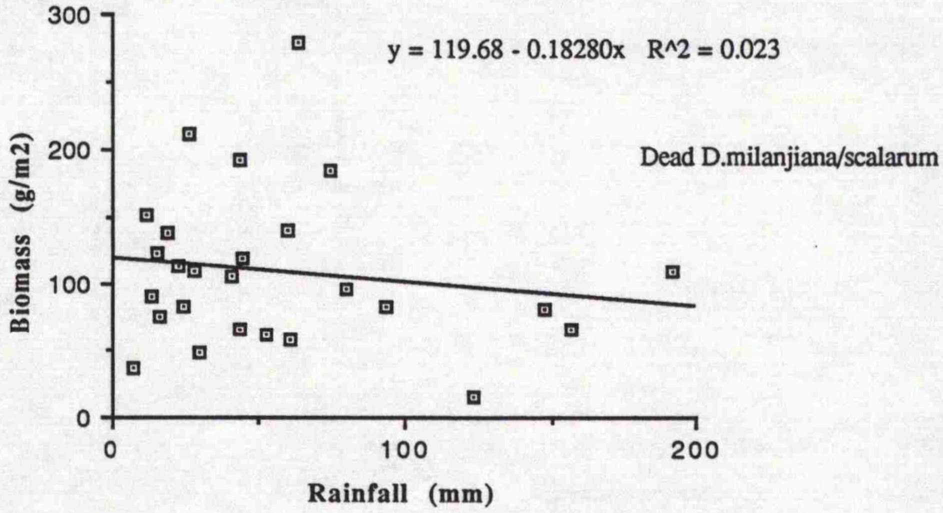


Fig.3.16: Regression of dead and live D. milanjiana/scalarum biomass on rainfall



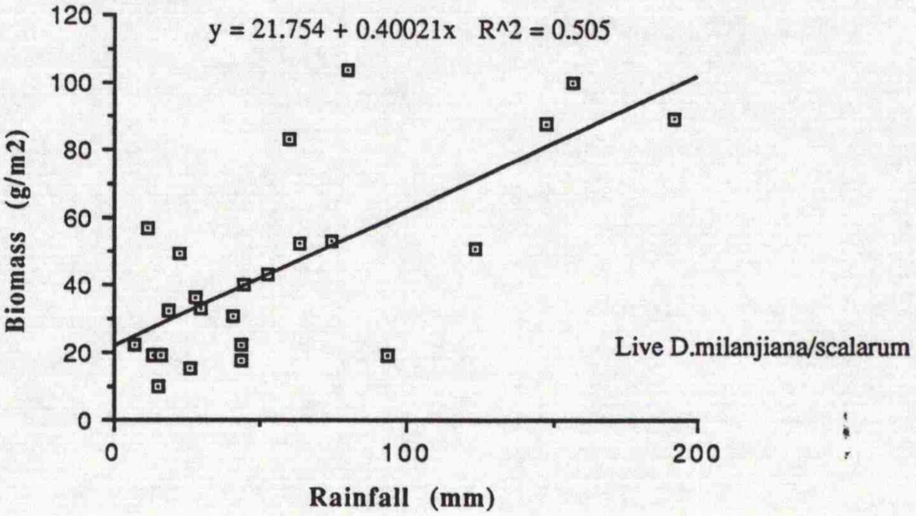
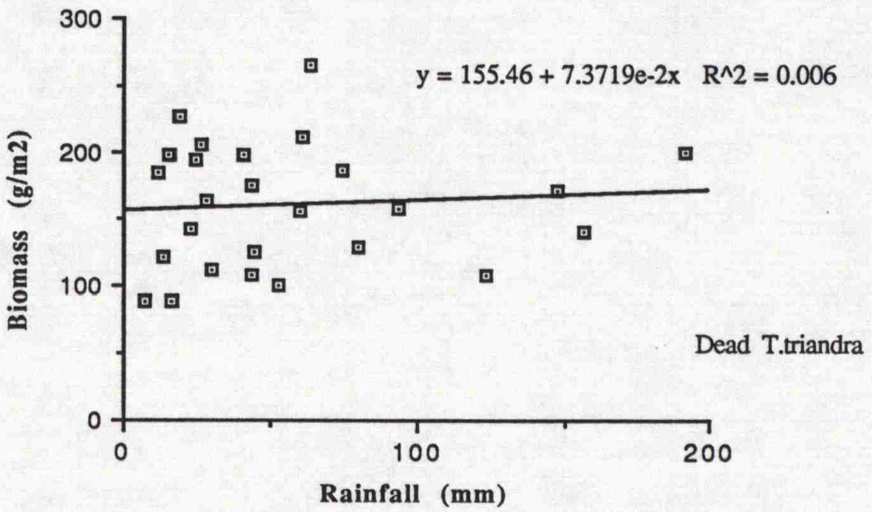


Figure 3.17: Regression of dead and live T. triandra biomass on rainfall



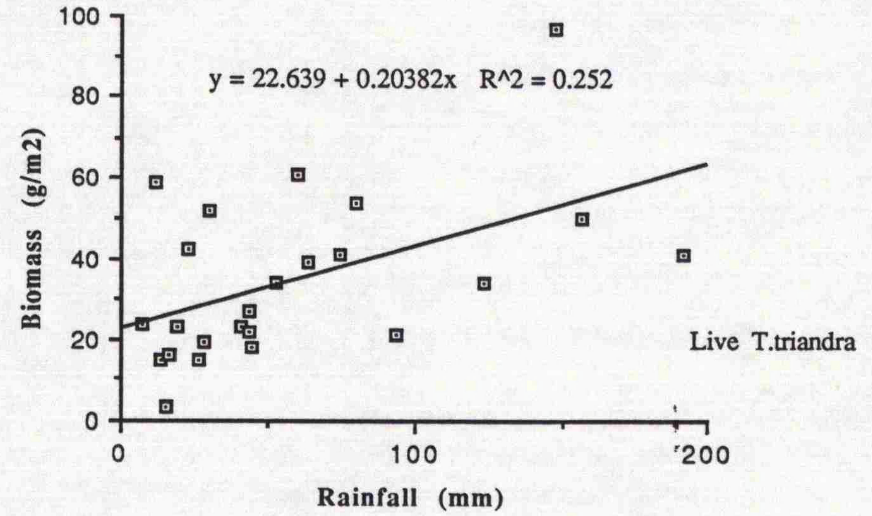
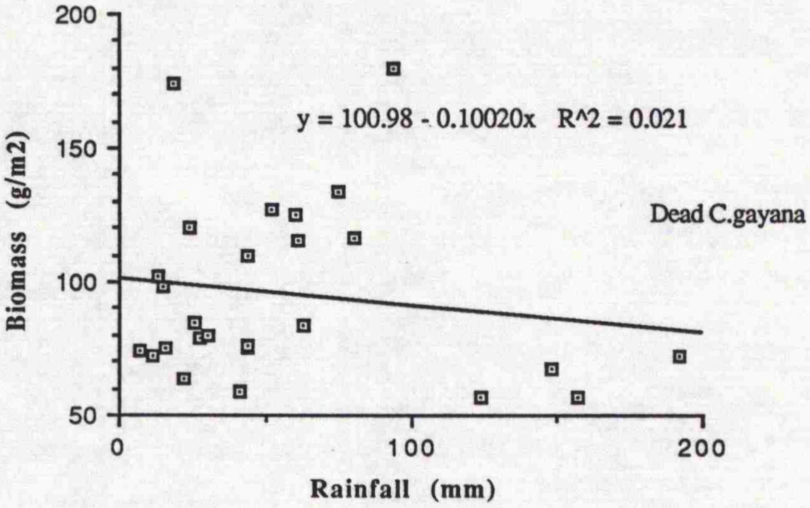
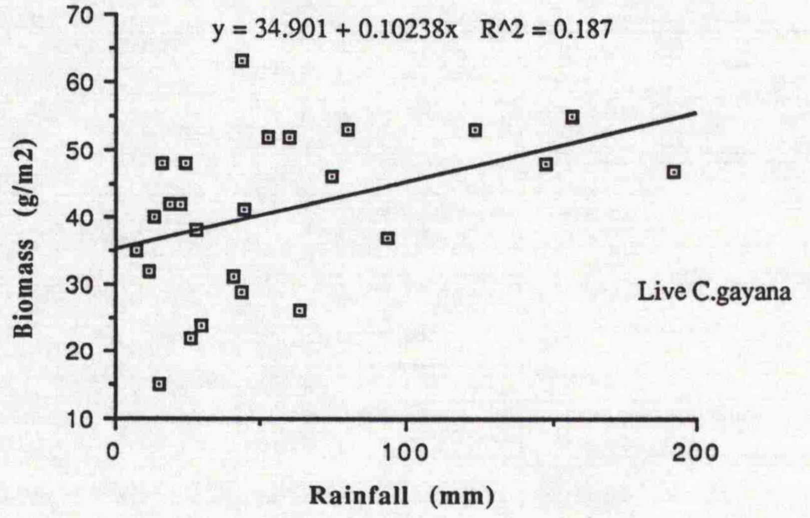


Figure 3.18: Regression of dead and live C. gayana biomass on rainfall





3.9.2 Decomposition of dead grass

Table 3.1 shows the monthly decomposition rates of the grasses. Decomposition rate ranged from 1mg/g/day (30mg/g/month) to 6mg/g/day (180mg/g/month). The mean decomposition rate of each species was:

C. dactylon	3.58mg/g/day (107.4mg/g/month)
D. milanjiana /scalarum	3.12mg/g/day (93.6mg/g/month)
T. triandra	3.04mg/g/day (91.2mg/g/month)
E. tenuifolia	2.38mg/g/day (71.4mg/g/month)
H. schimperi	3.19mg/g/day (95.7mg/g/month)
C. gayana	2.81mg/g/day (84.3mg/g/month)

For each species, the amount of net primary production that decomposed was: *C. dactylon* 2g/m^2/yr, *D. milanjiana / scalarum* 1.12g/m^2/yr, *T. triandra* 1.09g/m^2/yr, *C. gayana* 1.02g/m^2/yr, *H. schimperi* 1.01g/m^2/yr and *E. tenuifolia* 0.58g/m^2/yr. Simple linear regression test showed that there was no significant regression between the rate of decomposition and the amount of rainfall (Figure 3.19 - 3.21), *C. dactylon* $r=0.032$, *D. milanjiana / scalarum* $r=0.239$, *T. triandra* $r=0.369$, *C. gayana* $r=0.385$, *H. schimperi* $r=0.370$, *E. tenuifolia* $r=0.197$, $P > 0.05$, d.f=24 in each case.

3.9.3 Fate of net primary production

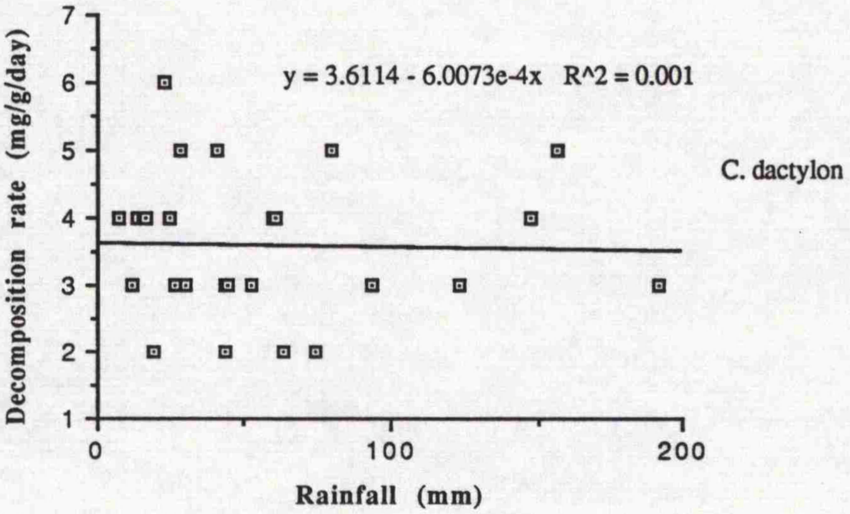
Figure 3.22 shows the fate of the net primary production of the four grass species that were mostly fed on by the large herbivores. Mean amount of their live biomass was 234g/m^2 with a net primary production of 588g/m^2/yr. Large mammal herbivory was 12g/m^2/yr which was 2 per cent of the net primary production, and this supported about 16,780 kg/km^2 of large herbivore fresh weight (data from Chapter 2). The largest proportion of the net primary production dried up to form dead biomass which was estimated to be 564g/m^2 or 96 per cent of the total net primary production. Decomposition of dead grass biomass accounted for 0.85 per cent or 5g/m^2/yr of the net primary production.

The maximum possible secondary production of the Park herbivores estimated using the estimated net primary production of the grassland was 12 kcal /m^2/yr. Secondary production estimated using estimated herbivore offtake and herbivore biomass supported by the grassland per unit area was 2.55 kcal /m^2/yr and 3.4 kcal /m^2/yr respectively. This represented about 1/4 of the maximum possible secondary production of the grassland.

Table 3.1: Decomposition rate of dead grass biomass (mg/g/day) - March 1990 - April 1992

Species	Mar'90	Apr'90	May'90	Jun'90	Jul'90	Aug'90	Sept'90	Oct'90	Nov'90	Dec'90	Jan'91	Feb'91	Mar'91	Apr'91	May'91	Jun'91	Jul'91	Aug'91	Sept'91	Oct'9	Nov'91	Dec'91	Jan'92	Feb'92	Mar'92	Apr'92
Cynodon dactylon	3	4	5	6	5	5	3	2	3	3	4	2	2	4	5	3	4	4	3	3	3	2	4	3	4	4
Digitaria milanjiana / scalarum	1	4	5	1	3	3	2	4	3	3	4	2	3	3	5	5	2	4	3	3	2	3	4	2	3	4
Themeda triandra	1	2	2	1	2	2	4	3	2	3	4	4	2	3	5	3	4	5	3	3	3	3	5	3	4	3
Eragrostis tenuifolia	1	2	2	1	1	1	3	3	1	1	3	3	2	4	4	2	2	5	3	2	2	4	2	2	3	3
Harpachne schimperi	2	3	4	2	3	3	4	2	2	3	4	4	2	3	4	2	4	5	4	3	4	4	4	3	3	2
Chloris gayana	1	2	1	2	2	1	3	3	3	3	4	2	2	2	5	4	4	5	3	3	3	4	4	3	2	2

Figure 3.19: Regression of decomposition rate on rainfall



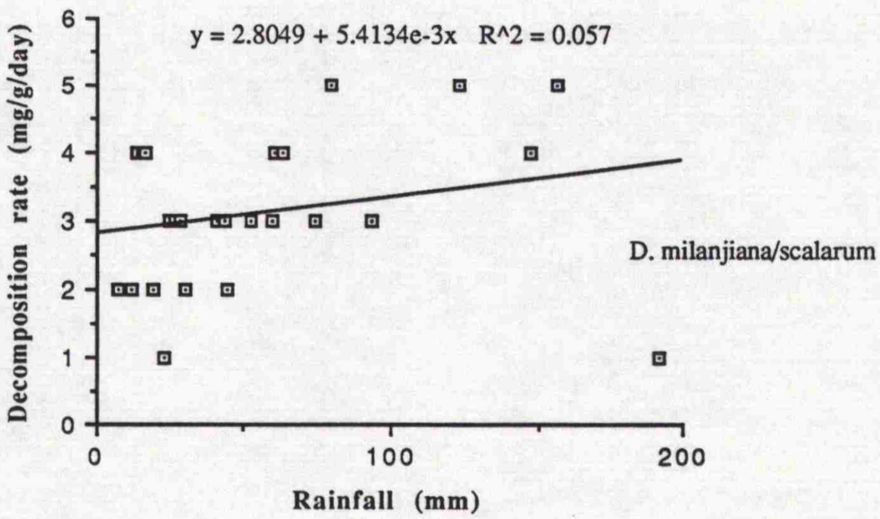


Figure 3.20: Regression of decomposition rate on rainfall

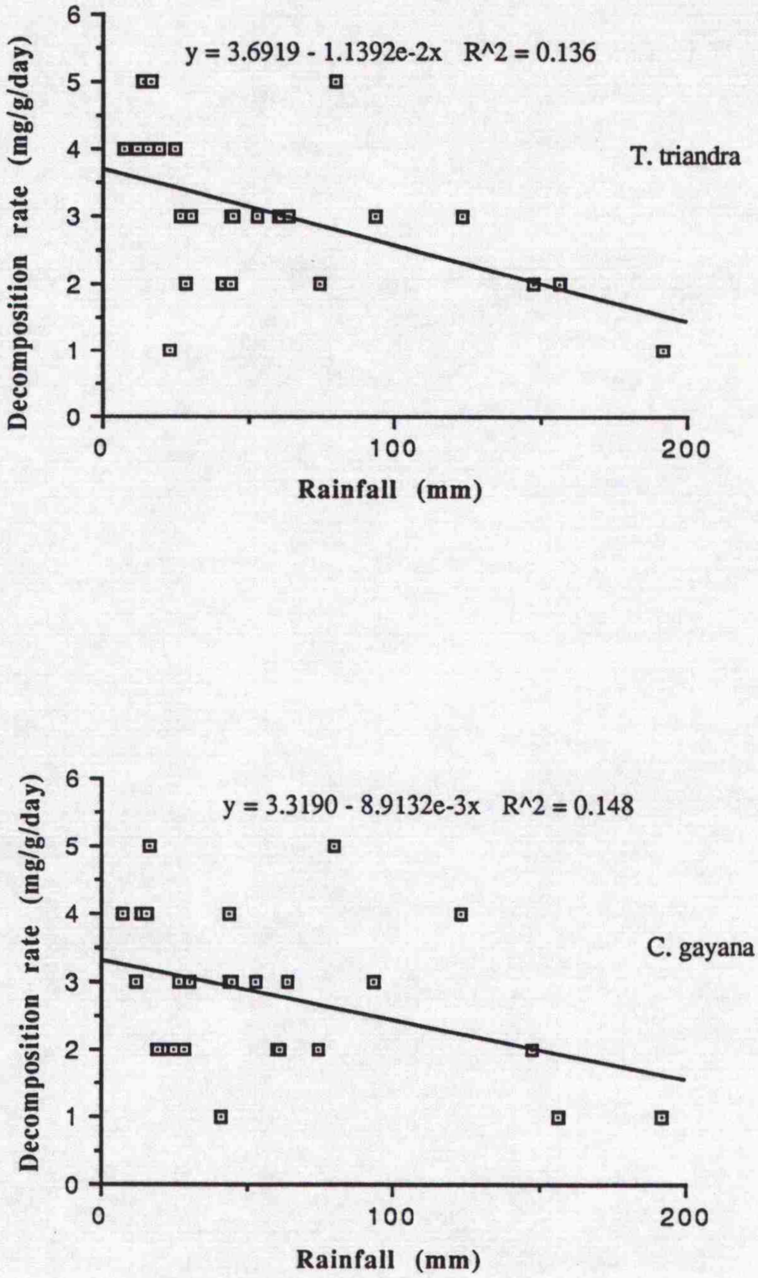
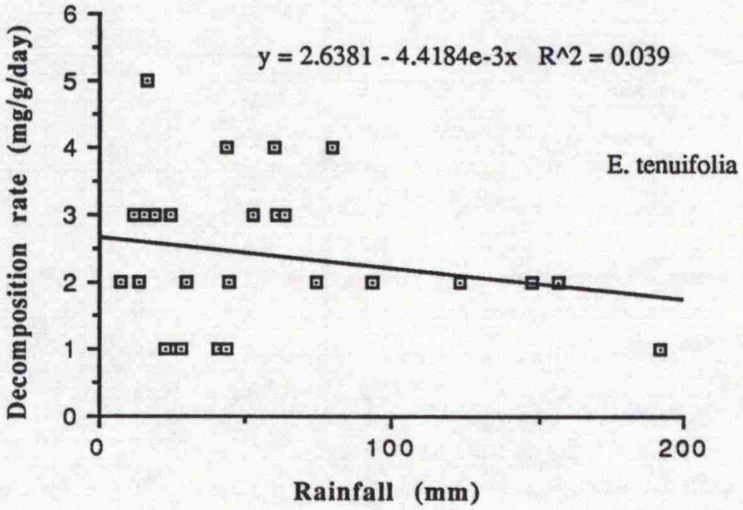


Figure 3.21: Regression of decomposition rate on rainfall



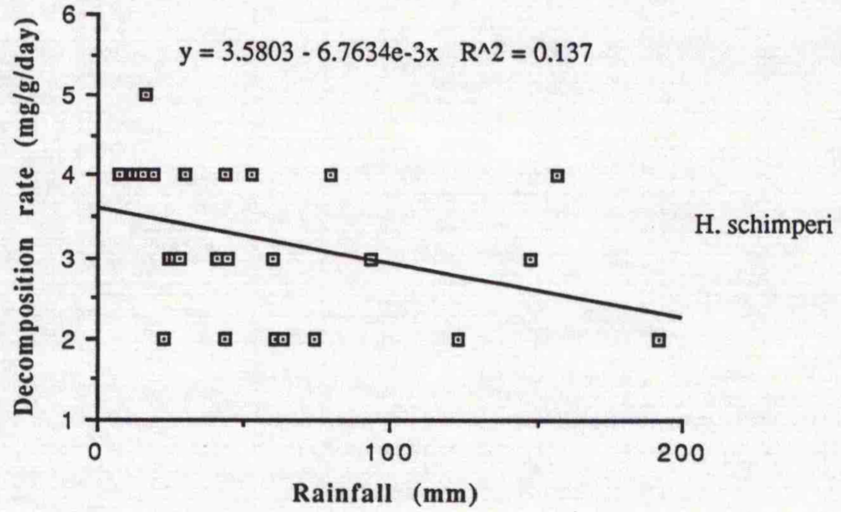


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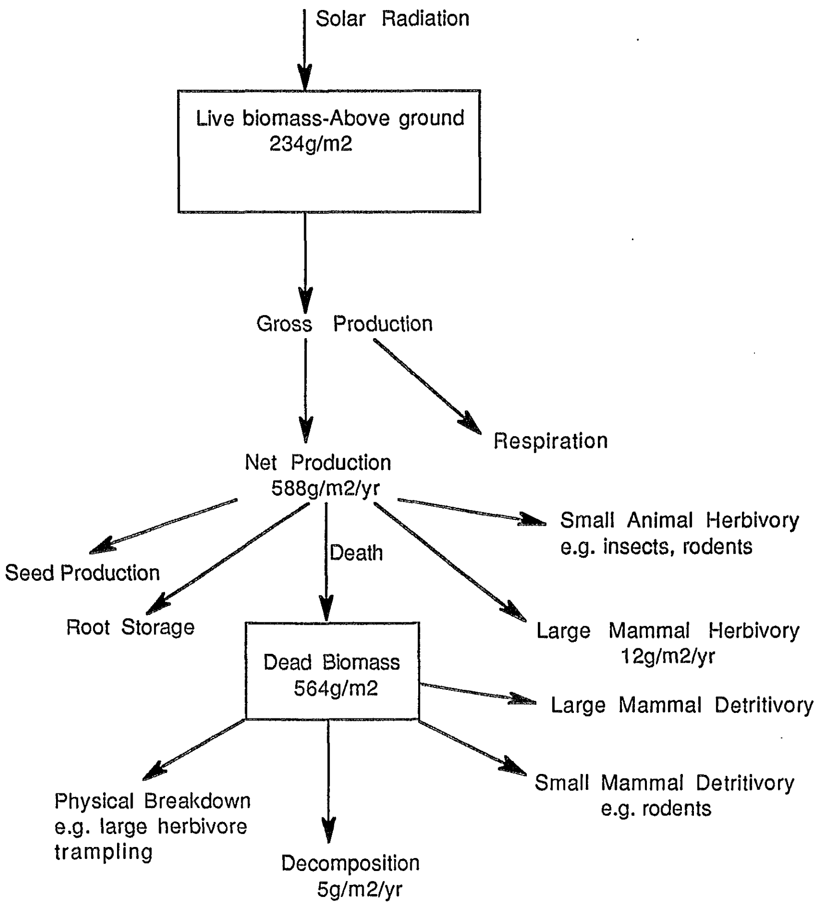
Figure 3.22: Flow diagram showing the fate of net primary production.



3.10 DISCUSSION

3.10.1 Above ground primary production and grazing

The pattern of above ground net primary production showed that production coincided with rainfall amount and availability. It was high during the long and short rains and low during the dry season. Since the Park lies in the tropics, temperature rarely limits primary production and rainfall was considered to be the limiting factor for primary production of the grasses. Soil nutrients may also have been a limiting factor during the rain season. Strugnell and Pigott (1978) working in Ruwenzori National Park, Uganda, Onyeanusi (1983) working in Masai-Mara, Kenya and Kinyamario (1987) working in Nairobi National Park also in Kenya found that primary production was correlated with rainfall as in this study. It is generally accepted that net primary production in arid and semi-arid areas is closely related to the annual precipitation (Cassady, 1973; Sims and Singh,1978a; Strugnell and Pigott, 1978; McNaughton, 1979b; Phillipson, 1975). Whittaker (1970) stated " In arid climates there is a linear increase in net primary production with annual increase in annual precipitation."

The total primary production for all the species in this study was lower than those that have been found elsewhere; e.g. Strugnell and Pigott (1978) reported a net primary production value of 180g/m^2/month for ungrazed grasslands in Ruwenzori National Park, Uganda. In Nairobi National Park, Kenya, Owaga (1980) and Kinyamario (1987) reported values of 37.3g/m^2/month and 109.5g/m^2/month respectively. In the same Park, Deshmukh [1986] found a net primary production value of 465.5g/m^2/month which is higher than my estimate. This difference in primary production in the same Park could have been due to differences in the time when sampling was done (i.e. whether sampling was done during the dry or wet season), rainfall variation from month to month and from year to year and the duration that sampling was done.

The overall productivity value for the Hell's Gate grassland is within the range reported for tropical grasslands which ranges from 200g/m^2/yr to 2000g/m^2/yr with a mean value of 700 to 900g/m^2/yr (Whittaker and Likens, 1975; Leith, 1975; San Jose and Medina, 1976). The productivity also compares with other productivity values that have been reported elsewhere. For example, Macharia (1981) found a production rate of 810g/m2/yr for an open *Themeda* grassland in Masai-Mara Game Reserve, Kenya. Hopkins (1965) and Phillipson (1975) reported production rate values of 680g/m2/yr and 648g/m^2/yr in a Nigeria savanna woodland and in a Kenya *Themeda* grassland (in Tsavo National Park) respectively. In other studies, Cassady (1973) found a productivity value of 596g/m^2/yr for a *Themeda - Cynodon - Pennisetum* grassland in Mutura and 500g/m^2/yr for a *Panicum - Digitaria* grassland at Buchuma both in Kenya. Murphy (1975) reported productivity of *Aristida papposa* in Lindney, Chad and *Cenchrus - Chloris* spp. in Richard-Toll, Senegal and savanna/forest mosaic grasslands in Lamto, Ivory Coast to range from 40 to 996g/m^2/yr. Since these areas had different annual rainfall (300mm/yr to 1300mm/yr respectivily) he concluded that the main factor limiting productivity was rainfall. In Nairobi National Park, Kenya Lusigi (1978) reported a production rate value of 394.7 g/m^2/yr, Sinclair (1975) found a production rate of 470.3g/m^2/yr for short grasslands in Serengeti, Tanzania while Owaga (1980) in Kaputei Plains of Kenya reported a mean productivity value of 447.8g/m^2/yr. These values are lower than the productivity value obtained in this study. More examples of production rates are presented in table 3.2. The table shows that productivity varies from place to place depending on the amount of rainfall. However, other factors like rainfall periodicity, evapo-transpiration, soil permeability, soil fertility, plant species characteristics and grazing pressure all can bring about variation in productivity (Murphy, 1975). Similarily, variation in enviromental parameters can induce changes in produtivity between seasons or years and within sites; for example, Phillipson (1975) observed annual productivity to vary from 545g/m^2/yr to 210 g/m^2/yr at Tsavo East National Park, Kenya in 1969 and 1976 respectively. Cassady (1973) reported a productivity of 500g/m^2/yr at Buchuma, Kenya which was a decrease based on earlier observation of 648g/m^2/yr. Productivity data of single grass species like those studied in Hell's Gate is lacking, and what has therefore been compared is the overall productivity of the grassland with what has been studied elsewhere.

Monthly variation in the amount of live and dead standing grass biomass followed the rainfall pattern. High amount of dead biomass occured during the dry season when most of the live grass biomass dried up as a result of decline in rainfall amount, while high amounts of live biomass occured during the rains. This has been found to be true in other similar studies by Strugnell and Pigott (1978) in Ruwenzori National Park, Deshmukh and Baig (1983), Deshmukh (1986) and Kinyamario (1987) all in Nairobi National Park. It is estimated that in the savanna ecosystem, 60 per cent of the net primary production dries up to form dead biomass (Reiners, 1973).

The mean values of live and dead biomass obtained in this study are lower than those which have been reported for other grasslands of East Africa. For example, Deshmukh (1986) reported a live and dead grass biomass of 332g/m^2 and 374g/m^2 respectively in Nairobi National Park, Kenya. In the same Park, Kinyamario (1987) reported a live and dead grass biomass of 300-338g/m^2 and 651g/m^2 respectively. Owaga (1980) working in the same park recorded values of 93g/m^2 of dead and 309g/m^2 of live biomass. These differences in

Table 3.2: Productivity in different tropical grassland communities

Site	Vegetation type	Annual rainfall (mm)	Production g/m2/yr	Authority
Serengeti	Short grasslands	613	470	Sinclair (1975)
Serengeti	Long grasslands	905	598	Sinclair (1975)
Ruwenzori N. : Uganda	Sporobolus-Chloris grassland	600	527	Strugnell and Pigot (1978)
Ruwenzori N. :	Themeda-Hyparrhenia grassland	600	549	Strugnell and Pigott (1978)
Kaptei Plains Kenya	Themeda grassland	600	402	Owaga (1980)
Masai-Mara	Open Themeda grassland	1034	810	Macharia (1981)
Nairobi N. P. both in Kenya	Themeda-Acacia grassland	729	364	Macharia (1981)
Hell's Gate N. Kenya	C. dactylon	550	180	Present study
	T. triandra	550	144	Present study
	C. gayana	550	132	Present study
	D. milanjiana/scalarum	550	132	Present study
	H. schimperi	550	48	Present study
	E. tenuifolia	550	84	Present study
Total for Hell's Gate		550	720	Present study

the same ecosystem may have been caused by the fact that the studies took different lengths of time. A study done for a longer period is likely to give a better estimate of the amount of dead or live biomass since it will include those months when the amount of dead or live biomass is low or high and therefore come up with a better estimate of the two components. On the other hand, a study carried out for only a short period is likely to concide with those months when the amounts of dead or live biomass are low or high and therefore will not give an overall true picture of variation in their amount. In other grasslands of East Africa, Sinclair (1975) recorded a peak value of 115g/m^2 of live biomass in the Serengeti National Park, Tanzania, while in Ruwenzori National Park (Uganda), Strugnell and Pigott (1978) reported a peak value of 405g/m^2.

Total annual rainfall in Hell's Gate National Park was 864.3mm (1990) and 615.35mm (1991). This however did not cause much difference in production and amount of dead and live biomass between the two years. The slight difference that may have occured could have been as a result of both differences in the rainfall amount and vegetation stagnation caused by accumulation of dead grass material (considering that dead biomass amount was greater than live biomass throughout the study period). Vegetation stagnation has been found to reduce production by smothering the live shoots (Tueller and Tower, 1979). However, grazing and fire have been found to remove this stagnation effect through stimulation of shoot growth by removing leaf shading caused by dead biomass (McNaughton, 1979b). This kind of stagnation may have affected both *Cynodon dactylon* and *Themeda triandra* more than the other species due to their high amount of dead material.

The overall percentage grass offtake by the Hell's Gate herbivores has given an idea of how much of the available grass biomass is consumed annually. Compared with other studies, the percentage offtake value is low. For example, McNaughton (1975) reported a grass biomass offtake measured in four days of 84.9 per cent by migratory herbivores (which included zebra, wildebeest and Thomson's gazelle) in Moru Kopjes area of Serengeti National Park, Tanzania. This figure was high since he determined offtake in the migratory route of the herbivores. In Masai-Mara Game Reserve, Kenya, Onyeanusi (1989) estimated herbivore grass offtake to be 44.98 per cent and 57.97 per cent for the wet and dry seasons respectively. Kevin (1990) recorded a herbivore utilization of annual grasslands in Mara Pool National Park, Zimbabwe to vary between 53 and 99 per cent. The percentage grass offtake value for Hell's Gate was low than found in these studies; and this could have been due to the fact that the number of cages used to estimate herbivory were too few to adequately cover the total area that was used for grazing by the wildlife, and therefore, grazing in some areas was not estimated during the random setting of the cages.

3.10.2 Decomposition rate of dead grass

This study has given an indication of the rate of decomposition of the Hell's Gate grass species. The rate of decomposition was low for all species and did not correlate with the amount of rainfall. One would have expected the rate to increase during the wet season but this was not the case. This could have been due to the low water retention capacity of the soil, coupled with high rates of evaporation. The Park soils are very sandy (50 per cent of the soil particles are sand) (Kiringe, 1990) resulting in a high water percolation rate. Water loss from the soil was further accelerated by high evaporation which is characteristic of semi-arid areas. The result was lack of enough moisture in the soil or dead plant material to enable a high population of decomposers to grow. Decomposition of the dead grass by micro-organisms was therefore low, and therefore most of it laid undecomposed.

Decomposition of grasses in East Africa grasslands has extensively been studied e.g. Deshmukh (1985), Kinyamario (1987) and Macharia (1981). The rates of decomposition have been found to vary among grasslands. For instance, Macharia (1981) in a study of decomposition rate of grasses in different grasslands in Kenya found that rates of decomposition varied from one grassland to the other depending on the amount of rainfall. In Masai-Mara Game Reserve he reported an average decomposition rate of 0.02g/g/month (20mg/g/month), 0.018g/g/month (18mg/g/month) for Nairobi National Park and 0.009g/g/month (9mg/g/month) in Amboseli National Park. The average monthly decomposition range found in my study were higher than those reported by Macharia (1981) and Wiegert and Evans (1964). They however compare and are within the range of those reported by other workers, for example, Kinyamario (1987) in Nairobi National Park, Kenya reported average monthly decomposition values of 0.09g/g/month (90mg/g/month) to 0.18g/g/month (180mg/g/month). Abouguendia and Whitman (1979) reported decomposition values ranging from 0.018g/g/month (18mg/g/month) to 0.128g/g/month (128mg/g/month) in Western North Dakota, U.S.A. Ohiagu and Wood (1979) recorded an average litter decomposition rate of 0.132g/g/month (132mg/g/month) in Southern Guinea savanna, Nigeria.

Grass biomass decomposition rates have been determined elsewhere, for example, Wiegert and Evans (1964) working in an old field of South Eastern Michigan, U.S.A found a rate of decomposition of dead material during winter ranging from 0.003g/g/month to 0.012g/g/month. The rate was low due to low temperatures associated with winter conditions. Abouguendia and Whitman (1979) found that decomposition correlated with enviromental variables, especially temperature and precipitation in a mixed grass prairie in Western North Dakota, U.S.A. Except in one case, all species studied had high rates of decomposition associated with increase in precipitation and moderate temperatures. Kinyamario (1987) in Nairobi National Park, Kenya, found a correlation between decomposition rate and rainfall, being high and low during the wet and dry season respectively.

3.10.3 Fate of net primary production

The flow diagram has given an idea of the fate of the of net primary production of the four main grass species that were mostly grazed on by the herbivores. Their annual net primary production is within the range reported for savanna ecosystems which is from 200-2000 $g/m^2/yr$ and compares with other tropical grasslands (see discussion part 3.10.1). In this study, only two main fates of the net primary production, that is, amount of dead grass biomass and large mammal herbivory were estimated. Other fates of the net primary production such as seed production, storage in roots and consumption by other herbivores like rodents and insects were not measured. However, these fates even when combined may not have been significant in their amount.

The amount of net primary production estimated to be consumed by large mammals may have been an underestimate of the true herbivory amount. Only ten cages were used to estimate monthly herbivory and these could have been inadequate. The assumption made during the study that grazing was uniform did not hold since the herbivores were observed to have preferred some areas in which grazing took place more often than in others. Due to the few number of cages used, and the area covered by the herbivores during grazing, it was likely that during the random setting of the cages, some or all of them were not set in areas where grazing was taking place and this could have lead to an underestimate of the monthly amount of grass biomass that was grazed on and therefore the overall estimate of the amount of net primary production consumed. Although there is no evidence that this was the case, it can be taken that the estimated large mammal herbivory was an underestimate of the actual amount of the net primary production that was consumed by large mammals. Compared with other studies and even for savanna ecosystems where about 15 per cent of the net primary production is consumed by animals (Whittaker and Likens, 1973), the estimated large mammal grazing in Hell's Gate is low. Deshmukh (1986) working in Nairobi National Park, Kenya estimated that total consumption of herbaceous vegetation by large herbivores for the period February 1980 to January 1981 was $40.6g/m^2/yr$ which was less than 4 per cent of the net primary production. My grazing estimate is lower than that reported by Owaga (1980) in the Athi-Kaputei Plains, Kenya who estimated that $33.6g/m^2/yr$ or 7.5 per cent of the net primary production was consumed by large herbivores.

The largest proportion of the net primary production of the four grass species dried up to form dead biomass. Other studies have shown that in most tropical grasslands and especially where consumption of the net primary production by herbivores is not much, most of the live biomass eventually dries up to form dead biomass. For instance, Kinyamario (1987) working in Nairobi National Park, Kenya estimated the amount of dead grass biomass to be 651g/m^2 which was about 50 per cent of the net primary production. In another study in Ruwenzori National Park, Strugnell and Pigott (1978) found amount of dead grass biomass to be 405g/m^2 which was 58 per cent of the net primary production. The percentage amount of these dead biomass estimates as a proportion of net primary production are lower than that obtained in this study.

The fate of the dead biomass is important since if it accumulates apart from causing vegetation stagnation which eventually leads to reduced primary production by smothering live shoots (Tueller and Tower, 1979), it acts as a drain for nutrients which when recycled by the material decomposing become available to other plants. Decomposition rate of the dead grass material obtained in this study indicated that the proportion of the net primary production that decomposed was low and this explains why there was an observed high amount of standing dead grass biomass. Other studies have also shown low decomposition proportions of the net primary production. For example, Macharia (1981) found that about 0.24g/m^2/yr and 0.22g/m^2/yr of the net primary production in Masai-Mara Game Reserve and Nairobi National Park, Kenya respectively decomposed. In Nairobi National Park, Kinyamario (1987) estimated that 2.1g/m^2/yr of the net production decomposed. The low proportion of net production that was found to decompose in these studies was observed to lead to most of the dead grass biomass laying undecomposed as observed in Hell's Gate.

Decomposition of dead material by micro-organisms is not the only way that the biomass can disappear from the environment. Some of it gets consumed by large herbivores, detritivores like insects and rodents, while some of it is physically broken down by trampling by large mammals and a certain amount may be blown away by the wind. In this study, these proportions as indicators of the fate of the standing dead biomass were not measured, and it is probable that their magnitude was not significant to lead to the conclusion that the obtained standing dead biomass was actually an overestimate of the true value if these fates were estimated together with microbial decomposition. It might be argued that in a grassland like that of Hell's Gate where grazing herbivores are the main mammalian species a significant amount of dead biomass especially attached material that has not fallen to form litter could be consumed and therefore lack of measuring this consumption may lead to an overestimation of the actual dead grass biomass. Although dead grass is relatively indigestible (Stanley Price, 1977), it is eaten by herbivores especially during the dry season when the amount of live biomass is low, but in most cases, they will (the herbivores) avoid eating it (dead grass material). It is therefore probable that although I did not measure the amount of dead biomass consumed by the large mammals this did not lead to an overestimate of the observed dead grass biomass.

The calculated percentage consumption of the net primary production by the large herbivores supported a mean large herbivore fresh biomass of 16,780 kg/km^2. The Park grassland was only achieving a secondary production value of about 1/4 of the maximum possible value of secondary production that it can support. If it is assumed that the estimated consumption level was an underestimate, but the true consumption value was not significantly higher than the observed value, then it can be argued that the Park grassland has a potential of supporting more herbivore biomass than it was supporting, although in reality it cannot reach the estimated maximum possible value. This deduction could be true considering that as already mentioned the realised secondary production was only 1/4 of the maximum possible value, and that most of the grass net production dried up to form dead biomass, and therefore if some of this biomass was consumed by the large herbivores before it dried up, such that if the overall proportion of the primary production consumed was higher, then it could lead to a more large herbivore biomass being supported without the grassland theoritically experiencing any over grazing.

In summary it can be said that the net primary production of the Hell's Gate National Park compares with that found in other tropical grasslands and the largest proportion of it eventually dries up to form dead biomass which due to its low decomposition rate lay undecomposed. The current level of large herbivore grass offtake of the net production is low, and if it increases such that the proportion forming dead biomass is lowered, then the Park can support a greater large herbivore biomass than is currently supporting. Since the obtained maximum possible secondary production value of 12kcal /m^2/yr includes insects and small mammals, what should be done is to estimate their secondary production after which a better estimate of the possible maximum value of the large herbivores can be made.

CHAPTER 4

VEGETATION TRAMPLING AROUND WATER TROUGHS BY WILDLIFE AND THE EFFECT OF LIVESTOCK GRAZING ON THE PARK VEGETATION

4.1 INTRODUCTION

During the dry season, wild ungulates in tropical Africa savannas need to drink more frequently in order to meet their body water requirements, which in the wet season are partly obtained from green forage (Western, 1975). In Parks and Reserves where there are no permanent rivers and waterholes, artificial water supply for wildlife is sometimes necessary. However, artificial water supply is controversial (Ayeni, 1975). The major argument advanced against provision of water is the degree of vegetation damage and rangeland deterioration that occurs due to concentration of wildlife around such areas (Ayeni, 1975; Kalikawa, 1990).

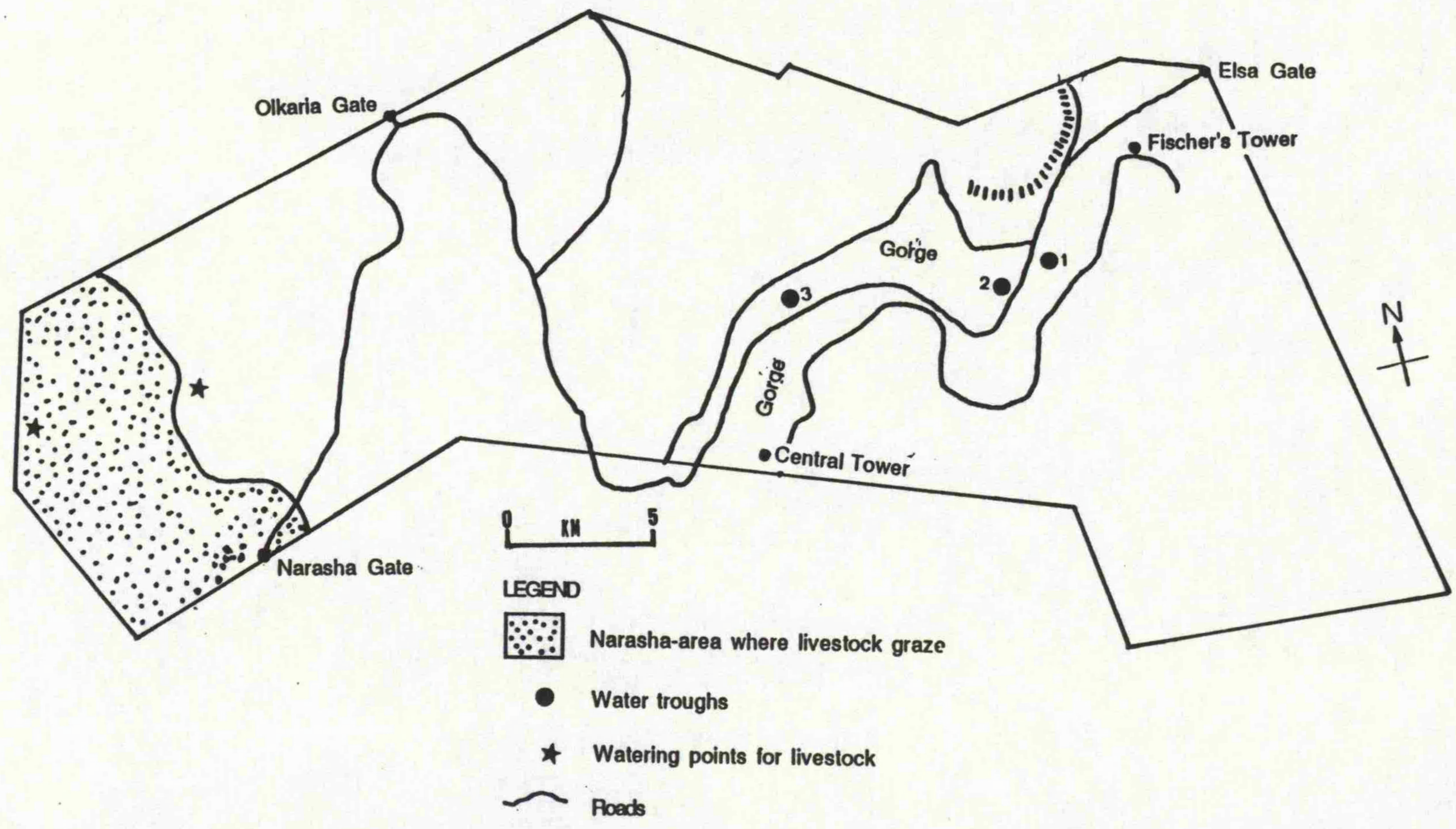
There is little knowledge of the effects of wildlife trampling on the vegetation around artificial water supply in Parks and Game Reserves of Africa. The few studies that have been carried out include that of Kalikawa (1990) in central Kalahari Game Reserve, Botswana, who studied vegetation trampling by wildlife around two artificial boreholes; Senzota and Mtahko (1990) who also studied vegetation trampling by wildlife around one artificial water dam in Mikumi National Park, Tanzania and Ayeni (1975) in Tsavo East National Park, Kenya. The latter studied the utilization of waterholes by wildlife, but did not study their trampling effect on the surrounding vegetation.

The effects of human trampling on the vegetation of recreation areas has been studied extensively (e.g. Grabherr, 1982; Weaver and Dale, 1978; Dale and Weaver, 1974; Liddle and Greig-Smith, 1975; Dan Sun, 1992). These studies have demonstrated that excessive vegetation trampling by man usually reduces plant species composition, species diversity, vegetation height, percentage cover and production. Similar vegetation changes might occur around artificial waterholes used by wildlife due to their hoof action. For management purposes, there is therefore a need to study the vegetation changes associated with wildlife trampling around artificial waterholes or troughs. The data obtained can be used elsewhere to formulate a plan of how such waterholes or troughs should be located relative to each other should the need to supply water for wildlife arise. The main objective of this study was therefore to find out what vegetation changes took place around three water troughs that were commonly used by Hell's Gate wildlife (Figure 4.1).

4.2 METHODS

Each month between April 1990 - April 1992 vegetation sampling was carried out around the three water troughs in areas where trampling (by herbivores drinking water) was expected and control areas where trampling was not expected. For each water trough, eight randomly chosen quadrats were placed in an area up to 20m radius from the edge of the troughs

Figure 4.1: Showing location of the water troughs and Narasha area



where trampling was expected. A further eight control quadrats were placed between 20 and 35m radius where no trampling was expected. Each quadrat was $4m^2$ in area, and located using random number tables. All plant species rooted in each quadrat were noted and recorded. Individuals of each species were counted except for *Digitaria milanjiana*, *Themeda triandra* and *Cynodon dactylon*, which due to their growth nature could not have their individual shoots counted. Their presence in each quadrat was noted. To determine the percentage cover of each species, a point frequency frame was systematically placed at five different positions in each quadrat. For each placement, ten wire pins were lowered through guide holes and the number of pins touching a given species were counted and recorded.

For each water trough, individual quadrats in both the areas expected to be trampled and untrampled did not have enough data on the vegetation in terms of species composition, percentage cover, frequency and density. Therefore, quadrat data were pooled in each area and frequency, density, percentage cover and species diversity were calculated as:

$$\text{Frequency} = \frac{\text{number of quadrats in which a species occurs}}{\text{total number of quadrats}}$$

$$\text{Density} = \frac{\text{total number of plants of each species}}{\text{total area (m}^2\text{) of all quadrats}}$$

$$\text{\% Cover} = \frac{\text{number of pins (hits) touching a species}}{\text{total number of pins}} \times 100$$

$$\text{Shannon-Wiener diversity index (H')} = \frac{n \log n - \sum f_i \log f_i}{n}$$

Where:

n = total number of plants of all the species in all the quadrats

f_i = total number of plants of the "i^{th}" species

Table 4.1 and 4.2 show the results of May 1990. These indicate some of the results obtained in the areas expected to be trampled and that untrampled respectively.

Observations of the monthly data from the three water troughs showed that their species composition was similar. Therefore, monthly data for the trampled areas of the three water troughs were pooled and mean frequency, density and species diversity calculated. Similarily, each month data for the untrampled areas of the three water troughs were also pooled and the same parameters calculated.

Monthly percentage vegetation cover was presented in the form of line graphs, and was subjected to a paired-sample t-test to see if it was significantly different between the

Table 4.1: Water trough 1: Vegetation of the area expected to be trampled - May 1990

Species	Density/m2	Percentage cover	Frequency
Digitaria milanjiana	-	56	0.88
Eragrostis tenuifolia	0.16	0.2	0.38
Harpachne schimperi	1	2.58	0.75
Euphorbia inaequilatera	2	-	0.5
Crotalaria tanganyikensis	0.13	-	0.3
Indigofera tanganyikensis	1.6	-	0.63
Indigofera spicata	0.78	1.56	0.2
Felicia muricata	0.41	0.25	0.6
Panicum maximum	0.16	-	0.13
Themeda triandra	-	4	0.5
Justacia sp.	0.4	-	0.13
Hypoestes verticillaris	0.16	-	0.3
Solanum incanum	0.5	-	0.5
Cynodon dactylon	-	5.5	0.38
Cyperus rigidifolius	0.25	-	0.38
Oxygonum sinuatum	0.06	-	0.13

Percentage cover =70.09

Shannon-Wiener diversty index =0.729

Table 4.2: Water trough number 1: Vegetation of the untrampled area - May 1990

Species	Density/m2	Percentage cover	Frequency
Cynodon dactylon	-	21.56	0.5
Digitaria milanjiana / scalarum	-	60.5	1
Eragrostis tenuifolia	1.03	2.65	0.75
Harpachne schimperi	1.5	0.15	.0.8
Felicia muricata	3	3.5	0.75
Indigofera tanganyikensis	0.56	-	0.75
Euphorbia inaequilatera	0.25	-	0.13
Crotalaria tanganyikensis	0.09	-	0.13
Indigofera spicata	0.06	-	0.14
Themeda triandra	-	1.15	0.25
Cyperus rigidifolius	0.06	-	0.13
Justacia sp.	0.13	-	0.88
Rhamphicarpa montana	0.09	-	0.13
Sida schimperiana	0.03	-	0.13
Monchma debile	0.09	-	0.13
Solanum incanum	0.31	-	0.25

Percentage cover = 89.51

Shannon-Wiener diversity index =0.768

trampled and untrampled areas. Mean +/-S.E of frequency and density of the common plant species between the trampled and untrampled areas were calculated and subjected to Mann-Whitney-U-test to see whether they were significantly different between the two areas. The mean species diversity data were also presented in the form of line graphs and subjected to Mann-Whitney-U-test to see if there was any significant difference in the monthly mean species diversity between the two areas. Monthly mean percentage vegetation cover and species diversity results were subjected to a linear correlation test to see if there was any correlation between them and rainfall.

4.3 RESULTS

The percentage cover, mean +/-S.E of frequency and density of the plant species that were sampled in the untrampled area are shown in appendix 4 - 6. *Digitaria milanjiana, Cynodon dactylon* and *Felicia muricata* were the abundant species by their frequency and percentage cover values. These species contributed the highest percentage of the ground cover in relation to other species. The common species were *Harpachne schimperi, Euphorbia inaequilatera, Eragrostis tenuifolia, Justacia* sp.,*Themeda triandra* and *Indigofera ambalensis*. Their contribution to the ground cover was however less compared with the dominant species.

The percentage cover, mean +/-S.E of frequency and density of the plant species that were sampled in the trampled area are shown in appendix 7 - 9. *Digitaria milanjiana* was the abundant species by the frequency and percentage cover values, followed by *Felicia muricata*.. The common species were *Eragrostis tenuifolia, Justacia* sp., *Themeda triandra* and *Cyperus rigidifolius*, but their overall contribution to the ground cover was less than that of the dominant species.

Thirty two plant species were found in the untrampled area and twenty five in the trampled area. Fourteen of the species were common to both areas (Table 4.3), and their mean frequency and density were not significantly different (Mann-Whitney-U-two tailed test, for mean frequency, calculated U=107, $U_{tab.}$(P=0.05, 2 tailed,d.f =14,14) =141, P>0.05, for mean density, calculated U=62.5, $U_{tab.}$(P=0.05, 2 tailed,d.f =11,11)=91, P>0.05). This suggests that the species composition of the two areas was almost similar, but as shown by table 4.4 eighteen species were only present in the untrampled area, while eleven species were only present in the trampled area. From this, it can be deduced that trampling may have favoured the growth of those species only found in the trampled area, while at the same time it led to the disappearance of those species that were only found in the untrampled area. However, some of the plant species may be so rare that they only occur in one set of quadrat samples by chance.

Table 4.3: Mean +/- S.E of frequency and density of the common plant species in the trampled and untrampled areas of the water troughs

	Trampled area		Untrampled area	
Species	Frequency	Density/m2	Frequency	Density/m2
Digitaria milanjiana	0.87+/-0.01	-	0.92+/-0.03	-
Cynodon dactylon	0.27+/-0.03	-	0.56+/-0.03	-
Themeda triandra	0.56+/-0.05	-	0.42+/-0.03	-
Felicia muricata	0.64+/-0.02	1.03+/-0.13	0.71+/-0.02	1.65+/-0.16
Indigofera spicata	0.27+/-0.03	0.71+/-0.24	0.29+/-0.03	0.42+/-0.08
Euphorbia inaequilatera	0.51+/-0.06	2.02+/-0.78	0.39+/-0.05	1.54+/-0.51
Solanum incanum	0.33+/-0.03	0.25+/-0.04	0.27+/-0.02	0.27+/-0.03
Justacia sp.	0.29+/-0.03	0.17+/-0.03	0.28+/-0.05	0.12+/-0.02
Cyperus rigidifolius	0.23+/-0.03	0.14+/-0.03	0.21+/-0.02	0.21+/-0.07
Eragrostis tenuifolia	0.38+/-0.05	0.74+/-0.24	0.38+/-0.04	1.14+/-0.28
Harpachne schimperi	0.65+/-0.04	0.87+/-0.09	0.45+/-0.04	0.71+/-0.13
Oldenlandia scopulorum	0.19+/-0.03	0.10+/-0.02	0.13+/-0.01	0.04+/-0.01
Chloris gayana	0.15+/-0.02	0.06+/-0.01	0.19+/-0.03	0.08+/-0.01
Indigofera ambalensis	0.59+/-0.07	3.97+/-1.22	0.26+/-0.04	1.04+/-0.43

Table 4.4: Plant species only found in the trampled and untrampled areas

Trampled area	Untrampled area	
Panicum maximum	*Aerva lanata*	*Commelina reptens*
Monchma dabile	*Commelina bengalensis*	*Solanum nigrum*
Crotalaria sp.	*Hypoestes verticillaris*	*Amaranthus* sp.
Pennisetum cladestinum	*Eragrostis racemosa*	*Abutilon mauritianum*
Oxygonum sinuatum	*Aristida keniensis*	*Conyza schimperi*
Commelina africana	*Aristida adoensis*	*Satureia biflora*
Sida schimperiana	*Cyperus* sp.	*Crotalaria spinosa*
Tribulus terrestris	*Cassia mimosoides*	
Chenopodium procerum	*Crotalaria incana*	
Leucas pratensis	*Conyza stricta*	
Amaranthus hybridus	*Indigofera tanganyikensis*	

Throughout the study, the monthly percentage cover appeared to follow the rainfall pattern such that a decrease in amount of rainfall was associated with a decrease in vegetation cover and vice versa when there was an increase in rainfall amount (Figure 4.2). However, there was no significant linear regression between rainfall and percentage vegetation cover in both the trampled and untrampled areas (Figure 4.3), (trampled area, r=0.170, d.f=23 (0.396), P> 0.05 and untrampled area, r=0.000, d.f=23 (0.396), P> 0.05).

The monthly percentage cover and mean±S.E species diversity both in the trampled and untrampled areas are shown on table 4.5 - 4.7. There was no significant difference between the monthly percentage cover in the trampled and untrampled areas (calculated t =1.442, t tab.(P=0.05, 2 tailed, d.f=24)=2.064, P< 0.05. Monthly mean species diversity appeared to follow the rainfall pattern, such that as the rainfall amount increased or decreased, there was an increase and a decrease in species diversity respectively (Figure 4.4). There was therefore a significant linear regression between rainfall and species diversity in both the trampled and untrampled areas (Figure 4.5), (trampled area, r=0.424, d.f=23 (0.396), P< 0.05, untrampled area, r=0.436, d.f=23 (0.396), P< 0.05). However, there was a significant difference between the mean species diversity between the two areas (Mann-Whitney-U-two tailed test, U calculated = 424, $U_{tab.}$(P=0.05, 2tailed,d.f= 25,25)=400, P< 0.05).

4.4 DISCUSSION

Although percentage vegetation cover differences between the trampled and untrampled areas were observed in certain months, overall vegetation cover between the two areas was not significantly different. Plant species composition and abundance were quite similar between the two areas, but certain species were only found in either of the two areas. This suggests that except for certain months, overall vegetation trampling by wildlife drinking from the water troughs did not cause a significant vegetation cover loss in the trampled area in relation to the untrampled. Trampling did not also lead to an overall distinct difference in plant species composition and abundance between the two areas. However, around water trough 1 and 2, there was bare ground within a radius of about 1.5m and 1m respectively from the edge of the troughs. This was caused by vegetation loss as a result of wildlife trampling, but beyond these areas, trampling effect was minimal, and that is why overall there was no difference in mean percentage vegetation cover and plant species composition and abundance between the trampled and untrampled areas.

Vegetation trampling by wildlife could have been expected to occur around the water troughs especially beyond their immediate vicinity leading to loss of vegetation cover, but trampling effect was minimal as to cause any significant loss in vegetation cover in the trampled area. This was due to the fact that the wildlife was not observed to aggregate in large numbers

Figure 4.2: Monthly percentage vegetation cover - April 1990 - April 1992

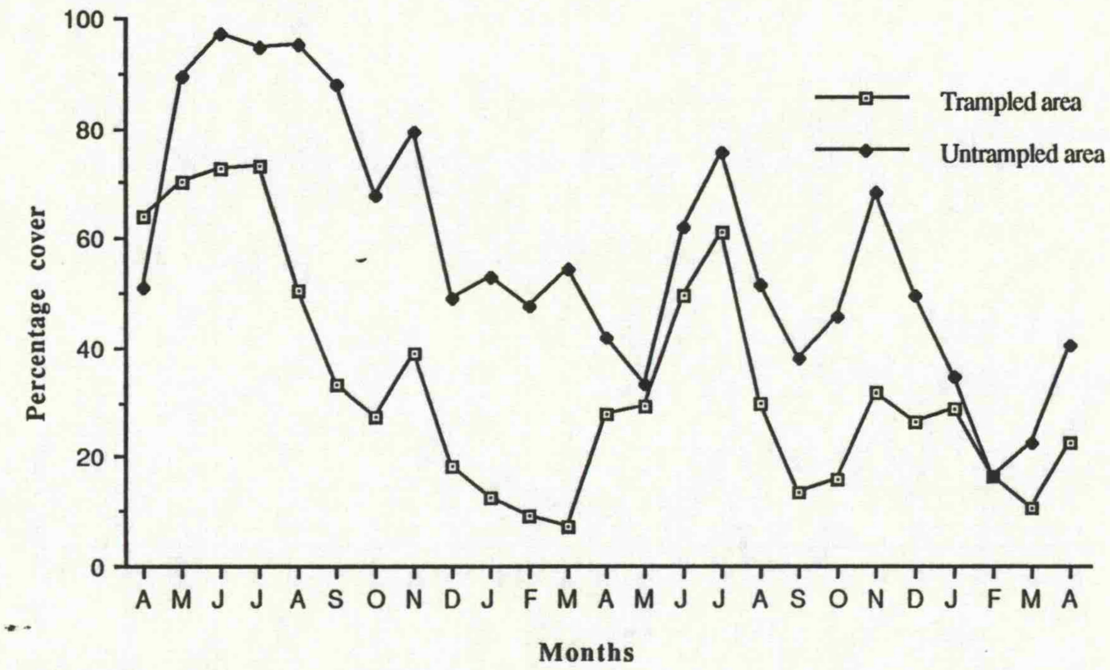
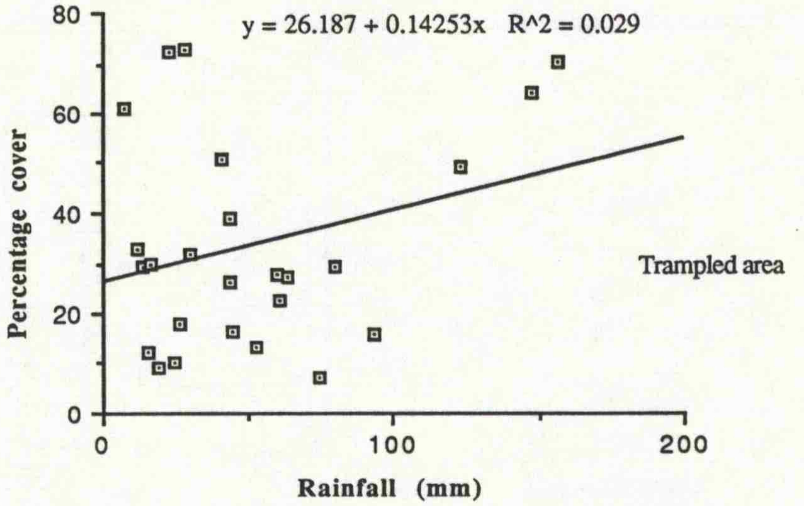


Figure 4.3: Regression of percentage vegetation cover on rainfall



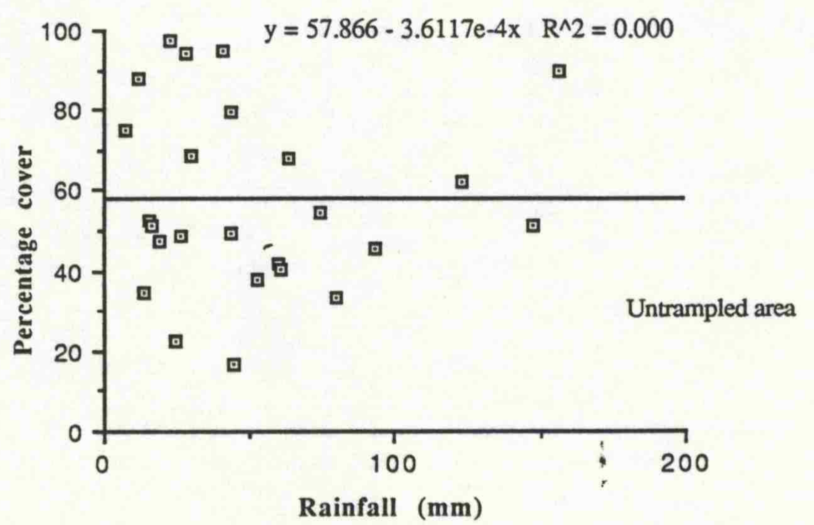


Table 4.5: Percentage vegetation cover and mean/S.E Shannon-Wiener diversity index

	April '90	May '90	June '90	July '90	Aug '90	Sept '90	Oct '90	Nov '90	Dec '90
Percentage vegetation cover in tramped area	64.01	70.09	72.5	73	50.6	33	27.3	39.05	18.1
Percentage vegetation cover in untrampled area	51.15	98.55	97.3	94.5	95	87.8	67.9	79.55	49
Shannon-Wiener diversity index trampled area	0.770/0.081	0.677/0.085	0.733/0.125	0.769/0.149	0.632/0.164	0.546/0.226	0.511/0.150	0.501/0.105	0.605/0.141
Shannon-Wiener diversity index untrampled area	0.839/0.039	0.796/0.082	0.790/0.099	0.821/0.104	0.704/0.045	0.708/0.036	0.716/0.060	0.705/0.047	0.606/0.026

Table 4.6: Percentage vegetation cover and mean/S.E Shannon-Wiener diversity index

	Jan '91	Feb '91	March '91	April '91	May '91	June '91	July '91
Percentage vegetation cover in trampled area	12.5	9.25	7.25	27.75	29.25	49.3	61.25
Percentage vegetation cover in untrampled area	52.8	47.55	54.55	41.75	33.3	62.05	75.25
Shannon-Wiener diversity index trampled area	0.196/0.050	0.182/0.018	0.224/0.046	0.608/0.080	0.762/0.062	0.820/0.101	0.601/0.050
Shannon-Wiener diversity index untrampled area	0.370/0.093	0.274/0.084	0.319/0.090	0.691/0.073	0.861/0.057	0.913/0.041	0.822/0.069

Table 4.6: Percentage vegetation cover and mean/S.E Shannon-Wiener diversity index (continued)

	Aug '91	Sept '91	Oct '91	Nov '91	Dec '91
Percentage vegetation cover in trampled area	29.75	13.5	16	31.55	26.3
Percentage vegetation cover in untrampled area	51.55	37.75	45.82	68.4	49.6
Shannon-Wiener diversity index trampled area	0.322/0.071	0.271/0.073	0.401/0.100	0.574/0.075	0.334/0.064
Shannon-Wiener diversity index untrampled area	0.646/0.096	0.451/0.117	0.435/0.120	0.728/0.093	0.505/0.104

Table 4.7: Percentage vegetation cover and mean/S.E Shannon-Wiener diversity index

	Jan '92	Feb '92	March '92	April '92
Percentage vegetation cover in tramped area	29.05	16.25	10.5	22.75
Percentage vegetation cover in untrampled area	34.55	16.5	22.55	40.5
Shannon-Wiener diversity index trampled area	0.294/0.060	0.241/0.030	0.204/0.008	0.550/0.020
Shannon-Wiener diversity index untrampled area	0.436/0.088	0.321/0.095	0.309/0.060	0.628/0.038

Figure 4.4: Mean monthly species diversity -April 1990 - April 1992

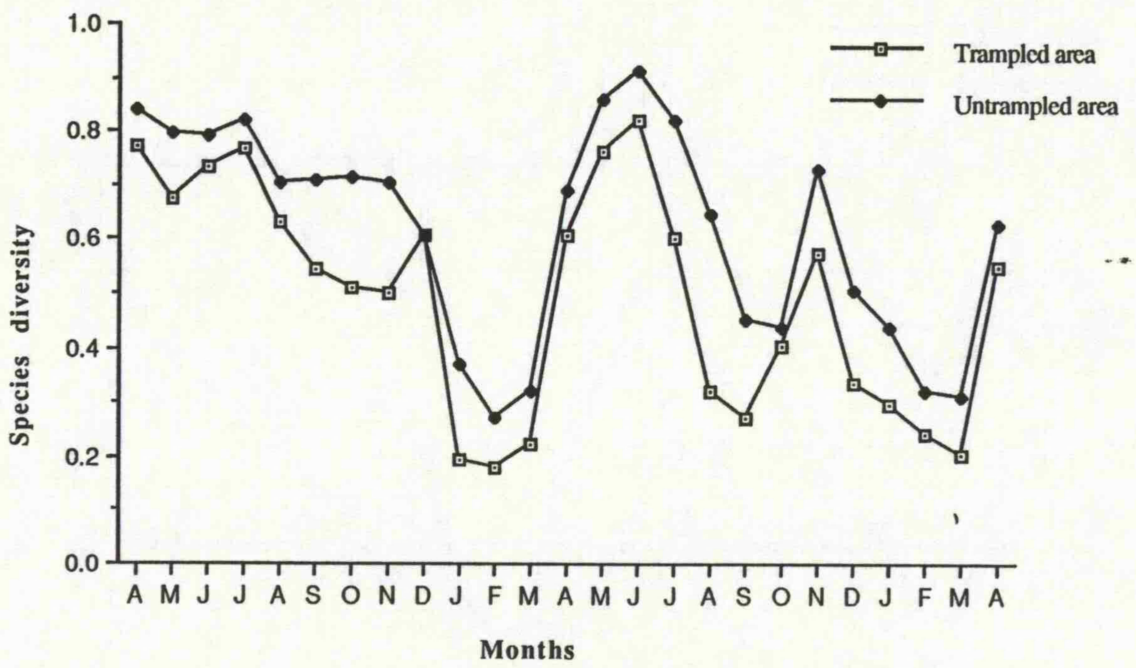
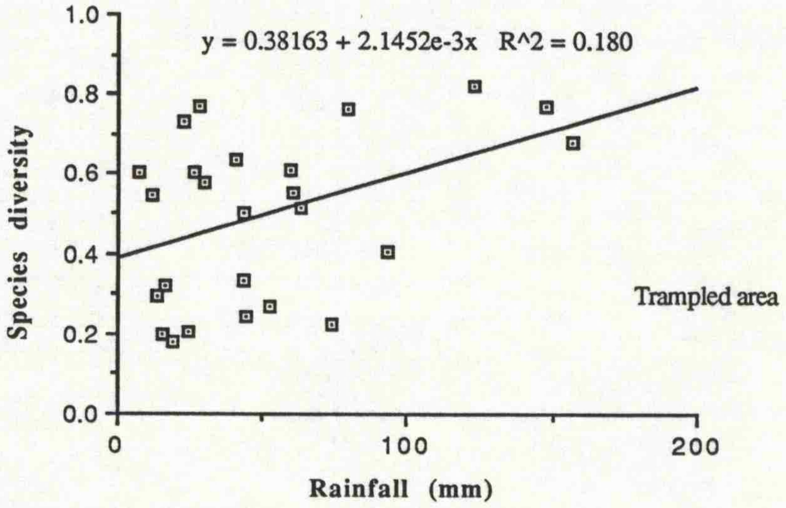
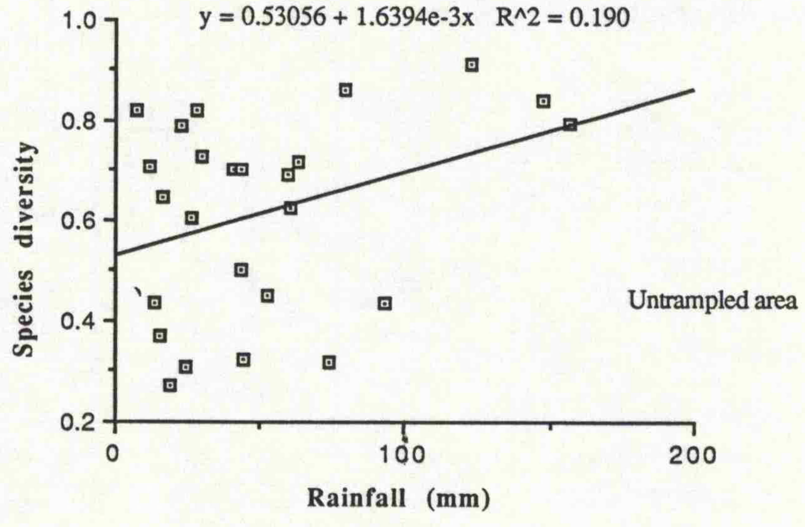


Figure 4.5: Regression of species diversity on rainfall





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around the troughs even during the dry months when their rate of drinking water could have been expected to increase. Although zebra were visually observed to be more frequent around the troughs during the dry months than during the wet months, they never aggregated around the troughs in large numbers, and everytime they drank water they left almost immediately. Buffalo, warthog and kongoni were also visually observed to drink water from the toughs more frequently during the dry months than the wet months, but they too did not spend much time around the troughs as to have any significant trampling effect on the vegetation. From my observations, grazing by wildlife within the immediate vicinity of the troughs did not occur, and this may have reduced any impact on the vegetation due to trampling and grazing.

Studies on the effect of wildlife trampling on the vegetation around artificial water supplies in Africa are scarce. However, studies done by Sentoza and Mtahko (1990) in Tanzania, Kalikawa (1990) in Central Kalahari Game Reserve, Botswana and Child *et al.* (1971) in Kalahari showed that wildlife aggregation around artificial water supplies led to vegetation cover loss within their immediate vicinity. The former who studied vegetation changes around Mwanambogo dam in Mikumi National Park, Tanzania (during the dry season) found that there was significantly less grass cover (mean percentage grass cover was 0.5+/-0.2) within a radius of 100m around the dam than in the outer region due to trampling by wildlife. Kalikawa (1990) in her study on the effect of wildlife trampling on the vegetation of two boreholes (Matswere and Sunday Pan) in Central Kalahari Game Reserve, Botswana, found out that both boreholes showed some degree of vegetation loss as a result of trampling by wildlife aggregating around them. For Matswere borehole, the percentage basal plant cover was 5.6% and for Sunday Pan borehole, the basal plant cover was 4.7%. Child *et al.* (1971) reported that for the borehole they studied in Kalahari, the amount of grass cover did not change at distances of 0.8km and 1.6km from the borehole, but they found significantly less grass cover at 46 and 229m from the borehole than at 0.8km and 1.6km as a result of trampling by wildlife.

Results of this study have shown that overall the wildlife in Hell's Gate were not altering significantly the vegetation cover, plant species composition and abundance in the trampled area of the water troughs compared with the untrampled area. The Park herbivore populations and densities were found to be low in comparison to other Parks of East Africa (Chapter 2), and this may explain why no large aggregations of the wildlife were observed around the troughs. However, this might change in future especially if Park fencing takes place as suggested in the 1985 management plan. If the Park is fenced, then the herbivore populations might increase in comparison with the present estimated numbers and their movement to adjoining areas will be cut, which may lead to a greater number of wildlife utilising the troughs, thus increasing trampling pressure around them. Assuming no fencing occurs, the present three water troughs are sufficient in meeting the water demands of the herbivores. From my personal observations and the results obtained in this study, no serious vegetation cover loss had occured around the troughs as to necessitate additional ones to be constructed to reduce vegetation trampling and cover loss of the existing troughs.

4.5 THE EFFECT OF LIVESTOCK GRAZING ON THE PARK VEGETATION

4.5.1 Introduction

The introduction of cattle in the semi-arid areas of Eastern and Southern Africa has caused severe degradation of natural vegetation for more than fifty years (Guy,1981; Strang, 1974). For instance, Van Vegten (1983) found that in Botswana, a grass savanna with scattered trees was changed into a vegetation with impenetrable thickets, mainly consisting of *Acacia* species and *Dischrostachys cinera* due to overgrazing by livestock. Field (1968) noted that in Uganda and East Africa as a whole, overstocking of domestic animals by pastoralists as a direct expression of their wealth leads to overgrazing and range destruction. In many cases, the importance of wildlife is neglected and it is the first to suffer following the degradation of the habitat. Thus the management of domestic animals affects and may even control the viability of some Parks and Game Reserves (Musoke, 1980).

In Africa at least, cattle do not inhibit woody plant regeneration (Field and Potere, 1972). They prefer grazing to browsing, while sheep like fine grass, forbs and shrubs. Goats are particularly known for browsing however (Field and Potere, 1972), and in this respect are destructive feeders (Field, 1968). Under high stocking levels of livestock, the common pattern of range deterioration is a 2-5 per cent reduction in biomass of the vegetation leading to 1-2 per cent reduction in water infiltration, which further reduces the rate of growth of the vegetation particularly of grasses (Walker *et al.*, 1981). The decrease in the biomass of grass is accompanied by an increase in that of woody vegetation (Walker *et al.*, 1981). In most intensely grazed livestock ranges, a replacement of relatively palatable perennial species by less palatable and /or annual ones has been reported (Acocks, 1975; Sparpe, 1986).

4.5.2 The study

Livestock grazing used to take place in the present Hell's Gate National Park before it was gazetted in 1984 (Robertson and Ruhiu pers. comm.). Upon gazetting, Park laws prohibited any livestock grazing. However, in the Narasha area (Figure 4.1) livestock, mainly cattle *Bos indicus*, sheep *Ovis aries*, goats *Capra hircus* and donkeys *Equus asinus*, often illegally graze and drink water in the Park. This occurs particularly during the dry season (late November-March and August-early October) when most of the neighbouring Masailand is dry, with water and forage for livestock unavailable. During this dry period, the Masai bring their animals to the Park daily from the neighbouring areas to graze and water them. When the rains start in late March or early April, they gradually stop bringing their animals in the Park, which then disperse in the neighbouring Masailand where forage and water are available. When the dry season starts again, they bring their animals back in the Park. A few herds of cattle, goats, sheep and donkeys (about 500 in number) belonging to the local Masai of the Narasha area are however left and these graze and drink water in the Park throughout the year.

The presence of livestock in the Park has some disease implications and there is therefore a chance there will be a spread of diseases like rinderpest, tick borne diseases, nagana, anthrax, foot and mouth disease and transmission of both ecto-and endo-parasites among the different herds. These diseases might also be transmitted from livestock to wildlife and vice versa. In view of the ecological implications that the presence of livestock might have on the Park ecology, one of the questions asked when this study was being planned was how the livestock does affect the vegetation of the Park especially at the Narasha area. The main objective of this study was therefore to find out how livestock grazing in the Narasha area affected the vegetation, and from the findings come up with recommendations for Park management.

4.6 METHODS

Before any vegetation sampling started, visual observations were made for three weeks to give an idea of which areas were grazed and those not grazed by livestock. From this information, those areas where most of the livestock were found grazing were considered to be the grazed areas, while those areas where few or no livestock were found were considered to be the ungrazed areas. From the results obtained on the Park wildlife census (Chapter 2), the Narasha area was found to have low wildlife counts compared with the Njorowa Gorge and therefore the level of wildlife grazing was probably low compared with that of livestock.

Following this preliminary investigation, monthly vegetation sampling from April 1990 - April 1992 was carried out in the grazed and ungrazed areas. In each of these areas, six transects each 100m long were randomly selected using a table of random numbers. Thirty quadrats (each 4 m^2) in each of the two areas were placed at 20m intervals on the ground along the transects. For every quadrat, all the rooted plant species were noted and recorded. Individuals of each species were counted except for *Digitaria milanjiana, Digitaria scalarum, Themeda triandra* and *Cynodon dactylon* which due to their growth nature could not have their individual shoots counted. Their presence in each quadrat was noted. To determine the percentage cover of each species, a point frequency frame was systematically placed at five different positions in each quadrat. For each placement, ten wire pins were lowered through guide holes and the number of pins touching a given species were counted and recorded.

From the data obtained for each transect in each area, mean +/-S.E frequency, density and percentage vegetation cover were calculated. Table 4.8 and 4.9 show results obtained in the grazed and ungrazed areas in June 1990 respectively. The results show that the standard errors were high due to the fact that in each area, I did not have enough number of quadrats. If I sampled until the standard errors were low, this could have consumed too much time and other parts of the whole study would have suffered.

Since quadrats in the grazed and ungrazed areas did not provide enough information on plant species composition, density, frequency and percentage cover, data collected for each quadrat in each area was pooled and frequency, density, percentage cover and species diversity were calculated as shown in section 4.2.

Table 4.10 and 4.11 show the kind of results that were obtained in the grazed and ungrazed areas respectively when data in all quadrats for each area were pooled.

A summary of the plant species occuring in both the grazed and ungrazed areas was made and their mean +/-S.E frequency and density were calculated. These data were then subjected to both Mann-Whitney-U-test and t-test to see if they were significantly different between the two areas. For this statistical analysis, both n_1 (grazed area sample) and n_2 (ungrazed area sample) had a sample size of thirty two data points each, and therefore, their distribution in the Mann-Whitney-test approaches the normal distribution (Zar, 1984), thus allowing the t-test to be done to test for any significant difference between the mean frequency and density of the plant species common to the two areas. A list of those plant species which only occured in the grazed and ungrazed areas was also prepared.

Monthly percentage vegetation cover in the grazed and ungrazed areas was presented in the form of line graphs, and subjected to a paired-sample t-test to see if it was significantly different between the two areas. Species diversity results for 1990-92 of both the grazed and ungrazed areas were also presented in the form of line graphs to obtain an idea of their monthly fluctuation, and then subjected to a t-test to see if there was any significant difference between the mean species diversity of the two areas. Results of monthly percentage vegetation cover and species diversity in each area were subjected to a linear correlation test to see if the was any correlation between them and rainfall.

Table 4.8: Mean +/- S.E of frequency, density and percentage vegetation cover of plant species in the grazed area - June 1990

Species	Frequency +/-S.E	Density/m2 +/- S.E	Percentage cover +/- S.E
Harpachne schimperi	0.23-/+0.20	0.06+/-0.05	-
Eragrostis racemosa	0.18+/-0.14	0.04+/-0.03	-
Eragrostis tenuifolia	0.48+/-0.39	0.14+/-0.10	-
Aristida adoensis	0.10+/-0.07	0.03+/-0.03	-
Chloris gayana	0.12+/-0.10	0.05+/-0.03	1.11+/-0.80
Themeda triandra	0.15+/-0.11	-	-
Digitaria milanjiana / scalarum	0.68+/-0.55	-	15.12+/-11.21
Indigofera spicata	0.11+/-0.08	0.08+/-0.04	-
Euphorbia inaequilatera	0.47+/-0.32	0.18+/-0.11	-
Cyperus rigidifolius	0.12+/-0.09	0.07+/-0.04	-
Sida schimperiana	0.08+/-0.05	0.04+/-0.02	0.45+/-0.25

Table 4.9: Mean +/- S.E of frequency, density and percentage vegetation cover of plant species in the ungrazed area - June 1990

Species	Frequency+/-S.E	Density/m2+/-S.E	Percentage cover+/-S.E
Digitaria milanjiana / scalarum	0.54+/-0.32	-	16.21+/-11.56
Harpachne schimperi	0.16+/-0.11	0.07+/-0.04	-
Cymbopogon caesius	0.48+/-0.30	0.35+/-0.22	9.17+/-5.62
Eragrostis tenuifolia	0.37+/-0.20	0.10+/-0.06	-
Satureia biflora	0.23+/-0.19	0.06+/-0.03	-
Hyparrhenia lintonii	0.11+/-0.05	0.05+/-0.03	-
Hypoestes verticillaris	0.10+/-0.06	0.04+/-0.02	-

Table 4.10: Frequency, density and percentage vegetation cover of plant species in the grazed area - May 1990

Species	Frequency	Density/m2	Percentage cover
Digitaria milanjiana / scalarum	0.67	-	20.9
Eragrostis tenuifolia	0.17	0.17	1.4
Harpachne schimperi	0.56	0.63	0.6
Indigofera spicata	0.33	0.11	-
Leucas pratensis	0.11	0.06	-
Chloris gayana	0.17	0.07	-
Rhamphicarpa montana	0.11	0.06	-
Themeda triandra	0.06	-	-
Oldenlandia scopulorum	0.17	0.08	-
Aristida adoensis	0.21	0.11	-
Dyschoriste radicans	0.11	0.03	-
Sida schimperiana	0.11	0.07	-
Conyza stricta	0.06	0.03	-
Satureia biflora	0.22	0.08	-
Commelina africana	0.06	0.03	-
Crotalaria sp.	0.06	0.04	-
Felicia muricata	0.11	0.06	-

Percentage cover = 22.90

Shannon-Wiener diversity index =0.956

Table 4.11: Frequency, density and percentage vegetation cover of plants in the ungrazed area - May 1990

Species	Frequency	Density/m2	Percentage cover
Digitaria milanjiana / scalarum	0.61	-	29.84
Eragrostis tenuifolia	0.28	0.11	-
Harpachne schimperi	0.28	0.07	-
Themeda triandra	0.17	-	-
Cymbopogon caesius	0.56	0.22	8.4
Oldenlandia scopulorum	0.11	0.06	-
Setaria sphacelata	0.22	0.11	2.56
Satureia biflora	0.28	0.13	-
Dyschoriste radicans	0.06	0.04	-
Commelina bengalensis	0.11	0.06	-
Cyperus sp.	0.06	0.08	-
Abutilon mauritianum	0.06	0.01	-
Plectranthus barbatus	0.06	0.03	-
Euphorbia inaequilatera	0.17	0.14	-

Percentage cover = 40.80

Shannon-Wiener diversity index =0.995

4.7 RESULTS

Appendix 10 - 12 show the frequency, density and percentage vegetation cover values of the plant species that were sampled in the grazed area. *Digitaria milanjiana* and *Digitaria scalarum* were the abundant species by the frequency and percentage cover values. Other species that were common included *Harpachne schimperi, Eragrostis tenuifolia, Chloris gayana, Euphorbia inaequilatera, Felicia muricata* and *Themeda triandra.*

The frequency, density and percentage vegetation cover of the plant species sampled in the ungrazed area are shown on appendix 13 - 15. *Digitaria milanjiana, Digitaria scalarum* and *Cymbopogon caesius* were the abundant species. Species like *Harpachne schimperi, Eragrostis tenuifolia, Sida schimperiana, Themeda triandra* and *Cyperus rigidifolius* were also common.

Fourty five and fourty three plant species were recorded in the grazed and ungrazed areas respectively. Thirty two of the species were common to both areas (Table 4.12), and their mean frequency and density were not significantly different (for mean frequency, Z=0.121, $t_{tab.}$ (P= 0.05, 2 tailed,∞=1.960, P> 0.05, for mean density, Z=0.103, $t_{tab.}$(P= 0.05, 2 tailed,∞ =1.960, P> 0.05). Thirteen species were only found in the grazed area and eleven in the ungrazed (Table 4.13), but their overall plant species composition was almost similar.

The monthly percentage vegetation cover of the two areas is shown in figure 4.6. Vegetation cover fluctuated from month to month. Paired-sample t-test analysis showed that throughout the study there was no significant difference between the monthly percentage vegetation cover of both areas (Table 4.14 - 4.16), calculated t =1.865, $t_{tab.}$(P=0.05, 2 tailed, d.f=24)=2.064, P> 0.05. For both areas, there was no significant linear regression between rainfall and percentage vegetation cover (Figure 4.7), (for grazed area, r=0.173, d.f=23 (0.396), P> 0.05), (for ungrazed area, r=0.338, d.f=23 (0.396), P> 0.05).

Figure 4.8 shows the monthly species diversity in the grazed and ungrazed areas. In the grazed area, there was no significant linear regression between species diversity and rainfall (Figure 4.9), r=0.114, d.f=23 (0.396), P> 0.05, but for the ungrazed area, there was a significant linear regression between rainfall and species diversity (Figure 4.9), r=0.645, d.f=23 (0.396), P< 0.05. However, there was no significant difference between the mean species diversity of the two areas (t calculated=0.733, $t_{tab.}$(P=0.05, 2 tailed, d.f=48) 2.021, P> 0.05).

Table 4.12: Mean +/-S.E of frequency and density of the common plant species in the grazed and ungrazed areas

	Grazed area		Ungrazed area	
Species	Frequency	Density/m2	Frequency	Density/m2
Digitaria milanjiana / scalarum	0.62+/-0.03	-	0.62+/-0.02	-
Eragrostis tenuifolia	0.45+/-0.03	0.72+/-0.21	0.43+/-0.02	0.48+/-0.07
Harpachne schimperi	0.35+/-0.03	0.47+/-0.12	0.32+/-0.03	0.29+/-0.04
Oldenlandia scopulorum	0.31+/-0.06	0.19+/-0.04	0.16+/-0.04	0.17+/-0.10
Justacia sp.	0.14+/-0.02	0.05+/-0.01	0.13+/-0.03	0.04+/-0.01
Dyschoriste radicans	0.09+/-0.02	0.09+/-0.05	0.13+/-0.03	0.06+/-0.01
Sida schimperiana	0.51+/-0.04	0.90+/-0.17	0.27+/-0.04	0.23+/-0.06
Satureia biflora	0.20+/-0.02	0.10+/-0.01	0.30+/-0.03	0.14+/-0.01
Cyperus sp.	0.36+/-0.07	0.23+/-0.09	0.09+/-0.03	0.07+/-0.01
Conyza stricta	0.07+/-0.01	0.03+/-0.01	0.10+/-0.02	0.05+/-0.01
Themeda triandra	0.27+/-0.03	-	0.33+/-0.03	-
Commelina bengalensis	0.03+/-0.01	0.04+/-0.02	0.10+/-0.03	0.06+/-0.02
Oxalis obliquifolia	0.19+/-0.03	0.08+/-0.02	0.20+/-0.07	0.10+/-0.03
Euphorbia inaequilatera	0.41+/-0.05	0.96+/0.25	0.29+/-0.09	0.91+/-0.34
Cyperus rigidifolius	0.19+/-0.03	0.11+/-0.01	0.28+/-0.08	0.35+/-0.13
Solanum incanum	0.10+/-0.01	0.04+/-0.01	0.11+/-0.02	0.04+/0.01
Polygala sphenoptera	0.03+/-0.01	0.02+/-0.01	0.10+/-0.04	0.05+/-0.04
Abutilon mauritianum	0.02+/-0.01	0.02+/-0.01	0.06+/-0.01	0.02+/-0.01
Setaria sphacelata	0.35+/-0.05	0.32+/0.11	0.19+/-0.03	0.11+/-0.02
Felicia muricata	0.16+/-0.03	0.07+/-0.01	0.30+/-0.03	0.17+/-0.02
Crotalaria incana	0.07+/-0.01	0.02+/-0.01	0.05+/-0.01	0.04+/-0.02
Eragrostis racemosa	0.17+/-0.04	0.19+/-0.09	0.13+/-0.02	0.06+/-0.01
Hyparrhenia lintonii	0.18+/-0.11	0.10+/-0.01	0.19+/-0.02	0.09+/-0.01
Oxygonum sinuatum	0.07+/-0.01	0.12+/-0.03	0.13+/0.04	0.14+/0.03
Aristida adoensis	0.14+/-0.02	0.07+/-0.01	0.10+/-0.03	0.08+/-0.06
Chenopodium procerum	0.11+/-0.04	0.02+/-0.01	0.22+/-0.18	0.20+/-0.04
Chloris gayana	0.21+/-0.02	0.10+/-0.02	0.17+/-0.04	0.07+/-0.02
Conyza schimperi	0.14+/-0.07	0.06+/-0.02	0.09+/-0.02	0.04+/-0.01
Crotalaria tanganyikensis	0.10+/-0.02	0.03+/-0.01	0.02+/-0.01	0.02+/-0.01
Kyllinga sp.	0.02+/-0.01	0.03+/-0.02	0.08+/-0.01	0.02+/-0.01
Crotalaria sp.	0.10+/-0.03	0.04+/-0.02	0.06+/-0.02	0.03+/-0.01
Achyranthus aspera	0.02+/-0.01	0.02+/-0.01	0.04+/-0.02	0.02+/-0.01

Table 4.13: Plant species only found in the grazed and ungrazed areas

Grazed area	Ungrazed area
Hyparrhenia sp.	*Cymbopogon caesius*
Leucas pratensis	*Zornia setosa*
Commelina africana	*Ocimum suave*
Eragrostis mamoena	*Rhyncheltrum* sp.
Indigofera spicata	*Helichrysum glumaceum*
Angustifolia montana	*Indigofera ambalensis*
Pennisetum cladestinum	*Plectranthus barbatus*
Cynodon dactylon	*Hypoestes verticillaris*
Aerva lanata	*Phyranthus ratundifolius*
Ocimum kilimandijaricum	*Conyza filipendula*
Cyperus laevigatus	*Commelina reptens*
Bulbine abyssinica	
Rhamphicarpa montana	

Figure 4.6: Monthly percentage vegetation cover - April 1990 - April 1992

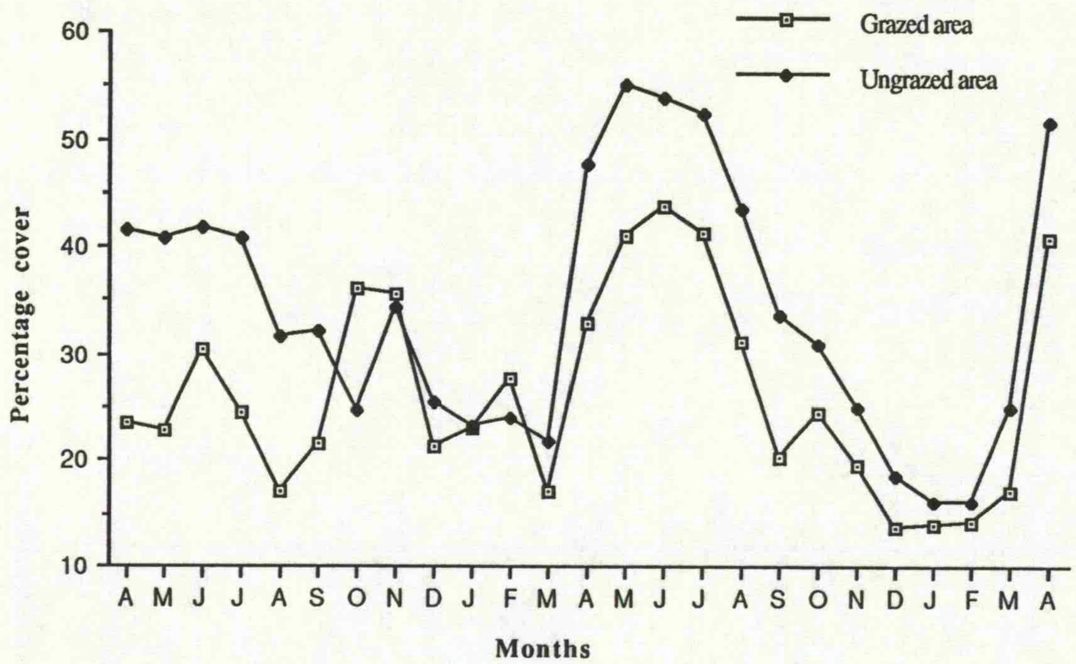


Table 4.14: Percentage vegetation cover and Shannon-Wiener diversity index

	April '90	May '90	June '90	July '90	Aug '90	Sept '90	Oct '90	Nov '90	Dec '90
Percentage vegetation cover in grazed area	23.45	22.9	30.56	24.43	17.22	21.57	36.21	35.69	21.44
Percentage vegetation cover in ungrazed area	41.54	40.76	41.89	40.83	31.7	32.26	24.85	34.39	25.62
Shannon-Wiener diversity index grazed area	0.709	0.956	0.987	0.656	0.912	0.884	0.971	0.954	0.864
Shannon-Wiener diversity index ungrazed area	0.965	0.995	0.944	0.708	0.767	0.652	0.827	0.756	0.663

Table 4.15: Percentage vegetation cover and Shannon-Wiener divresity index

	Jan '91	Feb '91	March '91	April '91	May '91	June '91	July '91
Percentage vegetation cover in grazed area	23.02	27.63	17.19	32.91	41.11	43.66	41.2
Percentage vegetation cover in ungrazed area	23.29	24.05	21.78	47.7	55.07	53.78	52.4
Shannon-Wiener diversity index grazed area	0.643	0.705	0.814	0.695	0.695	'0.800	0.751
Shannon-Wiener diversity index ungrazed area	0.726	0.721	0.799	'0.830	0.838	'0.840	0.801

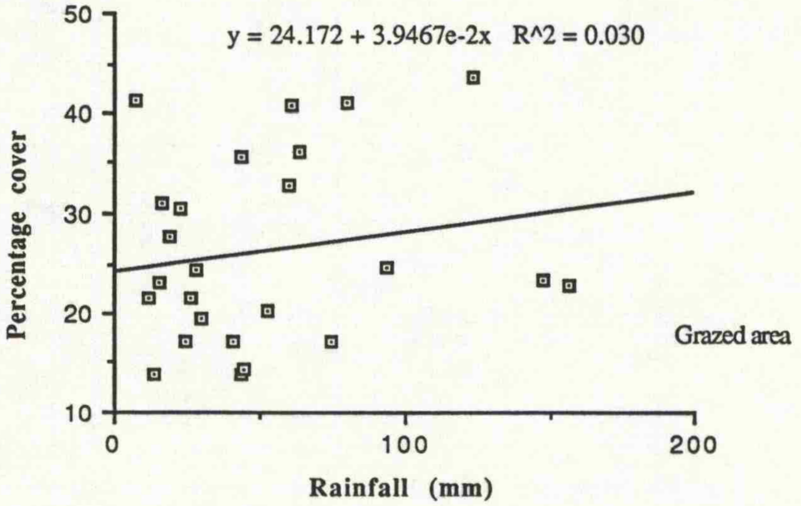
Table 4.15: Percentage vegetation cover and Shannon-Wiener divresity index (continued)

	Aug '91	Sept '91	Oct '91	Nov '91	Dec '91
Percentage vegetation cover in grazed area	31.11	20.35	24.6	19.61	13.72
Percentage vegetation cover in ungrazed area	43.4	33.75	30.95	25.07	18.51
Shannon-Wiener diversity index grazed area	0.809	'0.650	0.773	0.895	0.887
Shannon-Wiener diversity index ungrazed area	0.884	0.921	0.936	0.822	0.828

Table 4.16: Percentage vegetation cover and Shannon-Wiener diversity index

	Jan '92	Feb '92	March '92	April '92
Percentage vegetation cover in grazed area	13.87	14.26	17.08	40.79
Percentage vegetation cover in ungrazed area	16.14	16.06	24.92	51.54
Shannon-Wiener diversity index grazed area	0.592	'0.690	0.714	0.665
Shannon-Wiener diversity index ungrazed area	0.706	0.707	0.802	0.777

Figure 4.7: Regression of percentage vegetation cover on rainfall



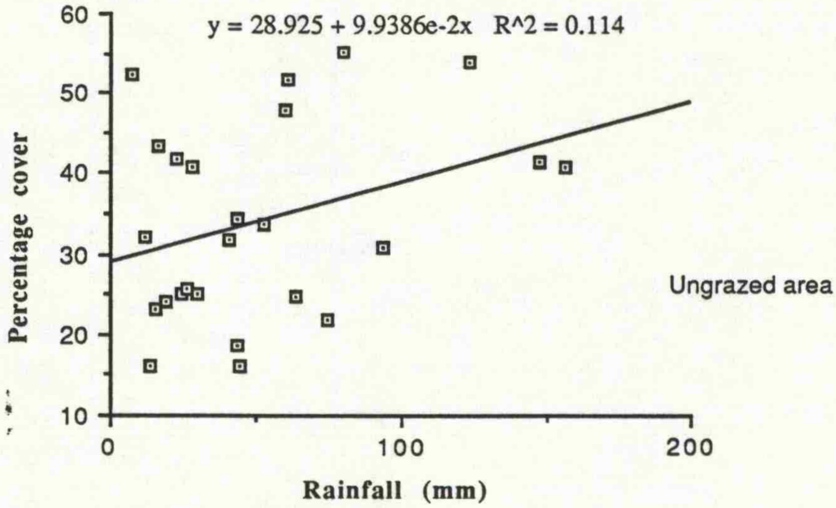


Figure 4.8: Monthly species diversity in the grazed and ungrazed areas - April 1990 - April 1992

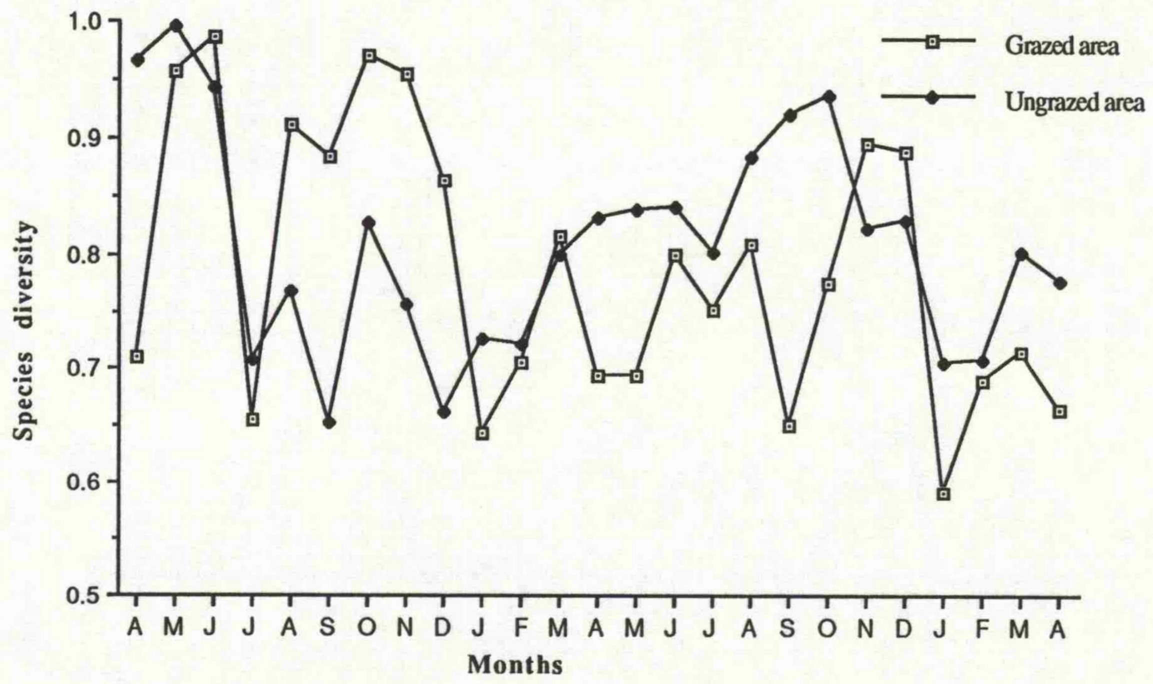
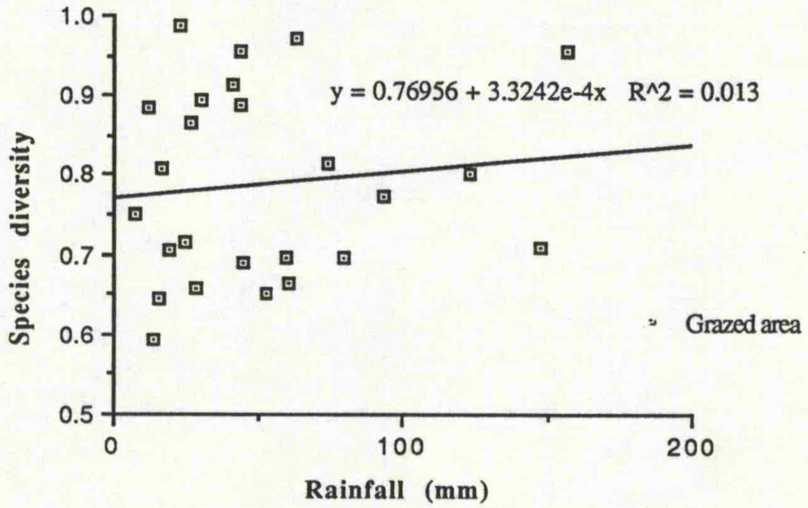
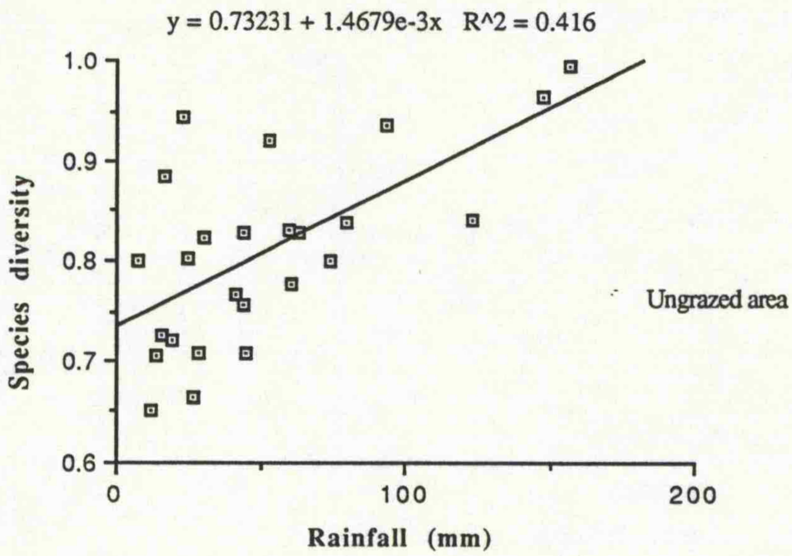


Figure 4.9: Regression of species diversity on rainfall





4.8 DISCUSSION

From the results obtained in this study, livestock grazing did not lead to a significant difference in percentage vegetation cover and mean species diversity between the grazed and ungrazed areas. Although some plant species were only found in either the grazed or ungrazed areas, grazing did not lead to a significant difference in plant species composition and abundance between the two areas.

The observed lack of difference in the percentage vegetation cover in the grazed and ungrazed areas through out the study can be explained in terms of the grazing pattern of Masai livestock in Narasha area and neighbouring Kongoni Ranch. In Kongoni Ranch, the area bordering the Park at Narasha had two water dams which were used by the Masai livestock as watering points together with one dam in the Park supplemented by water from a storage tank at Olkaria hill. The livestock therefore grazed and drank water both in the Park and the Kongoni Ranch, but more grazing took place in the ranch than in the Park (pers. obs.). There was therefore less livestock grazing pressure in the Park than in the ranch in 1990, which explains why during this time there was no difference between the percentage cover in the grazed and ungrazed areas.

From March - June 1991, a rise in percentage cover was realised both in the grazed and ungrazed areas, and their percentage cover between January - July 1991 was almost similar. Since there was no significant linear regression between percentage cover and rainfall both in the grazed and ungrazed areas, this rise in percentage cover can be attributed to a decrease in grazing pressure by livestock. During this period (actually starting from January-late June 1991), visual observations showed that there was far less livestock in the Park than in 1990, with most of them concentrated in Kongoni Ranch and therefore grazing pressure in the Park during this time was low.

Around mid-June 1991, Kongoni Ranch administration ploughed about 1,500 acres neighbouring the Park at Narasha (for wheat growing), which used to be the main grazing area for the Masai livestock. At almost the same time, they drained all the water in the two dams in the ranch that were used as drinking points by the livestock. This immediately forced all the Masai livestock to move to the Park at Narasha where they could graze and drink water. Therefore, by mid-July and early August 1991, the Masai livestock were all grazing in the Park in large numbers than before, and visual observations showed that during this time grazing took place both in the grazed and ungrazed areas leading to a reduction in vegetation cover in both areas. This explains why from July 1991-January 1992 there was a sudden decrease in percentage vegetation cover both in the grazed and ungrazed area.

Between late 1991 and early 1992, the Park administration became more concerned with the issue of livestock grazing in the Park especially at Narasha. Ranger patrols at Narasha were intensified to ensure that no grazing by livestock took place. Grazing pressure therefore gradually decreased and the Park vegetation cover in the grazed and ungrazed areas of Narasha slowly started to increase.

Apart from the Narasha area where the Masai livestock grazed in the Park, the area near Central Tower bordering the Park and Akira Ranch, livestock grazing did occur, and there were signs of overgrazing, but the area was too small in size (about $1km^2$) compared with the Narasha area. I therefore considered it not worthwhile to carry out my study there. My study was therefore concentrated at Narasha where a larger area was grazed by livestock compared with that near Central Tower.

The Njorowa Gorge grassland where the water troughs were located was dominated by *Digitaria milanjiana*, *Cynodon dactylon* and *Felicia muricata*. The common plant species in the grassland and around the water troughs were *Harpachne schimperi*, *Eragrostis tenuifolia*, *Justacia* sp., *Themeda triandra* and *Indigofera ambalensis*. Plant species composition of the water troughs, the gorge and Narasha grasslands were quite similar, and the dominant and common species were the same, but *Cynodon dactylon* was absent in the Narasha grassland. Therefore, although the vegetation study at Narasha was looking at the effect of livestock on plant species abundance while that of the water troughs was looking at the effect of wildlife trampling on the abundance of plant species, the plant species studied in both areas were quite similar.

Results of this study have shown that livestock grazing did not significantly alter the vegetation of the grazed area in relation to the ungrazed. It is therefore not worthwhile for the Park administration to prevent any livestock grazing at Narasha, and what could be done is to make some arrangements where a certain number of the Masai livestock can be allowed to graze in this section of the Park, so long as this does not lead to overgrazing. However, due to the implications that the presence of livestock might have especially in terms of disease transmission from the livestock to the wildlife and vice versa, the Park administration might feel that its not appropriate to have livestock grazing at Narasha. Allowing livestock to graze in this area might also be seen to be against the Park objectives of protecting both the wildlife and the flora. Further, plans were underway to open up Narasha area to tourists (Ruhiu pers. comm.), and it might not be desirable for them to see livestock grazing together with wildlife in a Park that has been designated for protection and conservation of wildlife.

Studies looking at the effect of livestock grazing on the vegetation have been done elsewhere in Africa. For instance, Georgiadis (1987) in a study of how grasslands respond to extreme use by pastoralist livestock in Kenya found that overgrazing led to a 10% decrease in vegetation cover, 4% decrease in plant species diversity, 6% decrease in number of palatable plant species and an 11% increase in unpalatable ones. He also found out that areas that were not overstocked with livestock were characterised by a good vegetation cover, high species diversity and an abundance of palatable plant species. In another study in Eastern Botswana, Tolsma *et al.* (1987) showed that overgrazing by livestock led to a 3% decrease in plant species composition and a 10% reduction in plant species diversity. Walter *et al.* (1988) working in the U.S.A reported that areas overgrazed by livestock were dominated by grazing resistant plant species and forage production was about 35% less on overgrazed than undergrazed areas.

CHAPTER 5

OLKARIA GEOTHERMAL PROSPECTING

5.1 INTRODUCTION

Olkaria Geothermal Station situated in Hell's Gate National Park (figure 5.1) is the only of its kind in Africa which utilises underground steam to generate electricity. One power station commisioned in 1981 is in operation and generates 15% of Kenya's electricity. Plans are at an advanced stage to construct a second station at Olkaria North East which is expected to be commisioned by 1994. Future expansion is expected as Kenya's electricity demands both for domestic and industrial use increase. The present station has both ecological and enviromental implications both within and ouside the Park. At present, discharge of waste water and gases like carbon dioxide, nitrogen and hydrogen sulphide are considered to be relatively safe (Ng'ang'a pers. comm.).

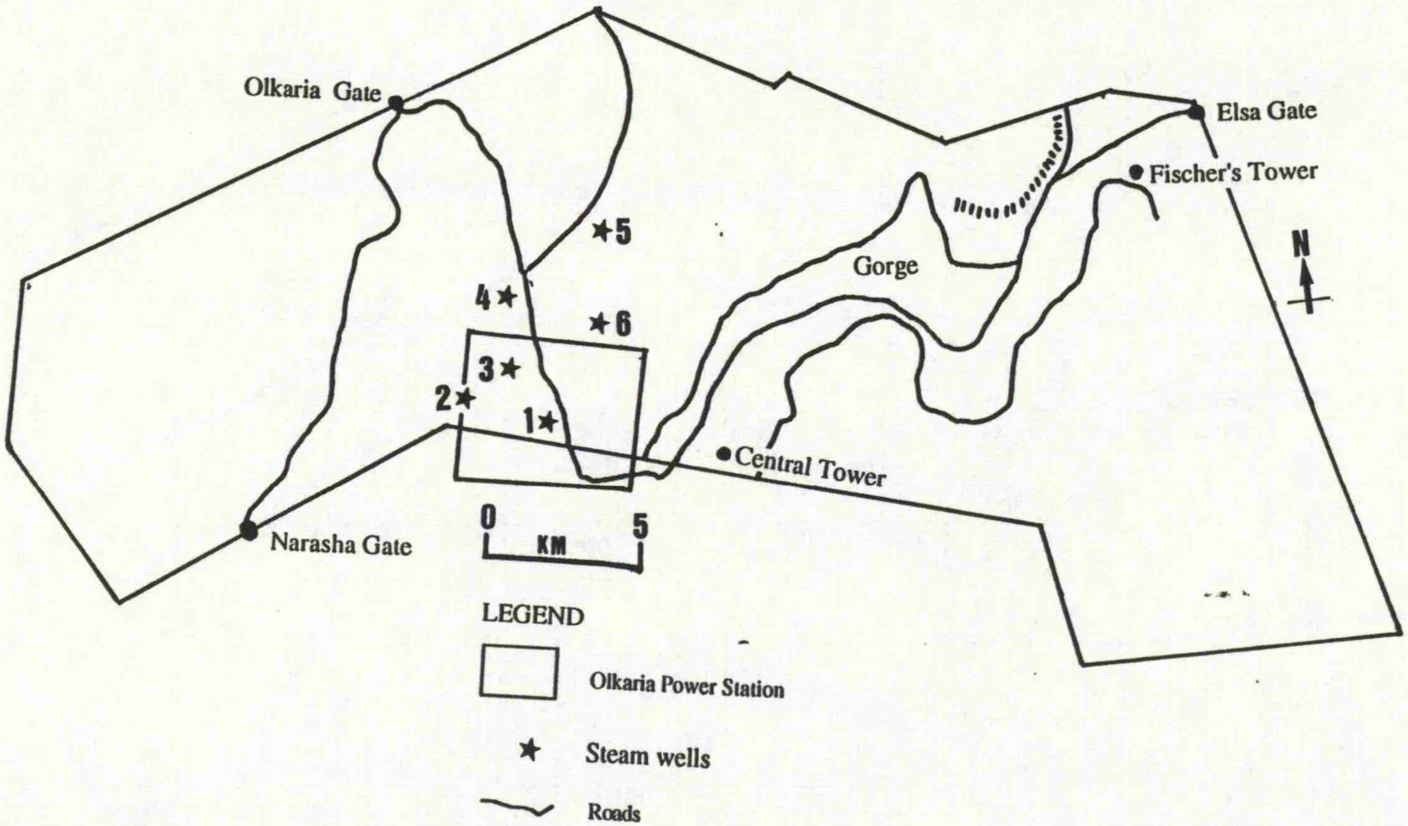
Wildlife conservation and preservation of the flora especially *Tarchonanthus - Acacia* shrubland is one of the main objectives of the Park. Geothermal prospecting is therefore in conflict with conservation objectives of the Park, and calls for the development of a strategy that will allow the two equally important activities to the country's economy operate without each adversely affecting the other. Currently, the project affects the viability of the Park by causing vegetation and landscape changes, wildlife displacement andwaste water disposal.

5.2 The study: Effects of geothermal exploration on the Park vegetation

Even before the Hell's Gate area was designated as a National Park in 1984, geothermal exploration was going on, having started in 1956. During prospecting, selected sites where drilling is to take place are first cleared off their vegetation and levelled using bulldozers. Such cleared sites can on average measure 80m by 60m. Before drilling, the cleared site is covered with a layer of murram in order to stabilise the ground so that it can support the weight and vibrations of the drilling machines. After drilling the murram is not removed and the site is left as bare ground with no vegetation cover. This clearing of the vegetation causes both landscape and floral changes.

A study was carried out to estabilish how geothermal prospecting affects the flora communities of the Park in terms of species composition, structure, species diversity and vegetation cover. It was not practical to do a detailed vegetation sampling on all the cleared sites due to their number. Before sampling started, a general vegetation survey using visual observations was carried out in all the cleared sites except those which were recently cleared and therefore did not have any vegetation cover. Observations showed that the plant species composition of the sites was almost similar. I therefore made more detailed vegetation sampling on six randomly selected sites, three of which were old and had regained their vegetation cover (Well 1, 2 and 3) and three which had not fully regained their vegetation

Figure 5.1: Showing Olkaria Power Station and the steam wells that were studied



cover (Well 4, 5 and 6) (figure 5.1).

5.3 METHOD/RESULTS

For each well, ten quadrats (each $4m^2$ and randomly chosen from a table of random numbers) were placed on the ground. In each quadrat, all the rooted plant species were counted except *Pennisetum cladestinum, Digitaria milanjiana* and *Cynodon dactylon,* which due to their growth nature could not have their individual shoots counted. Their presence in each quadrat was noted.

To determine the percentage cover of each species, a point frequency frame was used and ten pins were lowered each at a time through guide holes and the number of pins touching a given species were counted and recorded. From the data obtained, frequency, density, percentage cover and species diversity for each well site were calculated as shown in Chapter 4. Initially, sampling was planned to be done on a monthly base throughout the study period. However, after four months sampling (April to July 1990) and after observations of the data, it was found out that for all the study sites, there was no change in plant species composition, species diversity and percentage cover, after which further sampling was stopped. Some of the results obtained for well 2 and 3 for the months of April and May 1990 are shown in table 5.1 and 5.2.

5.4 DEDUCTIONS FROM THE RESULTS

The vegetation of the wells was dominated by *Cynodon dactylon* and *Chloris gayana,* which contributed the highest percentage of the vegetation cover. Species like *Harpachne schimperi* and *Eragrostis tenuifolia* were common in all the wells with high frequency and density values. Other species like *Felicia muricata, Conyza stricta, Oxygonum sinuatum* and *Satueria biflora* were less common.

From the results obtained and observations made throughout the study period, it was evident that geothermal prospecting was altering the species composition and vegetation structure of the Park plant communities particularly in the area set for its exploration. Sites whose initial vegetation was *Tarchonanthus camphoratus / Acacia drepanolobium* shrubland were being converted into open areas dominated by herbaceous species especially *C. dactylon* and *C. gayana.* Although no sampling was done to show how the woody species were being affected by site clearing, visual observations made on cleared site showed that *T. camphoratus* and *A. drepanolobium,* the main woody species of the Park were always absent on cleared sites even those which had regained their vegetation cover. The result was creation of scattered open areas dominated by herbaceous species with no *T. camphoratus* and *A. drepanolobium.*

Table 5.1: Frequency, density and percentage cover of plant species of Well 2 - April and May 1990

April '90

Species	Frequency	Density/m2	Percentage cover
Cynodon dactylon	0.67	-	9.81
Chloris gayana	0.5	0.17	5
Digitaria milanjiana	0.17	-	-
Sida schimperiana	0.17	0.08	-
Felicia muricata	0.33	0.17	-

Percentage cover = 14.81
Species diversity = 0.458

May '90

Species	Frequency	Density/m2	Percentage cover
Chloris gayana	0.33	0.21	6.11
Cynodon dactylon	0.5	-	7
Harpachne schimperi	0.33	0.21	-
Satureia biflora	0.17	0.04	-
Abutilon mauritianum	0.17	0.04	-
Conyza stricta	0.17	0.04	-

Percentage cover = 13.11
Species diversity = 0.576

Table 5.2: Frequency, density and percentage cover of plants of Well 3 - April and May 1990

April '90

Species	Frequency	Density/m2	Percentage cover
Cynodon dactylon	0.67	-	8.81
Chloris gayana	0.5	0.17	5.66
Leucas pratensis	0.17	0.08	-
Harpachne schimperi	0.33	0.17	-
Felicia muricata	0.17	0.07	-

Percentage cover = 14.47
Species diversity = 0.549

May '90

Species	Frequency	Density/m2	Percentage cover
Eragrostis tenuifolia	0.33	0.25	-
Cynodon dactylon	0.5	-	6.12
Chloris gayana	0.5	0.21	4.99
Harpachne schimperi	0.17	0.17	-
Conyza stricta	0.17	0.08	-

Percentage cover = 11.11
Species diversity = 0.573

It might be argued that after a number of years the cleared sites eventually get recolonised by plants and their vegetation cover is finally regained and therefore geothermal prospecting does not have any changes on the Park vegetation. However, once the sites have been cleared they are left bare and eventually get recolonised after 4 to 6 yrs (Ruhiu and Karingithi pers. comm.), but only herbaceous species like *C. dactylon*, *C. gayana, Harpachne schimperi* and *Eragrostis tenuifolia* among other species do colonise such cleared sites. *T. camphoratus* and *A. drepanolobium* are not able to re-establish themselves on such sites and this alters the vegetation structure resulting in open areas dominated by herbaceous species only.

Considering the duration taken by the cleared sites to regain their vegetation cover, the following suggestions might help to increase the rate of vegetation recolonization on such sites:

(a) The size of the cleared sites should be reduced in order to ensure that less of the original shrubland is not cleared.

(b) To accelerate the rate of vegetation recolonization on the cleared sites, all the murram used to stabilise the ground during drilling should be removed (since it is a hard substratum not easily recolonised by the plants) leaving bare ground which is easier to be recolonised by the plants.

(d) Species like *Hyparrhenia* sp. and *Cymbopogon caesius* can be planted on the cleared sites once the murram has been removed. This will ensure that vegatation recolonization is faster than waiting for it to regrow naturally.

In conclusion it can be said that in view of the implications that geothermal prospecting has on the vegetation, a more detailed study should be carried out to look at the effects of past, present and future geothermal prospecting on the Park vegetation.

CHAPTER 6

PARK MANAGEMENT

6.1 PARK MANAGEMENT ISSUES

The main purpose of creating Parks and Game Reserves is to protect their fauna, flora and landscape, and at the same time allow man to benefit by using them as recreational areas. However, due to the increasing human population and the associated demand for more land to settle and cultivate, the future of these conservation areas is not certain.

Wildlife conservation in the Hell's Gate National Park ecosystem is of great concern due to the various human activities that are taking place. Changes in human activities or ownership in areas like Kedong, Kongoni and Akira Ranches which act as important wildlife concentration areas will directly determine the future of the wildlife in the ecosystem. Wheat growing has already started in both Akira and Kongoni Ranches. In Kongoni Ranch, wheat growing started in April 1991 and over 3,000 acres of land had been ploughed for wheat growing by 1992 (plans were underway to plough more land). The ploughed land used to be an important habitat for most of the ranch wildlife mainly zebra, kongoni, eland, impala, warthog, dikdik, Masai giraffe, Thomson's gazelle and Grant's gazelle. The result was that these animals were displaced from their habitat and were left to concentrate in a smaller area which they shared with livestock. This kind of wildlife displacement also happened in Akira Ranch where nearly 10,000 acres of land formerly important to the wildlife was put under wheat growing in 1991. For Kedong Ranch, plans were underway to sell 6,000 acres bordering the railway line and sub-divide it among share holders. This area was important for most of the wildlife in the ranch which will therefore be displaced once this land is sold. The increasing population of livestock especially cattle in the ecosystem will also have a direct impact on the future of wildlife. Livestock and wildlife grazed in the same areas and as such there was a likelihood that they competed for the same food resources.

The proposed Park fencing (in the 1985 management plan) will also equally determine the future of wildlife in the Park. Since the Park wildlife moves between it and the adjoining areas, especially Kedong Ranch, it means that if fencing is done this free movement of wildlife will be cut. The result is that the Park herbivore population might increase in future to an extent of surpassing the "carrying capacity", considering that about 12.5 km^2 of the total Park area was the most utilised by the wildlife. Any plans to fence Akira, Kedong and Kongoni Ranches should also be discouraged in order to maintain the potential free movement of the wildlife in the ecosystem. However, in order for these private ranches to support wildlife conservation on their land, they should benefit directly from it. Kongoni and Kedong Ranches have realised the tourist potential of the wildlife on their land and they have been operating as game ranches since 1990 and 1989 respectively. Tourists visiting the ranches are provided with food and accommodation and are taken around to view game and by so doing the ranches generate revenue and create job opportunities. Kongoni Ranch has been allowed by Kenya Wildlife Service to utilise its wildlife for consumption purposes, but this has not been granted to Kedong and Akira Ranches (Ruhiu pers. comm.). With these benefits from wildlife, the ranches will feel obliged to protect the wildlife on their land and by so doing assist in wildlife conservation in the entire ecosystem.

The existence and expansion of the Olkaria geothermal power station will compromise the conservation objectives of the Park. The existing and proposed power station expansion will have some effects on the well being of the Park, both from an ecological point of view and tourism development. It has several conservation implications on the Park which include noise pollution, existence of an exploration village, soil erosion, gaseous emissions especially hydrogen sulphide, waste water disposal, wildlife displacement, landscape and flora destabilisation. The smell of hydrogen sulphide in the vicinity of the power station is not pleasing, while the noise from both the station and test wells is loud for most tourists visiting this part of the Park. An enviromental impact study has already been done to assess the effects of geothermal expansion and exploration on air pollution, waste water disposal, soil erosion, tourism potential of the area, landscape and flora distabilisation. The results of the impact study were not known by the time my project came to an end.

6.2 OTHER ASPECTS OF THE PARK

Hell's Gate National Park currently faces two main problems which are human related. One of these is the Olkaria power station and the other is agricultural expansion (both crop growing and livestock keeping) in neighbouring areas like Oserian, Kedong, Akira and Kongoni Ranches. These two problems have both direct and indirect ecological and management implications which threaten the viability of the Park as a conservation area. The implications of the two factors as far as the Park existence is concerned have already been discussed in Chapter 1 and section 6.1 of this Chapter.

Although the Park was initially gazetted as a National Park due to its geomorphological uniqueness and vegetation (W.C.M.D, 1985), its potential as a wildlife conservation area should not be overlooked. This study has shown that the Hell's Gate ecosystem is a region within the Rift Valley where a high concentration of wildlife is still in existence. However, in view of the human activities that are taking place within the ecosystem, the future of this wildlife is at stake. Therefore, the existence of Hell's Gate as a Park appears to be the only hope of ensuring that the various wildlife species in the ecosystem are conserved as their population sizes continue to be reduced by agricultural expansion that is currently taking place. The population estimates obtained in this study for the various wildlife species indicated the current status of the wildlife in the Park and its neighbouring areas. They are a reference point for studies that will be done in future to assess the wildlife population status of the Park and adjacent areas in the face of the increasing human activities.

Considering the potential threat that faces wildlife within the Hell's Gate ecosystem, the existence of the Park appears to be the only hope of conserving the wildlife in an ecosystem that is under threat from increasing human activities. Although the Park is not unique in any way compared with other Parks in Kenya, and the fact that it does not have any threatened or rare wildlife species, its ecological potential as an area of conservation of both flora and fauna in an ecosystem that is facing human encroachment should not be under-estimated. Therefore any human activities either within or outside the Park that threaten its ecological integrity should be dealt with appropriately so that the Park viability is not jeopardized. Furthermore, although it is possible to assess the economic potential of the Park in terms of the revenue that it can or generates for the government, its ecological value and importance as a conservation area cannot be assessed in monetary terms.

Geothermal prospecting alters the vegetation structure of the Park, and therefore poses a threat to the Park viability. Its integration in the Park management should be clearly spelt out since this is lacking in the management plan. Its effects on the Park ecology and possible solutions have already been discussed in Chapter 1, 5 and section 6.1 of this Chapter.

6.3 RECOMMENDATIONS

Although livestock grazing at Narasha was found not to have any significant effect on the vegetation, the Park administration might find it necessary to prevent livestock grazing in this section. To do this, the following could be done:

(a) A gate could be constructed at Narasha so that the Park rangers will be in charge of the area, and see to it that no livestock grazing occurs.

(b) Kenya Wildlife Service (K.W.S) in conjuction with Olkaria Geothermal administration should explore the possibility of supplying pumped water out of the Park for use by the livestock. By so doing, they will discourage the Masai from bring their livestock to drink water and graze in the Park.

In view of the ecological implications that geothermal prospecting might have on the Park ecology, it is important to understand how it will affect the flora and fauna of the Park. To solve some of the problems brought about by geothermal prospecting, the following might be useful:

(a) To minimise noise pollution, silencers should be installed both in the existing station and any others that might be constructed in future.

(b) To minimise the amount of hydrogen sulphide discharged into the air, the used steam should be treated before it is released into the atmosphere.

(c) All new and old roads in the geothermal production area should be tarmacked to minimise erosion from runoff. The soil heaps created as a result of site clearing should be stabilised. This can be done by planting grass especially *Hyparrhenia* sp.

and *Cymbopogon caesius*. These two species have fibrous roots which by offering a large surface area hold the soil particles together. Currently the Kenya Power and Lighting Company workers plant *Cynodon dactylon* which is not appropriate since it prefers fertile soils (while those of the test wells are poor) and its root system is poor compared with the already mentioned species.

(d) All the waste water generated during well testing, drilling and the one used to turn the turbines should be well disposed. Preferably it should be re-injected.

(e) The X-2 village at Olkaria Gate reduces the aesthetic value of this section of the Park. Its expansion should be discouraged and possibly it should be re-located once a new site is available outside the Park. It poses the danger of causing uncontrolled domestic waste disposal which might eventually become unmanageable.

(f) To increase the rate of plant re-colonisation on cleared sites, all the murram at finished drilling sites should be removed in order to expose the soil which is relatively easier to be re-colonised by plants.

(g) Waste disposal at drilling sites should be stopped in order to retain their aesthetic value and that of the Park.

(h) The existing steam pipes have an aluminium appearance which lowers the aesthetic value of the station. These should possibly be repainted with a colour that will match with the surrounding ground and vegetation. The same should be done for the proposed new station.

6.4 WIDER ECOLOGICAL ASPECTS

Hell's Gate National Park is in ecological zone four of Pratt *et al.* (1966) where *Tarchonanthus* - *Acacia* shrubland dominates. *Tarchonanthus camphoratus* - *Acacia drepanolobium* shrubland which covers most of the Park and its environs is gradually disappearing in most parts of the Rift Valley due to expansion in agriculture and associated settlement. Considering the vegetation of the Hell's Gate ecosystem, the Park vegetation is not unique in any way. However, with the current agricultural expansion in the ecosystem, it is very likely that this vegetation type in the region will only be left in the Park.

The vegetation type of Hell's Gate is not found in other Parks of Kenya including Lake Nakuru National Park which is on the floor of the Rift Valley. This difference in vegetation type between the two Parks yet they are close to each other can be attributed to differences in soils. The grass species composition of the Park grassland does not show any similarities with that of other Parks of Kenya (Kiringe, 1990; this study). It is dominated by *Themeda triandra, Cynodon dactylon, Digitaria milanjiana* and *Digitaria scalarum.*

Although most of the herbivores species like kongoni, zebra, buffalo, Thomson's gazelle, warthog and Grant's gazelle in Hell's Gate National Park do occur in other Parks of Kenya like Nairobi, Tsavo and Amboseli National Parks, their densities are different, and so is the overall herbivore assemblage of the Park. Within the Rift Valley floor and compared with other Parks in Kenya, the kind of herbivore assemblage in Hell's Gate is not found elsewhere. The Hell's Gate ungulate assemblage is mainly dominated by kongoni *Alcelaphus buselaphus* and zebra *Equus burchelli* and is therefore different from that of Lake Nakuru National Park which is dominated by defassa waterbuck *Kobus defassa* and to an extent warthog *Phacochoerus aethiopicus*. Although the past history of the Hell's Gate region may have altered to a certain extent the herbivore species assemblage in the region probably by hunting, vegetation type may be the main factor that make Hell's National Park ungulate assemblage different from that of Lake Nakuru National Park or other Parks in Kenya. It can then be concluded that the Hell's Gate herbivore species assemblage is to an extent unique compared with other Parks and is therefore worth conserving.

From my study, it is not conclusive whether the Hell's Gate herbivore assemblage is complete in its self and therefore a proposal cannot be put across for the possibility of introducing other herbivore species. Before such a proposal is arrived at, a more detailed study than mine is required to look at the feeding habits and habitat requirements of the existing ungulate species. In the 1985 management plan, it is suggested that the Park provides an ideal habitat for the introduction of endangered species like the rhino *Diceros bicornis* and the Rothschild giraffe *Giraffa camelopardalis* rothchildi. From my study of 1988/89 (Kiringe, 1990) and the present one, my conclusion is that these species should not be introduced due to the fact that about 82% of the Park is mainly dominated by *Tarchonanthus camphoratus* - *Acacia drepanolobium* shrubland which is not an important food source for these two species.

6.5 CONCLUSION

Fifteen large herbivore species (see appendix 1) dominate the Hell's Gate grassland and adjacent areas. Kongoni, zebra and Thomson's gazelle were the most abundant species in the ecosystem. This study has provided data on the population size and density estimates of the large herbivores in the Hell's Gate National Park ecosystem.

This study has shown the grass species that were commonly fed on by the Park herbivores. Out of the seven grass species that were found to be fed on by the ungulates (see Chapter 3), the most utilised as a source of forage were *Cynodon dactylon, Themeda triandra, Digitaria milanjiana, D.scalarum* and *Chloris gayana.* The net primary production of these species was found to be rainfall dependent, being high and low during the wet and dry seasons respectively. This subjected the wildlife to times when there was a high and low amount of grass forage, such that during the wet season there was abundant green grass forage available for consumption than during the dry season when most of the grass material dried up as a result of reduced rainfall.

From my observations, no signs were evident to indicate that the Park grassland was overgrazed. However, with the proposed Park fencing, there is a possibility that the grassland will be forced to support more herbivore biomass than is currently supporting since the free movement of the wildlife between it and the adjacent areas will be curtailed. It can be argued that the current free movement of the wildlife between the Park and neighbouring areas ensures that the grassland is not overused by the herbivores and therefore the issue of fencing the Park should be reconsidered if the grassland is to effectively continue to support the current herbivore populations.

The results on water troughs' utilisation by wildlife in the Park showed that their vegetation cover was not altered significantly due to wildlife trampling. This was due to the fact that they never concentrated in large numbers around the troughs during the dry season. It can therefore be concluded that the number of water troughs were adequate in meeting the water requirements of the wildlife. However, with the proposed Park fencing, there is a possibility that in future the vegetation cover of these troughs might be reduced as the population of herbivores in the Park build up, leading to a consequent overuse of the troughs.

Livestock grazing at Narasha area was found not to alter the Park vegetation significantly. Therefore, the Park administration could make arrangements where by some of the Masai livestock are allowed to graze in the Park especially during the dry season when water and forage availability in neighbouring Masailand is scarce. However, livestock grazing in the Park might be considered to be undesirable due to the ecological implications that they might have, especially transmission of diseases and ecto-parasites between them and the wildlife. Further more, plans are underway to open up the Narasha area to tourists who visit the Park and therefore the Park administration might feel that it is not proper for the tourists to see livestock grazing in a Park which is meant for wildlife conservation.

6.6 FURTHER STUDIES IN THE PARK

This study has given an understanding of some ecological aspects of Hell's Gate as a conservation area. However, the fact that the study was only done for a short period and only looked at certain aspects of the Park means that only a certain fraction of the total Park ecology was studied. Furthermore, the Park ecology is bound to change from time to time and therefore my study did not adequately cover the whole ecological aspects of the Park. For instance, although I demonstrated the grassland potential in supporting the Park herbivores (being their main grazing area), the role played by the shrubland as an area which supplies forage to the wildlife especially during the dry season was not studied. The habitat

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preference exhibited by the wildlife may have also been inadequately studied. It is worth studying it in more detail since it will lead to an understanding of the role played by each habitat in meeting the habitat requirements of the wildlife which was not clearly shown by my study. This will also lead to a better understanding of the seasonal utilization of the different habitats by the wildlife. Similarly, the study on food habits of the ungulates was too generalised, and did not show how exactly the different herbivore species were capable of co-existing through resource partitioning. A more detailed study is therefore required which will try and show how exactly the various wildlife species are able to co-exist without each out-competing the other.

The pattern of wildlife movement within the ecosystem was poorly understood from my study. It is therefore important that this be understood in more detail, especially finding out which are the main factors that induce herbivore movement within the entire ecosystem. For instance, is the movement related to the rainfall pattern and therefore the spatial and temporal variation in food resources or are other factors involved. Any study should also look at what will be the future ecological implications of wildlife conservation in the ecosystem if this movement is cut due to the expanding human activities.

Effects of livestock grazing on the Park vegetation should also be studied in more detail. Although this study showed that the livestock was not having any effect on the vegetation, it is likely that the time taken to carry out this aspect of my study was inadequate, and therefore more time is required so that the ecological effects of livestock grazing in the Park are better understood. From my own judgement, the data obtained on the trampling effect of the wildlife on the artificial water troughs clearly showed that currently there was no overuse. However, the trampling effect of the wildlife on the water trough's vegetation need to be regularly studied in order to detect any vegetation changes in the face of any increase in the wildlife populations.

The results obtained in this study have led to an understanding of the general ecology of the Park. Data on herbivore numbers and density indicated the abundance and present population status of the different ungulate species of the Park upon which their future changes can be assessed. Results of grassland net primary production and estimated grazing have shown the role played by the grassland in providing forage for most of the wildlife since it was their main grazing area. The three artificial water troughs that supply water to the wildlife were considered to be currently adequate in meeting the water demands of the wildlife. In future a need might arise to construct more troughs depending on the water requirements of the wildlife. This decision will be guided by the results obtained in this study. Livestock grazing in the Park is not a threat in causing vegetation changes, but for management purposes and the ecological implications that they might have as far as the Park is concerned, it might be necessary to prevent them from grazing and watering in the Park.

In view of the short comings of this study and considering that not many studies have been done in the Park, there is a need to carry out further studies in order to understand more clearly the Park ecology and dynamics. Future studies should be done in the following areas.

(a) Wildlife populations. This should focus on studying their sizes, structure, distribution, biomass, movement, reproduction and habitat preference. Their future trend should be predicted in the face of increasing human activities in adjacent areas and proposed Park fencing.

(b) Feeding habits of the herbivores. This should focus in more detail on how the different herbivore species are capable of co-existing through partitioning of available food resources. The role played by the shrubland in supplying forage for the herbivores should also be studied.

(c) A more detailed study should focus on the enviromental impact and ecological implications of present and future geothermal prospecting as far as the Park fauna and flora is concerned. This should also look at how geothermal prospecting lowers the aesthetic value of the Park as an area set for tourists to visit. Possible solutions should be proposed and their applicability evaluated.

APPENDIX 1

Large carnivores and herbivores of Hell's Gate and adjoining areas

Large Carnivores

African hunting dog	*Lycaon pictus*
African wild cat	*Felis libyca*
Bat eared fox	*Otooyon megalotis*
Cheetah	*Acinonyx jubatus*
Golden jackal	*Canis aureus*
Honey badger	*Mellivora capensis*
Leopard	*Panthera pardus*
Lion	*Panthera leo*
Serval cat	*Felis serval*
Silver backed jackal	*Canis mesomelas*
Spotted hyena	*Crocuta crocuta*
Caracal	*Felis caracal*

Large Herbivores

Bohor reedbuck	*Redunca redunca*
Buffalo	*Syncerus caffer*
Dikdik	*Rhynchotragus kirkii*
Eland	*Taurotragus oryx*
Masai giraffe	*Giraffa camelopardalis*
Reticulated giraffe	*Giraffa reticulata*
Grant's gazelle	*Gazella granti*
Thomson's gazelle	*Gazella thomsoni*
Impala	*Aepyceros melampus*
Klipsringer	*Oreotragus oreotragus*
Chanler's moutain reedbuck	*Redunca fulvorufula*
Kongoni	*Alcelaphalus buselaphus*
Warthog	*Phacochoerus aethiopicus*
Zebra	*Equus burchelli*
Defassa waterbuck	*Kobus defassa*

Other species

Aardvark	*Orycteropus afer*
Olive baboon	*Papio anubis*
Rock hyrax	*Heterohyrax brucei*
Hare	*Lepus capensis*

APPENDIX 2

Birds of Hell's Gate National Park

Ostrich	*Struthio camelus*
White Pelican	*Pelicanus onocrotalus*
Secretary Bird	*Saggitarius serpentarius*
Rupell's Vulture	*Gyps ruppellii*
White-backed Vulture	*Gyps bengalensis*
Nubian Vulture	*Torgos tracheliotus*
Egyptian Vulture	*Neophron percnopterus*
Harrier Hawk	*Polybariodes radiatus*
Batleur	*Terathopius ecaudatus*
Auger Buzzard	*Buteo rufofuscus*
Long-creasted Eagle	*Lophaetus occipitalis*
African Hawk eagle	*Hieraetus spilogaster*
Tawny Eagle	*Aquila rapax*
Verreaux's Eagle	*Aquila verrauxii*
Whalberg's Eagle	*Aquila wahlbergi*
African Fish Eagle	*Haliaetus vocifer*
Lanner Falcon	*Falco biarmicus*
Peregrine	*Falco peregrinus*
African Hobby	*Falco cuvieri*
Fox Kestrel	*Falco alopex*
Spotted Eagle Owl	*Bubo africanus*
Cocqui Francolin	*Francolinus coqui*
Hildebrandt's Francolin	*Francolinus hildebranti*
Scaly Francolin	*Francolinus squamatus*
Hemelted Guinea Fowl	*Numida melaegris*
Kori Bustard	*Ardeotis kori*
Crowned Plover	*Vanellus coronatus*
Common Sandpiper	*Tringa hypoleucos*
Temminck's Courser	*Cursorius temminckii*
Speckled Pigeon	*Columba guinea*
Red-eyed Dove	*Streptopelia semitorquata*
Ring-necked Dove	*Streptopelia capicola*
Laughing Dove	*Streptopelia senegalensis*
Red-chested Cuckoo	*Cuculus solitarius*
Didric Cuckoo	*Chrysococcyx caprius*
Klaas's Cuckoo	*Chrysococcyx klaas*
White-browed Coucal	*Centropus superciliosus*
Night jar	*Caprimulgus* sp.
Mottled Swift	*Apus aequatorialis*
Nyanza Swift	*Apus niansae*
Little Swift	*Apus affinis*
Horus Swift	*Apus horus*
Speckled Mousebird	*Colius striatus*
White-fronted Bee Eater	*Merops bullockoides*
African Hoopoe	*Upupa epops*
Abyssinian Scimitarbill	*Phoeniculus minor*
Gold-tailed Woodpecker	*Campethera cailliautii*
Bearded Woodpecker	*Thripias namaquus*
Plain-backed pipit	*Anthus leucophrys*
Rufus-naped Lark	*Mirafra africana*
Redwing Bush Lark	*Mirafra hypermetra*
African Rock Martin	*Hirundo fuligula*
European Swallow	*Hirundo rustica*
Red-rumped Swallow	*Hirundo daurica*

Grey-rumped Swallow	*Hirundo griseopyga*
Grey Wagtail	*Motacilla clara*
African Pied Wagtail	*Moticilla aguimp*
Richard's Pipit	*Anthus novaeseelandiae*
Yellow-vented Bulbul	*Pycnonotus barbatus*
Brown-headed Tchagra	*Tchagra australis*
Black-backed Puffback	*Dryscopus cubla*
Tropical Boubou	*Laniarius ferruineus*
Fiscal Shrike	*Lanius collaris*
Grey-backed Fiscal Shrike	*Lanius excubitorius*
Stone Chat	*Saxicola torquata*
Schalow's Wheatear	*Oenanthe lugubris*
Anteater Chat	*Myrmecocichla aethiops*
Robin Chat	*Cossypha caffra*
White-browned Robin Chat	*Cossypha heuglini*
Black-lored Babbler	*Turdoides melanops*
Wood Warbler	*Phylloscopus sibilatrix*
Brown Woodland Warbler	*Phylloscopus umbrovirens*
Willow Warbler	*Phylloscopus trochilus*
Rattling Cisticola	*Cisticola chiniana*
Tawny-franked Prinia	*Prinia sublava*
Black-breasted Apalis	*Apalis flavida*
Red-faced Apalis	*Apalis rufifrons*
Buff-bellied Warbler	*Phyllolais pulchella*
Grey-backed Camaroptera	*Camaroptera brevicaudata*
Crombec	*Sylvietta brachyura*
Dusky Flycatcher	*Alsenax adustus*
White-eyed Slaty Flycatcher	*Dioptornis fischeri*
Grey Flycatcher	*Bradornis microrhynchus*
Chin-spot Flycatcher	*Batis molitor*
Hunter's Sunbird	*Nectarinia hunteri*
Scarlet-chested Sunbird	*Nectarinia senegalensis*
Variable Sunbird	*Nectarinia venusta*
Bronze Sunbird	*Nectarinia kilimensis*
Golden brested Bunting	*Emberiza flaviventris*
Cinnamon-breasted Rock Bunting	*Emberiza tahapisi*
Yellow-rumped Seed Eater	*Serinus atrogularis*
Brimstone Canary	*Serinus sulphuratus*
Crimson-rumped Waxbill	*Estrilda rhodopyga*
Common Waxbill	*Estrilda astrild*
Purple Grenadier	*Uraeginthus ianthinogaster*
Pin-tailed Whydah	*Vidua macroura*
Richenow's Weaver	*Ploceus baglafeht*
Vitteline Masked Weaver	*Ploceus velatus*
Yellow Bishop	*Euplectes capensis*
Rufous Sparrow	*Passer motitensis*
Grey-headed Sparrow	*Passer griseus*
Redwing Starling	*Onychognathus morio*
Blue-eared Glossy Starling	*Lamprotornis chalybaeus*
Superb Starling	*Spreo superbus*
Red-billed Oxpecker	*Buphagus erythrorhynchus*
Blacked-headed Oriole	*Oriolus larvatus*
Drongo	*Dicurus adsimilis*

APPENDIX 3

Herbivore weights (kg) used to calculate biomass

Species	Weight (kg)
Kongoni	136
Zebra	238
Buffalo	500
Eland	363
Giraffe	772
Thomson's gazelle	20
Grant's gazelle	50
Warthog	59
Impala	45
Wildebeest	166

Source: Foster and Coe (1968), Western (1973).

APPENDIX 4: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Untrampled area 1990

	April			May			June			July		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88/0.09	-	42.7	1/0.06	-	60.5	0.88/0.08	-	62.3	1/0.04	-	67
Cynodon dactylon	0.38/0.11	-	3.55	0.5/0.20	-	21.6	0.5/0.20	-	19.5	0.38/0.15	-	7.25
Themeda triandra	0.4/0.20	-	1.48	0.25/0.11	-	1.15	0.38/0.15	-	1	0.75/0.26	-	1.5
Felicia muricata	0.5/0.13	0.38/0.15	0.25	0.75/0.28	3.00/1.00	3.5	0.75/16	1.28/0.06	3.75	0.88/0.08	3.44/1.00	15
Crotalaria tanganyikensis	0.75/0.15	1.09/0.08	-	0.13/0.07	0.09/0.04	-	0.13/0.06	0.03/0.01	-	0.25/0.10	0.19/0.08	0.5
Indigofera spicata	0.14/0.06	0.31/0.13	1	0.14/0.06	0.06/0.02	-	0.13/0.07	0.03/0.01	-	0.38/0.16	0.13/0.06	-
Euphorbia inaequilatera	0.5/0.20	1.44/0.09	-	0.13/0.05	0.25/0.09	-	0.25/0.11	0.19/0.08	-	0.38/0.14	0.5/0.20	-
Solanum incanum	0.5/0.30	0.41/0.21	-	0.25/0.11	0.31/0.15	-	0.25/0.10	0.59/0.08	1.5			
Justacia sp.	0.13/0.04	0.28/0.10	-	0.88/0.12	0.13/0.05	-	0.38/0.16	0.19/0.10	0.5	0.5/0.20	0.28/0.10	0.25
Cyperus rigidifolius	0.38/0.11	0.13/0.06	-	0.13/0.06	0.06/0.02	-	0.13/0.06	0.03/0.01	-	0.38/0.14	0.16/0.09	-
Panicum maximum	0.13/0.06	0.09/0.03	-									
Eragrostis tenuifolia	0.4/0.20	0.19/0.09	0.35	0.75/0.24	1.03/0.07	2.65	0.5/0.20	1.25/0.08	3.75	0.75/0.18	2.28/1.50	2.5
Harpachne schimperi	0.75/0.14	1/0.50	1.82	0.8/0.30	1.5/0.06	0.15	0.25/0.06	0.41/0.20	0.5	0.88/0.09	1.97/0.09	-
Indigofera tanganyikensis	0.3/0.10	0.06/0.03	-	0.75/0.15	0.56/0.16	-	0.62/0.12	0.47/0.10	0.25	0.88/0.09	0.94/0.24	-
Rhamphicarpa montana				0.13/0.07	0.09/0.04	-				0.13/0.05	0.03/0.02	-
Aristida keniensis							0.25/0.09	0.06/0.03	-	0.38/0.15	0.16/0.09	-
Oldenlandia scopulorum	0.13/0.07	0.06/0.04	-							0.13/0.05	0.03/0.01	-
Monchma dabile				0.13/0.07	0.09/0.05	-						
Crotalaria incana							0.13/0.08	0.03/0.02	-			
Chloris gayana										0.25/0.10	0.13/0.06	-
Crotalaria grantii							0.13/0.08	0.03/0.02	-			
Crotalaria spinosa							0.13/0.09	0.09/0.04	-			
Crotalaria sp.							0.25/0.11	1.01/0.05	4.25	0.13/0.04	0.03/0.02	-
Satureia biflora										0.25/0.11	0.09/0.05	-
Sida schimperiana	0.13/0.06	0.03/0.01	-	0.13/0.05	0.03/0.01	-	0.38/0.19	0.09/0.05	-	0.13/0.07	0.03/0.01	0.5

APPENDIX 4: Percentage cover (C), mean +/-S.E of frequency (A)and density (B) - Untrampled area 1990 (continued)

	Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	1/0.04	-	55.6	1/0.03	-	43.3	1/0.04	-	28.3	1/0.04	-	35	1/0.05	-	18
Cynodon dactylon	0.5/0.20	-	27.5	0.5/0.20	-	25.5	0.63/0.12	-	28.3	0.88/0.06	-	32.3	0.75/0.18	-	25
Themeda triandra	0.6/0.20	-	2.15	0.38/0.11	-	2.25	0.25/0.11	-	0.5	0.5/0.20	-	1.75	0.38/0.13	-	-
Felicia muricata	0.75/0.24	3.00/1.00	7.75	0.75/0.16	1.78/1.00	8.75	0.75/0.20	2.69/1.00	10	0.75/0.18	1.78/060	4.75	0.75/0.30		3.9
C . tanganyikensis	0.6/0.20	0.19/0.09	-				0.63/0.15	0.44/0.12	-						
Indigofera spicata	0.38/0.12	0.5/0.20	-	0.25/0.09	0.28/0.09	1.5	0.38/0.11	0.78/0.14	0.05	0.5/0.30	0.41/0.15	-			
E . inaequilatera	0.2/0.10	0.41/0.14	-	0.13/0.06	0.06/0.02	-	0.25/0.10	0.09/0.05	-	0.25/0.09	0.09/0.04	-			
Solanum incanum	0.2/0.10	0.28/0.11	-	0.13/0.07	0.09/0.03	-	0.25/0.12	0.19/0.08	0.25	0.25/0.11	0.38/0.11	-	0.25/0.09	0.22/0.20	-
Justacia sp.	0.4/0.10	0.19/0.06	-	0.38/0.11	0.16/0.04	-	0.13/0.04	0.16/0.07	0.25	0.13/0.06	0.06/0.04	-			
Cyperus rigidifolius				0.13/0.04	0.9/0.09	5.25	0.25/0.10	0.09/0.04	-	0.13/0.08	0.03/0.01	-			
Panicum maximum							0.25/0.13	0.09/0.06	-						
Eragrostis tenuifolia	0.5/0.20	1/0.04	2	0.25/0.11	0.09/0.05	0.75	0.5/0.20	0.28/0.11	-	0.5/0.20	0.47/0.18	-	0.5/0.20	0.63/0.22	-
Harpachne schimperi	0.6/0.30	1/0.06	-	0.68/0.16	0.53/0.21	0.5	0.5/0.30	0.78/0.25	-	0.5/0.30	3.00/1.00	1.75	0.38/0.16	0.63/0.19	-
I . tanganyikensis	0.5/0.15	0.28/0.10	-	0.13/0.05	0.03/0.02	-	0.38/0.16	0.09/0.04	-	0.38/0.14	0.22/0.08	-			
Rhamphicarpa montana										0.38/0.15	0.16/0.07	2.75	0.25/0.10	0.09/0.04	-
Conyza schimperi				0.25/0.07	0.06/0.03	-	0.13/0.04	0.03/0.02	-						
Aristida keniensis	0.15/0.08	0.06/0.03	-												
Monchma dabile				0.13/0.05	0.03/0.01	-									
Chloris gayana				0.38/0.15	0.16/0.08		0.13/0.05	0.03/0.01	-						
Crotalaria grantii										0.13/0.08	0.03/0.02	-			
Crotalaria sp.	0.13/0.06	0.03/0.01	-												
Satureia biflora							0.13/0.06	0.03/0.02	-						
Indigofera ambalensis										0.5/0.30	0.16/0.08	-			
Sida schimperiana				0.38/0.14	0.19/0.11	-	0.13/0.05	0.06/0.03	0.25	0.63/0.25	0.28/0.11	1.25	0.63/0.25	0.25/0.10	2.1

APPENDIX 5: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Untrampled area 1991

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	1/0.04	-	23.5	1/0.05	-	13.8	1/0.06	-	30.8	0.88/0.07	-	15.25
Cynodon dactylon	0.88/0.05	-	22.3	0.75/0.12	-	32	0.5/0.10	-	23	0.5/0.20	-	22.75
Themeda triandra	0.5/0.20	-	-	0.38/0.11	-	-	0.38/0.13	-	0.75	0.38/0.11	-	-
Felicia muricata	0.88/0.06	2.28/0.14	4.75	0.75/0.06	1.22/0.11	1.5	0.38/0.11	0.91/0.13	-	0.75/0.13	1.28	2.25
Commelina africana												
Indigofera spicata	0.5/0.10	0.66/0.20	-	0.5/0.30	1.22/0.14	-	0.13/0.06	0.16/0.08	-	0.13/0.07	0.09/0.04	-
Euphorbia inaequilatera	0.25/0.09	0.16/0.04	-									
Solanum incanum	0.38/0.11	0.31/0.11	-	0.25/0.11	0.22/0.12	-				0.38/0.13	0.31/0.12	-
Justacia sp.	0.38/0.12	0.16/0.08	-	0.13/0.06	0.03/0.02	-						
Cyperus rigidifolius	0.13/0.06	0.06/0.03	-							0.25/0.09	0.22/0.10	-
Hypoestes verticillaris												
Eragrostis tenuifolia	0.38/0.11	1.88/0.13	-	0.13/0.06	0.09/0.04	-				0.25/0.11	0.5/0.30	-
Harpachne schimperi	0.5/0.20	0.44/0.14	-	0.38/0.12	0.13/0.11	-	0.13/0.07	0.03/0.02	-	0.13/0.08	0.03/0.02	-
I . tanganyikensis	0.13/0.07	0.06/0.03	-	0.13/0.05	0.03/0.02	-				0.13/0.06	0.03/0.02	-
Rhamphicarpa montana												
Conyza sp.	0.03/0.01	0.06/0.03	-									
Oxygonum sinuatum												
Oldenlandia scopulorum												
Cyperus sp	0.25/0.11	0.31/0.14	-							0.13/0.08	0.31/0.13	-
Angustifolia montana												
Chloris gayana	0.38/0.13	0.13/0.08	-	0.13/0.08	0.06/0.04	0.25	0.09/0.04	0.13/0.06		0.13/0.07	0.03/0.02	-
Eleusine africana												
Leucas pratensis												
Amaranthus hybridus												
Tribulus terrestris												
Indigofera ambalensis	0.13/0.07	0.09/0.03	-							0.13/0.04	0.03/0.01	-
Cassia grantii	0.13/0.06	0.03/0.02	-							0.13/0.06	0.28/0.11	-
Solanum nigrum												
Aristida kenensis												
Sida schimperiana	0.5/0.20	0.31/0.11	2.25	0.13/0.06	0.06/0.03	-	0.13/0.07	0.13/0.05	-	0.25/0.10	0.09/0.04	1.5
Aerva lanata	0.13/0.07	0.03/0.02	-	0.13/0.09	0.06/0.05	-						

APPENDIX 5: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Untrampled area 1991 (continued)

	May			June				July		
Species	A	B	C	A	B	C	Species	A	B	C
Digitaria milanjiana	1/0.06	-	12	0.75/0.07	-	18.3	*Digitaria milanjiana*	0.88/0.09	-	31.75
Cynodon dactylon	0.63/0.05	-	16.8	0.5/0.20	-	36	*Cynodon dactylon*	0.5/0.20	-	31.75
Themeda triandra	0.25/0.10	-	-	0.38/0.11	-	-	*Themeda triandra*	0.5/0.30	-	-
Felicia muricata	0.63/0.11	1.22/0.18	3	0.63/0.13	2.25/0.25	7.75	*Felicia muricata*	0.75/0.11	1.09/0.16	9.5
Commelina africana							*Commelina africana*			
Indigofera spicata	0.38/0.11	1.31/0.19	-	0.5/0.30	1.19/0.15	-	*Indigofera spicata*	0.25/0.11	0.19/0.08	-
E . inaequilatera	0.5/0.20	0.5/0.20	-	0.88/0.08	4.09/1.02	-	*E . inaequilatera*	0.75/0.13	3.81/1.20	-
Solanum incanum	0.38/0.11	0.44/0.14	-	0.13/0.07	0.25/0.11	-	*Solanum incanum*	0.25/0.09	0.25/0.11	1.5
Justacia sp.	0.13/0.06	0.06/0.04	-	0.5/0.30	0.16/0.08	-	*Justacia* sp.	0.13/0.06	0.03/0.02	-
Cyperus rigidifolius	0.25/0.11	0.09/0.05	-	0.13/0.06	0.16/0.09	-	*Cyperus rigidifolius*	0.13/0.08	0.06/0.03	-
Hypoestes verticillaris				0.13/0.05	0.03/0.02	-	*Hypoestes verticillaris*			
Eragrostis tenuifolia	0.13/0.07	1.25/0.31	0.5	0.38/0.12	0.13/0.07	-	*Eragrostis tenuifolia*	0.38/0.13	1.06/0.08	0.75
H . schimperi	0.38/0.12	0.34/0.11	-	0.13/0.04	0.13/0.05	-	*H . schimperi*	0.5/0.20	0.31/0.11	-
I . tanganyikensis				0.25/0.10	0.13/0.09	-	*I . tanganyikensis*	0.38/0.13	0.22/0.10	-
R . montana	0.13/0.04	0.13/0.06	-				*R . montana*	0.13/0.07	0.03/0.02	-
Conyza sp.							*Crotalaria incana*	0.25/0.11	0.13/0.05	-
Oxygonum sinuatum	0.13/0.06	0.56/0.12	-	0.13/0.06	0.16/0.08	-	*Oxygonum sinuatum*	0.13/0.08	0.16/0.07	-
O . scopulorum	0.13/0.08	0.03/0.01	-				*O . scopulorum*			
Cyperus sp.	0.25/0.11	0.22/0.10	-	0.5/0.30	0.06/0.04	-	*Cyperus* sp.			
Chloris gayana	0.13/0.06	0.03/0.02	-				*Angustifolia montana*			
Angustifolia montana	0.13/0.05	0.03/0.01	-	0.13/0.07	0.06/0.04	-	*Chloris gayana*	0.25/0.11	0.06/0.04	-
Eleusine africana				0.13/0.08	0.06/0.04	-	*Eleusine africana*			
Leucas pratensis				0.13/0.07	1.97/0.14	-	*Leucas pratensis*			
Amaranthus hybridus				0.38/0.13	0.22/0.10	-	*Amaranthus hybridus*	0.13/0.06	0.13/0.08	-
Tribulus terrestris				0.13/0.07	0.03/0.02	-	*Conyza stricta*			
Indigofera ambalensis				0.38/0.13	3.94/1.15	-	*Indigofera ambalensis*	0.5/0.10	3.28/1.10	-
Cassia grantii	0.13/0.07	0.06/0.04	-	0.25/0.11	0.16/0.07	-	*Cassia grantii*	0.25/0.09	0.41/0.13	-
Solanum nigrum				0.13/0.05	0.03/0.02	-	*Solanum nigrum*			
Aristida keniensis				0.13/0.04	0.03/0.01	-	*Aristida keniensis*			
Sida schimperiana	0.25/0.11	0.16/0.10	1	0.13/0.10	0.13/0.07	-	*Sida schimperiana*	0.25/0.11	0.13/0.08	-
Aerva lanata	0.13/0.07	0.03/0.01	-	0.38/0.10	0.09/0.04	-	*Aerva lanata*	0.13/0.07	0.03/0.02	-

APPENDIX 5: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Untrampled area 1991 (continued)

	Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	1/0.08	-	22.3	1/0.09	-	9.75	0.75/0.08	-	13.9	0.6/0.04	-	22	0.88/0.11	-	19.8
Cynodon dactylon	0.5/0.10	-	25	0.5/0.10	-	23	0.5/0.10	-	30.1	0.8/0.30	-	45.2	0.5/0.10	-	24.3
Themeda triandra	0.5/0.20	-	1.75	0.38/0.14	-	1.25							0.50.20	-	2.25
Felicia muricata	0.63/0.11	0.78/0.12	1	0.88/0.12	1.97/0.14	3.75	0.5/0.20	1.56/0.18	1.82	0.4/0.10	0.4/0.10	1.2	0.75/0.14	1.09/0.16	1.25
C . tanganyikensis															
Indigofera spicata	0.25/0.11	0.16/0.08	-	0.25/0.11	0.19/0.06	-				0.2/0.04	0.15/0.08	-	0.38/0.14	0.88/0.15	0.5
E . inaequilatera	0.38/0.13	0.41/0.14	-							0.6/0.03	2.75/0.14	-	0.5/0.11	7.65/2.30	1
Solanum incanum	0.25/0.10	0.09/0.05	-							0.4/0.05	0.15/0.04	-	0.38/0.14	0.41/0.15	-
Justacia sp.				0.13/0.07	0.03/0.02	-	0.13/0.07	0.06/0.04	-						
Cyperus rigidifolius															
Hypoestes verticillaris				0.13/0.08	0.06/0.04	-	0.13/0.08	0.06/0.03	-	0.2/0.05	0.15/0.08	-			
Eragrostis tenuifolia	0.13/0.07	0.03/0.01	-	0.38/0.13	2.19/0.15	-							0.38/0.10	0.44/0.16	-
Harpachne schimperi	0.5/0.20	1.13/0.09	1	0.38/0.10	0.59/0.18	-	0.25/0.10	0.63/0.14	-	0.4/0.10	0.3/0.10	-	0.5/0.20	0.72/0.34	-
I. tanganyikensis	0.13/0.07	0.03/0.02	-	0.25/0.11	0.09/0.04	-							0.13/0.06	0.09/0.05	-
Rhamphicarpa montana													0.13/0.07	0.03/0.02	-
Crotalaria incana															
Oxygonum sinuatum															
Oldenlandia scopulorum															
Cyperus sp.	0.13/0.08	0.13/0.05	-							0.4/0.10	0.75/0.14	-	0.25/0.11	0.05/0.02	-
Angustifolia montana	0.13/0.06	0.03/0.02	-							0.2/0.05	0.05/0.02	-			
Chloris gayana															
Eleusine africana										0.2/0.10	0.2/0.10	-	0.13/0.07	0.22/0.11	-
Leucas pratensis															
Amaranthus hybridus										0.4/0.05	0.85/0.15	-	0.25/0.10	1.25/0.45	0.25
Conyza stricta															
Indigofera ambalensis	0.25/0.11	1.25/0.14	0.5							0.2/0.10	0.25/0.11	-	0.38/0.11	3.13/1.10	-
Cassia grantii	0.13/0.06	0.16/0.08	-							0.2/0.08	0.05/0.03	-	0.13/0.07	0.03/0.02	-
Solanum nigrum															
Aristida keniensis													0.25/0.10	0.06/0.04	-
Sida schimperiana	0.25/0.10	0.16/0.06	-	0.13/0.08	0.06/0.04	-	0.38/0.11	0.09/0.05	-	0.6/0.20	0.15/0.06	-	0.25/0.11	0.06/0.03	0.25
Aerva lanata	0.13/0.04	0.03/0.01	-				0.13/0.06	0.03/0.02	-						

APPENDIX 6: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Untrampled area January - April 1992

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88/0.11	-	11.5	0.5/0.10	-	4.5	1/0.10	-	4.25	1/0.11	-	14.25
Cynodon dactylon	0.5/0.10	-	19.3	0.5/0.20	-	10.5	0.38/0.11	-	12.3	0.5/0.20	-	17
Themeda triandra				0.25/0.11	-	-	0.5/0.10	-	1	0.5/0.20	-	-
Felicia muricata	0.63/0.11	1.75/0.14	2.25	0.63/0.14	0.75/0.16	-	0.63/0.14	1.94/0.15	4	0.75/0.11	2.69/0.15	7.25
Indigofera spicata	0.13/0.06	0.09/0.04	-	0.13/0.04	0.19/0.08	-	0.25/0.10	0.22/0.11	-	0.38/0.11	0.53/0.14	-
Euphorbia inaequilatera	0.25/0.11	3.44/1.10	-							0.38/0.10	0.38/0.14	-
Solanum incanum	0.13/0.07	0.06/0.04	-	0.25/0.10	0.19/0.09	-	0.13/0.06	0.28/0.12	-			
Justacia sp.				0.13/0.06	0.03/0.02	-	0.13/0.07	0.03/0.01	-	0.38/0.09	0.19/0.08	-
Cyperus rigidifolius							0.25/0.11	0.13/0.05	-	0.25/0.11	0.81/0.14	-
Hypoestes verticillaris	0.13/0.04	0.34/0.11	1.5	0.13/0.07	0.19/0.10	-						
Eragrostis tenuifolia	0.38/0.15	0.75/0.14	-	0.13/0.08	0.28/0.11	-	0.38/0.12	4.78/1.25	1	0.5/0.20	4.44/1.33	2
Harpachne schimperi	0.5/0.20	0.78/0.16	-	0.38/0.11	0.19/0.08	-	0.38/0.13	0.81/0.14	-	0.38/0.14	0.34/0.16	-
Indigofera tanganyikensis				0.13/0.07	0.03/0.02	-				0.13/0.06	0.09/0.04	-
Oldenlandia scopulorum										0.13/0.08	0.03/0.02	-
Chloris gayana	0.13/0.08	0.06/0.03	-	0.25/0.10	0.16/0.05	-	0.13/0.07	0.03/0.02	-	0.13/0.04	0.03/0.02	-
Cyperus sp	0.13/0.05	0.16/0.08	-	0.13/0.08	0.19/0.07	-				0.25/0.11	0.13/0.08	-
Indigofera ambalensis	0.25/0.11	0.16/0.07	-	0.13/0.08	0.09/0.05	-	0.13/0.08	0.03/0.02	-	0.13/0.07	0.06/0.03	-
Aerva lanata				0.13/0.07	0.03/0.02	-						
Aristida keniensis										0.13/0.08	0.03/0.02	-
Sida schimperiana	0.25/0.10	0.16/0.08	-	0.38/0.11	0.13/0.06	1.5				0.13/0.07	0.16/0.06	-
Abutilon mauritianum										0.13/0.05	0.03/0.01	-
Amaranthus sp.										0.13/0.06	0.16/0.05	-
Tribulus terrestris										0.25/0.10	0.06/0.04	-
Commelina bengalensis										0.13/0.07	0.06/0.03	-

APPENDIX 7: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Trampled area 1990

	April			May			June			July		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88/0.04	-	45.5	0.88/0.05	-	56	0.88/0.04	-	54	0.88/0.06	-	55.5
Cynodon dactylon	0.4/0.20	-	15.5	0.38/0.16	-	5.5	0.38/0.19	-	6.75	0.25/0.11	-	4.5
Themeda triandra	0.2/0.10	-	1.1	0.75/0.20	-	4	0.75/0.14	-	4	0.75/0.14	-	4.25
Felicia muricata	0.75/0.15	2/0.06	-	0.6/0.30	0.41/0.21	0.25	0.63/0.11	0.34/0.16	0.25	0.63/0.09	0.53/0.11	3.75
C . tanganyikensis	0.13/0.05	0.09/0.04	-	0.03/0.10	0.43/0.26	-	0.38/0.13	0.09/0.02	-	0.75/0.13	0.22/0.09	-
Indigofera spicata	0.13/0.04	0.09/0.03	-	0.2/0.05	0.78/0.35	1.56	0.5/0.20	0.91/0.34	2.25	0.13/0.08	0.94/0.25	0.5
E . inaequilatera	0.14/0.20	0.31/0.18	-	0.5/0.10	2/0.60	-	0.5/0.21	2.09/0.39	-	0.75/0.25	2.22/1.00	0.25
Solanum incanum	0.2/0.06	0.22/0.10	-	0.5/0.11	0.5/0.11	-	0.5/0.24	0.56/0.16	1	0.38/0.15	0.56/0.19	0.5
Justacia sp.	0.38/0.10	0.16/0.09	-	0.13/0.05	0.4/0.10	-	0.38/0.18	0.41/0.17	-	0.5/0.10	0.38/0.15	0.25
Cyperus rigidifolius	0.12/0.06	0.06/0.02	-	0.38/0.19	0.25/0.15	-	0.38/0.19	0.28/0.09	-	0.25/0.09	0.09/0.03	-
Hypoestes verticillaris	0.25/0.11	0.09/0.05	-	0.3/0.10	0.16/0.09	-	0.25/0.12	0.16/0.10	0.25	0.25/0.10	0.16/0.10	-
Eragrostis tenuifolia	0.75/0.26	0.63/0.21	1.75	0.38/0.16	0.16/0.07	0.2	0.38/0.18	0.16/0.08	0.25	0.25/0.08	0.16/0.09	0.25
Harpachne schimperi	0.75/0.11	1/0.50	0.16	0.75/0.05	1/0.50	2.58	0.75/0.14	1.28/0.15	3.25	0.75/0.14	1.19/0.15	1.5
I .tanganyikensis	0.75/0.18	0.38/0.16	-	0.63/0.29	1.6/0.09	-	0.63/0.12	1.66/0.19	-	1/0.50	0.94/0.24	-
R .montana	0.14/0.05	0.09/0.03	-									
Panicum maximum				0.13/0.10	0.16/0.08	-	0.13/0.10	0.16/0.10	0.5	0.13/0.05	0.13/0.06	1.5
Oxygonum sinuatum				0.13/0.06	0.06/0.03	-	0.13/0.11	0.6/0.20	-			
O . scopulorum	0.2/0.06	0.16/0.10	-				0.25/0.09	0.19/0.09	-	0.13/0.06	0.06/0.02	-
Monchma debile							0.25/0.11	0.06/0.02	-	0.13/0.04	0.03/0.01	-
Crotalaria incana										0.13/0.05	0.03/0.01	-
Chloris gayana										0.25/0.09	0.09/0.04	-
Crotalaria grantii										0.13/0.10	0.06/0.02	0.25
Crotalaria spinosa										0.25/0.11	0.06/0.01	-
Crotalaria sp.										0.25/0.10	0.13/0.05	-

APPENDIX 7: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Trampled area 1990 (continued)

	Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.87/0.04	-	36.5	0.88/0.06	-	21.5	0.88/0.06	-	20.8	0.88/0.07	-	27.8	0.88/0.07	-	16
Cynodon dactylon	0.5/0.10	-	5.5	0.75/0.15	-	6	0.25/0.10	-	1.5	0.25/0.10	-	1	0.13/0.04	-	-
Themeda triandra	0.65/0.11	-	2.25	0.25/0.09	-	0.75	0.88/0.07	-	2.75	0.75/0.26	-	3.5	0.63/0.12	-	2.1
Felicia muricata	0.6/0.12	0.56/0.21	3.25	0.5/0.02	0.53/0.11	2.5	0.5/0.10	0.59/0.20	1.5	0.63/0.24	1.03/0.06	4	0.63/0.20	0.63/0.25	-
C . tanganyikensis	0.13/0.05	0.16/0.09	0.05				0.25/0.09	0.06/0.02	-						
Indigofera spicata	0.38/0.13	0.52/0.20	1.25	0.38/0.18	0.28/0.10	0.5	0.25/0.09	0.66/0.24	0.25	0.25/0.09	0.66/0.30	-	0.13/0.04	0.09/0.03	-
E .inaequilatera	0.6/0.20	0.25/0.06	-	0.38/0.16	0.25/0.09	-	0.25/0.08	0.09/0.03	-	0.38/0.13	0.16/0.10	-	0.38/0.14	0.19/0.09	-
Solanum incanum	0.34/0.18	0.38/0.11	0.35	0.38/0.15	0.16/0.07	0.25	0.13/0.06	0.13/0.06	-	0.5/0.20	0.38/0.19	-	0.38/0.11	0.31/0.13	-
Justacia sp.	0.25/0.09	0.38/0.13	-	0.13/0.05	0.03/0.01	-	0.13/0.06	0.09/0.03	-	0.38/0.10	0.22/0.10	-	0.25/0.09	0.03/0.02	-
Cyperus rigidifolius	0.15/0.04	0.06/0.02	-				0.13/0.05	0.03/0.01	-	0.5/0.20	0.47/0.18	-	0.25/0.08	0.09/0.05	-
Hypoestes verticillaris	0.18/0.08	0.18/0.08	-	0.25/0.11	0.25/0.10	-	0.13/0.07	0.06/0.03	-						
Eragrostis tenuifolia	0.36/0.19	0.16/0.06	0.3	0.38/0.14	0.16/0.09	0.5				0.5/0.21	0.94/0.16	-	0.38/0.11	0.81/0.09	-
Harpachne schimperi	0.65/0.25	1/0.26	1.15	0.63/0.18	0.75/0.25	1	0.63/0.15	0.94/0.36	0.5	0.88/0.07	1.41/0.30	0.75	0.88/0.09	0.56/0.14	-
I . tanganyikensis	0.75/0.17	0.56/0.21	-	0.5/0.10	0.13/0.08	-	0.38/0.12	0.19/0.11	-	0.5/0.20	0.13/0.05	-			
Rhamphicarpa montana				0.13/0.06	0.06/0.01	-				0.13/0.08	0.03/0.01	-	0.13/0.04	0.03/0.01	-
Panicum maximum				0.13/0.07	0.16/0.05	-									
Oxygonum sinuatum										0.13/0.06	0.16/0.10	-			
Oldenlandia scopulorum				0.13/0.06	0.06/0.01	-				0.38/0.12	0.16/0.11	-			
Monchma dabile															
Crotalaria incana				0.13/0.05	0.03/0.01	-									
Chloris gayana															
Crotalaria grantii										0.25/0.08	0.31/0.11	-			
Crotalaria spinosa															
Crotalaria sp.															
Conyza stricta				0.13/0.05	0.06/0.01	-									
Indigofera ambalensis										0.63/0.24	0.34/0.15	-	0.38/0.11	0.31/0.19	-
Cassia grantii													0.13/0.06	0.16/0.10	-
Commelina africana										0.13/0.05	0.03/0.01	-			
Pennisetum cladestinum										0.13/0.06	-	2			

APPENDIX 8: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Trampled area 1991

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88/0.05	-	10.5	0.75/0.08	-	4.25	0.88/0.09	-	5.75	0.88/0.10	-	21.25
Cynodon dactylon	0.25/0.10	-	-	0.38/0.11	-	3.25	0.25/0.07	-	-	0.38/0.16	-	1
Themeda triandra	0.75/0.25	-	2	0.63/0.11	-	-	0.25/0.12	-	-	0.63/0.11	-	1.25
Felicia muricata	0.63/0.10	0.47/0.16	-	0.5/0.30	0.22/0.11	1.75	0.5/0.30	0.5/0.20	1.5	0.75/0.12	1.31/0.45	4.25
Eragrostis mamoena												
Indigofera spicata	0.13/0.05	0.13/0.06	-				0.25/0.11	0.06/0.03	-	0.25/0.11	0.09/0.05	-
Euphorbia inaequilatera	0.63/0.16	0.34/0.11	-	0.25/0.09	0.09/0.04	-				0.25/0.12	0.41/0.16	-
Solanum incanum	0.5/0.20	0.34/0.09	-	0.25/0.07	0.09/0.06	-						
Justacia sp.	0.25/0.09	0.06/0.03	-	0.13/0.05	0.06/0.04	-				0.25/0.14	0.13/0.08	-
Cyperus rigidifolius	0.25/0.11	0.06/0.04	-							0.25/0.09	0.13/0.10	-
Hypoestes verticillaris												
Eragrostis tenuifolia	0.38/0.11	0.66/0.25	-	0.13/0.06	0.06/0.04	-						
Harpachne schimperi	0.88/0.09	0.81/0.11	-	0.63/0.17	0.41/0.12	-				0.63/0.12	0.31/0.11	-
Indigofera tanganyikensis										0.13/0.06	0.06/0.04	-
Rhamphicarpa montana										0.13/0.07	0.03/0.02	-
Aristida keniensis												
Oxygonum sinuatum	0.13/0.05	0.03/0.01	-							0.13/0.08	0.03/0.01	-
Oldenlandia scopulorum										0.13/0.11	0.06/0.04	-
Aristida adoensis												
Crotalaria incana												
Chloris gayana	0.13/0.05	0.06/0.03	-									
Crotalaria grantii	0.13/0.06	0.13/0.07	-									
Angustifolia montana												
Crotalaria sp.												
Conyza stricta												
Indigofera ambalensis	0.38/0.11	0.38/0.13	-	0.25/0.11	0.09/0.05	-				0.25/0.11	0.06/0.04	-
Cassia grantii										0.13/0.06	0.03/0.01	-
Commelina africana												
Pennisetum cladestinum												
Sida schimperiana	0.13/0.05	0.03/0.02	-									

APPENDIX 8: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) -Trampled area 1991 (continued)

	May			June				July		
Species	A	B	C	A	B	C	Species	A	B	C
Digitaria milanjiana	0.88/0.09	-	24.5	0.88/0.10	-	41.8	*Digitaria milanjiana*	0.88/0.09	-	42.75
Cynodon dactylon	0.38/0.11	-	1.75	0.38/0.11	-	-	*Cynodon dactylon*	0.13/0.05	-	5.25
Themeda triandra	0.5/0.30	-	-	0.5/0.20	-	2.25	*Themeda triandra*	0.63/0.15	-	3.5
Felicia muricata	0.75/0.11	1.69/0.14	3	0.63/0.10	1.34/0.32	2.25	*Felicia muricata*	0.75/0.16	1.09/0.31	2.25
Eragrostis mamoena				0.13/0.06	0.09/0.03	-	*Crotalaria tanganyikensis*			
Indigofera spicata	0.5/0.30	5.94/1.29	-	0.03/0.02	0.44/0.11	0.75	*Indigofera spicata*	0.13/0.06	0.34/0.11	-
E .inaequilatera	0.88/0.09	4.63/1.30	-	0.88/0.12	13.84/2.35	1.75	*Euphorbia inaequilatera*	1/0.04	9.41/2.35	1.25
Solanum incanum	0.25/0.10	0.19/0.09	-	0.13/0.07	0.19/0.09	0.5	*Solanum incanum*	0.13/0.04	0.06/0.04	-
Justacia sp.	0.38/0.14	0.34/0.11	-	0.13/0.08	0.06/0.04	-	*Justacia* sp.	0.25/0.10	0.13/0.05	-
C .rigidifolius	0.13/0.07	0.13/0.07	-	0.25/0.11	0.19/0.08	-	*Cyperus rigidifolius*	0.13/0.05	0.13/0.08	-
Hypoestes verticillaris							*Hypoestes verticillaris*			
E .tenuifolia	0.13/0.08	0.03/0.01	-	0.38/0.13	0.44/0.13	-	*Eragrostis tenuifolia*	0.13/0.06	0.13/0.09	-
H .schimperi	0.38/0.14	0.38/0.14	-	0.5/0.20	0.78/0.15	-	*Harpachne schimperi*	0.63/0.19	0.81/0.13	1
Indigofera tanganyikensis				0.25/0.13	0.09/0.04	-	*I . tanganyikensis*	0.38/0.13	0.5/0.20	-
Rhamphicarpa montana				0.13/0.08	0.03/0.01	-	*Aristida kenensis*			
Aristida keniensis				0.13/0.07	0.13/0.06	-	*Leucas pratensis*			
O . sinuatum	0.13/0.08	0.5/0.20	-	0.5/0.30	0.34/0.11	-	*Oxygonum sinuatum*	0.13/0.06	0.06/0.03	-
Oldenlandia scopulorum				0.13/0.10	0.06/0.03	-	*Oldenlandia scopulorum*			
Aristida adoensis				0.13/0.08	0.06/0.04	-	*Monchma debile*			
Crotalaria incana				0.25/0.13	0.22/0.10	-	*Crotalaria incana*			
Chloris gayana							*Chloris gayana*			
Crotalaria grantii	0.13/0.05	0.06/0.04	-	0.25/0.10	0.28/0.09	-	*Crotalaria grantii*	0.25/0.11	0.06/0.04	-
Angustifolia montana				0.13/0.08	0.03/0.02	-	*Chenopodium procerum*	0.13/0.05	0.06/0.03	-
Crotalaria sp.							*Crotalaria* sp.			
Conyza stricta							*Conyza stricta*			
I . ambalensis	0.25/0.11	0.19/0.10	-	0.88/0.13	13.59/3.16	-	*Indigofera ambalensis*	0.88/0.09	13.81/3.1	5.25
Cassia grantii							*Cassia grantii*			
Commelina africana	0.13/0.06	0.06/0.04	-	0.13/0.05	0.09/0.05	-	*Commelina reptens*	0.13/0.07	0.03/0.02	-
Pennisetum cladestinum							*Angustifolia montana*	0.13/0.05	0.03/0.01	-
Sida schimperiana							*Sida schimperiana*			
Datura stramonium				0.13/0.06	0.03/0.01	-	*Datura stramonium*			
Eragrotis racemosa				0.25/0.10	0.06/0.03	-	*Eragrostis racemosa*	0.13/0.07	0.03/0.02	-
Tribulus terrestris				0.5/0.30	0.25/0.09	-	*Tribulus terrestris*	0.13/0.08	0.16/0.08	-

APPENDIX 8: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) -Trampled area 1991 (continued)

	Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88/0.11	-	23.5	0.88/0.13	-	6	0.88/0.11	-	11.6	0.88/0.13	-	20.8	0.75/0.14	-	19
Cynodon dactylon	0.13/0.07	-	2.25	0.13/0.05	-	2.5	0.13/0.05	-	1.4	0.13/0.06	-	3	0.13/0.05	-	-
Themeda triandra	0.5/0.20	-	1.25	0.13/0.05	-	1.25				0.5/0.30	-	2.5	0.5/0.20	-	1
Felicia muricata	0.63/0.13	0.81/0.13	0.5	0.75/0.14	1.69/0.25	3.75	0.75/0.15	0.94/0.24	3	0.75/0.11	0.91/0.18	3.25	0.63/0.13	2.53/0.23	2.5
Crotalaria tanganyikensis															
Indigofera spicata	0.13/0.05	0.03/0.01	0.5	0.25/0.10	0.44/0.16	-	0.25/0.10	0.63/0.19	-	0.38/0.13	1.25/0.14	-	0.63/0.11	1.53/0.13	-
E. inaequilatera	0.88/0.14	0.88/0.11	-				0.25/0.09	0.25/0.11	-	0.5/0.20	0.75/0.19	-	0.63/0.14	2.16/1.10	1
Solanum incanum										0.13/0.05	0.09/0.04	-	0.38/0.10	0.09/0.03	-
Justacia sp.	0.25/0.10	0.06/0.03					0.25/0.08	0.06/0.04	-	0.63/0.17	0.28/0.11	-	0.5/0.20	0.16/0.08	-
Cyperus rigidifolius							0.13/0.07	0.06/0.03	-	0.13/0.06	0.16/0.11	-			
Hypoestes verticillaris															
Eragrostis tenuifolia	0.13/0.06	0.09/0.06	-				0.25/0.11	0.31/0.12	-	0.5/0.30	1.13/0.14	0.25	0.75/0.11	4.84/1.10	0.5
H .schimperi	0.63/0.14	0.59/0.11	-	0.13/0.07	0.41/0.13	-	0.38/0.13	0.56/0.19	-	0.75/0.11	1.25/0.15	-	0.63/0.14	0.47/0.13	0.5
Indigofera tanganyikensis										0.25/0.09	0.09/0.03	-	0.38/0.11	0.13/0.07	-
Aristida keniensis													0.25/0.09	0.28/0.11	-
Leucas pratensis	0.13/0.06	0.03/0.02	-												
O .sinuatum	0.13/0.07	0.03/0.01	-							0.25/0.09	0.09/0.04	-			
Oldenlandia scopulorum															
Monchma dabile															
Crotalaria incana	0.25/0.11	0.06/0.04	-												
Chloris gayana				0.13/0.07	0.06/0.03	-							0.13/0.07	0.03/0.01	0.3
Crotalaria grantii	0.25/0.11	0.09/0.05	-							0.38/0.13	0.09/0.06	-	0.25/0.11	0.06/0.03	-
Chenopodium procerum															
Crotalaria sp.															
Conyza stricta															
I .ambalensis	0.88/0.13	9.19/2.14	1.75				0.75/0.11	4.69/1.25	-	1/0.03	6.72/2.31	1.75	0.63/0.11	4.56/1.13	1.5
Cassia grantii							0.13/0.05	0.09/0.04	-						
Commelina reptens															
Angustifolia montana															
Sida schimperiana										0.13/0.04	0.06/0.03	-	0.13/0.07	0.06/0.04	-
Datura stramonium															
Eragrostis racemosa															
Tribulus terrestris													0.13/0.06	0.03/0.02	-

APPENDIX 9: Percentage vegetation cover (C), mean +/-S.E of frequency (A) and density (B) - Trampled area January - April 1992

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88/0.11	-	18.8	0.88/0.12	-	2.5	0.88/0.12	-	8.5	0.88/0.11	-	20.75
Cynodon dactylon	0.13/0.06	-	4	0.13/0.07	-	1.75	0.13/0.05	-	1			
Themeda triandra	0.38/0.13	-	-	0.25/0.11	-	-	0.5/0.20	-	-	0.63/0.11	-	-
Felicia muricata	0.63/0.12	1.56/0.14	5.25	0.63/0.15	1.03/0.17	2	0.75/0.15	2.5/0.14	1	0.63/0.12	1.13/0.14	-
Indigofera spicata	0.13/0.07	0.25/0.11	-	0.25/0.10	0.16/0.07	-	0.38/0.11	0.22/0.08	-	0.5/0.20	0.63/0.11	-
Euphorbia inaequilatera										0.13/0.06	0.03/0.01	-
Solanum incanum	0.25/0.11	0.06/0.04	-									
Justacia sp.	0.13/0.08	0.06/0.04	-	0.13/0.05	0.03/0.02	-	0.5/0.10	0.19/0.10	-	0.38/0.13	0.09/0.04	-
Cyperus rigidifolius	0.13/0.07	0.16/0.08	-				0.25/0.09	0.06/0.04	-	0.25/0.10	0.13/0.08	-
Eragrostis tenuifolia	0.25/0.11	0.78/0.14	-	0.13/0.04	0.31/0.11	-	0.75/0.13	0.91/0.14	-	0.75/0.13	2.59/0.15	2
Harpachne schimperi	0.88/0.11	1.38/0.13	-	0.25/0.10	0.16/0.07	-	0.88/0.12	1.41/0.25	-	0.75/0.12	2.03/0.18	-
Angustifolia montana	0.13/0.08	0.06/0.04	-									
Oxygonum sinuatum										0.13/0.07	0.03/0.01	-
Oldenlandia scopulorum										0.13/0.08	0.06/0.03	-
Eragrostis mamoena										0.13/0.04	0.03/0.01	-
Chloris gayana				0.13/0.05	0.06/0.03	-				0.13/0.06	0.06/0.04	-
Crotalaria grantii	0.13/0.07	0.03/0.01	-									
Indigofera ambalensis	0.88/0.11	7.59/2.15	1	0.25/0.11	0.22/0.09	-	0.75/0.12	1.03/0.11	-	0.38/0.11	0.69/0.14	-
Cassia sp.										0.13/0.05	0.03/0.02	-
Sida schimperiana	0.13/0.06	0.06/0.04	-				0.13/0.08	0.03/0.02	-			

APPENDIX 10: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the grazed area-April-December 1990

Species	April			May			June			July			Aug			Sept		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
D . milanjiana / scalarum	0.82	-	22.5	0.67	-	20.9	0.78	-	26.6	0.69	-	19.0	0.56	-	15.7	0.61	-	16.23
Eragrostis tenuifolia	0.13	0.28	0.14	0.17	0.17	1.4	0.56	0.21	-	0.44	0.13	-	0.33	0.08	-	0.17	0.11	-
Harpachne schimperi	0.28	1.8	0.4	0.56	0.63	0.6	0.33	0.1	-				0.33	0.07	-	0.22	0.07	-
Oldenlandia scopulorum	0.27	0.29	-	0.17	0.08	-												
Commelina africana	0.05	0.01	-	0.06	0.03	-												
Indigofera spicata	0.01	0.07	-	0.33	0.11	-	0.17	0.11	-	0.11	0.13	-				0.11	0.04	-
Chloris gayana	0.22	0.08	0.41	0.17	0.07	-	0.17	0.08	2.56	0.22	0.14	1.25	0.22	0.07	1.52			
Rhamphicarpa montana	0.11	0.06	-	0.11	0.06	-	0.11	0.04	-									
Themeda triandra	0.05	-	-	0.06	-	-	0.22	-	-				0.17	-	-	0.11	-	-
Aristida adoensis	0.22	0.1	-	0.21	0.11	-	0.17	0.06	-				0.11	0.07	-			
Justacia sp.	0.17	0.11	-							0.11	0.04	-						
Satureia biflora	0.17	0.07	-	0.22	0.08	-				0.17	0.08	-						
Dyscoriste radicans	0.11	0.04	-	0.11	0.03	-												
Oxalis obliquifolia	0.17	0.14	-				0.11	0.04	-									
Sida schimperiana				0.11	0.07	-	0.11	0.07	1.4									
Cymbopogon caesius																		
Cyperus sp.																		
Commelina bengalensis																		
Hyparrhenia sp.																0.17	0.14	3.82
Eragrostis mamoena																0.11	0.04	-
Leucas pratensis				0.11	0.06	-										0.06	0.01	-
Conyza stricta				0.06	0.03	-												
Crotalaria sp.				0.06	0.04	-										0.06	0.01	-
Felicia muricata				0.11	0.06	-				0.22	0.11	0.59	0.06	0.04	-			
Setaria sphacelata													0.11	0.06	-			
Abutilon mauritianum																0.06	0.01	-
Plectranthus barbatus																		
Euphorbia inaequilatera							0.61	0.35	-									
Cyperus rigidifolius							0.28	0.14	-							0.17	0.11	1.52
Solanum incanum							0.06	0.04	-				0.06	0.03	-	0.11	0.03	-
Eragrostis racemosa							0.22	0.07	-				0.06	0.04	-	0.06	0.03	-
Hypoestes verticillaris																		
Hyparrhenia lintonii										0.28	0.1	3.59						

APPENDIX 10: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the grazed area-April-December 1990 (continued)

	Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C
D. milanjiana / scalarum	0.72	-	22.9	0.78	-	26.9	0.72	-	18.3
Eragrostis tenuifolia	0.5	0.14	-	0.5	0.21	1.45	0.56	0.19	0.52
Harpachne schimperi	0.33	0.11	-	0.33	0.14	-	0.22	0.13	-
Oldenlandia scopulorum				0.44	0.18	-			
Commelina africana	0.06	0.04	-						
Indigofera spicata				0.17	0.07	-	0.17	0.08	-
Chloris gayana				0.22	0.07	2.82	0.22	0.11	-
Rhamphicarpa montana				0.33	0.15	-			
Themeda triandra				0.44	-	4.52	0.39	-	2.62
Crotalaria incana							0.06	0.01	-
Justacia sp.	0.17	0.06	-						
Satureia biflora	0.28	0.15	-						
Dyscoriste radicans	0.17	0.07	-						
Angustifolia montana	0.11	0.03	-						
Sida schimperiana									
Cymbopogon caesius	0.11	0.28	10.8						
Cyperus sp.									
Commelina bengalensis	0.17	0.06	-						
Commelina reptens									
Chenopodium procerum									
Leucas pratensis				0.06	0.01	-	0.11	0.07	-
Conyza stricta									
Polygala sphenoptera	0.06	0.01	-						
Felicia muricata				0.22	0.08	-	0.17	0.06	-
Setaria sphacelata	0.17	0.08	2.51						
Abutilon mauritianum									
Plectranthus barbatus									
Euphorbia indequilatera									
Cyperus rigidifolius				0.28	0.13	-	0.17	0.14	-
Solanum incanum									
Eragrostis racemosa				0.17	0.07	-	0.11	0.06	-
Oxygonum sinuatum	0.06	0.07	-						

APPENDIX 11: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the grazed area -January-December 1991

Species	Jan A	Jan B	Jan C	Feb A	Feb B	Feb C	March A	March B	March C	April A	April B	April C	May A	May B	May C	June A	June B	June C
D . milanjiana / scalarum	0.53	-	14.1	0.6	-	12.0	0.67	-	9.5	0.87	-	22.3	0.53	-	26.89	0.67	-	32.67
Eragrostis tenuifolia	0.53	1.82	2.52	0.4	0.42	0.56	0.6	0.3	-	0.67	1.33	-	0.73	5.07	4.67	0.6	1.25	-
Harpachne schimperi	0.4	0.83	1.65	0.13	0.05	-	0.27	0.13	-							0.67	1.33	-
Oldenlandia scopulorum													0.27	0.25	-	0.2	0.25	-
Conyza schimperi										0.27	0.1	-						
Indigofera spicata	0.33	0.12	-	0.2	0.05	-	0.2	0.08	-							0.07	0.08	-
Chloris gayana	0.27	0.47	-	0.07	0.1	-	0.2	0.08	-							0.2	0.1	-
Pennisetum cladestinum	0.4	-	1.35	0.07	-	-	0.13	-	1.25	0.13	-	-	0.87	-	6.1			
Themeda triandra				0.27	-	2.68	0.2	-	-	0.53	-	2.15						
Aristida adoensis	0.07	0.08	-													0.13	0.07	-
Justacia sp.										0.2	0.07	-				0.07	0.02	-
Rhamphicarpa montana	0.13	0.06	-													0.13	0.08	-
Dyscoriste radicans				0.07	0.33	-												
Oxalis obliquifolia													0.2	0.1	-			
Sida schimperiana	0.6	1.67	3.4	0.4	0.63	1.89	0.53	0.5	1.58	0.6	0.43	2.67	0.67	1.45	3.45	0.67	1.5	10.99
Cymbopogon caesius																		
Cyperus sp	0.27	0.14	-	0.47	0.17	-	0.13	0.08	-	0.6	0.2	1.81	0.67	0.83	-			
Cynodon dactylon				0.07	-	-												
Crotalaria incana	0.07	0.01	-							0.07	0.02	-						
Eragrostis mumoena							0.13	0.1	-									
Leucas pratensis																0.07	0.05	-
Aerva lanata										0.07	0.03	-						
Crotalaria sp.	0.07	0.02	-				0.07	0.05	-				0.27	0.12	-			
Ocimum kilimandijaricum													0.13	0.07	-			
Setaria sphacelata				0.4	1.17	10.5	0.47	0.2	4.86	0.4	0.27	3.98	0.2	0.1	-			
Crotalaria tanganyikensis										0.13	0.03	-						
Plectranthus barbatus																		
Euphorbia inaequilatera													0.33	1.83	-	0.4	1.48	-
Cyperus rigidifolius																		
Solanum incanum										0.13	0.07	-						
Eragrostis racemosa				0.27	0.13	-							0.33	1.03	-	0.2	0.17	-
Tribulus terrestris																		
Commelina africana																0.07	0.02	-

APPENDIX 11: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the grazed area -January-December 1991 (continued)

	July			Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
D . milanjiana / scalarum	0.67	-	29.6	0.6	-	25.1	0.47	-	16.7	0.53	-	20.1	0.47	-	17.0	0.4	-	10.11
Eragrostis tenuifolia	0.53	0.83	-	0.4	1	-	0.12	0.58	-	0.33	0.67	-	0.53	0.67	-	0.4	0.5	-
Harpachne schimperi	0.53	1.13	-	0.47	0.8	-							0.4	0.5	-	0.33	0.27	-
Oldenlandia scopulorum													0.53	0.1	-			
Aerva lanata										0.07	0.07	-	0.07	0.02	-	0.07	0.02	-
Indigofera spicata	0.2	0.07	-	0.07	0.08	-	0.07	0.03	-	0.13	0.07	-	0.27	0.1	-	0.13	0.05	-
Chloris gayana	0.13	0.07	-	0.2	0.07	-	0.13	0.07	-	0.2	0.1	-	0.53	0.03	-	0.27	0.13	-
Pennisetum cladestinum																0.2	-	-
Themeda triandra	0.53	-	-	0.4	-	-	0.27	-	-	0.33	-	-	0.13	-	-			
Aristida adoensis	0.07	0.07	-	0.13	0.05	-	0.13	0.03	-									
Justacia sp.	0.07	0.03	-															
Satureia biflora				0.2	0.13	-				0.13	0.08	-						
Dyscoriste radicans	0.07	0.02	-															
Oxalis obliquifolia										0.27	0.05	-	0.07	0.05	-			
Sida schimperiana	0.6	1.3	11.6	0.6	1	6.01	0.53	0.83	3.65	0.53	0.6	4.5	0.6	0.5	2.61	0.53	0.67	3.61
Rhamphicarpa montana							0.07	0.03	-	0.07	0.03	-						
Bulbine abyssinica	0.07	0.08	-															
Cyperus laevigatus				0.07	0.08	-												
Kyllinga sp.				0.07	0.02	-												
Achyranthus aspera	0.07	0.02	-															
Leucas pratensis													0.07	0.03	-	0.07	0.02	-
Oxygonum sinuatum													0.07	0.08	-			
Angustifolia montana													0.13	0.03	-			
Aristida keniensis							0.07	0.02	-									
Setaria sphacelata				0.53	0.33	-												
Conyza schimperi													0.07	0.05	-			
Plectranthus barbatus																		
Euphorbia inaequilatera	0.27	0.83	-							0.33	1	-	0.53	0.25	-			
Cyperus rigidifolius							0.07	0.07	-									
Solanum incanum							0.07	0.02	-	0.2	0.08	-	0.13	0.05	-	0.13	0.03	-
Eragrostis racemosa	0.13	0.07	-	0.13	0.07	-	0.4	0.2	-	0.07	0.05	-				0.07	0.05	-
Tribulus terrestris										0.27	0.08	-						
Chenopodium procerum																0.27	0.02	-

APPENDIX 12: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the grazed area-January-April 1992

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
D. milanjiana / scalarum	0.4	-	8.1	0.6	-	8.01	0.53	-	7.51	0.73	-	15.89
Eragrostis tenuifolia	0.47	0.2	1.66				0.53	0.17	-	0.53	0.83	5.68
Harpachne schimperi	0.53	0.58	1.55	0.2	0.17	-	0.13	0.1	-			
Sida schimperiana				0.47	0.33	2.22	0.53	0.42	3.68	0.67	1.33	7.89
Indigofera spicata	0.27	0.1	-	0.13	0.07	-						
Chloris gayana	0.2	0.06	2.56	0.13	0.07	-	0.13	0.03	-			
Pennisetum cladestinum	0.13	-	-	0.07	-	-				0.2	-	4.62
Themeda triandra	0.27	-	-	0.2	-	1.51	0.13	-	2.61	0.47	-	6.71
Eragrostis mamoena							0.07	0.05	-			
Justacia sp.										0.2	0.01	-
Dyscoriste radicans										0.13	0.05	-
Conyza schimperi										0.07	0.03	-
Crotalaria incana										0.07	0.02	-
Crotalaria tanganyikensis										0.13	0.03	-
Cyperus sp	0.2	0.17	-	0.13	0.08	-				0.4	0.2	-
Aerva lanata	0.07	0.02	-	0.07	0.02	-	0.07	0.02	-	0.07	0.02	-
Crotalaria sp.										0.07	0.02	-
Conyza stricta										0.07	0.03	-
Cynodon dactylon										0.07	-	-
Setaria sphacelata				0.4	0.42	2.52	0.47	0.25	3.28			
Solanum incanum							0.07	0.03	-	0.07	0.02	-
Oxygonum sinuatum										0.07	0.17	-

APPENDIX 13: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the ungrazed area -April-December 1990

	April			May			June			July			Aug			Sept		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
D . milanjiana / scalarum	0.72	-	32.4	0.61	-	29.8	0.72	-	23.9	0.67	-	17.9	0.61	-	20.6	0.5	-	19.05
Eragrostis tenuifolia	0.33	0.22	-	0.28	0.11	-	0.44	0.15	-	0.33	0.14	-						
Harpachne schimperi	0.22	0.15	0.35	0.28	0.07	-	0.28	0.11	-	0.22	0.17	2.13	0.17	0.06	-			
Oldenlandia scopulorum	0.17	0.07	-	0.11	0.06	-				0.06	0.03	-						
Crotalaria incana							0.06	0.1	-									
Conyza schimperi										0.11	0.04	-				0.17	0.07	-
Polygala sphenoptera													0.06	0.01	-			
Themeda triandra	0.33	-	2.64	0.17	-	-	0.17	-	0.56	0.17	-	-				0.17	-	-
Aristida adoensis																		
Justacia sp.													0.22	0.01	-			
Satureia biflora	0.56	0.17	-	0.28	0.13	-	0.33	0.11	-									
Dyscoriste radicans	0.11	0.04	-	0.06	0.04	-							0.11	0.04	-	0.06	0.03	
Oxalis obliquifolia																		
Sida schimperiana	0.17	0.07	-															
Cymbopogon caesius	0.67	0.26	6.15	0.56	0.22	8.4	0.56	0.42	15.5	0.5	0.5	20.8	0.56	0.21	8.95	0.56	0.28	10.46
Cyperus sp.	0.11	0.06	-	0.06	0.08	-												
Commelina bengalensis	0.22	0.07	-	0.11	0.06	-	0.06	0.03	-									
Commelina reptens	0.11	0.03	-															
Chenopodium procerum	0.04	0.21	-															
Zornia setosa																0.06	0.01	-
Conyza stricta							0.06	0.03	-									
Pennisetum cladestinum																0.06	-	1.52
Kyllinga sp.							0.06	0.01	-									
Setaria sphacelata				0.22	0.11	2.56							0.17	0.07	0.67	0.11	0.06	1.23
Abutilon mauritianum				0.06	0.01	-	0.06	0.01	-				0.06	0.01	-			
Plectranthus barbatus				0.06	0.03	-	0.11	0.04	-	0.06	0.03	-	0.06	0.01	-			
Euphorbia inaequilatera				0.17	0.14	-				0.11	0.07	-						
Cyperus rigidifolius																0.06	0.07	-
Solanum incanum																0.06	0.03	-
Eragrostis racemosa							0.17	0.07	-									
Oxygonum sinuatum							0.11	0.07	-									
Hypoestes verticillaris							0.17	0.07	0.41	0.22	0.11	-	0.17	0.08	1.48			
Hyparrhenia lintonii							0.17	0.08	1.52									

APPENDIX 13: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the ungrazed area -April-December 1990 (continued)

	Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C
D . milanjiana / scalarum	0.56	-	20.6	0.78	-	24.2	0.67	-	15.9
Eragrostis tenuifolia	0.33	0.21	1.68						
Harpachne schimperi	0.22	0.14	-				0.56	0.28	-
Oldenlandia scopulorum				0.17	0.14	-			
Kyllinga sp.	0.06	0.04	-						
Indigofera spicata	0.17	0.07	-				0.22	0.08	-
Crotalaria sp.	0.06	0.03	-						
Themeda triandra	0.17	-	2.58	0.39	-	-	0.44	-	2.82
Crotalaria incana				0.06	0.01	-			
Justacia sp.				0.11	0.04	-			
Satureia biflora				0.28	0.13	-			
Dyscoriste radicans							0.11	0.06	-
Conyza schimperi				0.06	0.04	-			
Sida schimperiana									
Cymbopogon caesius				0.28	0.28	8.5	0.33	0.22	5.65
Cyperus sp.									
Commelina bengalensis									
Commelina reptens									
Chenopodium procerum									
Leucas pratensis									
Conyza stricta	0.11	0.06	-	0.06	0.03	-			
Pennisetum cladestinum									
Felicia muricata									
Setaria sphacelata	0.11	0.04	-	0.33	0.21	1.69	0.22	0.15	1.25
Abutilon mauritianum	0.06	0.01	-				0.06	0.01	-
Solanum incanum	0.06	0.04	-						

APPENDIX 14: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the ungrazed area-January-December 1991

	Jan			Feb			March			April			May			June		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
D . milanjiana / scalarum	0.67	-	11.7	0.53	-	9.87	0.73	-	8.89	0.73	-	25.8	0.67	-	28.7	0.6	-	35.12
Eragrostis tenuifolia	0.47	0.5	-	0.53	0.33	-	0.4	0.25	-				0.53	1.33	-	0.47	1.18	-
Harpachne schimperi	0.27	0.25	-							0.53	0.67	-	0.53	0.33	-	0.4	0.42	-
Oldenlandia scopulorum													0.4	0.83	-	0.07	0.13	-
Felicia muricata										0.33	0.17	-				0.27	0.17	-
Indigofera spicata	0.13	0.07	-	0.2	0.07	-	0.2	0.07	-				0.13	0.03	-	0.07	0.08	-
Chloris gayana	0.13	0.07	-															
Hyparrhenia lintonii				0.2	0.1	-												
Themeda triandra	0.4	-	2.84	0.33	-	3.68				0.53	-	-	0.4	-	5.87			
Cassia mimosoides										0.07	0.03	-	0.07	0.02	-			
Justacia sp.							0.07	0.02	-	0.2	0.02	-	0.27	0.13	-	0.13	0.05	-
Satureia biflora				0.33	0.17	-	0.27	0.13	-	0.33	0.25	-	0.33	0.13	-			
Dyscoriste radicans										0.4	0.17	-	0.2	0.08	-			
Oxalis obliquifolia													0.13	0.07	-	0.27	0.13	-
Sida schimperiana	0.47	0.5	-				0.4	0.42	1.69									
Cymbopogon caesius	0.53	0.67	8.75	0.53	0.58	10.5	0.53	0.47	11.2	0.67	0.6	21.9	0.67	0.83	20.5	0.53	0.8	18.66
Conyza filipendula	0.07	0.02	-															
Achyranthus aspera				0.07	0.02	-												
Eragrostis mamoena							0.07	0.02	-									
Crotalaria incana										0.07	0.02	-						
Leucas pratensis																		
Conyza stricta							0.07	0.03	-	0.13	0.07	-	0.2	0.1	-	0.07	0.02	-
Rhyncheltrum repens										0.07	-	-						
Kyllinga sp.				0.07	0.02	-										0.13	0.03	-
Oxygonum sinuatum																0.07	0.17	-
Abutilon mauritianum																0.07	0.02	-
Plectranthus barbatus							0.07	0.02	-	0.2	0.07	-	0.13	0.07	-			
Euphorbia inaequilatera													0.73	2.5	-	0.53	1.63	-
Cyperus rigidifolius										0.4	0.25	-	0.53	0.6	-			
Polygala sphenoptera																0.13	0.08	-
Eragrostis racemosa	0.13	0.08	-	0.13	0.02	-	0.07	0.05	-									
Helichrysum glumaceum																0.07	0.05	-
Hypoestes verticillaris				0.2	0.13	-	0.2	0.07	-									

APPENDIX 14: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the ungrazed area-January-December 1991 (continued)

	July			Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
D. milanjiana / scalarum	0.73	-	30.5	0.67	-	24.6	0.6	-	18.8	0.6	-	21.3	0.4	-	15.2	0.53	-	10.35
Eragrostis tenuifolia	0.53	0.82	-	0.42	0.58	-	0.4	0.35	-	0.33	0.5	-	0.47	0.35	-	0.47	0.5	-
Harpachne schimperi	0.4	0.35	-	0.33	0.5	-	0.27	0.5	-	0.27	0.33	-	0.33	0.33	-	0.4	0.33	-
Oldenlandia scopulorum													0.13	0.03	-	0.13	0.05	-
Indigofera ambalensis										0.4	0.5	-				0.13	0.17	-
Indigofera spicata	0.13	0.07	-										0.07	0.02	-			
Indigofera tanganyikensis										0.07	0.02	-				0.07	0.02	-
Ocimum suave							0.2	0.17	-				0.27	0.17	-	0.27	0.08	-
Themeda triandra													0.4	-	-	0.4	-	-
Aristida adoensis				0.13	0.13	-							0.07	0.02	-			
Justacia sp.							0.07	0.02	-									
Satureia biflora				0.2	0.2	-	0.2	0.1	-									
Dyscoriste radicans				0.07	0.07	-												
Conyza schimperi													0.07	0.02	-	0.07	0.02	-
Sida schimperiana				0.27	0.27	-				0.27	0.1	-	0.13	0.05	-			
Cymbopogon caesius	0.6	0.83	21.9	0.67	1	18.8	0.53	0.67	11.7	0.53	0.58	9.65	0.6	0.58	9.87	0.6	0.67	8.16
C. tanganyikensis	0.07	0.02	-															
Commelina benglensis	0.07	0.02	-	0.13	0.13	-				0.03	0.03	-						
Aerva lanata				0.07	0.07	-	0.07	0.02	-				0.07	0.03	-			
Phyranthus ratundifolius	0.07	0.05	-				0.07	0.02	-									
Leucas pratensis										0.07	0.03	-						
Conyza stricta	0.2	0.1	-													0.07	0.02	-
Eragrostis mamoena										0.27	0.05	-	0.2	0.05	-			
Commelina reptens										0.07	0.03	-				0.07	0.02	-
Crotalaria ambalensis				0.2	0.53	-	0.13	0.52	-									
Tribulus terrestris										0.13	0.08	-						
Plectranthus barbatus				0.07	0.02	-	0.07	0.02	-				0.07	0.02	-	0.07	0.02	-
Euphorbia inaequilatera	0.2	1.17	-	0.13	0.5	-	0.13	0.33	-									
Cyperus rigidifolius							0.2	0.17	-	0.2	0.13	-						
Solanum incanum	0.07	0.02	-	0.07	0.07	-	0.27	0.08	3.25				0.2	0.07	-			
Eragrostis racemosa																0.2	0.1	-
Helichrysum glumaceum	0.07	0.02	-															
Chenopodium procerum										0.4	0.2	-						

APPENDIX 15: Frequency (A), density (B) and percentage vegetation cover (C) of plants in the ungrazed area-January-April 1992

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
D. milanjiana / scalarum	0.47	-	8.68	0.53	-	4.11	0.53	-	10.1	0.67	-	16.11
Eragrostis tenuifolia	0.4	0.42	-	0.47	0.3	-	0.4	0.2	-	0.47	0.67	-
Harpachne schimperi	0.13	0.07	-									
Conyza schimperi										0.07	0.02	-
Indigofera spicata	0.13	0.02	-									
Kyllinga sp.				0.07	0.02	-						
Themeda triandra	0.33	-	1.79				0.4	-	-	0.4	-	5.87
Crotalaria incana										0.07	0.03	-
Justacia sp.							0.07	0.03	-	0.07	0.02	-
Satureia biflora				0.27	0.1	-	0.27	0.1	-			
Dyscoriste radicans							0.07	0.03	-	0.07	0.05	-
Sida schimperiana	0.07	0.03	-				0.33	0.33	4.25	0.33	0.33	8.68
Cymbopogon caesius	0.53	0.6	5.67	0.6	0.58	6.26	0.47	0.43	7.68	0.73	0.83	15.89
Ocimum suave	0.4	0.2	-	0.2	0.1	3.33	0.33	0.07	2.89	0.4	0.13	4.99
Conyza stricta	0.07	0.02	-							0.07	0.02	-
Abutilon mauritianum				0.07	0.02	-						
Plectranthus barbatus				0.13	0.03	-				0.07	0.02	-
Solanum incanum	0.07	0.02	-	0.07	0.03	-	0.13	0.05	-	0.07	0.02	-
Eragrostis racemosa	0.13	0.05	-	0.07	0.05	-						
Oxygonum sinuatum										0.2	0.17	-
Hypoestes verticillaris	0.07	0.03	-	0.13	0.03	2.36	0.13	0.13	-	0.2	0.1	-
Aerva lanata										0.07	0.02	-

APPENDIX 16

Above ground primary production g/m2/month - March 1990 - April 1992

Months	C. dactylon	D. milanjiana/scalarum	T. triandra	C. gayana	H. schimperi	E. tenuifolia
M	7	8	10	12	2	4
A	11	9	12	19	3	6
M	21	13	15	26	3	7
J	27	21	27	14	6	8
J	22	12	24	12	4	9
A	12	11	22	11	3	7
S	9	9	12	9	3	6
O	13	12	17	13	4	6
N	12	14	20	11	5	7
D	10	12	17	9	3	6
J	10	6	5	6		
F	7	5	4	5		
M	8	5	4	5		
A	17	18	14	9		
M	27	20	17	22		
J	30	10	12	13		
J	17	9	6	12		
A	13	9	6	11		
S	15	11	10	12		
O	19	13	11	12		
N	17	12	11	14		
D	12	11	9	12		
J	12	5	7	4		
F	11	5	6	4		
M	11	5	6	4		
A	16	12	13	13		

APPENDIX 17

Correlation between rainfall and primary production(g/m2/month)

Rainfall(mm)	C. dactylon	D. milanjiana /scalarum	T. triandra	C. gayana	H. schimperi	E. tenuifolia
192.1	21	9	15	19	6	7
147.3	27	13	27	26	4	8
157	22	21	24	14	3	9
22.6	12	12	22	12	3	7
28	9	11	12	11	4	6
41.1	13	9	17	9	5	6
12	12	12	20	13	3	7
63.4	10	14	17	11		6
43.7	10	12	5	9		
26.5	7	6	4	6		
15.71	8	5	4	5		
18.56	17	5	14	5		
74.45	27	18	17	9		
60.03	30	20	12	22		
79.89	17	10	6	13		
123.43	13	9	6	12		
7.31	15	9	10	11		
16.41	19	11	11	12		
52.08	17	13	11	12		
93.46	12	12	9	14		
30.21	12	11	7	12		
43.81	11	5	6	4		
13.31	11	5	6	4		
44.18	16	5	13	4		
24.03		12		13		
60.82						

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APPENDIX 18

Mean +/-S.E dead and live biomass(g/m2) - March 1990 - April 1992

Months	C. dactylon					D. milanjiana/scalarum			
	Dead biomass	S.E	Live biomass	S.E		Dead biomass	S.E	Live biomass	S.E
M	200	12	125	15		110	10	40	9
A	174	10	140	14		80	9	56	10
M	192	28	176	26		66	13	89	12
J	137	23	168	18		114	17	88	10
J	151	16	116	14		110	15	100	16
A	226	18	100	16		106	17	49	8
S	248	28	92	25		151	18	36	6
O	308	22	82	12		278	20	31	7
N	229	19	113	16		193	20	57	11
D	264	16	96	8		212	8	52	10
J	182	10	109	9		123	8	22	4
F	228	12	78	12		139	8	15	3
M	277	17	107	8		185	13	10	2
A	235	9	116	6		140	10	32	4
M	189	13	130	5		96	11	53	5
J	135	10	165	8		16	4	83	7
J	134	11	159	10		36	7	104	8
A	201	7	117	10		75	8	51	10
S	245	13	110	7		62	9	22	2
O	209	6	99	8		83	7	19	4
N	111	8	95	10		48	10	43	9
D	139	9	83	7		65	6	19	8
J	148	8	107	9		90	10	33	3
F	195	10	105	8		120	10	18	5
M	191	8	107	6		83	9	19	6
A	284	15	56	9		58	6	40	4

APPENDIX 18 (continued)

Mean +/-S.E dead and live biomass(g/m2) - March 1990 - April 1992

Months	T. triandra Dead biomass	S.E	Live biomass	S.E	C. gayana Dead biomass	S.E	Live biomass	S.E
M	200	10	25	3	72	6	38	4
A	172	12	29	4	67	8	47	6
M	140	14	41	12	57	5	48	4
J	142	5	97	5	63	8	55	5
J	164	8	50	9	79	7	42	6
A	198	14	42	10	59	4	38	5
S	184	14	19	8	72	7	31	4
O	265	21	23	10	84	8	32	3
N	175	16	59	6	75	5	26	5
D	205	13	39	8	85	6	29	4
J	198	9	22	6	98	6	22	2
F	226	10	15	3	174	12	15	1
M	186	11	3	1	134	9	42	5
A	156	8	23	4	125	6	46	4
M	128	9	41	7	116	8	52	6
J	107	5	61	5	57	4	53	6
J	88	4	54	8	74	10	53	8
A	88	6	34	7	75	7	35	7
S	100	6	24	4	127	12	48	5
O	158	12	16	4	180	10	52	4
N	111	8	34	6	80	11	37	7
D	108	7	21	3	76	12	24	3
J	121	9	52	8	102	8	63	11
F	125	12	27	5	110	11	40	3
M	195	7	15	5	120	8	41	8
A	212	6	18	6	115	10	48	5

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APPENDIX 19

Correlation between rainfall, dead and live grass biomass(g/m2)

		C. dactylon	D. milanjiana/scalarum		T. triandra		C. gayana	
Rainfall(mm)	Dead biomass	Live biomass	Dead biomass	Live biomass	Dead biomass	Live biomass	Dead biomass	Live biomass
192.1	200	176	110	89	200	41	72	47
147.3	174	168	80	88	172	97	67	48
157	192	116	66	100	140	50	57	55
22	137	100	114	49	142	42	63	42
28	151	92	110	36	164	19	79	38
41	226	82	106	31	198	23	59	31
12	248	113	151	57	184	59	72	32
63.4	308	96	278	52	265	39	84	26
43.7	229	109	193	22	175	22	75	29
26.5	264	78	212	15	205	15	85	22
15.71	182	107	123	10	198	3	98	15
18.56	228	116	139	32	226	23	174	42
74.45	277	130	185	53	186	41	134	46
60.03	235	165	140	83	156	61	125	52
79.89	189	159	96	104	128	54	116	53
123.43	135	117	16	51	107	34	57	53
7.31	134	110	36	22	88	24	74	35
16.41	201	99	75	19	88	16	75	48
52.08	245	95	62	43	100	34	127	52
93.46	209	83	83	19	158	21	180	37
30.21	111	107	48	33	111	52	80	24
43.81	139	105	65	18	108	27	76	63
13.31	148	107	90	19	121	15	102	40
44.18	195	56	120	40	125	18	110	41
24.03	191		83		195		120	48
60.82	284		58		212		115	

APPENDIX 20

Correlation between rainfall and decomposition rate(mg/g/day) of dead grass biomass

Rainfall(mm)	C. dactylon	D. milanjiana/scalarum	T. triandra	E. tenuifolia	H. schimperi	C. gayana
192.1	3	1	1	1	2	1
147.3	4	4	2	2	3	2
157	5	5	2	2	4	1
22.6	6	1	1	1	2	2
28	5	3	2	1	3	2
41.1	5	3	2	1	3	1
12	3	2	4	3	4	3
63.4	2	4	3	3	2	3
43.7	3	3	2	1	2	3
26.5	3	3	3	1	3	3
15.71	4	4	4	3	4	4
18.56	2	2	4	3	4	2
74.45	2	3	2	2	2	2
60.03	4	3	3	4	3	2
79.89	5	5	5	4	4	5
123.43	3	5	3	2	2	4
7.31	4	2	4	2	4	4
16.41	4	4	5	5	5	5
52.08	3	3	3	3	4	3
93.46	3	3	3	2	3	3
30.21	3	2	3	2	4	3
43.81	2	3	3	4	4	4
13.31	4	4	5	2	4	4
44.18	3	2	3	2	3	3
24.03	4	3	4	3	3	2
60.82	4	4	3	3	2	2

APPENDIX 21

Monthly summed counts of the six most common herbivore species in the three study areas - Feb. 1990 - April 1992

Months	Kongoni	Zebra	Thomson's gaz.	Impala	Grant's gaz.	Eland
F	734	486	1161	265	243	283
M	1077	1128	757	319	198	348
A	1335	1297	900	352	252	558
M	1787	1164	1397	418	239	419
J	1593	1527	1457	379	273	546
J	1365	1260	1137	340	260	328
A	1547	1134	1219	222	272	269
S	975	838	891	174	245	245
O	1189	893	923	316	220	357
N	1322	968	1245	333	249	556
D	970	852	995	345	191	285
J	1025	731	666	253	173	105
F	609	707	416	249	126	134
M	943	616	327	244	132	132
A	646	559	1203	323	170	166
M	956	718	1466	311	219	184
J	1368	1240	1406	371	236	232
J	1226	1061	667	256	230	75
A	923	918	877	246	166	222
S	1181	826	840	205	241	120
O	1191	767	1056	339	271	205
N	1245	911	1167	297	269	143
D	1404	896	1186	342	374	133
J	890	764	833	331	311	119
F	1398	1034	1209	342	303	101
M	878	639	1161	314	267	92
A	1872	1399	1770	417	280	730

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APPENDIX 22

Monthly percentage population structure of kongoni in the three study areas - Feb. 1990 - April 1992

	Park			Kedong			Kongoni		
Months	Adults	Sub-adults	Juv.	Adults	Sub-adults	Juv.	Adults	Sub-adults	Juv.
F	66	9	25	73	10	17	75	7	18
M	79	6	15	78	3	19	83	4	13
A	77	6	17	82	5	13	69	5	26
M	74	7	19	77	6	17	72	6	22
J	76	9	15	80	6	14	75	6	19
J	74	11	15	77	6	17	79	5	16
A	78	5	17	77	6	17	86	3	11
S	71	10	19	69	7	24	76	5	19
O	80	7	13	74	7	19	71	7	22
N	75	6	19	79	4	17	70	6	24
D	74	4	22	83	4	13	68	11	21
J	70	13	17	80	4	16	86	6	8
F	69	9	22	80	7	13	94	2	14
M	85	6	9	82	6	12	85	4	11
A	80	8	12	81	4	15	85	2	13
M	82	5	13	84	5	11	81	3	16
J	74	8	18	82	7	11	71	6	23
J	79	8	13	87	3	10	77	8	15
A	85	3	12	82	6	12	81	7	12
S	82	6	12	86	4	10	81	8	11
O	89	3	8	87	4	9	91	3	6
N	91	3	6	88	3	9	86	5	9
D	90	5	5	90	2	8	80	9	11
J	81	5	14	94	3	3	83	5	12
F	81	7	12	84	5	11	87	3	10
M	84	5	11	88	1	11	81	8	11
A	82	3	15	87	1	12	82	11	7

APPENDIX 23

Monthly percentage population structure of zebra in the three study areas - Feb. 1990 - April 1992

	Park			Kedong			Kongoni		
Months	Adults	Sub-adults	Juv.	Adults	Sub-adults	Juv.	Adults	Sub-adults	Juv.
F	72	20	8	76	15	9	76	14	10
M	81	14	5	79	15	16	83	4	13
A	93	4	3	81	11	8	86	7	7
M	76	17	7	78	12	10	82	10	8
J	70	19	11	75	10	15	84	8	8
J	63	23	14	73	12	15	84	8	8
A	79	10	11	75	11	14	84	8	8
S	75	17	8	61	15	24	84	8	8
O	78	15	7	74	11	15	79	12	9
N	64	30	6	71	14	15	76	15	9
D	83	7	10	71	14	15	82	11	7
J	76	17	7	79	12	9	80	15	5
F	83	10	7	81	14	5	85	8	7
M	88	5	7	74	16	10	75	16	9
A	83	11	6	75	17	8	81	11	8
M	81	12	7	76	12	12	79	12	9
J	78	15	7	79	13	8	80	12	8
J	80	9	11	74	20	6	65	26	9
A	82	12	6	80	11	9	83	13	4
S	84	11	5	78	13	9	85	13	2
O	90	7	3	87	4	9	87	9	4
N	91	7	2	84	11	5	85	10	5
D	78	19	3	74	22	4	67	24	9
J	83	15	2	83	14	3	85	11	4
F	74	2	6	88	10	2	80	16	4
M	84	12	4	82	13	5	83	14	3
A	84	15	1	82	16	2	81	15	4

APPENDIX 24

Monthly percentage population structure of Thomson's gazelle in the three study areas- Feb.1990 - April 1992

	Park			Kedong			Kongoni		
Months	Adults	Sub-adults	Juv.	Adults	Sub-adults	Juv.	Adults	Sub-adults	Juv.
F	80	16	4	81	12	7	83	10	7
M	84	13	3	78	13	9	83	6	11
A	83	12	5	83	10	7	89	4	7
M	79	16	5	85	11	4	88	6	6
J	78	14	8	87	10	3	87	7	6
J	78	15	7	87	10	3	89	5	6
A	90	7	3	89	8	3	85	10	5
S	82	9	9	88	9	3	92	5	3
O	84	8	8	90	8	2	86	8	6
N	87	11	2	80	12	8	83	10	7
D	76	11	13	81	10	9	72	19	9
J	86	11	3	92	4	4	80	5	15
F	82	9	9	85	11	4	79	12	9
M	85	12	3	93	3	4	75	14	11
A	90	4	6	97	2	1	91	6	3
M	85	12	3	93	6	1	87	8	5
J	85	6	9	94	5	1	91	5	4
J	85	9	6	92	6	2	72	13	15
A	82	13	5	94	5	1	86	10	4
S	70	17	13	88	11	1	84	13	3
O	87	10	3	90	8	2	82	14	4
N	82	13	5	91	7	2	79	17	4
D	75	13	12	86	13	1	74	21	5
J	77	15	8	87	11	2	77	18	5
F	84	12	4	87	12	1	71	26	3
M	80	17	3	83	14	3	81	13	6
A	78	12	10	90	9	1	94	2	4

APPENDIX 25

Monthly percentage population structure of Grant's gazelle in the three study areas - Feb. 1990 - April 1992

		Park				Kedong				Kongoni	
Months	Adults	Sub-adults	Juv.		Adults	Sub-adults	Juv.		Adults	Sub-adults	Juv.
F	64	21	15		59	27	14		61	25	14
M	60	24	16		64	24	10		56	29	15
A	70	16	14		71	25	4		64	22	14
M	74	14	12		61	28	11		61	28	11
J	79	14	7		78	13	9		61	29	10
J	56	40	4		83	10	7		59	32	9
A	65	24	11		87	9	4		65	28	7
S	50	46	4		71	18	11		68	23	9
O	48	46	6		73	18	9		67	26	7
N	61	37	2		68	28	4		68	25	7
D	59	35	6		75	18	7		65	30	5
J	57	36	7		84	11	5		79	17	4
F	64	30	6		71	22	7		75	20	5
M	49	43	8		68	21	11		77	19	4
A	64	26	10		75	18	7		74	21	5
M	63	35	2		73	19	8		69	25	6
J	64	28	8		80	13	7		73	22	5
J	60	31	9		66	26	8		68	28	4
A	62	28	10		65	24	11		74	23	3
S	64	25	11		73	22	5		71	25	4
O	53	41	6		60	34	6		71	27	2
N	52	39	9		80	16	4		68	29	3
D	56	39	5		73	23	4		70	28	2
J	72	24	4		74	23	3		69	28	3
F	80	17	3		64	32	4		69	27	4
M	64	31	5		74	16	10		71	25	4
A	61	31	8		76	19	5		70	27	3

APPENDIX 26

Monthly percentage population structure of eland in the three study areas - Feb. 1990 - April 1992

	Park			Kedong			Kongoni		
Months	Adults	Sub-adults	Juv.	Adults	Sub-adults	Juv.	Adults	Sub-adults	Juv.
F	56	28	16	45	21	34	54	14	32
M	56	27	17	51	19	30	57	10	33
A	59	29	12	63	17	20	58	14	28
M	60	25	15	55	14	31	55	12	33
J	51	19	30	60	10	30	44	13	43
J	54	21	25	55	12	33	50	12	38
A	55	34	11	58	10	32	60	16	24
S	57	23	20	64	10	26	66	14	20
O	62	20	18	68	6	26	74	10	16
N	59	24	17	57	18	25	73	12	15
D	53	27	20	48	24	28	77	11	12
J	50	33	17	50	23	27	68	22	10
F	63	23	14	45	27	28	71	21	8
M	61	20	19	41	28	31	46	38	16
A	59	23	18	45	25	30	41	25	34
M	68	21	11	56	16	28	54	18	28
J	69	18	13	57	19	24	46	23	31
J	53	17	30	61	17	22	59	19	22
A	52	16	32	57	26	17	55	31	14
S	63	21	16	56	22	22	58	27	15
O	61	25	14	67	16	17	70	21	9
N	67	20	13	76	10	14	68	23	9
D	69	17	14	71	18	11	72	20	8
J	65	20	15	60	23	17	62	25	13
F	57	24	19	71	15	14	68	21	11
M	55	20	25	52	34	14	69	17	14
A	49	18	33	52	27	21	65	21	14

APPENDIX 27

Monthly percentage population structure of impala in Kedong and Kongoni Ranches - Feb.1990 - April 1992

	Kedong Ranch				Kongoni Ranch		
Months	Adults	Sub-adults	Juv.		Adults	Sub-adults	Juv.
F	69	21	10		56	28	16
M	77	17	6		58	29	13
A	71	20	9		70	22	8
M	62	24	14		73	20	7
J	57	26	17		75	17	8
J	63	24	13		78	16	6
A	68	21	11		75	18	7
S	70	17	13		73	20	7
O	79	13	8		81	10	9
N	74	15	11		75	14	11
D	75	19	6		75	14	11
J	83	10	7		76	15	9
F	82	11	7		62	26	12
M	82	10	8		76	19	5
A	77	10	13		69	26	5
M	74	16	10		67	26	7
J	77	20	3		69	26	5
J	78	16	6		64	32	4
A	81	12	7		77	16	7
S	79	11	10		76	17	7
O	80	9	11		73	22	5
N	80	11	9		71	25	4
D	85	8	7		67	27	6
J	81	10	9		76	21	3
F	81	13	6		76	20	4
M	78	15	7		75	22	3
A	77	17	6		79	16	5

APPENDIX 28

Monthly summed biomass(kg) of the most common herbivore species in the three study areas - Feb. 1990 - April 1992

Months	Kongoni	Zebra	Thomson's gaz.	Impala	Grant's gaz.	Eland
F	99824	115668	23220	11925	12150	102729
M	146472	268464	15140	14355	9900	126324
A	181560	308686	18000	15840	12600	202554
M	243032	277032	27940	18810	11950	152097
J	216648	363426	29140	17055	13650	198198
J	185640	299880	22740	15300	13000	119064
A	210392	269892	24380	9990	13600	97647
S	132600	199444	17820	7830	12250	88935
O	161704	212534	18460	14220	11000	129591
N	179792	230384	24900	14985	12450	201828
D	118320	202776	19900	15525	9550	103455
J	139400	173978	13320	11385	8650	38115
F	82824	168266	8320	11205	6300	48642
M	128248	146608	6540	10980	6600	47916
A	87856	133042	24060	14535	8500	60258
M	130016	170884	29320	13995	10950	66792
J	186048	295120	28120	16695	11800	84216
J	166736	252518	13340	11520	11500	27225
A	125528	218484	17540	11070	8300	80586
S	106616	196588	16800	9225	12050	43560
O	161976	182546	21120	15255	13550	74415
N	169320	216818	23340	13365	13450	51909
D	190944	213248	23720	15390	18700	48279
J	121040	181832	16660	14895	15550	43197
F	190128	246092	24180	15390	15150	36663
M	119408	152082	23220	14130	13350	33396
A	254592	332962	35400	18765	14000	264990

APPENDIX 29: Water trough number 1: Trampled area - April-December 1990, A= Frequency, B= density/m2 and C= Percentage cover

	April			May			June			July			Aug			Sept		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88	-	45.5	0.88	-	56	0.88	-	54	0.88	-	55.5	0.87	-	36.5	0.88	-	21.5
Cynodon dactylon	0.4	-	15.5	0.38	-	5.5	0.38	-	6.75	0.25	-	4.5	0.5	-	5.5	0.75	-	6
Themeda triandra	0.2	-	1.1	0.5	-	4	0.75	-	4	0.75	-	4.25	0.65	-	2.25	0.25	-	0.75
Felicia muricata	0.75	2	-	0.6	0.41	0.25	0.63	0.34	0.25	0.63	0.53	3.75	0.6	0.56	3.25	0.5	0.53	2.5
Crotalaria tanganyikensis	0.13	0.09	-	0.03	0.43	-	0.38	0.09	-	0.75	0.22	-	0.13	0.16	0.05			
Indigofera spicata	0.13	0.09	-	0.2	0.78	1.56	0.5	0.91	2.25	0.13	0.94	0.5	0.38	0.52	1.25	0.38	0.28	0.5
Euphorbia inaequilatera	0.14	0.31	-	0.5	2	-	0.5	2.09	-	0.75	2.22	0.25	0.6	0.25	-	0.38	0.25	-
Solanum incanum	0.2	0.22	-	0.5	0.5	-	0.5	0.56	1	0.38	0.56	0.5	0.34	0.38	0.35	0.38	0.16	0.25
Justacia sp.	0.38	0.16	-	0.13	0.4	-	0.38	0.41	-	0.5	0.38	0.25	0.25	0.38	-	0.13	0.03	-
Cyperus rigidifolius	0.12	0.06	-	0.38	0.25	-	0.38	0.28	-	0.25	0.09	-	0.15	0.06	-			
Hypoestes verticillaris	0.25	0.09	-	0.3	0.16	-	0.25	0.16	0.25	0.25	0.16	-	0.18	0.18	-	0.25	0.25	-
Eragrostis tenuifolia	0.75	0.63	1.75	0.38	0.16	0.2	0.38	0.16	0.25	0.25	0.16	0.25	0.36	0.16	0.3	0.38	0.16	0.5
Harpachne schimperi	0.75	1	0.16	0.75	1	2.58	0.75	1.28	3.25	0.75	1.19	1.5	0.65	1	1.15	0.63	0.75	1
Indigofera tanganyikensis	0.75	0.38	-	0.63	1.6	-	0.63	1.66	-	1	0.94	-	0.75	0.56	-	0.5	0.13	-
Rhamphicarpa montana	0.14	0.09	-													0.13	0.06	-
Panicum maximum				0.13	0.16	-	0.13	0.16	0.5	0.13	0.13	1.5				0.13	0.16	-
Oxygonum sinuatum				0.13	0.06	-	0.13	0.6	-									
Oldenlandia scopulorum	0.2	0.16	-				0.25	0.19	-	0.13	0.06	-				0.13	0.06	-
Monchma dabile							0.25	0.06	-	0.13	0.03	-						
Crotalaria incana										0.13	0.03	-				0.13	0.03	-
Chloris gayana										0.25	0.09	-						
Crotalaria grantii										0.13	0.06	0.25						
Crotalaria spinosa										0.25	0.06	-						
Crotalaria sp.										0.25	0.13	-						
Conyza stricta																0.13	0.06	-
Indigofera ambalensis																		
Cassia grantii																		
Commelina africana																		
Pennisetum cladestinum																		
Sida schimperiana																		
Datura stramonium																		

APPENDIX 29: Water trough number 1: Trampled area - April-December 1990 (continued)

Species	Oct A	Oct B	Oct C	Nov A	Nov B	Nov C	Dec A	Dec B	Dec C
Digitaria milanjiana	0.88	-	20.75	0.88	-	27.75	0.88	-	15.6
Cynodon dactylon	0.25	-	1.5	0.25	-	1	0.13	-	-
Themeda triandra	0.88	-	2.75	0.75	-	3.5	0.63	-	2.1
Felicia muricata	0.5	0.59	1.5	0.63	1.03	4	0.63	0.63	-
Crotalaria tanganyikensis	0.25	0.06	-						
Indigofera spicata	0.25	0.66	0.25	0.25	0.66	-	0.13	0.09	-
Euphorbia inaequilatera	0.25	0.09	-	0.38	0.16	-	0.38	0.19	-
Solanum incanum	0.13	0.13	-	0.5	0.38	-	0.38	0.31	-
Justacia sp.	0.13	0.09	-	0.38	0.22	-	0.25	0.03	-
Cyperus rigidifolius	0.13	0.03	-	0.5	0.47	-	0.25	0.09	-
Hypoestes verticillaris	0.13	0.06	-						
Eragrostis tenuifolia				0.5	0.94	-	0.38	0.81	-
Harpachne schimperi	0.63	0.94	0.5	0.88	1.41	0.75	0.88	0.56	-
Indigofera tanganyikensis	0.38	0.19	-	0.5	0.13	-			
Rhamphicarpa montana				0.13	0.03	-	0.13	0.03	-
Panicum maximum									
Oxygonum sinuatum				0.13	0.16	-			
Oldenlandia scopulorum				0.38	0.16	-			
Monchma dabile									
Crotalaria incana									
Chloris gayana									
Crotalaria grantii				0.25	0.31	-			
Crotalaria spinosa									
Crotalaria sp.									
Conyza stricta									
Indigofera ambalensis				0.63	0.34	-	0.38	0.31	-
Cassia grantii							0.13	0.16	-
Commelina africana				0.13	0.03	-			
Pennisetum cladestinum				0.13	-	2			
Sida schimperiana									
Datura stramonium									

APPENDIX 30:	Water trough number 1: Untrampled area - April-December 1990, F= Frequency, B= Density/m2 and C= Percentage cover																	
		April			May			June			July			Aug			Sept	
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.88	-	42.7	1	-	60.5	0.88	-	62.3	1	-	67	1	-	55.6	1	-	43.3
Cynodon dactylon	0.38	-	3.55	0.5	-	21.6	0.5	-	19.5	0.38	-	7.25	0.5	-	27.5	0.5	-	25.5
Themeda triandra	0.4	-	1.48	0.25	-	1.15	0.38	-	1	0.75	-	1.5	0.6	-	2.15	0.38	-	2.25
Felicia muricata	0.5	0.38	0.25	0.75	3	3.5	0.75	1.28	3.75	0.88	3.44	15	0.75	3	7.75	0.75	1.78	8.75
Crotalaria tanganyikensis	0.75	1.09	-	0.13	0.09	-	0.13	0.03	-	0.25	0.19	0.5	0.6	0.19	-			
Indigofera spicata	0.14	0.31	1	0.14	0.06	-	0.13	0.03	-	0.38	0.13	-	0.38	0.5	-	0.25	0.28	1.5
Euphorbia inaequilatera	0.5	1.44	-	0.13	0.25	-	0.25	0.19	-	0.38	0.5	-	0.2	0.41	-	0.13	0.06	-
Solanum incanum	0.5	0.41	-	0.25	0.31	-	0.25	0.59	1.5				0.2	0.28	-	0.13	0.09	-
Justacia sp.	0.13	0.28	-	0.88	0.13	-	0.38	0.19	0.5	0.5	0.28	0.25	0.4	0.19	-	0.38	0.16	-
Cyperus rigidifolius	0.38	0.13	-	0.13	0.06	-	0.13	0.03	-	0.38	0.16	-				0.13	0.9	5.25
Panicum maximum	0.13	0.09	-															
Eragrostis tenuifolia	0.4	0.19	0.35	0.75	1.03	2.65	0.5	1.25	3.75	0.75	2.28	2.5	0.5	1	2	0.25	0.09	0.75
Harpachne schimperi	0.75	1	1.82	0.8	1.5	0.15	0.25	0.41	0.5	0.88	1.97	-	0.6	1	-	0.68	0.53	0.5
Indigofera tanganyikensis	0.3	0.06	-	0.75	0.56	-	0.62	0.47	0.25	0.88	0.94	-	0.5	0.28	-	0.13	0.03	-
Rhamphicarpa montana				0.13	0.09	-				0.13	0.03	-						
Conyza schimperi																0.25	0.06	-
Aristida keniensis							0.25	0.06	-	0.38	0.16	-	0.15	0.06	-			
Oldenlandia scopulorum	0.13	0.06	-							0.13	0.03	-						
Monchma dabile				0.13	0.09	-										0.13	0.03	-
Crotalaria incana							0.13	0.03	-									
Chloris gayana										0.25	0.13	-				0.38	0.16	12.5
Crotalaria grantii							0.13	0.03	-									
Crotalaria spinosa							0.13	0.09	-									
Crotalaria sp.							0.25	1.01	4.25	0.13	0.03	-	0.13	0.03	-			
Satureia biflora										0.25	0.09	-						
Indigofera ambalensis																		
Cassia grantii																		
Commelina africana																		
Amaranthus hybridus																		
Sida schimperiana	0.13	0.03	-	0.13	0.03	-	0.38	0.09	-	0.13	0.03	0.5				0.38	0.19	-
Heliotropium steudneri							0.13	0.09	-									

APPENDIX 30: Water trough number 1: Untrampled area - April-December 1990 (continued)

	Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	1	-	28.3	1	-	35	1		18.27
Cynodon dactylon	0.63	-	28.3	0.88	-	32.3	0.75		24.56
Themeda triandra	0.25	-	0.5	0.5	-	1.75	0.38		-
Felicia muricata	0.75	2.69	10	0.75	1.78	4.75	0.75		3.89
Crotalaria tanganyikensis	0.63	0.44	-						
Indigofera spicata	0.38	0.78	0.05	0.5	0.41	-			
Euphorbia inaequilatera	0.25	0.09	-	0.25	0.09	-			
Solanum incanum	0.25	0.19	0.25	0.25	0.38	-	0.25	0.22	-
Justacia sp.	0.13	0.16	0.25	0.13	0.06	-			
Cyperus rigidifolius	0.25	0.09	-	0.13	0.03	-			
Hypoestes verticillaris	0.25	0.09	-						
Eragrostis tenuifolia	0.5	0.28	-	0.5	0.47	-	0.5	0.63	-
Harpachne schimperi	0.5	0.78	-	0.5	3	1.75	0.38	0.63	-
Indigofera tanganyikensis	0.38	0.09	-	0.38	0.22	-			
Cyperus sp.				0.38	0.16	2.75	0.25	0.09	-
Conyza schimperi	0.13	0.03	-						
Oxygonum sinuatum									
Oldenlandia scopulorum									
Monchma dabile									
Crotalaria incana									
Chloris gayana	0.13	0.03	-						
Crotalaria grantii				0.13	0.03	-			
Crotalaria spinosa									
Crotalaria sp.									
Conyza stricta	0.13	0.03	-						
Indigofera ambalensis				0.5	0.16	-			
Rhamphicarpa montana									
Commelina africana									
Amaranthus hybridus									
Sida schimperiana	0.13	0.06	0.25	0.63	0.28	1.25	0.63	0.25	2.14
Heliotropium steudneri									

APPENDIX 31:	Water trough number 1: Trampled area - January-December 1991, A= Frequency, B= Density/m2 and C= Percentage cover																	
	Jan			Feb			March			April			May			June		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88	-	10.5	0.75	-	4.25	0.88	-	5.75	0.88	-	21.3	0.88	-	24.5	0.88	-	41.8
Cynodon dactylon	0.25	-	-	0.38	-	3.25	0.25	-	-	0.38	-	1	0.38	-	1.75			
Themeda triandra	0.75	-	2	0.63	-	-	0.25	-	-	0.63	-	1.25	0.5	-	-	0.5	-	2.25
Felicia muricata	0.63	0.47	-	0.5	0.22	1.75	0.5	0.5	1.5	0.75	1.31	4.25	0.75	1.69	3	0.63	1.34	2.25
Eragrostis mamoena																0.13	0.09	-
Indigofera spicata	0.13	0.13	-				0.25	0.06	-	0.25	0.09	-	0.5	5.94	-	0.03	0.44	0.75
Euphorbia inaequilatera	0.63	0.34	-	0.25	0.09	-				0.25	0.41	-	0.88	4.63	-	0.88	13.8	1.75
Solanum incanum	0.5	0.34	-	0.25	0.09	-							0.25	0.19	-	0.13	0.19	0.5
Justacia sp.	0.25	0.06	-	0.13	0.06	-				0.25	0.13	-	0.38	0.34	-	0.13	0.06	-
Cyperus rigidifolius	0.25	0.06	-							0.25	0.13	-	0.13	0.13	-	0.25	0.19	-
Hypoestes verticillaris																		
Eragrostis tenuifolia	0.38	0.66	-	0.13	0.06	-							0.13	0.03	-	0.38	0.44	-
Harpachne schimperi	0.88	0.81	-	0.63	0.41	-				0.63	0.31	-	0.38	0.38	-	0.5	0.78	-
Indigofera tanganyikensis										0.13	0.06	-				0.25	0.09	-
Rhamphicarpa montana										0.13	0.03	-				0.13	0.03	-
Aristida keniensis																0.13	0.13	-
Oxygonum sinuatum	0.13	0.03	-							0.13	0.03	-	0.13	0.5	-	0.5	0.34	-
Oldenlandia scopulorum										0.13	0.06	-				0.13	0.06	-
Aristida adoensis																0.13	0.06	-
Crotalaria incana																0.25	0.22	-
Chloris gayana	0.13	0.06	-															
Crotalaria grantii	0.13	0.13	-										0.13	0.06	-	0.25	0.28	-
Angustifolia montana																0.13	0.03	-
Crotalaria sp.																		
Conyza stricta																		
Indigofera ambalensis	0.38	0.38	-	0.25	0.09	-				0.25	0.06	-	0.25	0.19	-	0.88	13.6	-
Cassia grantii										0.13	0.03	-						
Commelina africana													0.13	0.06	-	0.13	0.09	-
Pennisetum cladestinum																		
Sida schimperiana	0.13	0.03	-															
Datura stramonium																0.13	0.03	-

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APPENDIX 31: Water trough number 1: Trampled area - January-December 1991 (continued)

	July			Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88	-	42.8	0.88	-	23.5	0.88	-	6	0.88	-	11.6	0.88	-	20.8	0.75	-	19
Cynodon dactylon	0.13	-	5.25	0.13	-	2.25	0.13	-	2.5	0.13	-	1.4	0.13	-	3	0.13	-	-
Themeda triandra	0.63	-	3.5	0.5	-	1.25	0.13	-	1.25				0.5	-	2.5	0.5	-	1
Felicia muricata	0.75	1.09	2.25	0.63	0.81	0.5	0.75	1.69	3.75	0.75	0.94	3	0.75	0.91	3.25	0.63	2.53	2.5
Crotalaria tanganyikensis																		
Indigofera spicata	0.13	0.34	-	0.13	0.03	0.5	0.25	0.44	-	0.25	0.63	-	0.38	1.25	-	0.63	1.53	-
Euphorbia inaequilatera	1	9.41	1.25	0.88	0.88	-				0.25	0.25	-	0.5	0.75	-	0.63	2.16	1
Solanum incanum	0.13	0.06	-										0.13	0.09	-	0.38	0.09	-
Justacia sp.	0.25	0.13	-	0.25	0.06					0.25	0.06	-	0.63	0.28	-	0.5	0.16	-
Cyperus rigidifolius	0.13	0.13	-							0.13	0.06	-	0.13	0.16	-			
Hypoestes verticillaris																		
Eragrostis tenuifolia	0.13	0.13	-	0.13	0.09	-				0.25	0.31	-	0.5	1.13	0.25	0.75	4.84	0.5
Harpachne schimperi	0.63	0.81	1	0.63	0.59	-	0.13	0.41	-	0.38	0.56	-	0.75	1.25	-	0.63	0.47	0.5
Indigofera tanganyikensis	0.38	0.5	-										0.25	0.09	-	0.38	0.13	-
Aristida keniensis																0.25	0.28	-
Leucas pratensis				0.13	0.03	-												
Oxygonum sinuatum	0.13	0.06	-	0.13	0.03	-							0.25	0.09	-			
Oldenlandia scopulorum																		
Monchma dabile																		
Crotalaria incana				0.25	0.06	-												
Chloris gayana							0.13	0.06	-							0.13	0.03	0.25
Crotalaria grantii	0.25	0.06	-	0.25	0.09	-							0.38	0.09	-	0.25	0.06	-
Chenopodium procerum	0.13	0.06	-															
Crotalaria sp.																		
Conyza stricta																		
Indigofera ambalensis	0.88	13.8	5.25	0.88	9.19	1.75				0.75	4.69	-	1	6.72	1.75	0.63	4.56	1.5
Cassia grantii										0.13	0.09	-						
Commelina reptens	0.13	0.03	-															
Angustifolia montana	0.13	0.03	-															
Sida schimperiana													0.13	0.06	-	0.13	0.06	-
Datura stramonium																		

APPENDIX 32: Water trough number 1: Untramped area - January-December 1991, A= Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April			May			June		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	1	-	23.5	1	-	13.8	1	-	30.8	0.88	-	15.3	1	-	12	0.75	-	18.3
Cynodon dactylon	0.88	-	22.3	0.75	-	32	0.5	-	23	0.5	-	22.8	0.63	-	16.8	0.5	-	36
Themeda triandra	0.5	-	-	0.38	-	-	0.38	-	0.75	0.38	-	-	0.25	-	-	0.38	-	-
Felicia muricata	0.88	2.28	4.75	0.75	1.22	1.5	0.38	0.91	-	0.75	1.28	2.25	0.63	1.22	3	0.63	2.25	7.75
Commelina africana										0.13	0.03	-						
Indigofera spicata	0.5	0.66	-	0.5	1.22	-	0.13	0.16	-	0.13	0.09	-	0.38	1.31	-	0.5	1.19	-
Euphorbia inaequilatera	0.25	0.16	-										0.5	0.5	-	0.88	4.09	-
Solanum incanum	0.38	0.31	-	0.25	0.22	-				0.38	0.31	-	0.38	0.44	-	0.13	0.25	-
Justacia sp.	0.38	0.16	-	0.13	0.03	-							0.13	0.06	-	0.5	0.16	-
Cyperus rigidifolius	0.13	0.06	-							0.25	0.22	-	0.25	0.09	-	0.13	0.16	-
Hypoestes verticillaris																0.13	0.03	-
Eragrostis tenuifolia	0.38	1.88	-	0.13	0.09	-				0.25	0.5	-	0.13	1.25	0.5	0.38	0.13	-
Harpachne schimperi	0.5	0.44	-	0.38	0.13	-	0.13	0.03	-	0.13	0.03	-	0.38	0.34	-	0.13	0.13	-
Indigofera tanganyikensis	0.13	0.06	-	0.13	0.03	-				0.13	0.03	-				0.25	0.13	-
Rhamphicarpa montana													0.13	0.13	-			
Conyza sp.	0.03	0.06	-															
Oxygonum sinuatum													0.13	0.56	-	0.13	0.16	-
Oldenlandia scopulorum													0.13	0.03	-			
Cyperus sp.	0.25	0.31	-							0.13	0.31	-	0.25	0.22	-	0.5	0.06	-
Angustifolia montana													0.13	0.03	-			
Chloris gayana	0.38	0.13	-	0.13	0.06	0.25	0.09	-		0.13	0.03	-	0.13	0.03	-	0.13	0.06	-
Eleusine africana																0.13	0.06	-
Leucas pratensis																0.13	1.97	-
Amaranthus hybridus																0.38	0.22	-
Tribulus terrestris																0.13	0.03	-
Indigofera ambalensis	0.13	0.09	-							0.13	0.03	-				0.38	3.94	-
Cassia grantii	0.13	0.03	-							0.13	0.28	-	0.13	0.06	-	0.25	0.16	-
Solanum nigrum																0.13	0.03	-
Aristida keniensis																0.13	0.03	-
Sida schimperiana	0.5	0.31	2.25	0.13	0.06	-	0.13	0.13	-	0.25	0.09	1.5	0.25	0.16	1	0.13	0.13	-
Aerva lanata	0.13	0.03	-	0.13	0.06	-							0.13	0.03	-	0.38	0.09	-

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APPENDIX 32: Water trough number 1: Untrampled area - January-December 1991 (continued)

	Jul			Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.88	-	31.8	1	-	22.3	1	-	9.75	0.75	-	13.9	0.6	-	22	0.88	-	19.8
Cynodon dactylon	0.5	-	31.8	0.5	-	25	0.5	-	23	0.5	-	30.1	0.8	-	45.2	0.5	-	24.3
Themeda triandra	0.5	-	-	0.5	-	1.75	0.38	-	1.25							0.5	-	2.25
Felicia muricata	0.75	1.09	9.5	0.63	0.78	1	0.88	1.97	3.75	0.5	1.56	1.82	0.4	0.4	1.2	0.75	1.09	1.25
Crotalaria tanganyikensis																		
Indigofera spicata	0.25	0.19	-	0.25	0.16	-	0.25	0.19	-				0.2	0.15	-	0.38	0.88	0.5
Euphorbia inaequilatera	0.75	3.81	-	0.38	0.41	-							0.6	2.75	-	0.5	7.65	1
Solanum incanum	0.25	0.25	1.5	0.25	0.09	-							0.4	0.15	-	0.38	0.41	-
Justacia sp.	0.13	0.03	-				0.13	0.03	-	0.13	0.06	-						
Cyperus rigidifolius	0.13	0.06	-															
Hypoestes verticillaris							0.13	0.06	-	0.13	0.06	-	0.2	0.15	-			
Eragrostis tenuifolia	0.38	1.06	0.75	0.13	0.03	-	0.38	2.19	-							0.38	0.44	-
Harpachne schimperi	0.5	0.31	-	0.5	1.13	1	0.38	0.59	-	0.25	0.63	-	0.4	0.3	-	0.5	0.72	-
Indigofera tanganyikensis	0.38	0.22	-	0.13	0.03	-	0.25	0.09	-							0.13	0.09	-
Rhamphicarpa montana	0.13	0.03	-													0.13	0.03	-
Crotalaria incana	0.25	0.13	-															
Oxygonum sinuatum	0.13	0.16	-															
Oldenlandia scopulorum																		
Cyperus sp.			0.13	0.13	-								0.4	0.75	-	0.25	0.05	-
Angustifolia montana			0.13	0.03	-								0.2	0.05	-			
Chloris gayana	0.25	0.06	-															
Eleusine africana													0.2	0.2	-	0.13	0.22	-
Leucas pratensis																		
Amaranthus hybridus	0.13	0.13	-										0.4	0.85	-	0.25	1.25	0.25
Conyza stricta																		
Indigofera ambalensis	0.5	3.28	-	0.25	1.25	0.5							0.2	0.25	-	0.38	3.13	-
Cassia grantii	0.25	0.41	-	0.13	0.16	-							0.2	0.05	-	0.13	0.03	-
Amaranthus sp.																0.13	0.09	0.25
Aristida keniensis																0.25	0.06	-
Sida schimperiana	0.25	0.13	-	0.25	0.16	-	0.13	0.06	-	0.38	0.09	-	0.6	0.15	-	0.25	0.06	0.25
Aerva lanata	0.13	0.03	-	0.13	0.03	-				0.13	0.03	-						

APPENDIX 33: Water trough number 1: Trampled area -January-April 1992, A= Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	0.88	-	18.8	0.88	-	2.5	0.88	-	8.5	0.88	-	20.75
Cynodon dactylon	0.13	-	4	0.13	-	1.75	0.13	-	1			
Themeda triandra	0.38	-	-	0.25	-	-	0.5	-	-	0.63	-	-
Felicia muricata	0.63	1.56	5.25	0.63	1.03	2	0.75	2.5	1	0.63	1.13	-
Crotalaria tanganyikensis												
Indigofera spicata	0.13	0.25	-	0.25	0.16	-	0.38	0.22	-	0.5	0.63	-
Euphorbia inaequilatera										0.13	0.03	-
Solanum incanum	0.25	0.06	-									
Justacia sp.	0.13	0.06	-	0.13	0.03	-	0.5	0.19	-	0.38	0.09	-
Cyperus rigidifolius	0.13	0.16	-				0.25	0.06	-	0.25	0.13	-
Hypoestes verticillaris												
Eragrostis tenuifolia	0.25	0.78	-	0.13	0.31	-	0.75	0.91	-	0.75	2.59	2
Harpachne schimperi	0.88	1.38	-	0.25	0.16	-	0.88	1.41	-	0.75	2.03	-
Indigofera tanganyikensis												
Rhamphicarpa montana												
Angustifolia montana	0.13	0.06	-									
Oxygonum sinuatum										0.13	0.03	-
Oldenlandia scopulorum										0.13	0.06	-
Eragrostis mamoena										0.13	0.03	-
Crotalaria incana												
Chloris gayana				0.13	0.06	-				0.13	0.06	-
Crotalaria grantii	0.13	0.03	-									
Crotalaria spinosa												
Cyperus sp.												
Conyza stricta												
Indigofera ambalensis	0.88	7.59	1	0.25	0.22	-	0.75	1.03	-	0.38	0.69	-
Cassia sp.										0.13	0.03	-
Aerva lanata												
Aristida keniensis												
Sida schimperiana	0.13	0.06	-				0.13	0.03	-			
Abutilon maurutianum												

APPENDIX 34: Water trough number 1: Untramped area - January-December 1992, A=Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April					
Species	A	B	C	A	B	C	A	B	C	A	B	C			
Digitaria milanjiana	0.88	-	11.5	0.5	-	4.5	1	-	4.25	1	-	14.25			
Cynodon dactylon	0.5	-	19.3	0.5	-	10.5	0.38	-	12.3	0.5	-	17			
Themeda triandra				0.25	-	-	0.5	-	1	0.5	-	-			
Felicia muricata	0.63	1.75	2.25	0.63	0.75	-	0.63	1.94	4	0.75	2.69	7.25			
Crotalaria tanganyikensis															
Indigofera spicata	0.13	0.09	-	0.13	0.19	-	0.25	0.22	-	0.38	0.53	-			
Euphorbia inaequilatera	0.25	3.44	-							0.38	0.38	-			
Solanum incanum	0.13	0.06	-	0.25	0.19	-	0.13	0.28	-						
Justacia sp.				0.13	0.03	-	0.13	0.03	-	0.38	0.19	-			
Cyperus rigidifolius							0.25	0.13	-	0.25	0.81	-			
Hypoestes verticillaris	0.13	0.34	1.5	0.13	0.19	-									
Eragrostis tenuifolia	0.38	0.75	-	0.13	0.28	-	0.38	4.78	1	0.5	4.44	2			
Harpachne schimperi	0.5	0.78	-	0.38	0.19	-	0.38	0.81	-	0.38	0.34	-			
Indigofera tanganyikensis				0.13	0.03	-				0.13	0.09	-			
Rhamphicarpa montana							0.25	0.06	-						
Angustifolia montana															
Oxygonum sinuatum															
Oldenlandia scopulorum										0.13	0.03	-			
Eragrostis mamoena															
Crotalaria incana															
Chloris gayana	0.13	0.06	-	0.25	0.16	-	0.13	0.03	-	0.13	0.03	-			
Crotalaria grantii															
Crotalaria spinosa															
Cyperus sp.	0.13	0.16	-	0.13	0.19	-				0.25	0.13	-			
Conyza stricta															
Indigofera ambalensis	0.25	0.16	-	0.13	0.09	-	0.13	0.03	-	0.13	0.06	-			
Cassia grantii															
Aerva lanata				0.13	0.03	-									
Aristida keniensis										0.13	0.03	-			
Sida schimperiana	0.25	0.16	-	0.38	0.13	1.5				0.13	0.16	-			
Abutilon maurutianum										0.13	0.03	-			

APPENDIX 35:	Water trough number 2: Trampled area - April-December 1990, A= Frequency, B= Density/m2 and C= Percentage cover																	
		April			May			June			July			Aug			Sept	
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	1	-	26.8	1	-	35.2	1	-	52.8	1	-	48.4	1	-	30.2	1	-	16
Cynodon dactylon	1	-	34	0.8	-	36	1	-	39.6	0.8	-	16	0.8	-	9.16	0.8	-	2.4
Themeda triandra																		
Felicia muricata	0.4	2.95	0.8				0.6	1.25	4.8	0.6	0.75	1.2	0.4	0.5	1	0.4	0.4	2.4
Crotalaria tanganyikensis																		
Indigofera spicata	0.2	0.35	1.6	0.3	0.05	-	0.4	0.1	0.4									
Euphorbia inaequilatera	0.8	4.2	0.4				0.6	1	-	0.2	0.3	1						
Solanum incanum	0.2	0.1	-	0.3	0.1	-	0.4	0.1	-	0.2	0.15	0.4				0.2	0.05	0.4
Justacia sp.																		
Cyperus rigidifolius	0.4	0.25	-	0.2	0.1	-												
Hypoestes verticillaris	0.02	0.1	-							0.2	0.5	-						
Eragrostis tenuifolia	1	16	12.8	1	15	11.2	1	8.45	12	0.8	6.3	2.4	0.8	3	1	0.6	0.35	2
Harpachne schimperi	0.4	0.1	0.8	0.25	0.2	0.5	0.2	0.2	0.8	0.2	0.4	0.4	0.2	0.1	-			
Indigofera tanganyikensis																		
Rhamphicarpa montana																		
Abutilon mauritianum	0.6	0.2	-															
Oxygonum sinuatum	0.6	0.25	-				0.2	0.1	-									
Oldenlandia scopulorum	0.2	0.1	-	0.4	0.4	-	0.6	0.25	-	0.2	0.45	-						
Monchma dabile																		
Crotalaria incana	0.2	0.05	-															
Chloris gayana																		
Crotalaria grantii																		
Crotalaria spinosa																		
Crotalaria sp.	0.4	0.15	-															
Conyza stricta																		
Indigofera ambalensis																		
Cassia grantii																		
Commelina africana	0.2	0.05	-				0.2	0.05	-									
Conyza schimperi				0.2	0.05	-										0.4	0.2	0.4
Sida schimperiana	1	3.35	6.4	1	4	6.75	1	1.2	2	1	4.05	11.6	0.8	4	12	0.8	4.55	13.2
Eleusine africana										1.2	0.5	-						

APPENDIX 35: Water trough number 2: Trampled area - April-December 1990 (continued)

	Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.8	-	18.1	0.5	-	20.5	0.6	-	5.8
Cynodon dactylon	0.8	-	6.29	0.75	-	7	0.8	-	2.25
Themeda triandra									
Felicia muricata	0.2	0.05	0.4	0.5	0.75	1	0.4	0.25	1
Crotalaria tanganyikensis									
Indigofera spicata									
Euphorbia inaequilatera				0.25	0.13	-			
Solanum incanum				0.75	0.56	-	0.2	0.1	-
Justacia sp.				0.25	0.19	-			
Cyperus rigidifolius									
Hypoestes verticillaris				0.25	0.06	-			
Eragrostis tenuifolia	0.6	0.65	-	1	0.94	-	0.6	0.4	-
Harpachne schimperi				0.25	0.75	-	0.4	0.25	-
Indigofera tanganyikensis									
Rhamphicarpa montana				0.25	0.13	-			
Abutilon mauritianum									
Oxygonum sinuatum									
Oldenlandia scopulorum				0.25	0.13	-			
Monchma dabile									
Crotalaria incana									
Chloris gayana									
Crotalaria grantii									
Crotalaria spinosa									
Crotalaria sp.									
Conyza stricta									
Indigofera ambalensis				0.25	0.06	-			
Cassia grantii									
Commelina africana									
Conyza schimperi									
Sida schimperiana	0.8	2.8	14.4	1	2.5	10.5	0.8	2.5	7.5
Eleusine africana									

APPENDIX 36:	Water trough number 2: Untrampled area - April-December 1990, A= Frequency, B= Density/m2 and C= Percentage cover																	
			April			May			June			July			Aug			Sept	
Species		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum		1	-	65.2	1	-	64.8	1	-	69.6	1	-	68.4	1	-	50	1	-	44.4
Cynodon dactylon		0.6	-	9.6	0.8	-	13.7	0.8	-	40	1	-	10.8	0.8	-	11.2	0.2	-	2.4
Themeda triandra		0.2	-	0.4													0.4	-	1.6
Felicia muricata		0.4	0.5	1.2	0.88	2	4.55	1	2.15	2.8	0.8	1.9	6.8	0.8	0.8	5.8	0.8	1.2	8
Crotalaria tanganyikensis		0.2	0.05	-															
Indigofera spicata					0.1	0.05	-				0.4	0.85	2.4						
Euphorbia inaequilatera		0.8	6.1	1.2	0.8	4	-	1	2.2	-	0.4	0.25	-	0.2	0.2	-			
Solanum incanum		0.2	0.1	-	0.4	0.2	-	0.4	0.3	-	0.2	0.15	2	0.8	0.15	-	0.2	0.2	-
Justacia sp.		0.2	0.05	0.4															
Cyperus rigidifolius																			
Hypoestes verticillaris											0.4	0.3	-				0.4	0.25	-
Eragrostis tenuifolia		1	13.7	13.2	0.8	10	10.5	0.8	1	2.8	0.8	2.85	7.2	0.6	2.5	5.1	0.6	3.05	4.8
Harpachne schimperi		0.6	0.6	0.4	0.4	0.5	-							0.3	0.5	-	0.4	1	0.4
Indigofera tanganyikensis																			
Rhamphicarpa montana																			
Cyperus sp.		0.4	0.45	-															
Oxygonum sinuatum		0.6	0.6	-															
Oldenlandia scopulorum		0.4	0.25	-	0.3	0.7	-	0.6	1.8	-									
Cyperus laevigatus		0.2	0.1	-															
Oxalis obliquifolia								0.2	0.2	-									
Chloris gayana																			
Crotalaria grantii								0.4	0.25	-									
Crotalaria spinosa		0.2	0.1	-				0.4	0.2	-									
Crotalaria sp.		0.6	0.5	-							0.2	0.1	-						
Conyza stricta								0.4	0.1	-				0.2	0.05	-			
Indigofera ambalensis																			
Cassia grantii																			
Commelina africana																			
Conyza schimperi																			
Sida schimperiana		0.8	2.8	2.4	0.8	3	8.65	0.8	3.05	13.2	1	1.3	10.8	0.8	2	5.86	0.2	0.15	-
Eragrostis racemosa								0.6	0.55	-									

APPENDIX 36: Water trough number 2: Untrampled area - April-December 1990 (continued)

	Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	1	-	25.2	0.8	-	15	0.8	-	10.1
Cynodon dactylon	1	-	31.2	0.8	-	25.0	0.6	-	15.68
Themeda triandra									
Felicia muricata	0.6	0.4	1.2	0.6	0.3	1.05			
Crotalaria tanganyikensis									
Indigofera spicata									
Euphorbia inaequilatera	0.2	0.15	-	0.4	0.2	-			
Solanum incanum	0.2	0.1	-						
Justacia sp.									
Cyperus rigidifolius									
Hypoestes verticillaris	0.2	0.5	-	0.2	0.1	-	0.2	0.15	-
Eragrostis tenuifolia	0.4	1.25	0.4	0.6	0.75	-	0.6	0.4	-
Harpachne schimperi				0.4	0.3	-	0.4	0.2	-
Indigofera tanganyikensis									
Rhamphicarpa montana									
Cyperus sp.									
Oxygonum sinuatum									
Oldenlandia scopulorum									
Cyperus laevigatus									
Oxalis obliquifolia									
Chloris gayana	0.2	0.5	0.4						
Crotalaria grantii									
Crotalaria spinosa									
Crotalaria sp.									
Conyza stricta	0.2	0.5	-						
Indigofera ambalensis									
Cassia grantii									
Commelina africana									
Conyza schimperi									
Sida schimperiana	1	3.7	18.8	0.4	1.25	14.5	0.4	0.5	8.68
Eleusine africana									

APPENDIX 37: Water trough number 2: Trampled area -January-December 1991, A= Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April			May			June		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.8	-	1.2							0.6	-	2.8	0.8	-	4	1	-	32.8
Cynodon dactylon	0.8	-	2	0.5	-	-	0.2	-	0.8	1	-	13.2	1	-	8.4	1	-	26.8
Themeda triandra																		
Felicia muricata	0.4	0.2	-	0.33	0.25	-	0.2	0.3	-				0.1	0.05	-	0.4	0.2	0.4
Eragrostis mamoena													0.2	0.3	-	0.4	0.35	-
Indigofera spicata																0.2	1.5	-
Euphorbia inaequilatera										0.2	0.25	-				0.8	3.65	0.8
Solanum incanum	0.2	0.1	-	0.17	0.13	-	0.4	0.2	-				0.4	0.2	-	0.2	0.25	-
Justacia sp.							0.2	0.1	-							0.2	0.05	0.4
Cyperus rigidifolius	0.2	0.15	-										0.2	0.2	-	0.4	0.45	-
Hypoestes verticillaris																		
Eragrostis tenuifolia	0.6	0.3	-							0.2	0.1	-	0.2	0.25	-	1	9.75	4.4
Harpachne schimperi	0.2	0.1	-													0.2	0.1	-
Indigofera tanganyikensis																		
Rhamphicarpa montana																		
Abutilon mauritianum																		
Oxygonum sinuatum										0.8	0.75	-	0.4	0.5	-	1	1.95	-
Oldenlandia scopulorum										0.2	0.15	-						
Cyperus sp.										0.2	0.5	-				0.2	0.15	-
Crotalaria incana																		
Leucas pratensis													0.2	0.05	-			
Eragrostis mamoena																		
Amaranthus sp													0.4	0.4	-	0.6	6.25	1.2
Amaranthus hybridus													0.2	0.3	-	0.6	1.2	-
Tribulus terrestris																0.6	2.25	0.8
Indigofera ambalensis																0.4	0.7	-
Eragrostis racemosa																0.4	4	3.6
Commelina africana																		
Cassia mimosoides																0.2	0.05	-
Sida schimperiana	0.8	4.7	11.6	1	4.25	12.7	1	2.35	10.8	0.8	1.65	7.6	1	2.6	11.2	0.8	2.1	9.2
Eleusine africana													0.4	0.15	-	1	20.4	4

APPENDIX 37: Water trough number 2: Trampled area -January-December 1991 (continued)

	July			Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.6	-	3.6	1	-	18.8	1	-	6.8	0.8	-	4.6	0.8	-	4	1	-	6
Cynodon dactylon	0.8	-	21.6	1	-	8.8	1	-	9.2	0.8	-	6	0.8	-	8.4	1	-	12
Themeda triandra																		
Felicia muricata	0.4	0.75	1.6							0.4	0.2	-	0.4	0.15	-			
Crotalaria tanganyikensis																		
Indigofera spicata	0.2	0.3	0.8	0.2	0.1	0.4	0.2	0.05	-									
Euphorbia inaequilatera	0.6	1.2	-										0.6	1.25	-	0.2	0.4	0.4
Solanum incanum	0.2	0.2	-							0.4	0.1	-	0.2	0.05	-	0.2	0.05	-
Justacia sp.																		
Cyperus rigidifolius																		
Hypoestes verticillaris																		
Eragrostis tenuifolia	1	16.6	18.8							0.6	1	3.5	1	9.5	5.2	1	8.4	4.8
Harpachne schimperi													0.2	0.1	-	0.2	0.1	-
Indigofera tanganyikensis	0.2	0.05	-															
Rhamphicarpa montana																		
Abutilon mauritianum	0.2	0.15	-															
Oxygonum sinuatum	0.8	1.9	1.6										0.2	0.15	-			
Oldenlandia scopulorum																		
Cyperus sp.																		
Crotalaria incana	0.4	0.1	-	0.2	0.1	-												
Leucas pratensis	0.4	0.45	-	0.2	0.05	-												
Eragrostis mamoena	0.2	1.5	0.8															
Amaranthus sp	0.4	0.1	-										0.4	0.35	-	0.2	0.2	-
Amaranthus hybridus	0.2	0.02	-										0.2	1	-			
Tribulus terrestris	0.2	0.05	-										0.4	0.2	-			
Indigofera ambalensis																		
Cassia grantii																		
Dactylocterum aegyptium	0.2	0.05	-															
Cassia mimosoides	0.2	0.2	-															
Sida schimperiana	0.8	1.8	6	0.6	1.1	2.4	0.8	1.1	6.8	0.8	1.2	5.51	1	1.3	4	1	1.2	5.6
Eleusine africana	0.6	3.7	3.6															

APPENDIX 38: Water trough number 2: Untrampled area -January-December 1991, A= Frequency, B= Density/m2 and C= Percentage cover

Species	Jan			Feb			March			April			May			June		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	1	-	12.4	1	-	17.3	0.6	-	16.8	1	-	8.4	1	-	2.4	1	-	17.6
Cynodon dactylon	1	-	12.5	1	-	22.3	0.8	-	19.3	1	-	32	0.8	-	12.8	1	-	65.6
Tribulus terrestris																0.8	0.7	-
Felicia muricata				0.67	0.67	2.67	0.8	0.5	0.98	0.4	0.25	-				0.2	0.15	-
Cyperus sp.	0.2	0.5	-							0.2	0.2	-				0.4	0.15	-
Amaranthus hybridus													0.2	0.5	-	1	2.7	0.8
Euphorbia inaequilatera	0.2	0.1	-										0.2	0.3	-	0.8	4.05	0.4
Solanum incanum										0.4	0.1	-	0.2	0.1	-			
Leucas pratensis																0.2	0.05	-
Cyperus rigidifolius										0.4	0.3	-	0.2	5	-			
Hypoestes verticillaris	0.2	0.05	-	0.17	0.25	-	0.4	0.2	-	0.4	0.2	-	0.2	0.05	-	0.2	0.1	-
Eragrostis tenuifolia	1	3.2	-	0.17	0.13	-							0.2	0.5	-	0.4	2.25	1.2
Harpachne schimperi	0.2	0.05	-															
Eragrostis mamoena																0.2	0.25	-
Rhamphicarpa montana																		
Abutilon mauritianum																		
Oxygonum sinuatum										0.2	0.1	-	0.2	0.6	-	0.2	0.15	-
Oldenlandia scopulorum																		
Amaranthus sp.	0.4	0.1	-										0.6	1.8	-	1	6.3	2
Crotalaria incana																0.2	0.05	-
Chloris gayana																		
Aerva lanata	0.4	0.15	-	0.17	0.13	-				0.2	0.1	-						
Crotalaria spinosa																		
Angustifolia monsonia													0.2	0.05	-			
Tagetes minuta																0.2	0.05	-
Indigofera ambalensis																		
Commelina bengalensis																0.2	0.15	-
Commelina africana																		
Eragrostis racemosa																0.6	4.25	0.8
Sida schimperiana	1	2.35	9.6	1	2.33	7.67	0.8	2.25	6.7	1	1.8	8.4	1	1.75	11.2	1	2.05	3.6
Eleusine africana																1	13.8	16

APPENDIX 38: Water trough number 2: Untrampled area -January-December 1991 (continued)

	July			Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.67	-	16.3	0.8	-	13.2	1	-	8.8	1	-	10.1	1	-	14.4	0.8	-	6.4
Cynodon dactylon	0.5	-	20	1	-	50	1	-	16	1	-	18.9	1	-	24.8	1	-	62.4
Eragrostis mamoena	0.33	0.38	-				0.2	0.4	1.2									
Felicia muricata	0.5	0.54	2.33	0.4	0.1	-	1	0.75	-									
Cyperus sp.													0.2	1	-	0.2	0.15	2
Indigofera spicata	0.33	0.7	-	0.4	0.1	-												
Euphorbia inaequilatera	0.5	2.08	0.67										0.8	16.6	-	1	18	0.4
Solanum incanum				0.2	0.05	-							0.2	0.15	-	0.6	0.4	0.4
Justacia sp.	0.33	0.08	-															
Amaranthus hybridus	0.17	0.08	-	0.2	0.1	1.6							0.4	7	-	0.2	1	-
Hypoestes verticillaris				0.4	0.55	0.4				0.2	0.15	-				0.4	0.1	-
Eragrostis tenuifolia	0.33	1.63	1.67										0.8	1.3	-	0.4	0.5	0.8
Harpachne schimperi	0.17	0.17	-															
Indigofera tanganyikensis	0.17	0.13	-															
Leucas pratensis	0.33	0.25	-				0.2	0.05	-	0.2	0.1	-						
Abutilon mauritianum																0.2	0.05	0.4
Oxygonum sinuatum	0.33	0.21	-	0.2	0.25	-							0.2	0.05	-			
Tribulus terrestris				0.2	0.05	-												
Amaranthus sp.													0.2	3.5	-			
Crotalaria incana	0.17	0.08	-															
Galinsoga parviflora													0.2	1	-			
Aerva lanata				0.2	0.1	1												
Crotalaria spinosa																		
Angustifolia monsonia																		
Tagetes minuta																		
Indigofera ambalensis	0.17	1.04	-				0.2	0.15	-	0.2	0.15	-						
Commelina bengalensis																0.2	0.45	-
Chenopodium procerum	0.17	0.13	-															
Commelina reptens	0.17	0.17	-															
Sida schimperiana	1	0.96	2.33	0.8	0.75	6	0.8	0.9	0.8	0.8	0.7	2.1	1	0.75	3.6	0.8	0.5	-
Eleusine africana	0.17	0.08	-															

APPENDIX 39: Water trough number 2: Trampled area - January-April 1992, A= Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.4	-	-				0.2	-	-	0.8	-	5.2
Cynodon dactylon	1	-	7.2	0.2	-	1.2	0.8	-	-	1	-	26.8
Themeda triandra												
Felicia muricata				0.4	0.2	-	0.4	0.35	-	0.4	0.5	-
Crotalaria tanganyikensis												
Indigofera spicata	0.2	0.5	-	0.4	0.1	-						
Euphorbia inaequilatera												
Solanum incanum	0.2	0.15	-									
Justacia sp.												
Cyperus rigidifolius												
Hypoestes verticillaris												
Eragrostis tenuifolia	1	8.2	2.4	0.4	1.75	-	0.4	0.45	-	1	6.8	4.4
Harpachne schimperi				0.2	0.1	-	0.2	0.3	-	0.2	0.5	-
Indigofera tanganyikensis												
Rhamphicarpa montana										0.2	0.05	-
Abutilon mauritianum												
Oxygonum sinuatum										0.8	6.25	-
Oldenlandia scopulorum												
Tribulus terrestris	0.2	0.05	-							0.2	0.95	-
Crotalaria incana				0.2	0.05	-						
Eragrostis mamoena										0.2	0.15	-
Crotalaria grantii												
Crotalaria spinosa												
Crotalaria sp.												
Conyza stricta												
Indigofera ambalensis												
Cassia grantii												
Commelina africana												
Conyza schimperi												
Sida schimperiana	1	1.85	2.4	1	1.65	-	1	4.05	4	1	1.4	3.2

APPENDIX 40: Water trough number 2: Untrampled area - January-April 1992, A= Frequency, B= Density/m2 and C= Percen

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.2	-	-	0.8	-	10.4	0.6	-	8.8	1	-	24.4
Cynodon dactylon	0.8	-	28.8	0.8	-	16.4	0.8	-	16	1	-	30.8
Themeda triandra												
Felicia muricata												
Crotalaria tanganyikensis												
Indigofera spicata												
Euphorbia inaequilatera	0.25	0.5	-	0.2	0.35	-				0.2	0.75	-
Solanum incanum	0.2	0.1	-	0.2	0.15	-				0.2	0.15	-
Justacia sp.												
Cyperus rigidifolius										0.2	0.75	-
Hypoestes verticillaris	0.4	0.15	-				0.4	0.3	-	0.2	0.25	-
Eragrostis tenuifolia	0.4	0.7	1.6				0.4	0.75	2	0.2	1.5	-
Harpachne schimperi												
Indigofera tanganyikensis												
Rhamphicarpa montana												
Abutilon mauritianum												
Oxygonum sinuatum												
Oldenlandia scopulorum												
Amaranthus hybridus	0.2	0.25	-	0.2	0.5	-	0.2	0.35	-	0.8	10.95	-
Crotalaria incana												
Amaranthus sp.	0.2	0.25	-							0.8	7	-
Aerva lanata	0.2	0.1	-				0.2	0.05	-			
Crotalaria spinosa												
Cyperus sp.	0.2	0.2	-									
Conyza stricta												
Indigofera ambalensis												
Cassia grantii												
Tribulus terrestris										0.2	2	-
Leucas pratensis										0.2	0.5	-
Sida schimperiana	1	0.6	3.6	1	2.55	3.6	0.8	3.05	3.2	0.8	2.95	5.2
Eleusine africana	0.2	0.2	-				0.2	0.25	-			

APPENDIX 41: Water trough number 3: Trampled area - April-December 1990, A= Frequency, B= Density/m2 and C= Percentage cover

	April			May			June			July			Aug			Sept		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.88	-	10.8	0.88	-	20.8	1	-	34.3	0.86	-	24.6	0.7	-	15	0.29	-	19.7
Cynodon dactylon	1	-	70	1	-	50	1	-	45.1	1	-	50	0.88	-	22.4	0.87	-	18.6
Cyperus sp.	0.13	0.09	-															
Felicia muricata	0.25	0.09	0.5	0.5	0.25	-	0.57	0.21	1.43	0.29	0.07	-	0.16	0.07	-	0.14	0.11	0.57
Crotalaria tanganyikensis				0.1	0.04	-	0.14	0.04	-	0.14	0.07	0.29						
Indigofera spicata							0.14	0.04	-									
Euphorbia inaequilatera	0.75	2.75	-	0.75	2	-	1	2.36	1.14	0.86	1.07	-	0.4	1	-	0.14	0.07	-
Solanum incanum										0.14	0.07	-	0.14	0.07	-	0.14	0.04	-
Justacia sp.	0.13	0.13	1	0.13	0.14	-	0.14	0.14	-	0.14	0.04	-	0.14	0.04	-	0.14	0.04	-
Cyperus rigidifolius				0.12	0.07	-	0.14	0.07	-	0.29	0.11	-	0.2	0.04	-			
Hypoestes verticillaris	0.13	0.03	1															
Eragrostis tenuifolia	0.5	4.88	3.25	0.7	4	5.15	0.86	7.71	7.71	0.71	5.5	4.29	0.71	6.5	4	0.87	8.11	3.14
Harpachne schimperi	0.25	0.56	0.75	0.5	1.5	1	0.57	1.64	3.71	0.43	1.75	2.29	0.4	1	1.5	0.14	0.43	-
Commelina bengalensis							0.14	0.04	-									
Solanum nigrum	0.13	4.69	-															
Panicum maximum										0.14	0.07	-						
Oxygonum sinuatum				0.45	0.29	-	0.57	0.25	-	0.43	0.18	-						
Oldenlandia scopulorum				0.12	0.1	-	0.14	0.04	-	0.14	0.11	-						
Monchma dabile										0.14	0.11	-						
Crotalaria incana	0.13	0.09	0.5	0.24	1	-	0.29	0.18	-	0.29	0.18	-						
Setaria sphacelata	0.13	0.06	-															
Ocimum suave	0.13	0.38	1.25															
Satureia biflora	0.38	0.19	-				0.14	0.14	-	0.14	0.04	-						
Crotalaria sp.	0.13	0.06	0.75							0.29	0.04	-						
Conyza stricta	0.38	0.44	0.75	0.8	1.5	-	0.86	1.96	-	0.86	2.61	-	0.7	1.5	-	0.57	0.75	-
Angustifolia monsonia	0.13	0.03	5.74															
Cyperus laevigatus	0.13	0.13	0.5															
Commelina africana																		
Conyza schimperi				0.11	0.14	-				0.56	0.64	-	0.5	0.5	-	0.29	0.57	-
Sida schimperiana	0.25	1.28	-				0.14	0.07	-							0.14	0.04	-
Eragrostis mamoena				0.04	0.04	-	0.14	0.04	-	0.57	0.61	-						

APPENDIX 41: Water trough number 3: Trampled area - April-December 1990 (continued)

	Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.57	-	4.57	0.43	-	2			
Cynodon dactylon	1	-	24.6	1	-	12.5	1	-	7.5
Cyperus sp.									
Felicia muricata	0.14	0.04	-	0.14	0.07	-	0.14	0.11	-
Conyza sp.	0.71	1.11	0.57						
Indigofera spicata									
Euphorbia inaequilatera	0.14	0.04	-	0.29	0.11	-			
Solanum incanum	0.29	0.18	-						
Justacia sp.	0.14	0.07	-	0.29	0.07	-	0.14	0.07	-
Cyperus rigidifolius	0.14	0.07	-				0.14	0.11	-
Hypoestes verticillaris	0.29	0.25	-						
Eragrostis tenuifolia	0.57	3.5	2.57	0.43	1.43	-	0.29	0.54	-
Harpachne schimperi	0.14	0.14	0.29	0.29	0.14	-	0.29	0.18	-
Indigofera tanganyikensis									
Solanum nigrum									
Panicum maximum									
Oxygonum sinuatum									
Oldenlandia scopulorum									
Monchma dabile									
Crotalaria incana									
Chloris gayana									
Ocimum suave									
Satureia biflora									
Crotalaria sp.									
Conyza stricta	0.14	0.14	-	0.57	0.64	-			
Angustifolia monsonia									
Cyperus laevigatus									
Commelina africana									
Conyza schimperi									
Sida schimperiana									
Eragrostis mamoena									

APPENDIX 42: Water trough number 3: Untrampled area - April-December 1990, A= Frequency, B= Density/m2 and C= Percentage cover

	April			May			June			July			Aug			Sept		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	1	-	60	1	-	65	1	-	76	1	-	69.1	1	-	62.0	1	-	51.7
Cynodon dactylon	1	-	32	0.88	-	29.5	0.86	-	28	0.71	-	30.3	0.8	-	22.5	0.71	-	24
Commelina bengalensis	0.13	0.03	-	0.14	0.07	-	0.14	0.07	-	0.24	0.07	-						
Felicia muricata	0.25	0.06	-	0.65	1	2.55	0.71	1.07	4.29	0.57	1.79	3.43	0.71	1.4	3	0.87	1.43	2.57
Crotalaria tanganyikensis				0.26	0.11	-	0.43	0.46	0.86	0.29	0.14	-	0.2	0.07	-			
Cyperus sp.	0.75	0.56	-	0.12	0.64	0.15				0.14	0.71	1.14	0.14	0.18	-			
Euphorbia inaequilatera	0.75	2.63	0.25	0.7	2.63	-	0.71	1.39	0.29	0.43	0.32	-				0.29	0.14	-
Solanum incanum	0.38	0.25	0.25	0.38	0.25	-	0.43	0.32	-	0.29	0.07	-				0.29	0.11	-
Justacia sp.	0.25	0.19	0.5	0.42	0.46	-	0.43	0.61	-	0.24	0.11	-	0.24	0.1	-	0.29	0.11	-
Cyperus rigidifolius				0.4	0.11	-	0.29	0.21	-	0.43	0.32	-						
Hypoestes verticillaris							0.14	0.04	-									
Eragrostis tenuifolia	0.25	2.19	3.25	0.75	1.5	2.15	0.86	1.61	2.29	0.71	1.93	2.29	0.71	1.5	2	0.71	0.82	0.57
Harpachne schimperi	0.75	1.72	1.5	0.6	1.61	1	0.57	1.5	0.86	0.71	1.04	0.29	0.71	2	0.45	0.87	3.14	0.57
Indigofera tanganyikensis										0.43	0.25	-	0.3	0.1	-	0.29	0.25	-
Eragrostis mamoena							0.43	0.43	-									
Plectranthus barbatus	0.13	0.06	-				0.14	0.07	-							0.14	0.07	-
Oxygonum sinuatum	0.38	0.25	-	0.38	0.18	-	0.29	0.14	-									
Oldenlandia scopulorum							0.14	0.04	-									
Monchma dabile							0.29	0.07	0.29	0.14	0.04	-						
Crotalaria incana	0.13	0.03	-				0.42	0.11	0.29	0.29	0.07	-				0.43	0.32	-
Amaranthus hybridus	0.13	0.03	-															
Satureia biflora	0.13	0.03	-	0.11	0.04	-	0.29	0.21	-	0.14	0.04	-						
Abutilon mauritianum	0.25	0.09	-															
Crotalaria sp.	0.38	0.25	-															
Conyza stricta	0.13	0.03	-	0.13	0.14	-	0.14	0.18	-	0.14	0.57	-	0.14	0.18	-	0.14	0.04	-
Ocimum suave	0.13	0.03	-	0.4	0.04	-				0.14	0.04	-	0.29	0.07	-			
Galinsoga parviflora	0.13	0.03	-				0.14	0.04	-									
Eleusine africana	0.13	0.03	-				0.14	0.25	-									
Setaria sphacelata	0.13	0.03	-	0.13	0.11	-				0.14	0.11	1.43						
Aristida adoensis							0.14	0.14	-							0.14	0.11	0.29
Conyza schimperi				0.14	0.07	-	0.14	0.04	-	0.14	0.04	-	0.13	0.07	-			

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APPENDIX 42:	Water trough number 3: Untrampled area - April-December 1990 (continued)								
		Oct			Nov			Dec	
Species	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	1	-	64	1	-	35.8	1	-	16.5
Cynodon dactylon	0.89	-	36.29	0.71	-	18	0.71	-	15.91
Commelina bengalensis									
Felicia muricata	0.57	0.32	2.86	0.57	0.36	2.4	0.57	0.25	1.5
Crotalaria tanganyikensis									
Indigofera spicata									
Euphorbia inaequilatera									
Solanum incanum	0.29	0.11	-	0.29	0.14	-	0.29	0.07	-
Justacia sp.	0.43	0.14	-						
Cyperus rigidifolius	0.14	0.11	-	0.14	0.07	-	0.14	0.07	-
Hypoestes verticillaris									
Eragrostis tenuifolia	0.43	1	1.14	0.29	0.54	-	0.29	0.29	-
Harpachne schimperi	0.43	0.39	0.29	0.43	0.29	0.15	0.43	0.18	-
Indigofera tanganyikensis									
Eragrostis mamoena									
PLectranthus barbatus									
Oxygonum sinuatum									
Oldenlandia scopulorum									
Monchma dabile									
Crotalaria incana									
Amaranthus hybridus									
Satureia biflora									
Abutilon mairutianum									
Crotalaria sp.									
Conyza stricta									
Ocimum suave	0.29	0.07	-	0.14	0.07	-			
Galinsoga parviflora									
Eleusine africana	0.29	0.97	-						
Setaria sphacelata									
Sida schimperiana									
Conyza schimperi									

APPENDIX 43: Water trough number 3: Trampled area - January-December 1991, A= Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April			May			June		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.4	-	3.8	0.14	-	1.43	0.4	-	0.8	1	-	7.2	0.6	-	5.6	0.6	-	22.8
Cynodon dactylon	1	-	5.54	0.86	-	5.71	0.8	-	6	0.2	-	12	1	-	18.4	-	-	39.6
Conyza filipendula	0.2	0.05	-															
Felicia muricata	0.6	0.15	-	0.14	0.14	-										0.2	0.05	0.8
Crotalaria tanganyikensis													0.2	0.1	-			
Indigofera spicata																		
Euphorbia inaequilatera										0.6	1.3	-				1	5.7	1.2
Solanum incanum				0.14	0.04	-							0.2	0.05	-			
Cassia mimosoides										0.2	0.05	-	0.4	1.2	-			
Cyperus rigidifolius	0.2	0.15	-							0.6	0.6	-				0.2	0.15	-
Hypoestes verticillaris	0.2	0.15	-															
Eragrostis tenuifolia	0.6	2	-										0.4	0.65	-	0.4	9.75	7.2
Harpachne schimperi	0.2	0.5	-															
Tribulus terrestris																0.4	0.4	-
Cassia sp.	0.2	0.05	-															
Leucas pratensis	0.2	0.15	-										0.2	0.25	-	0.2	1.3	-
Oxygonum sinuatum	0.2	0.05	-							1	2.95	-	1	0.45	-	1	7.65	3.2
Eragrostis racemosa																0.2	0.65	-
Chenopodium procerum													0.2	0.2	-	0.4	1.3	-
Crotalaria incana													0.2	0.05	-	0.4	0.2	-
Amaranthus sp.													0.2	0.25	-	0.4	2	0.4
Galinsoga parviflora																0.2	0.1	-
Eragrostis mamoena													0.6	0.55	-	0.4	0.55	-
Aerva lanata																0.2	0.05	0.4
Conyza stricta	0.2	0.15	-															
Indigofera ambalensis																0.6	0.55	-
Dactyloctenium aegyptium																0.6	2.4	-
Commelina bengalensis																0.4	0.15	-
Eleusine africana																0.6	2.1	-
Sida schimperiana	0.2	0.05	-							0.2	0.05	-						
Amaranthus hybridus										0.2	0.15	-	0.4	0.25	-	0.6	1	-

APPENDIX 43: Water trough number 3: Trampled area - January-December 1991 (continued)

	July			Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana/scalarum	0.71	-	11.1	0.6	-	6.4							1	-	10.8	0.33	-	0.67
Cynodon dactylon	1	-	24.5	1	-	15.2	1	-	4	1	-	4.02	1	-	14.4	1	-	14.67
Indigofera sp.													0.2	0.05	-			
Felicia muricata													0.2	0.05	-			
Crotalaria tanganyikensis																		
Indigofera spicata																		
Euphorbia inaequilatera	0.57	1.75	-										0.8	43.1	6	0.17	1.25	0.33
Solanum incanum	0.14	0.04	-															
Justacia sp.													0.2	0.05	-			
Cyperus rigidifolius													0.2	0.1	-			
Hypoestes verticillaris																		
Eragrostis tenuifolia	0.71	18.4	5.43	0.6	0.4	6.4							0.8	13.8	3.2	0.67	7.29	2
Harpachne schimperi	0.14	0.07	-										0.2	0.05	-			
Indigofera tanganyikensis	0.29	0.11	-															
Cassia sp.																		
Leucas pratensis	0.43	0.43	-															
Oxygonum sinuatum	0.86	2	-										0.2	3.85	-			
Oldenlandia scopulorum																		
Chenopodium procerum	0.14	0.36	-										0.2	3.2	-			
Crotalaria incana	0.29	0.07	-										0.2	0.1	-			
Amaranthus sp.	0.14	0.04	-										0.2	0.2	-	0.17	0.33	-
Cassia mimosoides	0.29	0.4	-										0.2	0.15	-			
Eragrostis mamoena	0.57	1.86	1.43															
Tribulus terrestris	0.14	0.04	-	0.2	0.1	-							0.2	0.15	-			
Eragrostis racemosa	0.57	1.75	-															
Indigofera ambalensis	0.14	0.07	-															
Dactyloctenium aegyptium	0.14	0.07	-															
Commelina bengalensis	0.14	0.18	-															
Eleusine africana	0.14	0.04	-															
Sida schimperiana																		
Amaranthus hybridus	0.14	0.54	-										0.2	2	-			

APPENDIX 44: Water trough number 3: Untrampled area - January-December 1991, A= Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April			May			June		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	1	-	15	0.43	-	6.86	0.8	-	5.28	1	-	10.8	0.8	-	15.6	0.8	-	23.2
Cynodon dactylon	0.86	-	7.71	0.57	-	10.8	0.8	-	10.7	0.4	-	15.7	0.6	-	26	0.8	-	28.8
Aerva lanata	0.14	0.04	-										0.2	0.05	-			
Felicia muricata	0.71	0.89	3.43	0.57	1.14	1.43	0.6	1.4	1.1	0.8	3.25	4.8	0.8	1.25	-	0.6	0.55	-
Crotalaria tanganyikensis																		
Indigofera spicata													0.4	1.75	-			
Euphorbia inaequilatera										0.6	0.7	-	0.6	1.85	-	0.8	3	-
Solanum incanum	0.43	0.25	-	0.29	0.18	-	0.4	0.2	-	0.2	0.05	-	0.4	0.15	-	0.4	0.15	0.4
Justacia sp.	0.14	0.04	-													0.2	0.05	-
Cyperus rigidifolius	0.43	0.57	-							0.6	2.2	-	0.4	0.4	-	0.2	0.65	0.8
Hypoestes verticillaris																		
Eragrostis tenuifolia	0.43	2	-													0.8	4	5.6
Harpachne schimperi	0.71	4.32	-							0.4	0.3	-	0.4	0.1	-	0.2	0.1	-
Indigofera tanganyikensis																		
Amaranthus sp.	0.14	0.14	-										0.2	0.2	-	0.8	2.7	-
Commelina bengalensis	0.14	0.04	-										0.2	0.05	-	0.2	0.7	0.4
Oxygonum sinuatum										0.6	1.65	-	0.4	0.4	-	0.6	0.45	-
Oldenlandia scopulorum	0.14	0.04	-															
Leucas pratensis	0.14	0.04	-															
Crotalaria incana																0.6	0.35	-
Amaranthus hybridus																0.8	0.65	-
Chenopodium procerum																		
Cyperus sp.																		
Eragrostis mamoena													0.2	0.1	-	0.4	0.35	0.4
Conyza stricta																		
Indigofera ambalensis																0.2	0.2	-
Galinsoga parviflora													0.2	0.05	-			
Dactyloctenium aegyptium																0.2	0.1	-
Tribulus terrestris																0.4	0.2	0.4
Sida schimperiana	0.14	0.04	-										0.2	0.05	-			
Eragrostis racemosa																0.2	0.3	-

APPENDIX 44: Water trough number 3: Untrampled area - January-December 1991 (continued)

	July			Aug			Sept			Oct			Nov			Dec		
Species	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	1	-	33.5	1	-	27.2	0.67	-	6.67	0.67	-	10.5	1	-	24	1	-	11.3
Cynodon dactylon	0.88	-	25.3	0.8	-	44	0.5	-	22.7	0.5	-	15.7	0.6	-	10	0.5	-	23.3
Aerva lanata																		
Felicia muricata	0.63	1.72	2	0.4	0.6	1.6	0.67	0.83	1.33	0.67	0.9	1	0.4	1.05	1.6	0.33	0.41	7
Crotalaria tanganyikensis																		
Indigofera spicata	0.13	0.03	-															
Euphorbia inaequilatera	0.75	6.91	1.5										0.4	7.95	-	0.33	2.21	-
Solanum incanum																		
Justacia sp.	0.63	0.34	-										0.2	0.1	-			
Cyperus rigidifolius	0.63	3.72	-															
Hypoestes verticillaris													0.2	0.1	-			
Eragrostis tenuifolia	0.38	6	2.5	0.4	1.25	4							0.8	1.85	1.2	0.67	6.29	-
Harpachne schimperi	0.63	1.25	-	0.6	0.75	2.8				0.17	0.1	-	0.6	0.4	1.6	0.67	1.13	1
Indigofera tanganyikensis	0.13	0.11	-															
Amaranthus sp.	0.13	0.03	-										0.2	0.15	-	0.17	0.04	-
Commelina bengalensis													0.4	0.25	-			
Oxygonum sinuatum	0.63	1.75	-										0.6	0.25	-	0.33	0.17	1
Oldenlandia scopulorum																		
Leucas pratensis	0.25	0.11	-															
Crotalaria incana	0.5	0.13	-	0.4	0.15	0.4							0.2	0.1	-			
Amaranthus hybridus													0.4	0.7	-	0.17	0.33	-
Chenopodium procerum																		
Cyperus sp.																		
Eragrostis mamoena	0.5	0.66	-															
Conyza stricta																		
Indigofera ambalensis	0.75	4.53	0.75															
Cassia mimosoides	0.13	0.28	-													0.17	0.29	-
Eragrostis racemosa	0.5	0.75	-	0.2	0.3	0.4							0.2	0.05	-	0.17	0.08	-
Angustifolia montana	0.38	0.16	-															
Sida schimperiana	0.13	0.03	-										0.2	0.05	-			
Plectranthus barbatus	0.13	0.06	-				0.17	0.21	-									

APPENDIX 45: Water trough number 3: Trampled area - January-April 1992, A= Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana							0.17	-	-	0.2	-	-
Cynodon dactylon	1	-	7	1	-	3.67	1	-	1	1	-	30.4
Eragrostis mamoena										0.2	0.05	-
Angustifolia montana	0.17	0.04	-									
Crotalaria tanganyikensis												
Indigofera spicata												
Euphorbia inaequilatera										0.4	0.7	-
Solanum incanum												
Justacia sp.										0.4	0.1	-
Cyperus rigidifolius										0.2	0.5	-
Hypoestes verticillaris												
Eragrostis tenuifolia	0.3	2.54	-	0.33	0.75	-	0.33	0.13	-	0.6	3.1	1.6
Harpachne schimperi												
Indigofera tanganyikensis												
Rhamphicarpa montana												
Amaranthus hybridus										0.2	0.75	-
Oxygonum sinuatum										1	8.25	-
Oldenlandia scopulorum												
Amaranthus sp.										0.2	0.05	-
Crotalaria incana												
Chloris gayana												
Crotalaria grantii												
Crotalaria spinosa												
Crotalaria sp.												
Conyza stricta												
Indigofera ambalensis												
Cassia grantii												
Commelina africana												
Pennisetum cladestinum												
Sida schimperiana												
Tribulus terrestris										0.2	0.15	-

APPENDIX 46: Water trough number 3: Untrampled area - January-April 1992, A= Frequency, B= Density/m2 and C= Percentage cover

	Jan			Feb			March			April		
Species	A	B	C	A	B	C	A	B	C	A	B	C
Digitaria milanjiana	1	-	7	0.67	-	8.67	0.84	-	-	1	-	12.67
Cynodon dactylon	0.67	-	28	0.67	-	4	0.33	-	1.67	0.33	-	11
Plectranthus barbatus												
Felicia muricata	0.33	1.42	-	0.67	1.33	-	0.83	0.88	-	0.5	0.92	-
Crotalaria tanganyikensis												
Indigofera spicata												
Euphorbia inaequilatera	0.33	1.29	-									
Solanum incanum										0.33	0.08	-
Justacia sp.												
Cyperus rigidifolius	0.17	0.04	-							0.33	1.88	-
Hypoestes verticillaris				0.17	0.13	-						
Eragrostis tenuifolia	0.67	2.46	-							0.33	1.63	-
Harpachne schimperi	0.67	0.92	-							0.5	1.96	-
Indigofera tanganyikensis												
Rhamphicarpa montana												
Angustifolia montana	0.17	0.04	-							0.17	0.04	-
Oxygonum sinuatum	0.33	0.25	-							0.33	0.65	-
Oldenlandia scopulorum												
Aerva lanata	0.17	0.08	-									
Crotalaria incana	0.17	0.04	-									
Chloris gayana												
Crotalaria grantii												
Crotalaria spinosa												
Crotalaria sp.												
Conyza stricta												
Indigofera ambalensis												
Cassia grantii												
Commelina africana												
Pennisetum cladestinum												
Sida schimperiana												
Cassia mimosoides	0.17	0.08	-									

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