ASSESSMENT OF THE EXTENT OF ELEPHANT DAMAGE ON BAOBAB TREES (*ADANSONIA DIGITATA*) IN MKATA FLOOD PLAIN OF MIKUMI NATIONAL PARK, TANZANIA.

BY

WILLIAM NICOLAUS

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ABSTRACT

A study was conducted in Mkata flood plain of Mikumi National Park (Tanzania) during the dry season of 2003. The aim of the study was to assess the extent of elephant damage to baobab trees and other woody vegetation, with special consideration that elephants will use baobabs extensively when water is limited. Ground survey was employed to assess 50 baobab trees and 724 other woody species in 20 belt transects. Baobab trees were assessed five times at 3-week intervals to monitor new elephant damage. The Mkata river survey was undertaken to see whether there was any area with water. Qualitative survey of baobabs showed 96% of all trees had old damage, 40% of all trees had recent damage and 20% of all trees had new damage. Quantitative survey of baobabs revealed that, recent damage was significantly higher than new one. There was no significant difference in damages between young, medium sized and large baobabs. Medium sized baobabs were damaged more significantly than large baobabs. Damage to baobabs did not differ significantly between different transects. The study revealed 44.6% of woody vegetation of other species to have elephant damage, 55.4% damaged by unknown agents and 0.6% were not damaged. The extent of damage to other woody vegetation was low. Regardless of the cause of damage, 53.6% of the woody species were lightly browsed, 33.3% were intermediately damaged and 13.1% were seriously damaged. Mikumi elephants selectively damaged younger woody species more than larger ones. In overall, *Lonchocarpus capassa* and *Acacia spp.* had significantly higher elephant damage than other species. However, *Acacia spp.* and *Commiphora africana* had relatively high percentage of new damages (11% and 10.7% respectively), and high preference ratio. It was concluded that, Mikumi elephants were not a threat to baobabs and other woody vegetation. A long-term study to compare elephant damage to baobabs in different dry years is recommended.

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DECLARATION

I, **William Nicolaus**, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and it has not been submitted for a degree award in any other University.

Signature: ....

Date: 26th July 2006

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DEDICATION

This work is dedicated to GOD, the creator, and my father Mr. Nicolaus Mmari and mother Mrs. Ruth Mmari who devoted their money to sponsor my studies. My young brothers Emmanuel and Frank, who worked hard and tirelessly for years and managed to support my long lasted studies. Kelvin, sister Lillian and son Helton for their love and courage. "**I love you all**".

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LIST OF ABBREVIATIONS

ABRU	Animal Behaviour Research Unit
a.s.l.	above sea level
cm	centimetre
DBH	Diameter at Breast Height
df	degree of freedom
GBH	Girth at Breast Height
GLM	General Linear Model
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature and Natural Resource
kg	kilogram
km	kilometre
km^2	kilometre square
km^{-2}	per kilometre square
km/h	kilometre per hour
LSD	Least Significant Difference
m	metre
MNP	Mikumi National Park
PR	Preference Ratio
SAS	Statistical Analysis System
SPSS	Statistical Package for Social Science
TWMP	Tanzania Wildlife Monitoring Programme.

CHAPTER ONE

1.0 INTRODUCTION

1.1 General background

The effect of browsing on vegetation by elephants and other herbivores has been a major concern to the managers of several wildlife protected areas and has been reported in over 22 National Parks that contain elephants (Barnes, 1983). The effect of elephants browsing may vary from negligible to severe, and may result in habitat degradation. This is especially more pronounced when the grass has been exhausted, and no other pastures are available. The elephants then increasingly tend to satisfy their hunger through trees. In this study the terms browsing and damage will be used interchangeably and will imply not only excessive vegetation utilization by elephant, but also all easily noticeable utilization of wood material, whether excessive or not.

In Mikumi National Park (MNP), the concern that elephant over utilized the habitat and thus killed affected trees, initiated the Animal Behaviour Research Unit (ABRU) to start collecting data on woody vegetation dynamics in 1992. Maige, (1990) studied the effect of elephant concentration and fire on woody vegetation in Mikumi National Park. Before then, no vegetation survey in relation to elephant use was documented in MNP. It is thought that, the current elephant population in MNP, which is estimated to be between 4000 and 6000 (Norton *et al.*, 2001), has substantial effect on the vegetation. The effect seems to be more pronounced in the northern one third of the park (within which the Mkata flood plain is located), where elephants are concentrated (Norton *et al.,* 2001). According to Ihde (1991), the acceptable population density of elephants in areas with less than 1000mm rain per year is estimated at 1 elephant km^{-2}. But in MNP, Norton *et al* (2001) and Caro (1999), found a mean estimated density of elephant to be 1.96 and 1.73 elephants km^{-2}, respectively. This evidence shows that MNP, with a mean annual rainfall of 860 mm (Norton, 1994), except in the hills where it is as high as 1500 mm (Lovett and Norton, 1989) (and where animals are not commonly found) has high elephant population. This in turn might have led into elephant over utilization of the habitat. Maige (1990) urged that, one does not have to be an ecologist to note the precarious state of trees in the central part of MNP.

The African elephant, *Loxodonta africana* (Blumenback) has been implicated many times in the destruction of woodlands (Barnes, 1980, 1985; Maganga, 1985; Weyerhaeuser, 1985; Okula and Sise, 1986; Kalemera, 1987; Jachmann, 1991; Kabigumila, 1993). Baobab trees (*Adansonia digitata*) are one of the tree species elephants are widely reported to use in a variety of locations in Africa (Caughley, 1976; Barnes, 1980; Barnes *et al.*, 1994; Weyerhaeuser, 1985; Swanepoel, 1993; Nahonyo, 1996; Foley, 2002).

Likewise elephants are known to use baobabs in MNP (Maige, 1990), however there was little quantitative information on the pattern and extent of baobab use in MNP. The aim of this study therefore was to assess the extent of elephant damage to baobab trees in MNP with special consideration that elephant will use baobabs extensively when water is limited. The study also aimed to find what other woody vegetations are utilized by elephants in MNP for the purpose of obtaining water, apart from food, when rivers and waterholes are dry.

The Mkata flood plain was chosen in particular to represent MNP. This is owing to the following reasons: the flood plain is the most important topographical feature and a major wildlife habitat for most of the year (Maige, 1990). The area is readily accessible. There is high concentration of both baobab trees and elephants (Maige, 1990). In addition, many elephant population studies have been conducted around the area (Norton *et al.*, 2001, Norton, G.W. personal communication, 2003). The results of population counts and densities may therefore be highly applicable to this particular area than others in the park. Furthermore, high elephant density in the area, in the past (2.5 km^{-2}) as reported by Balozi (1989) has been reported to affect the woody vegetation and opened this part into almost a treeless grassland (Maige, 1990).

1.2 Problem statement and Justification

Many researchers all over Africa have studied the effects of elephants on vegetation. (Leuthold and Sale, 1973; Anderson and Walker, 1974; Barnes, 1983; Okula and Sise, 1986; Cumming *et al.*, 1997; Leuthold, 1977; Maganga 1985; Kabigumila, 1993; Nahonyo 1996). In MNP, the concern that elephant over utilized habitat, initiated ABRU to start a long-term vegetation and habitat monitoring project aimed at surveying patterns of elephant use of vegetation and habitat in 1992. Despite the fact that the assessment did not suggest a large increase in elephant use of the habitat (Norton *et al.*, 2001; Maige, 1990), their studies did not take into account the baobab tree damage especially in the dry season. Hitherto, no study in MNP, has attempted to find out what elephant use as source of water and food during the dry season.

This study aimed at assessing the extent of elephant use of baobabs and other woody vegetation in MNP during the dry season for the following reasons. Firstly, baobabs are one of the tree species elephants are widely reported to use in a variety of locations in Africa (Weyerhaeuser, 1985; Barnes, 1980; Kabigumila, 1993; Barnes *et al*; 1994; Nahonyo, 1996). Secondly, elephants are known to use baobabs in MNP (Maige, 1990) and this use can be quite apparent and dramatic. Thirdly, there was little quantitative information on the pattern and extent of baobab use by elephants especially in Mikumi. Fourthly while there was little quantitative information, qualitative observation suggested that most trees have been at one time or another used by elephants and apparently much of this use was old and healed. This is consistent with the hypothesis that baobab use is intermittent and perhaps occurs under particular conditions of resource limitation. Water limitation has been suggested as a motivator of elephant baobab use (Fenner, 1980). The 2003 wet season in MNP was particularly dry (about 220mm less than the average of 860mm which is 25% below the mean) (Norton, 1994). Conducting the study during the dry season in the park helped to provide an answer to whether elephants use baobab trees extensively when water is limited and also to find out what other woody species were used by elephants in an extended dry season as a source of food and water. The survey of elephant damage on baobabs may serve as an indicator of water shortage, not only to elephants but also to other large mammals using the same habitat. The study was further expected to help MNP management with useful information that can be used in decision making such as provision of more artificial waterholes to supply water to animals during the dry season.

The ongoing research conducted by ABRU on elephant transects together with previous studies on elephant populations in MNP such as that of Ihde (1991); Norton *et al.*, (2001); Douglas–Hamilton *et al.*, (1986); Balozi (1989); Poole, (1989); and Anderson and Eltringham (1997), helped to provide useful information on elephant population density, distribution and range.

1.3 Objectives

The general objective of this study was to assess the extent of elephant use of baobabs and other woody vegetation in Mkata flood plain of Mikumi National Park.

Specific objectives were:

- To assess the type and extent of baobab damage by elephants
- To compare the extent of damage between new damage (occurred within 2003) and the average of recent damage (assumed to have occurred within five years ago).
- To assess percentage of elephant damage on other woody vegetation and to find what were the preferred food species in the study area

1.4 Study questions

This study sought to answer the following questions:

- To what extent can elephants cause damage to baobabs and other woody vegetation?
- Do elephants damage baobab trees more during an extended dry period?
- Is the size of the baobab tree related to extent of damage?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Elephants

2.1.1 Classification and general characteristics

Elephants belong to the order Proboscidea and family Elephantidae. There are only two living species: the Indian elephant, *Elephas maximus* and the African elephant *Loxodonta africana.* The latter has two subspecies, the forest elephant (*Loxodonta africana cyclotis*) and the savanna elephant (*Loxodanta a. africana*) (IUCN, 1993). The African forest elephant can be distinguished from the savanna elephant by its smaller body size, small ears, and its straight, downward projecting tusks (IUCN, 1993).

Elephants live in a social hierarchy dominated by older females. Females travel and live in long lasting social units of about half a dozen adult females and their offspring, with the unit being led by a single older female, the matriarch. Males do not maintain long-term social bonds, remaining in the unit only into their teens. They then live out their lives in loose bachelor groups or wandering on their own (Kagwana, 1996).

Female elephants attain sexual maturity earlier than males and the first oestrous occurs at about 10 years and a single calf is born after a gestation period of 22 months (Grizmek, 1975). Females between 14-45 years may give birth to calves approximately every 4 years with the mean inter-birth intervals increasing to 5 years between age 52, and to 6 years by age 60 (IUCN, 1993). Inter-birth intervals of up to 13 years may occur depending upon habitat conditions and population densities. The mean calving interval varies from population to population, with high-density populations or otherwise nutritionally stressed populations exhibiting longer intervals between births (IUCN, 1993). Calving can occur at any time of the year if food is plentiful all year round. In areas where food is scarce during dry seasons, most births occur during rainy seasons. In contrast males may take up to 15 years to mature.

An adult bull savannah elephant can weigh up to 7500 kg and reach a length of 9 m. Females are smaller, weighing up to 3232 kg and measuring 2.6 m at shoulder height (IUCN, 1993). Elephants are unusual among mammals in that they continue to grow throughout their life, although their rate of growth slows after they reach sexual maturity (IUCN, 1993). An elephant can live up to 70 years and when an elephant dies of old age the cause of death is often starvation (IUCN, 1993).

2.1.2 Elephant population, distribution and range

During the 15th century approximately 10 million elephants populated the entire area of Sub Saharan Africa. Human population at that time has been estimated at approximately 16 million. Today, the population of Africa is at 500 million and continues to rise (Ihde, 1991). In contrast, a census of the entire African continent established a stock of 1.3 million elephants, constituted by a large amount of separately existent populations (Douglas-Hamilton, 1987). The results of elephant population census in MNP and the adjoining Selous Game Reserve between 1976 and 1986 showed a decrease of 50% in the elephant population (Douglas-Hamilton *et al;* 1986). In 1986 the Selous Game Reserve had an elephant population of 55000, and the MNP of 1920 elephants, as opposed to a total of 109000 in 1976. The number of spotted dead elephants rose to 11400, (75%) in 1986 compared with 1976 (Douglas - Hamilton *et al.* 1986). This might be due to severe poaching pressure in the mid-late 1980's (Norton *et al.*, 2001). Cumming *et al.* (1997) also reported great reduction of elephant population in many East African parks during the 1970's and 1980's following illegal hunting for ivory. The elephant population in MNP was reported to be recovering following the decline of poaching and imposition of a ban on the ivory trade in 1989 (Norton *et al.*, 2001). Norton *et al.* (2001) have also suggested a great increase of current population estimates in MNP related to earlier ones. More recent studies in MNP have been trying to estimate the elephant population size as summarized in Table 1. Results of these studies do also show that MNP elephant population has increased considerably in recent years.

Table 1: Elephant population estimates in Mikumi National Park

Researcher	Year	Population estimates
Balozi, J	1989	2000
TWMP	1989	3800
Ihde, S	1991	2000 – 3000
Ereckson	2001	5000
Norton *et al.*	2001	4000 – 6000

Source: Modified from Norton *et al.* (2001)

Highly adaptable elephants can survive in forest, bush or savannah. The largest populations are found in southern, eastern and central Africa (IUCN, 1993). The African forest elephant is restricted to equatorial forests of the African basin and the West Africa (Maganga, 1985).

The African savanna elephant is found from sea level to about 3700m a.s.l. on mountains, and throughout the grass plains, woodlands, swamps, and bush land (IUCN, 1993). Its range is affected by availability of water during the dry season. Jachmann (1991) and Barnes *et al.* (1992) pointed out that the distribution of free-ranging animals is often related to availability of food, water and cover. Within their overall distribution they are most abundant where there are least people, and where grass, suitable trees and water are also plentiful (Pomeroy and Service, 1989). The African forest elephant is restricted to the equatorial forest of African basin and West Africa. Because of the nature of the habitat, little is known about this subspecies

The seasonal changes in overall distribution of elephants as well as various casual observations indicate considerable seasonal variations in habitat utilization. Leuthold and Sale (1973) reported food availability, which in turn is largely determined by the spatial and temporal pattern of rainfall to be the primary proximal factor governing movements and distribution of elephants in Tsavo National Park, Kenya. The lack of open water in large parts of the park virtually precludes their use by elephants during the dry season, and the elephants are compelled to concentrate within reach of permanent water supplies (Leuthold, 1977). Dry season ranges are all located relatively near one of the permanent water supplies.

Elephants require vast areas to meet their needs. Their home ranges vary from population to population and habitat-to-habitat and individual home ranges vary from 15 to 3700 km^2 (IUCN, 1993). Eltrihgham (1982) also reported home ranges for elephant family units to vary from one area to another depending upon the habitat type, productivity, and water availability. In productive areas like Lake Manyara National Park, elephant family group of 10 individuals may require a home range of about 14 to 52 km^2 (Eltrihgham, 1982), while in less productive habitats, such as Tsavo National Park, Kenya, the mean home range for individual elephant was found to be 350 km^2 in Tsavo west and 1580 km^2 in Tsavo east (Leuthold and Sale, 1973). In MNP (which forms part of Selous-Mikumi ecosystem), the elephant population is unique in being able to freely range over a vast area greater than 55000 km^2 (Stronach, 1998). This area provides the greatest diversity of habitat and hence highest level of protection for elephants (Norton *et al.*, 2001).

Range reduction has occurred because of the elephant's conflict with human for living space. In southern Africa, human and elephant populations are growing at rates of about 3 and 5% per annum, respectively (Spinage, 1990; Hall-Martin, 1992). The result is further reduction in elephant range, increased density of elephant within protected areas (Hanks, 1979), and human expansion into marginal lands. Furthermore, only small proportions of entire elephant ranges are protected. For example, in Tanzania in 1976, 87% of the country was considered elephant range, but elephants were protected only in 17% of their range that contained only 20% of the elephants in the country (IUCN, 1980).

2.1.3 Elephant, population density and composition

Ihde, (1991) reported the acceptable population density of the elephant in areas with less than 1000 mm rain per year to be 1elephant km^{-2} and 1.5 km^{-2} in areas of over 1000 mm per year. Cumming *et al.* (1997), reported the acceptable population density to be approximately 0.5 km^{-2}. In contrast MNP with a mean annual rainfall of 860 mm have population density of 1.73 elephants km^{-2} as reported by Caro (1999) and of 1.96 elephants km^{-2} as reported by Norton *et al.* (2001). MNP elephant population is composed of a family group size of approximately 5, and a female biased sex ratio (Norton *et al.,* 2001). The authors also reported an apparent persistence of a young population in MNP in findings of studies between 1987 and 2000. They further noted that these results might be due to severe poaching pressure and in particular because adult bulls were the prime target of poachers due to the large size of their tusks. However, these patterns have persisted across a period of 14 years mostly in the absence of any evidence of serious poaching. On this they suggested a possibility of high adult and male mortality even in the absence of poaching. Ihde (1991) reported a mean average family size in MNP to be 6.5 individuals. However, the author noted that, there was a decrease in proportion of single males in the population. The author found sex ratio of the sub-adult population to be composed of 59% females and 41% males (in sub-adult population), and 93.5% female and 6.5% males (in adult population).

2.1.4 Elephant food and habitat requirements

The African Savannah elephant is a relatively unspecialised herbivore, eating a great variety of plant materials. Being non-ruminants, elephant have an inefficient digestive system and digest only 40% of what they eat. They therefore require large volumes of food, as they can spend 18–20 hours of a day for selecting, picking, preparing and eating food (Dougall, 1964). Its food depends as much on availability as on choice and it varies with season (Maganga, 1985). The elephant diet consists of grasses, bamboo, roots, barks, wood herbs and fruits of specific plants (Grizmek, 1975; Pomerey and Service, 1986). The number of plant species eaten by one elephant may vary but it is likely to be more than fifty (Redmond, 1993). An elephant's choice of food plants will be determined partly by what grows locally, what was learned from its mother, and from what it has discovered by trying novel food items (Redmond, 1993). They also select their meals taking into account the time it takes to prepare each mouthful. The optimal daily food requirements are about 6% of live weight on a wet weight basis. Thus an average fully adult bull elephant (5000 kg) requires 300 kg of food (green weight) per day and an adult cow (2800 kg) about 170 kg (green weight) (Laws, 1971). The composition of food varies according to season. During the wet season, food consists of up to 88% of grass and other root plants, 10% of bushes and small trees and up to 2% of the leaves and barks of trees. During the dry season the share of grass is reduced to 74% that of bushes increased to 16%, and of leaves and bark to 10% (Ihde 1991). At the early and mid-wet season, the protein content of grass is high (Barnes, 1982) hence elephants tend to eat more grass. Elephants require wood material for nutrients missing in grass and fibre for digestion. Laws (1971) reported that, a protein requirement of a coarse feeder like elephant, especially in the dry season when the fibre content of the whole grass plant is high, can only be met by browse and herbs. However, the author further showed that increasing amounts of grass in the elephants' diet are correlated with conversion of wood habitats towards grassland and with increasing elephant mobility, poor physical condition, and progressively increasing natural regulatory process leading to decrease in numbers. Optimum elephant habitat should therefore, contain as much or more readily available twigs and shoots of woody vegetation as grass (Laws, 1971). This requirement is met by elephant living in forest edge, woodland and bushland or bushed grassland. In these habitats elephants are also provided with shade, which is very important for calf survival (Barnes, 1983). Elephants usually rest during the hot hours of the day. Members of family herds usually huddle together in the shade during this time, when the day is over; the herd goes to drink water and bath. These basic ecological requirements determine an elephants' home range. The availability and distribution of these requirements changes seasonally and is reflected in seasonal changes in movement and habitat use. As a result, elephants are more sensitive to manipulation of their environment than direct manipulation of their numbers (Caughley, 1976).

Water has to be taken at least every two days. Where abundant surface water is not available, elephants have to move daily between feeding grounds and streams or permanent water holes. An adult elephant can drink about 225 litters of fresh water per day (Redmond, 1993).

2.1.5 Elephant's, behavioural feeding pattern

In feeding, elephants use mostly their trunks and tusks and their feeding is rather destructive when compared to other browsers (Jachmann and Bell, 1985). Feeding by elephants may involve damage to trees through felling, breaking branches, debarking, fraying, uprooting and gouging (IUCN, 1993).

2.1.5.1 Feeding hours

Daily activities of elephants as was studied by Kabigumila (1993) in Ngorongoro Conservation Area included: feeding (handling, ingesting, and moving while handling or ingesting food; activities associated with water (drinking, mud bathing); resting (standing in the open or shade); walking. Studies show that, elephant spend much of their time feeding (Wyatt and Eltrigham, 1974; Barnes, 1983; Kabigumila, 1993). However, the total time spent varies with place. Wyatt and Eltrigham (1974) reported that elephant spend 74% of the time feeding in Rwenzori National Park, Uganda while Kabigumila (1993) reported elephant in Ngorongoro Crater use about 69% of their time feeding. In Mikumi National Park, elephants use between 56% and 85% of their time feeding, depending on the season (Barnes, 1983). He further noted that feeding may take place at all hours but there is a drastic reduction in feeding activity in early hours of the morning between 04.00 and 07.00, which are the principal sleeping period. Another reduction in feeding activity is around mid-day, which is correlated with short rest period. The proportion of the total feeding time spent in browsing increased in the dry season. Walking took place mainly at dusk, they moved slowly, feeding as they go. The rate of progress through the bush averaged 0.5 km/h. Drinking takes place at any time of the day or night and the timing is influenced more by availability of water; an average of 1.3 times a day was recorded. After drinking, the elephants usually throw mud over themselves.

2.1.5.2 Variation in plant species and parts eaten

Barnes (1982) studied the variation in plant species and parts eaten in Ruaha National Park, Tanzania and revealed that in wet season elephants eat mainly green grass and small amounts of green browse and in the dry season, after the grass are withered and browse leaves disappeared, elephants turn to eating woody browse. Similar results were reported by Field (1971), Wyatt and Eltrihgham (1974), and Guy (1976). Despite the fact that browse contain higher concentration of proteins and fatty acids than are found in grass (Field, 1971), and green leafy browse are abundant in wet season, elephants have been observed to prefer browse only in dry season when the grasses have withered (Wyatt and Eltrihgham, 1974; Guy, 1976; Barnes, 1982) and not in wet season as it could be expected. However, in MNP, observations showed that, elephants have a general tendency to take less browse than grass (Barnes, 1980; Maige, 1990) regardless of dry or wet seasons. Similar findings were reported by Field (1971) in Kabalega National Park, Uganda.

Toxic secondary compounds are more likely to be found in vulnerable plant parts (Mc Key, 1974) such as leaves than in woody plant parts. Barnes (1982) reported this to be possible explanation to why in the wet season bulls obtained food from green browse (leaves and shoots) from a variety of species spending shorter time per species so as to be able to obtain the nutrients in leaves without ingesting lethal dose of toxins from any one species. In the dry season, where feeding is mainly from woody browse (twigs and branches) they spent much longer time on each species and their feeding was less evenly distributed. In addition, for a given area, the concentration of minerals like magnesium, calcium and sodium may be two to four times lower in grasses than in browse, on a year round basis (Douglass *et al.*, 1964). Other studies came up with similar results; Croze (1974) found that *Acacia tortilis* was eaten because of high calcium content in the leaves and twigs. Dougall (1964) found that elephants in Tsavo National Park, Kenya preferred plants rich in calcium and protein. Bax and Shedrick (1963) agree with these, but state that general palatability is also important. Jachmann and Bell (1985) found significant positive correlation between utilization of certain species by elephant and the protein and sodium content of leaves. The authors also reported that, crude fiber content was relatively low in highly favoured species and concluded that chemical composition and mechanical properties of browse determine its palatability. However, Anderson and Walker (1974) did not find any significant relationship between extent of elephant damage and chemical composition of vegetation.

On the same scenario, Barnes (1982) urges that one aspect of elephant feeding behavior of great concern to park managers is their habit of bark stripping trees. Bark stripping occurs either in the wet season (Croze, 1974; Laws *et al.*, 1975; Vancuylenberg, 1977) or dry season (Barnes, 1982) depending upon the tree species and the area. This is due to variation in the chemical content of the tree species, which in turn depends on the chemical content of the soils in the area. Barnes (1982) found that some tree species were damaged before flowering (e.g. *Acacia tanganyikiensis*) or producing leaves (e.g. *Lannea humilis*) whereas others were damaged during flowering (e.g. *Cassia abbreviata*) or leaf production (e.g. *Acacia tortilis*). Croze (1974) argued that elephant bark strip trees possibly for roughage and to search for some nutrients, such as calcium, which are low in other items of the diet. A similar study by Williamson (1975) reported that in Wankie National Park, *Pterocarpus angolensis* is ring barked extensively when the sap is rising and Guy (1976) suggested that elephant barked trees in the late dry season because of the increased nutrient translocation from the roots towards the new leaves.

However, Barnes (1982) concluded that debarking might be a consequence of physiological changes in both elephants and trees. He further pointed out that chemical content (i.e. minerals, protein, and sap) in the tree might have varied due to phenological changes. Because chemical levels vary between tree species and within trees during different stages of the life cycle, elephants may be responding to these changes. Therefore elephants may be debarking trees to meet their physiological needs of minerals, amino acids, fatty acids, sap, and possibly vitamins. These needs vary from season to season and result in the elephant feeding on certain plant species and parts in different seasons. However, physical condition of the plant (such as softness, moisture content, height, thickness, and thorns) has also proved to contribute to species and part of the plant selectivity. The baobab tree stem and branches are evidently browsed by elephants due to their softy pulpy tissues (Barnes, 1980; Barnes *et al.*, 1994; Fenner, 1980; Wickenns, 1982; Wayerhauser, 1985; Redmond, 1993; Caughley, 1976 and Nahonyo, 1996). These studies suggest that baobab trees are browsed due to their high moisture content. In a similar study, Anderson and Walker (1974) reported relatively little damage to *Combretum* *imberbe* because of its extremely hard wood. Hayashi (1992) reported that there was high preference of the *Commiphora* by elephant in Kitui, Kenya probably because of its softwood and high water content. Anderson and Walker (1974); Caughley (1976); Van Wyk and Fairall, 1969 and Nahonyo (1996) suggested that elephants select the small trees in preference to the large ones. Jachmann and Bell (1985) suggested that the selected species are constantly browsed and kept at the preferred feeding level, while non selected species are subjected to lighter browsing and a proportion of them are allowed to grow to a canopy height. Barnes (1982) reported that elephants in Ruaha National Park preferred thorned and scorched plants because they had less inhibiting compounds.

Another factor determining selectivity of tree species by elephant is abundance. In MNP, Maige (1990) reported *Cassia abbreviata* to be over browsed by elephants. His study further reported that, *C. abbreviata* was the dominant tree species in Mkata flood plain (MNP). Over-browsing of *C. abbreviata* by elephants hence might be related to its abundance relative to others. In Seronera National Park, some species of *Acacia* were eaten by elephant probably because they were the dominant species. Nahonyo (1996) obtained similar results in Ruaha National Park. However, Anderson and Walker (1974) reported *Dyspiros senensis and Combretum mossambicence* to be least damaged tree species despite being most abundant. Moreover it seems that some individual trees taste better than others. In the Ruaha National Park, Barnes (1982) noted that some trees were fed on by elephants while some were just smelt and left.

Another interesting phenomenon in elephant feeding behaviour is their habit to prefer previously damaged trees. Studies by Anderson and Walker (1974), Jachmann and Bell (1985), Lewis (1991), and Smallie and O'Connor (2000) have all revealed this. Jachmann and Bell (1984) states that, herbivores can browse on a single tree with its canopy within feeding range during a relatively long period. This results in an increased density of short trees in selected species in heavily utilized areas (Jachmann and Bell, 1985).

2.1.5.3 Variation between sexes

In his study on elephant feeding behaviour in Ruaha National Park, Barnes (1982) noted that there is a difference between bulls and cows on the plant parts eaten in different seasons, and time spent eating each plant. He revealed that bulls ate barks of trees throughout the year, particularly in early and late dry season, at the same time cows ate barks only occasionally. He further noted that bulls spent more time than cows feeding on each tree or shrub i.e. bulls moved from plant to plant less often. He further argued that if bulls tend to spend longer feeding on each individual woody plant, then there might be a difference between bulls and cows in their impact upon the vegetation. Guy (1976) concluded that a mean of 1.6 trees were destroyed every day by one bull elephant in the Sengwa Research Area, Rhodesia (now Zimbabwe). If bulls damage food plants more severely than do cows, but browse on fewer plants per unit feeding time, then there may be a difference in the distribution of browsing damage over the plant population. Bulls are larger than cows (Laws and Parker, 1968; Laws, 1971) and if they have a higher absolute food intake and cause more damage per individual plant, bulls may have a greater impact on the habitat than equal number of cows (Barnes, 1982). Barnes (1980) showed that for baobab tree (*Adansonia digitata* L.) there is a significant difference between bulls and cows in the time spent feeding on individual trees. He further noted that, bulls only were responsible for killing the adults of this species and he suggested that this was a consequence of the different social groups formed by bulls and cows. Barnes (1982) suggested that cows' shorter feeding bouts might be a result of the necessity to avoid harmful doses of toxins, as cows are smaller than bulls.

Elephants also are evidently known to uproot/push over trees (Croze, 1974; Guy, 1976; Wickens, 1982; Jachmann and Bell, 1985). Croze (1974); Guy (1976) and Wickens (1982), reported this behaviour to be a social display, especially by young bulls. However, Jachmann and Bell (1985) suggested this to be part of feeding strategy that leads to increase of browse production of preferred species.

2.2 The baobab tree

2.2.1 Overview

The African baobab and its allied species are members of the small pantropical family Bombacaceae (Wickens, 1982). This family is mainly indigenous to tropical America and includes about 140 species (Van Wyak, 1972). Familiar species include the kapok tree *Ceiba petandra,* balsa wood tree *Ochroma pyramidale* as well as the durian, *Durio zibethinus* (Wickens, 1982). Although a number of genera have soft, water-storing woody tissue, none quite attain the monstrous proportions of

Adansonia spp (Wickens, 1982). The baobab thrives best on deep well drained soils at altitudes of between 450 m and 600 m above sea level with a rainfall between 300-500 mm per annum. This would explain for its distribution throughout tropical Africa, except that here frost becomes the limiting factor (Wickens, 1982). Of the 8 species of *Adansonia*, *A. digitata* is the only species that occurs in tropical Africa. Most of the species are found in Madagascar, but the genus also occurs in Australia (Wickens, 1982). Baobabs can grow to a moderate height of about 10-22 m; the trunk is huge and broad which can reach over 15 m in diameter. The tree is deciduous and it has the appearance of having been turned upside down, hence the name, up side-down tree (Mbuya *et al.*, 1994). Baobabs are extremely long lived, with some trees believed to be as much as 3000 years old (Mbuya *et al.*, 1994).

2.2.2 Natural distribution and ecology

Very little is known about the habitat requirements of baobabs (Wickens, 1982). The ecology of baobabs has also not been well studied (Wickens, 1982; Swanepoel, 1993). However, baobabs are basically a characteristic representative of the drier plant communities, with a possible extension to higher rainfall areas by humans (Wickens, 1982). Wickens (1982) reported that the baobab shows preference for free-draining soils, more specifically with sandy topsoil overlying a loamy substrate and where the water table is fairly high.

Baobabs occur in semi arid areas of Sub Saharan Africa, where the annual rainfall is in the range of 150 to 1500 mm (Fenner, 1980). It is also found from sea level up to areas 1250 m in altitude (Fenner, 1980). Its range extends across the African continent south of the Sahel region, also into east, central and Southern Africa (Fenner, 1980).

In east Africa; there are no reports from Uganda, and in Kenya it is found chiefly in *Acacia – Commiphora* bushland and scrub and the semi desert grassland of northern Kenya (Wickens, 1982). In Tanzania and Mozambique, it is a conspicuous emergent of the *Afzelia guineensis* coastal forest, especially on outcrops of coral limestone (Wickens, 1982). Elsewhere in Tanzania it is a conspicuous emergent in many parts of the deciduous bushlands or a relic in areas of upland plateau cleared for cultivation (Wickens, 1982).

2.2.3 Ecological importance of baobabs

The baobab provides food and shelter for a number of insects, reptiles, mammals and birds (Wickens, 1982). It also acts as an important source of water for both humans and animals during drought (Fenner, 1980). The wood has a high moisture content that may reach 40% or above. Apart from being a source of water and fibre, nothing else has been documented to attract elephants to use baobabs. Fruit bats eat the young tender leaves (Wickens, 1982). Baboons, monkeys, elephants and impala eat the fruit. Elephants also browse, uproot baobabs, strip off the bark and chew the fibrous wood (Wickens, 1982). Baobab also provides shelter for the bushbaby and various venomous snakes including boomslang. Many birds frequently roost or nest in the baobab, including red-winged starlings, swifts and the gregarious buffaloweavers. Others such as hornbills, parrots and king-fishers use holes in the trunk. Wild bees, sweet bees, stick insects and many others also nest in the trees (Wickens, 1982). The tree is also a source of fibre to humans (Fenner 1980).

The extensiveness of the root system may limit the density of the baobabs themselves (Fenner, 1980). From aerial survey, the trees appear rather evenly distributed, suggesting a mutual antagonism probably caused by competition for water (Fenner, 1980). The shallow root system typical of baobabs indicates an adaptation to the rapid absorption of water from the surface layers of the soil (Fenner, 1980). This is useful in areas where most of the annual rainfall is in the form of occasional heavy showers in which there may be run-off on the hard soil surface. An extensive shallow root system may provide the most effective means of exploiting these situations (Fenner, 1980).

2.2.4 Effect of elephant on baobabs

2.2.4.1 Seasonal variation in damage

Elephants are known to use baobabs as source of food and water (Laws, 1969; Caughley, 1976; Barnes, 1980; Weyerhaeser, 1985; Barnes *et al.,* 1994; Nahonyo, 1996). Elephants eat branches and stems of the baobab tree since the wood is soft and has high moisture content. Because of this, the tree is preferred by elephants during the dry season and therefore most of the damage occurs in the dry season (Barnes, 1980, Weyerhaeser, 1985; Caughley, 1976; Barnes *et al.*, 1994; Nahonyo, 1996). Swanepoel (1993) reported that, in Mana Pool National Park, Zimbabwe, elephants severely damaged baobabs before the first rains, when these trees were producing leaf and flower buds. However, he did not give reasons for the relationship. In another study, Laws (1969) reported baobabs to be damaged both in dry and wet seasons at the same rate in Tsavo National Park, Kenya.

2.2.4.2 Pattern of damage

It has been shown that elephants prefer young baobab trees to older ones. Caughley (1976) reported that elephants find young baobabs irresistible and therefore, damage them more frequently and Barnes (1980), Barnes *et al.* (1994) reported high rate of disappearance of the young baobab trees in Ruaha National Park due to elephant's preference for eating the youngest trees. Similar results were observed by Weyerhaeser (1985), who reported all of the baobab trees killed by elephants in the Lake Manyara National Park were in smaller size classes. However, elephants also fall mature trees with a frequency that declines with the size of the tree (Caughley, 1976). Weyerhaeser (1985) found a strong positive linear relationship between baobab circumferences and bark damage. Regarding the type of damage, Weyerhaeser (1985) found that large proportion of mature trees were more bark-stripped as compared to those that were gauged, while Nahonyo (1996) reported many baobab trees in Ruaha National Park to be debarked and gauged. For young baobab trees, both branches and stems are browsed. Elephants also uproot baobabs (Wickens, 1982).

2.2.4.3 Variation between sexes

It has been generally shown that overpopulation of elephants in a given habitat will cause substantial damage on that habitat and in particular to woody vegetation, including baobabs (Jachmann and Bell, 1985; Maganga, 1985; Okula and Sise, 1986; Barnes, 1980; Weyerhaeser, 1985; Tchamba, 1995, Kalemera, 1987; Jachmann, 1991; Barnes *et al.*, 1994; Nahonyo, 1996; Cumming *et al.*, 1997). Some of these studies tried to relate differences in severity of damage between males and females. Barnes (1982) and Eltrihgham (1980) found that bulls generally have a greater impact on the habitat than cows, but none of these findings were significant. For baobab trees however, Barnes (1980) found that there was a significant difference between bulls and cows in the time spent feeding on individual tree. Furthermore, Barnes, 1980; 1982, and Barnes *et al.*, 1994 noted that only bulls were responsible for killing baobab trees because of their habit of prolonged gnawing at the bole. The study by Barnes *et al.*, 1994 can further support this; they revealed that there was no significant increase in number of dead baobab trees between 1982 and 1989 survey as compared to that between 1976 and 1982 (Table 2). They ascribed the decline in bull numbers due to poaching (Barnes and Kapela, 1991).

Table 2: The numbers of live and dead trees recorded in three baobab surveys in the Ruaha National Park, Tanzania.

Year	Live	Dead
1976	328	9
1982	163	15
1989	354	4

Source: Barnes *et al.* (1994).

2.2.4.4 Damage to baobab trees

Some studies have tried to assess percentage damage to baobab trees. Laws (1969) reported baobab trees in Tsavo National Park, Kenya to be killed by elephant at an estimated rate of 2% per year, and Barnes (1980) found that baobabs were killed at a rate of 2.7% a year in Ruaha National Park. Laws (1969) suggested that the species can be expected to disappear from the area in a relatively short time since there was virtually no regeneration. Barnes (1980) predicted a possible extinction of baobabs in Ruaha National Park within a period of 30-170 years assuming elephant will continue to damage baobabs at the same rate. In another study, Barnes *et al.* (1994) reported a complete disappearance of baobab trees with GBH less than 1m in Ruaha National Park. Weyerhaeser (1985) reported elephants to be responsible for collapse and death of baobab trees in the Lake Manyara National Park due to their habit of gauging out the wood with their tusks. However, more recent studies showed a decrease in elephant impact on baobabs. Barnes *et al.* (1994) reported a drop in mortality rate of baobabs in 1982 and 1986 survey. Nahonyo (1996) reported that although all of the baobabs observed in the Ruaha National Park were debarked and gauged, most of them have recovered and suggested that the level of debarking and gauging was lower than the ones observed in the past.

The exceptional longevity of baobabs means that any short-term changes in mortality as a result of present elephant damage may have long-term consequences for the population (Weyerhaeser, 1985). The present baobab population structure is, to a large degree, the result of environmental factors that existed long ago (Weyerhaeser, 1985).

2.3 Effect of elephant on woody vegetation

2.3.1 Factors leading to habitat damage

Damage of habitat by wild animals is generally a sign that the animals' requirements are not in balance with the resources of the environment. This can happen when there is an overpopulation of animals in a habitat, which results in habitat damage (Maganga, 1985). Climatic condition such as drought might also be the cause of the imbalance due to the reduction in food production of the habitat. In his stable limit cycles hypothesis of the elephant - forest relationship, Caughley (1976) support this. He pointed out that elephant population and tree population trends are similar to sine waves but the elephant population number lags behind trees. When trees increase to the highest density, the elephant density is at the lower level.

Displacement of the stable limit cycle by external factors may occur but the cycle can re-establish after the external forces are removed. This hypothesis has some theoretical appeal for understanding the problem. However, at present, this cycle appears to have been permanently interrupted by some human-induced external factors, causing localized elephant over populations. Consequently, damage to woodland habitats has been severe in these areas. Maganga (1985) argued that the present over-population in certain areas was not directly related to births and immigration, but rather to factors affecting immigration. He reviewed these factors to include shrinking of elephant range, blocking of migration routes, and protection afforded by National Parks. All of these factors are induced by humans.

The habitat of the African elephant (and other animals) is steadily decreasing through expanding civilization and utilization of the land for farms and ranches. The destruction of the habitat in this way has long-term consequences for the elephant population, which is pushed back into smaller, isolated patches. In southern Africa for example, human and elephant populations are growing at rates of about 3% and 5% per annum, respectively (Spinage, 1990; Hall-Martin, 1992) and in some areas wild land is being converted to subsistence agriculture at similar rates (Cumming, 1994). The results are a further reduction in elephant range, increased elephant density within protected areas (Owen-Smith, 1988) and human expansion into marginal lands. Together, these processes are leading to the deforestation of large areas of savannah woodland (Huston, 1993). When the habitat of the elephants was not restricted to this extent, equilibrium between vegetation and feeding habits had been established. The animals had the opportunity to migrate from areas stripped bare and search for new pastures leaving the vegetation behind to regenerate. This is no longer possible, as the establishment of reservations provides a refuge for the animals but undermines natural migration. The resulting increased population density in turn has a destructive effect on the protected area vegetation.

The problem is even more enhanced by the feeding behaviour of elephants, their longevity and their large size. When the grass has been exhausted, and no other pastures are available, the elephants increasingly tend to browse on trees. They debark trees and push them in order to get at the leafage. The tree stock has no opportunity to regenerate, as elephant cannot leave the protected area (Barnes, 1983). In addition, due to their large body size and being non-ruminants, elephants require a large amount of food intake in order to meet their daily minimum energy requirements; the elephant thus has to feed unselectively.

In an undisturbed habitat, elephants can self-regulate their numbers to adjust to declining resources by lengthening their calving interval, deferred maturity and increased calf mortality (Laws, 1981b). However, since elephants have large body size and slow growth, manipulation of their population to cope with environmental change will take place slowly. It will also take time to have an effect because of the elephants' longevity, compelled with high adult survival rate of between 94 to 96% (Laws, 1981a).

2.3.2 Damage to trees

Feeding on woody parts by elephant damages the plant because these parts take many years to grow and they are not easily replaced by the individual plant (Barnes, 1982). In areas faced with elephant damage, woodlands are eventually converted to shrub-land or open grasslands as elephants kill mature trees and suppress regeneration (Leuthold, 1977; Barnes, 1980; 1983; Cumming *et al.*, 1997). The effect of browsing on vegetation depends on the animal's biomass and method of feeding (Field, 1975). For example, mature trees are damaged by elephants eating twigs and shoots, breaking off branches, stripping off bark, and knocking down whole trees, while heavily trampling and uprooting saplings. Elephants also destroy fire-resistant tree species and then fires kill the trees because they become less fire-resistant than when they are intact. In MNP, Maige (1990) observed that, *Cassia* *abbreviata* trees were killed by fire that started burning from old scars originally inflicted by elephant tusking. High elephant densities, combined with fire, have had a major effect on formally pristine miombo wood-lands in many protected areas of Southern Africa from South Tanzania to Zimbabwe and from Angola across to Mozambique (White, 1983). In Kabalega Falls National Park, Uganda, exclusion of elephants with continued regular burning resulted in regeneration of woody vegetation (Laws *et al*., 1970). Furthermore, elephant damage will leave the tree very vulnerable to wood borers (beetles) and wood rot caused by fungi. Eltrihgham (1980) observed trees, which have been debarked, or tusked by elephants to be rapidly destroyed by wood-boring insects and termites. And Anderson and Walker (1974) obtained similar result in Sengwa Wildlife Research Area, Rhodesia. This accelerates tree destruction and the rate of changing woodlands to grasslands. Furthermore, several studies have revealed that elephant induced habitat change, has negative impact on biodiversity. Thus, elephants do not only have a negative effect on these habitats, but also to animals inhabiting such habitats, including the elephants themselves. For example, the initial collapse of elephant and black rhino populations in Tsavo National Park, Kenya (Botkin, 1990; Martin and Martin, 1982) and the extinction of bushbuck and lesser kudu from Amboseli National Park, Kenya, were a result of elephant-induced habitat change (Western and Gichohi, 1993). Cumming *et al.* (1997) reported species richness of woodland birds and ants to be significantly lower where elephants had removed the tree canopy in Southern Africa.

Many studies have attempted to quantify the impact of elephant on woodlands in African National Parks. All the studies have revealed excessive tree damage during the dry season. In the Ruaha National Park, Barnes (1985) reported woody vegetation damage by elephants, of between 45% and 72% depending on the tree species. In the Sengwa Wildlife Research Area, Rhodesia (now Zimbabwe), Anderson and Walker (1974) reported a total of old and new elephant tree damage of 33.9% and 4.1%, respectively. Okula and Sise (1986) reported elephant tree damage of 28% in Waza National Park, Cameroon, while Eltrihgham (1980) reported tree mortality of 5.7% per annum in Mweya Peninsula, Rwenzori National Park, Uganda mainly as a result of elephant damage. Field (1971) estimated that in the crater region of Queen Elizabeth National Park, tree damage caused by elephants amounted to nearly 7% per annum. However, Nahonyo (1996) did not find elephants a threat to habitat modification as a result of browsing in the Ruaha National Park. The study by ABRU in MNP did not suggest increased elephant use of the habitat (Norton *et al.*, 2001). Similarly, a study by Maige (1990) reported that, MNP as a whole was not threatened by the elephant problem. His study reported only 5.9% of trees with damages more than 50% of the tree canopy or their stems ring barked. He further reported 11.1% of trees to be browsed to about 50% of stem circumference or their stem ring barked. However, he reported localised tree damages around the park headquarters.

Some of the studies have tried to relate tree and/or habitat damage to elephant population densities. Cumming *et al.* (1997) found positive relationship between elephant damage and elephant population densities. They reported that when elephant densities exceed approximately 0.5 km^{-2}, savannah woodlands are generally converted to shrub-lands or grasslands. Anderson and Walker (1974) did not find any positive relationship between elephant damage and average elephant densities (approximately 1 km^{-2}). Eltrihgham (1980) found no direct proportional relationship between tree mortality rate and degree of elephant densities. He rather related tree mortality to behaviour of individual elephant. Studies by Spinage (1990) and Martin *et al.* (1989) have also revealed that localized woodland damage and loss of certain species will occur even at elephant densities of < 0.2 elephant km^{-2}.

2.5.4 Highly damaged tree species

Studies have shown that some tree species are highly preferred by elephant to other species. Factors governing species preference by elephant include chemical composition (e.g. high mineral contents), physical condition (e.g. size of the tree) and presence of toxic secondary compounds (e.g. tannins) (Sect. 2.1.5.2). Species preference by elephants will hence depend on one or a combination of the above factors that will lead to excessive destruction of that particular species. However, abundance of individual tree species and location of tree species (such as trees located close to waterholes) may also force elephant to utilize some species regardless of whether they prefer that particular species or not.

In MNP, Maige (1990) reported *Cassia abbreviata* to be severely browsed by elephants. He further reported that, fire and not elephants, was primarily responsible for damage of *D. melanoxylon*. In the Sengwa Wildlife Research Area, Rhodesia, Anderson and Walker (1974) reported *Acacia robusta* to be heavily damaged (99.0% old damage), 55% of new elephant damage on *Combretum apiculatum*, 75.9% old damage on *Lonchocarpus capasa*, 83.8% old damage on *Acacia tortilis*. Nahonyo (1996) reported *Commiphora spp*, *Acacia spp*, *A. digitata*, *Brachystegia spp* and *Combretum spp* to be highly selected in the Ruaha National Park. The author further noted that most of these species were only lightly damaged. However, he did not quantify these damages. Tchamba (1995) reported 93% of damage on *Piliostigma reticulum*, 83% on *Acacia seyal*, 76% damage on *Combretum aculeatum* and 52% damage on *Combretum glutinosum*. Studies by Van Wyk and Fairell (1969), Anderson and Walker (1974), Caughley (1976) Guy (1976) and Smallie and O'Connor (2000) have shown that *Colophospermum mopane* was selected by elephant.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study area

3.1.1 Location

Mikumi National Park lies approximately 300 km west of Dar es Salaam City along the Tanzania–Zambia highway and it extends from 37 00 E to 37 30 E and 7 00 S (Norton *et al.*, 1987) with an altitude range of 430 to 1253 m above sea level. However, most of the park lies at 500 m above sea level (Park records). Mikumi is the third largest National Park in Tanzania and it covers an area of about 3230 km^2 and is contiguous with the much larger Selous Game Reserve (Norton *et al.*, 1987). They, together with the Kilombero Valley form the Selous ecosystem, which covers about 75,000 km^2 (Ihde, 1991). The park is bordered in the east by the Uluguru Mountains, in the west by the Rubeho Mountains, in the southwest by the Lumango Mountains and in the south by the Selous Game Reserve.

The wet plains of the Mkata River and its arms represent the main part of the park. These plains lie at an average altitude of 548 m a.s.l. (Maige, 1990). The Mkata River flows through the park from the south into Tendigo swamp in the north. The floodplain is an important topographical feature. Another important feature is the species endemism of the Malundwe Hill (Lovett and Norton, 1989). The hill is covered by the afromontane rain forest and rises to 1253 m a.s.l., at the highest point.

3.1.2 Soils

The Mkata floodplain is composed of interspaced hardpan ridges separated by narrow depressions of black montimorillonite soils (Snelson, 1987) commonly referred to as "black cotton soils" in the low-lying plains called "mbugas". It is a vertisol type of soil (Strahler and Strahler, 1987) which is characterised by a high clay content that shrinks and swells greatly with changes in soil–water storage, forming deep cracks in the dry season.

Soils of other areas of the park are influenced by drainage. Most of the soils in the plains are alkaline and sodic. Such soils have exchangeable sodium content of more than 15% of all exchangeable bases (Russel, 1961). Saline/sodic soils are a result of sodium coming through the ground water and replacing the calcium content. As a result, the sodium level is raised and the soil becomes generally alkaline in nature.

3.1.3 Climate

MNP lies within the eco–climate zone IV of Pratt and Gwynne (1977). The park area has a single wet season starting from November to May. The dry season usually begins in June and ends in October (Norton *et al.*, 1987). However, the dry season climax in August, when all surface water has dried up and the animals are dependent on the water reserves of the waterholes and the main reaches of the river. During the dry season, bush fires occur regularly. The average rainfall in MNP from 1964 to 1993 was 860 mm (Appendix 3) (Norton, 1994). The moist area of the park is the Malundwe Hill with an annual rainfall of 1500 – 2000 mm (Lovett and Norton, 1989).

3.1.4 Vegetation

MNP lies within the Zambezian floristic region (White, 1983). *Brachystegia* (miombo) tree species predominate the higher elevations and the rocky eastern hills of the park. East to west, the park is covered by *Brachystegia* trees, which emerge into open woodland and culminate into wooded and open grassland in the Mkata floodplain (Maige, 1990).

The seasonally inundated Mkata plain is open grassland with numerous grass species. Tree species found scattered in the floodplain include *Cassia abbreviata*, *Combretum hereroense*, *Cassia auriculata*, *Dalbegia melanoxylon* and *Diospyros usambarensis*. Baobab trees are found in most dry areas regardless of altitudinal differences within and outside the park (Maige, 1990).

3.2 Sampling techniques

Choice of techniques for sampling of vegetation depends on the purpose of study, type of vegetation being studied, availability of equipments, time, personnel, and funds (Kent and Coker, 1992). In this study, ground survey of baobabs and other woody vegetation damage.by elephants was employed.

3.3 Study of baobabs

3.3.1 Ground survey of baobabs

The northern one third of the park, with an area approximately 1000 km^2 was the target of the study. This part of the park is easily accessible as the remaining part is heavily wooded and hilly or mountainous (Norton *et al.*, 2001). However, due to the study objectives, the survey was further limited to the area where baobabs and elephants were relatively common and easy to observe. This area is found within the southern and eastern areas of the Mkata river system (Figure 1).

The technique was that of belt transect (Barnes, 1985; Kent and Coker, 1992). This method is suitable for evaluating plant damage (Kent and Coker, 1992). Belt transects of approximately 300 m width and length of 1000 m each were located perpendicular to the baseline. The Chamgore tourist road was chosen as a baseline instead of imaginary line in order to ease accessibility. The distance between transects was 1000 m and a total of 20 transects were marked using a Global Positioning System (GPS). Transects were named by numbers from 1 – 20. The numbers were then rearranged randomly and the data were taken based on these random numbers until a sample size of 50 baobabs was attained. A GPS was again used to mark and map grid location for all sample trees.

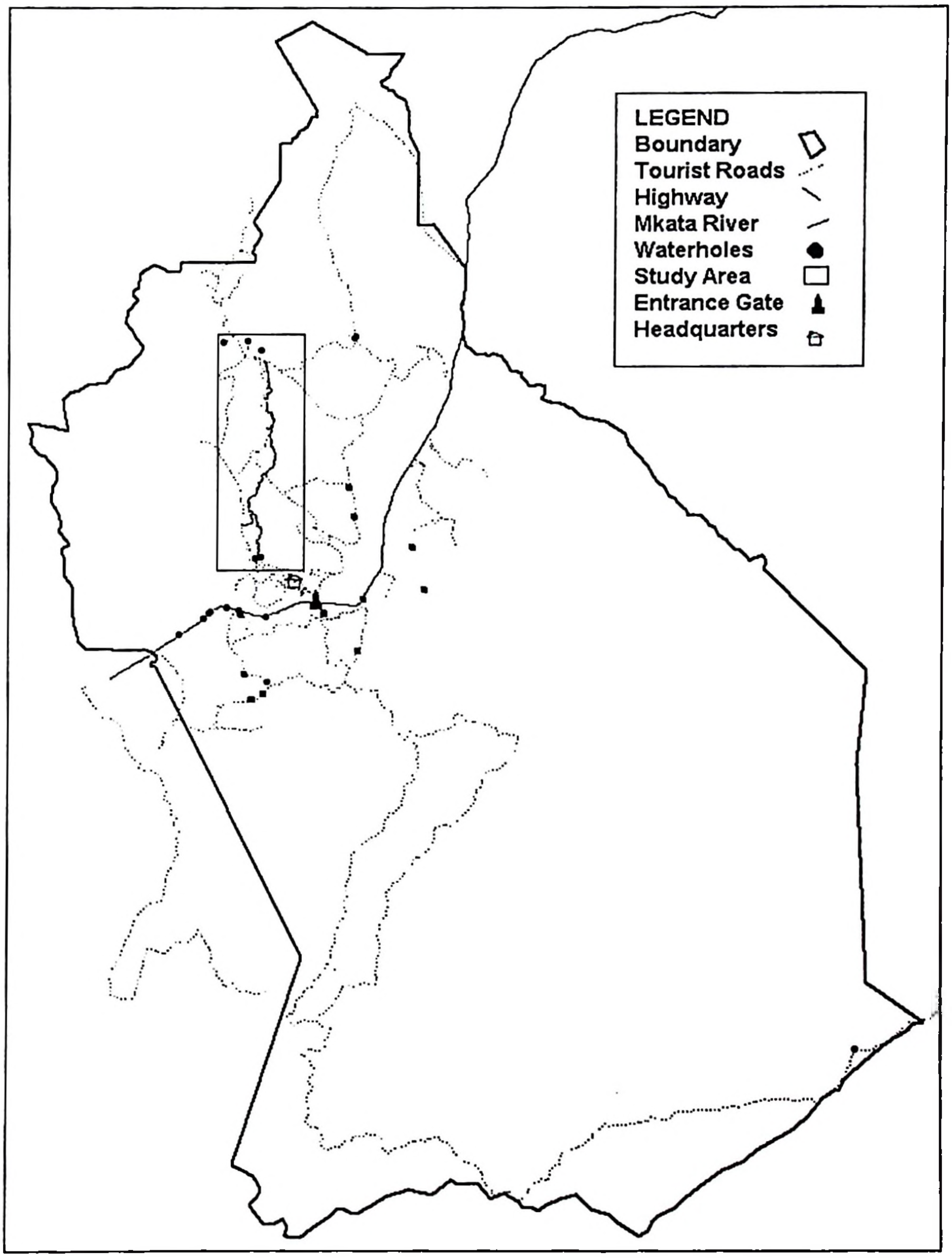


Figure 1: A map of Mikumi National Park showing the study area (Drawn from GPS points)

3.3.2 Data collection

3.3.2.1 Parameters measured

The following parameters were measured and recorded on a data sheet (Appendix 1).

❖ **Size of the tree**

Size classes can be used as indices of plant age (Leuthold, 1977; Okula and Sise, 1986). The following parameters hence were used to categorize size classes. Girth at breast height (GBH), adapted from Barnes *et al.* (1994) was measured directly using a measuring tape. Height of the tree was measured in meters using a Suunto hypso-clinometer, a target and range finder. The range finder was hung on a tree at approximately the breast height. Through the range finder, which is incorporated in the hypsometer, the observer moves forward or backward until the middle marks on the target fuse to become one mark. This was the correct position for the observer. The tree height was read directly in the hypso-clinometer (Malimbwi, 1997). Canopy size was determined by measuring from the ground point, maximum length of canopy multiplied by its perpendicular (in meters).

Using the above measurements, and with the help of a control tree whose size was monitored by ABRU for more than 15 years, baobab trees were categorized into three size groups as young, medium and large.

❖ **Duration of damage**

Types of damage were recognized as gauges and strips. For each type of damage, duration of damage was categorised as old, recent and new. Old damage, assumed to have occurred more than five years ago, was that whose scars were almost healed but could still be visible. Recent damage (assumed to have been within the past five years) had the scars unhealed but not fresh. New damage was that which had occurred since the beginning of 2003 wet season; the scars hence were still fresh and could easily be differentiated from recent damage.

❖ **Extent of damage**

The extent of damage was quantified in recent and new damage only by measuring depth and width of gauges and width and height of strips (in cm) and recorded in a data sheet. Gauged and stripped areas (cm^2) for each tree were calculated using these measurements. Total damaged area was also obtained for each tree by adding gauge and strip damaged areas.

In addition to the above parameters, the following were also observed and recorded:

❖ Habitat type surrounding each individual baobab tree: Eight types of habitat in MNP as identified and used by ABRU project were adapted. These included; grassland, wooded grassland, open woodland, woodland, ravine thicket, ravine forest, waterhole and ravine.

❖ Evidence of animal signs such as elephant dung, elephant rubbing on trees, footprints, and other vegetation damage around baobabs.

3.3.2.2 Assessment of new damage

Assessment and monitoring of any new elephant damage was carried out at three week intervals and in total there were four monitoring periods.

3.3.3 Statistical data analysis for baobabs

Frequency and means of GBH, height of tree, canopy size, habitat type, animal signs and duration of damage for all trees were coded and analysed using SPSS Version 11.5 for Windows.

Gauge, strip, and total damaged areas were analysed using SAS (1998) statistical system. Three classes were identified to influence extent of gauge, strip, and total damaged areas. These were, size of the tree (young, medium and large), periods of damage (recent and new), and location of different transects. A General Linear Model (GLM) was adopted in the study as follows:

$$Y_{ijk} = \mu + \tau_{jk} + \beta_{ik} + \alpha_{ij} + \varepsilon_{ijk}$$

Where: Y_{ijk} = Damaged area on the i^{th} size category in the j^{th} period of the k^{th} transect

μ = Overall mean

τ_{jk} = Effect of the i^{th} size category in the j^{th} period of the k^{th} transect

β_{ik} = Effect of the j^{th} period on the i^{th} size category of the k^{th} transect

α_{ij} = Effect of the k^{th} transect on the i^{th} size category of the j^{th} period

ε_{ijk} = Error term.

Means of damaged areas for different periods, size category and transects were compared using Least Significant Difference (LSD).

3.4 Mkata River survey

Mkata River was tracked from Chamgore to hippo pools observing any points with water. Whenever a watering point was found, the point was marked using a GPS and a map of Mkata River to show watering points was produced (Figure 5).

3.5 Study of other woody vegetation

The same sampling technique as per baobab study was employed and the same transects were used (Section 3.2).

3.5.1 Ground survey of woody vegetation

Out of 20 transects, 10 were chosen randomly. In each chosen transect, standing at the transect centre line at the starting point, a plot was established every 100 m. In total there were 10 plots in each transect. Standing at the plot centre, a radius of 5 m was measured. All woody vegetation ≥ 1 m tall falling within the plot were recorded on a data sheet. Woody vegetation/species was used interchangeably in this study instead of trees because all vegetation sampled were not necessarily trees.

3.5.2 Data collection

The following parameters were observed, measured and recorded (Appendix 1):

- Botanical name for each tree sampled.
- Height of the tree (m): For relatively short trees, a tape measure was used and for taller trees, a long stick was used. For multi-stemmed trees, the highest point was chosen.
- Stem diameter (m): This was taken for both live and dead stems. For large trees, DBH was taken and for smaller trees (< 1.3 m height), the diameter was taken at the highest point of the steam. For diameter < 0.01 m, the record was taken just as < 1 m. Whenever multi-stemmed trees occurred, the stem

diameters were taken separately unless the stems were distinctly joined at the base.

- Type of damage: Damage was estimated in four types on the basis of cause of damage. The categories were: old elephant, old unknown, new elephant and new unknown. All damages that had occurred since the previous wet season were considered as "new damage". Whenever there was any doubt as to the cause of damage, it was placed into the unknown category. Damage due to unknown agents probably included browse by other large herbivores (such as giraffe, buffalo, wildebeest, and zebra), fire, old age, termites and diseases. With the help of experienced ABRU rangers and researchers, there were no difficulties in differentiating browse caused by elephants and that caused by other browsers.

- Proportion of tree damaged

  For elephant damage (old and new), trees were rated according to four percentage damage categories, namely 0% (no damage), 1 – 25% (lightly browsed), 26 – 50% (intermediately browsed), 51 – 75% (over browsed), and 76 – 100% (seriously browsed). The boundaries for these ranges were derived after much trial and error. Different types of damages such as browsing of leaves and shoots, stripping, broken branches, broken stems and uprooted trees were not recorded separately but were just rated to fit the above percentage ranges.

3.5.3 Statistical data analysis for other woody species

Data for woody vegetation damage were coded and analysed using SPSS Version 11.5 for Windows. Tables of means, frequencies and percentages for woody species size category (young i.e. 1-2.9 m tall and mature i.e. >3 m tall), type of damage (old elephant, old unknown, new elephant and new unknown) and damage categories (lightly browsed, intermediately browsed, over browsed and seriously browsed) were presented for all woody species. The χ^2 test was then used to examine variation in proportion of damages among woody species, and among woody species size categories. Correlation was used to check relationship between proportion of woody species damage and their respective size category.

3.5.4 Woody species Preference Ratio (PR) by elephants

Woody species selection by the elephants (new damage only) was examined by calculating the preference ratio using the following equation adapted from Tchamba (1995) and Smallie and O'Connor (2000):

$$\text{PR} = \frac{\text{Percentage Utilization (browsed) (U)}}{\text{Percentage Availability (A)}}$$

Where:

$$\text{Percentage utilization (U)} = 100 \times \frac{\text{Number of browsed trees of a given species}}{\text{Total number of available trees of a given species}}$$

$$\text{Percentage Availability (A)} = 100 \times \frac{\text{Total number of available trees of a given species}}{\text{Total number of available trees of all species}}$$

Preference ratio (PR > 1) was defined as one that was utilized proportionately more frequently by elephants than its proportion of available trees, whilst avoided species had PR < 1.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Study of baobabs

4.1.1 Distribution of baobabs

A total of 17 out of 20 transects were surveyed before optimum number of 50 baobabs were attained. Out of the 17 surveyed transects, only 8 had baobabs. (Figure 2) although some baobabs were seen just few meters out of transect boundaries. Four habitat types were identified namely grassland, wooded grassland open grassland and ravine.

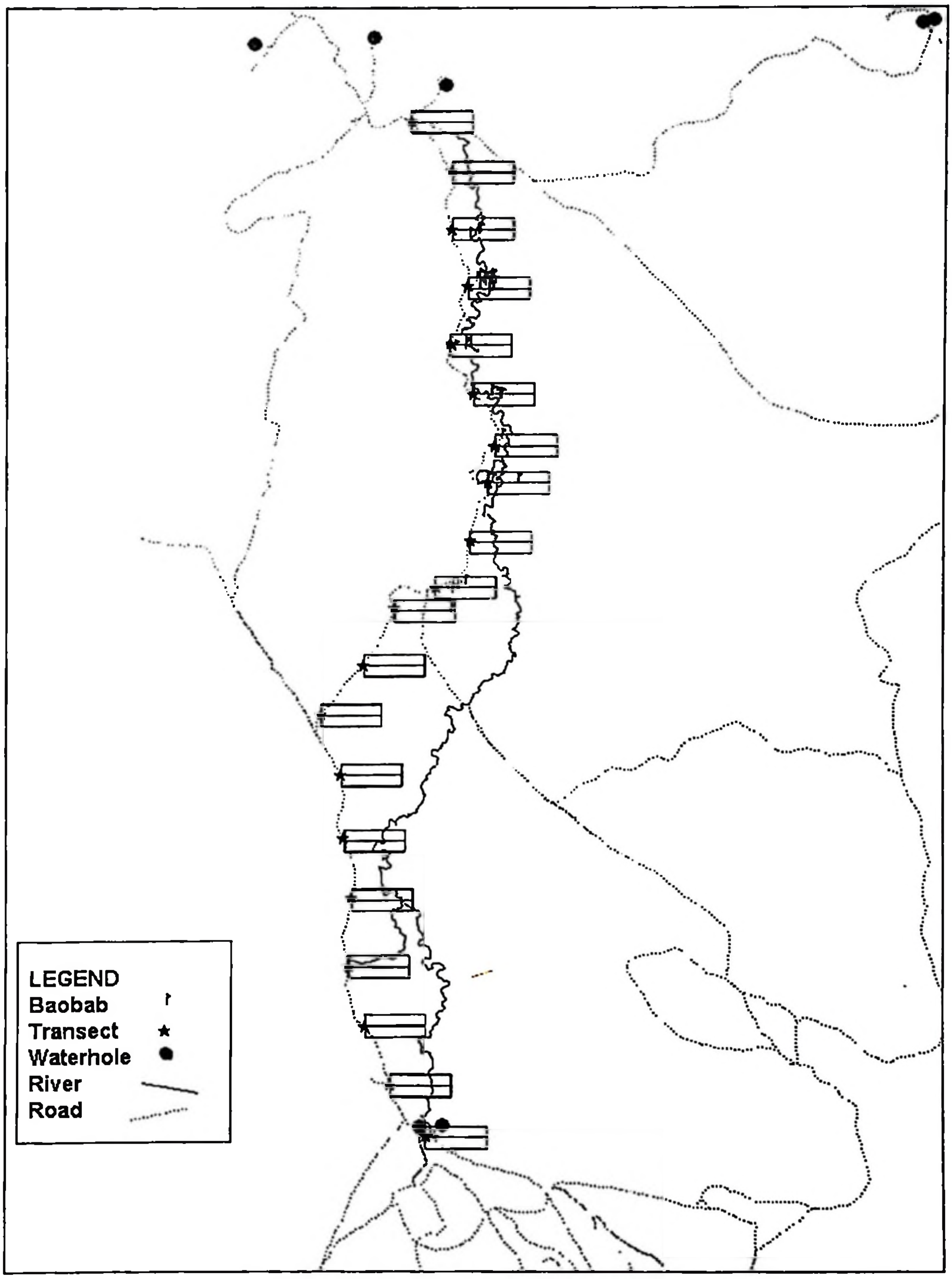


Figure 2: A map of study area showing baobabs distribution (Generated from GPS points)

The distribution of the baobab trees in the four habitats is shown in Fig. 3

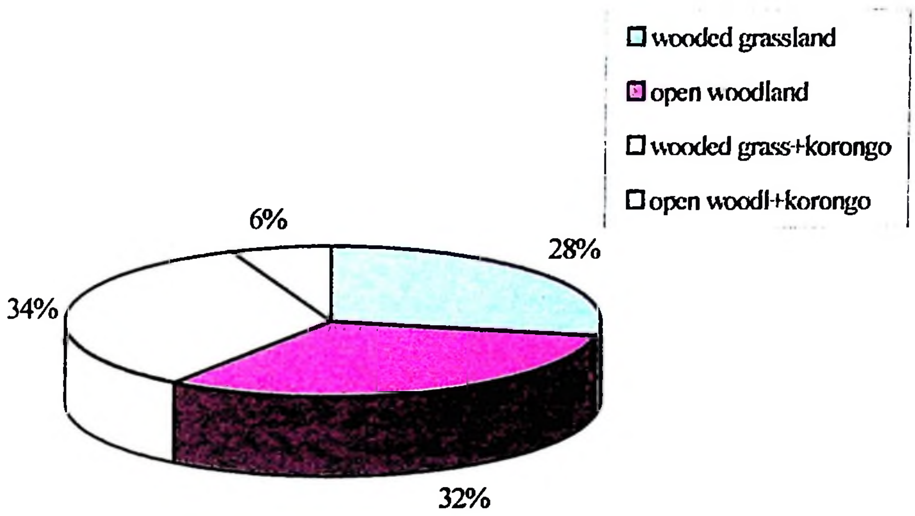


Figure 3: Percentage distribution of the baobab trees in different habitats

Baobab distribution in the study area seemed to be biased. The distribution of baobabs was probably influenced by habitat and soil type that are found around the area. Most of the tree locations were associated with ravine as 34% of trees were located at the edges of ravine in wooded grassland habitat and 6% located at the edges of ravine in open woodland habitat. Hence a total of 40% of baobabs were found at the edges of ravine. Wickens (1982) and Mbuya *et al.* (1994) showed that, the edges of ravine support top soils which are sandy and hence free draining. Additionally the water table is mostly high along the edges of the ravine. May be baobabs have shallow root systems which can tap water from areas with higher water tables. The rest of the trees were distributed fairly equally to the wooded grassland and open woodland. Wickens (1982) also reported baobabs to be associated with other woody vegetation.

4.1.2 Tree size categories

Size distribution of baobabs based on GBH is shown in Fig. 4.

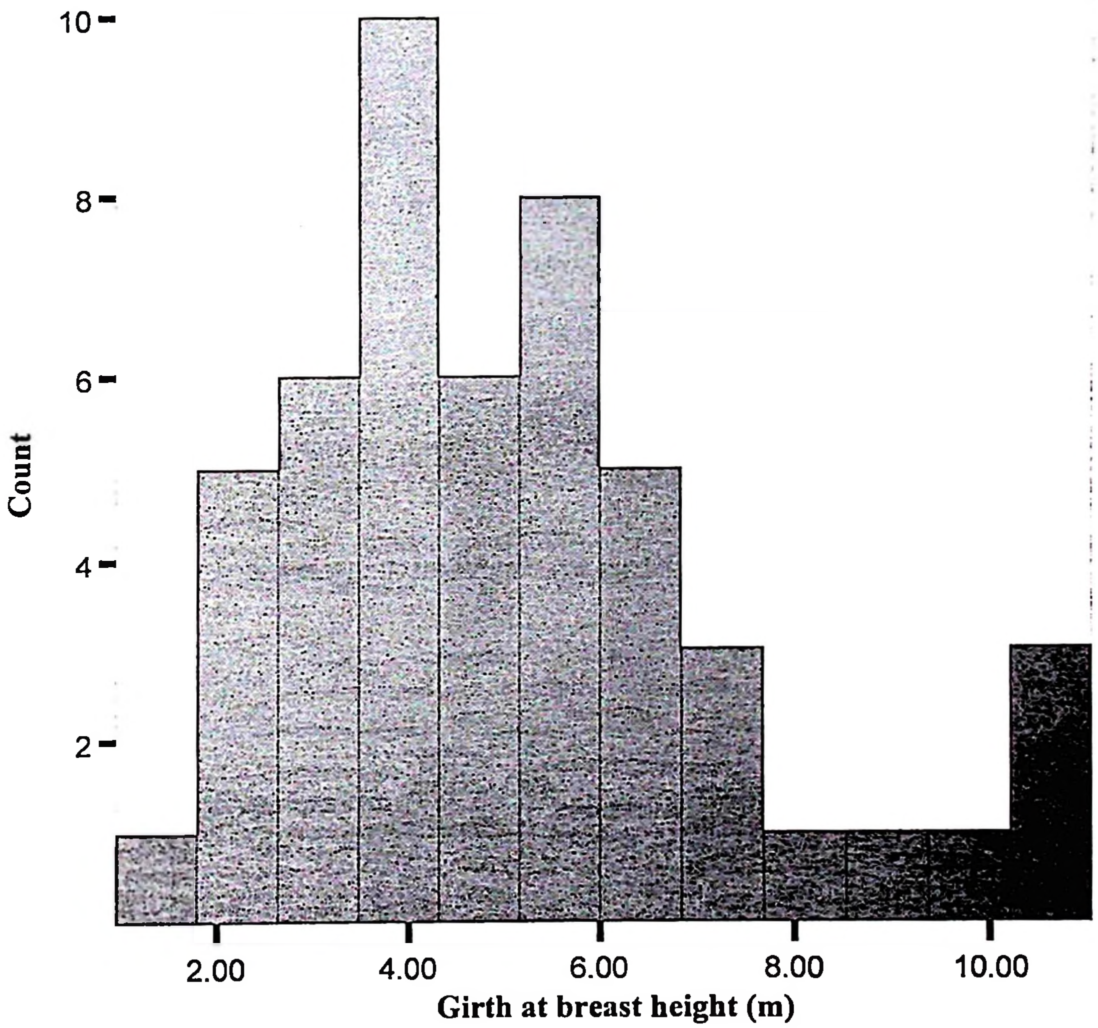


Figure 4: Histogram of GBH against number of trees at MNP

Tree height, canopy size and GBH could not be used collectively as determinants of size category because their relationship though directly proportional, the variations were doubtful and made it difficult to categorise tree sizes. For example one tree with a height of 14 meters tall had a GBH of 4.33m while another tree with the same height had a GBH of 10.77m. The reasons for such variations are beyond the scope of this study. GBH was then used to determine size category as it reflects growth rings and hence age of trees. Barnes *et al.* (1994) also used GBH to categorize baobab tree size. The trend for size distribution in MNP baobabs was in favour of large trees. Barnes *at al.* (1994) reported similar results in Ruaha National Park. The current study reported only one baobab with GBH < 1m. This may be attributed by the elephant's preference for eating the youngest trees (Barnes *et al.*, 1994). MNP baobab population structure is assumed to be a result of damages that occurred many years ago. Weyerhaeser (1985) argued that any short-term changes in baobab mortality as a result of elephant damage might have long-term consequence for the population.

4.1.4 Presence of elephants in the study area

Elephant signs were studied to reflect the presence of elephants in the study area. The presence of animal signs differed between months. Table 3 shows the availability of animal signs in the study area in different months.

Table 3: Percentage presence of elephant signs in different months of the year at Mikumi National Park, Tanzania

Animal sign	October, 2003	November, 2003	December, 2003	January, 2004	February, 2004
Dung	92	4.0	8.0	6.0	8.0
Foot prints	2	34.0	14.0	30.0	46.0
Rub	22	4.0	0.0	0.0	0.0
Vegetation damage	74	4.0	8.0	18.0	52.0

In October, high percentage of elephant signs was observed. However, this could be as a result of accumulation of these signs over months. Footprints and vegetation damage were more pronounced in February than the rest of the time in which the study was carried out (Table 3).

These results indicate relatively lower presence of elephants in the study area in the dryer months of the study period. The findings agree with Norton *et al.*, 2001, in showing that in the dry season, Mikumi elephants have a habit of moving to the hilly, heavily wooded areas of the park. Apart from using these areas as their refuge during the periods of heavy poaching, elephants might also be using them to explore food resources, which might be less available in other parts of the park

4.1.4 Duration of damage

When considering the duration of damage for gauges and strips separately, most damages (78.2%) were old gauges. Recent gauges accounted for 30% while new gauges accounted only for 18%. Similarly, old strips accounted for about 85.8%, recent ones 24% and new ones only 6% of all strip damages. Regardless of the type of damage, 96% of trees had old damages, 40% of the trees had recent damages and 20% had new damages. These results may generally indicate that, in the past, elephants were damaging baobabs more frequently than at present.

Old damage was very severe to the extent that it is still very prominent, despite scars being healed. Similar observations were reported by Barnes *et al.* (1994) and

Nahonyo (1996) in the Ruaha National Park. Explanation for this was that the damage was higher to baobabs in the past, before elephant poaching became a problem in the East African National Parks. Douglass–Hamilton *et al.* (1986) reported a 50% decrease in elephant population in MNP and the adjoining Selous Game Reserve in a census conducted between 1976 and 1986. Poole (1989) reported the loss of a large number of elephants, especially bulls, in the E. African National Parks. The reason for such a dramatic drop was severe poaching pressure in the mid to late 1980s (Norton *et al.*, 2001). Adult bulls were the prime targets of poachers due to their large tusks (Norton *et al.*, 2001) and therefore, were more affected. More evidence of the reduction of the number of bulls in MNP was reported by Ihde (1991), who stated that mature bulls comprised only 6.5% of the adult population of elephants in MNP. The fact that only bulls were responsible for killing baobabs (Barnes, 1980, 1982; Barnes *et al.*, 1994) and that bulls spent significantly more time feeding on baobabs than cows leaves it unquestionable that a reduction of the number of bulls resulted in lower elephant impact to baobabs. Another possible explanation for this is the habit of Mikumi elephants to use hills as refuge during the periods of heavy poaching (Stronach, 1998). It is possible that after elephants were poached heavily, they opted for these areas to ensure their security and those that remained around the study area had no significant impact to baobabs. However, one question is yet to be answered. If the decline in poaching and the ivory ban in 1989 resulted in increased elephant numbers in the current population estimates related to earlier ones (Norton *et al.*, 2001; Erickson, 2001); how come damage to baobabs is still at low levels 13 years later. It is assumed that if males comprised 41% of sub adult population (Ihde, 1991), which are currently assumed to have been recruited to mature bulls; the effect, together with other mature bulls (6.5% of adult population by then) (Ihde, 1991) would be expected to be even higher to baobabs. The possible explanation for this is a report by Norton *et al.* (2001), which revealed a female biased sex ratio and an apparent persistence of a young population in MNP. On this, they suggested a possibility of high adult and male mortality even in the absence of poaching. If this is the case, then until other reasons are found, elephant damages to baobabs will remain at low levels in MNP.

4.1.5 Extent of damage

Table 4 summarises means for gauge, strip and total damaged areas.

Table 4: Comparison of extent of damaged area (cm^2) between recent and new at Mikumi National Park, Tanzania

Period	Gauge	Strip	Total
Recent damage	24.55±16.09[a]	1782.17±369.33[a]	990.81±283.18[a]
New damage	115.95±19.48[b]	2146.29±731.57[a]	135.06±406.39[b]

Means with the same letter are not significantly (P<0.05) different

NB: Means for gauges were very low compared to those for strips, this resulted into pooling means for total damages between the two.

Gauging was higher in new damage than in recent damage. For strips, damage was not significantly different between the two periods. In the total damages, recent damages were higher, than new damages.

Higher gauge damages than strip damages may indicate that elephants truly (gauge) damaged baobabs following shortages of water. However, most of these new damages were evidently tusk marks. On the other hand it seems damage to baobabs was actually lower as tusk marks are rather signs of damages and not actual damages. So elephants were just attempting to damage and then leave the trees alone. Less variation between recent and new damages, as far as strip damages were concerned may seem to agree with the above assumption (Sect. 5.1.3) that both recent and new damages were lower compared to old damages due to the reasons already stated. However more important is total damaged area. Recent damages were higher than new damages. These results opposed the assumption that, following shortage of water in the year 2003, elephants would damage baobabs extensively to seek for water. The Mkata River and both the Hippo Pools and Mwanambogo dams were dry, unlike the recent years (except 1998), but damages were still low. Then it is possible that elephants had a source of water other than baobabs. It was reported that, MNP elephants use the hilly wooded areas extensively in the dry season (Norton *et al.*, 2001) and observations from the present study have proved this, as elephant signs were higher in February than in the dryer months. It is possible that there are some reliable sources of water or at least woody species rich in water reserves that attracted elephants to hilly areas. On the other hand, though year 2003 was relatively drier than previous years, it is possible that it was not dry enough for elephants to suffer a shortage of water.

Despite the fact that all waterholes and Mkata River that normally provide water for elephants through the dry season (Maige, 1990) were completely dry, the Mkata river survey (Fig. 5) showed five watering holes dug by elephants along the riverbanks. The Mkata river survey was done towards the end of the dry season; may be some more water points would have been observed had this been done earlier. It is possible that MNP elephants use this alternative to acquire water during the dry period rather than using baobabs. On the other hand, presence of artificial waterhole with water throughout the year, at the Mikumi Wildlife Camp around Kikoboga area, served to some extent as an alternative source of water for elephants.

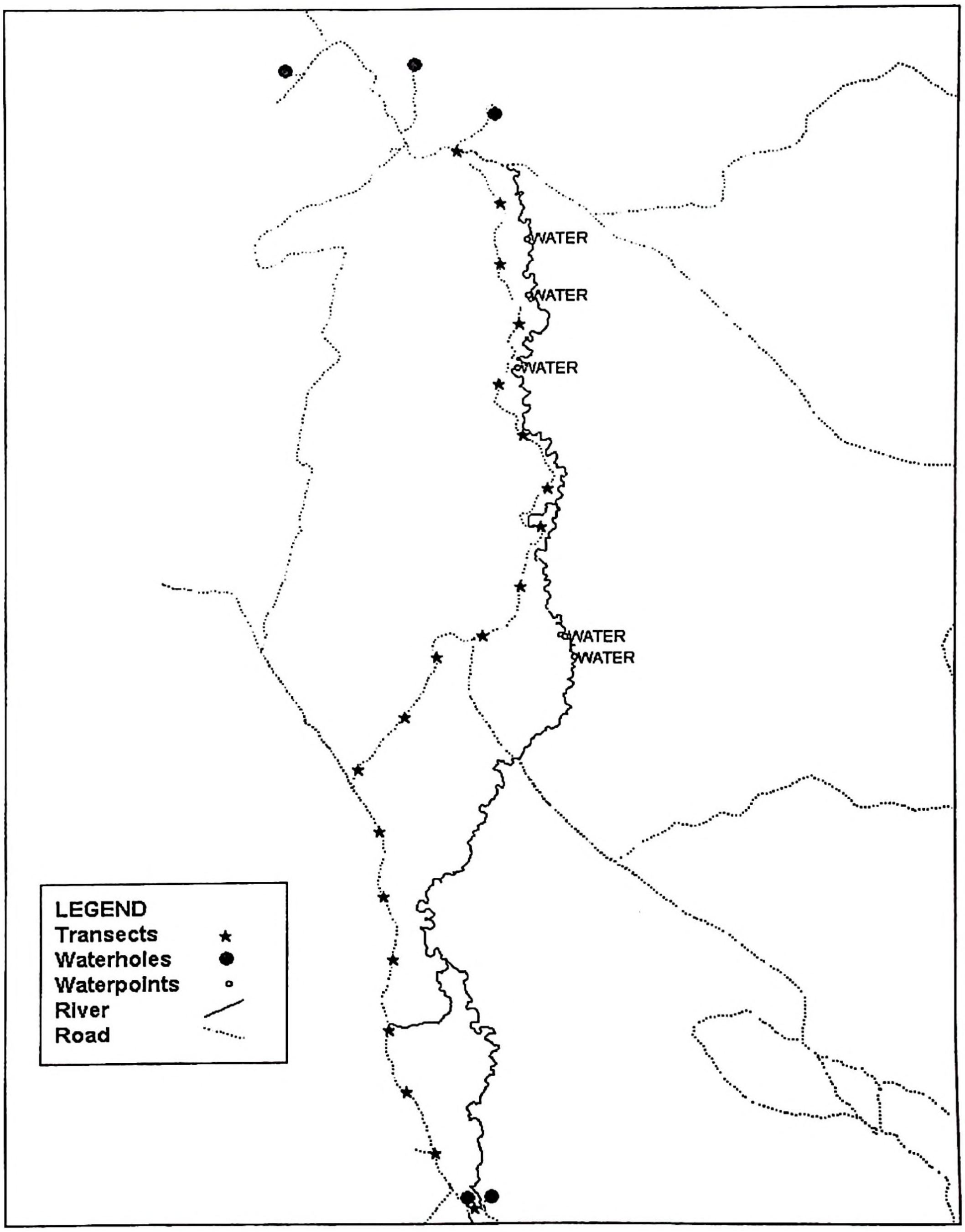


Figure 5: The map of Mkata river showing watering points (Drawn from GPS points)

Then there is a question of higher recent damages than new ones. It is possible that some damage recorded as recent actually occurred more than 5 years ago and should have been considered as old as far as this study was concerned. This was because ages of these damages were somehow subjective to the observer. Another possibility is that, high recent damages might be a result of accumulation of damages over these five years. If this was true, then the ratio of new to recent damages was expected to be 1:5. However, means for total recent damages were about seven times those of new damages, which meant a 1:7 ratio. It is possible that somewhere within those five years, higher damages occurred to baobabs. If this were true, then may be those higher damages occurred in 1998. According to Norton G.W. (personal communication, 2005), apart from 2003, the Hippo Pools and Mwanambogo dams were last dry in 1998.

From Table 4, medium and large sized trees were damaged higher than young trees and there were no differences between medium and large trees. For strips, there was no difference between young and large trees; however, medium sized trees had higher damages than young and large ones. Regarding total damage, there was no difference between young and medium sized trees, and young and large trees. However, medium sized trees were damaged significantly ($P<0.05$) more than large trees.

Table 5: Comparison of extent of damage (cm^2) among young, medium and large trees at Mikumi National Park, Tanzania

Tree size	Gauge	Strip	Total
Young	27.52±20.85[a]	273.41±871.30[a]	392.12±405.00[ab]
Medium	87.78±18.69[b]	4131.26±640.69[b]	1296.47±401.23[a]
Large	95.46±21.90[b]	1488.02±543.58[a]	211.4± 411.41[b]

Means with the same letter are not significantly ($P<0.05$) different

NB: Means for gauges were very low compared to those for strips, this resulted into pooling means for total damages between the two.

These results differed from those reported by other researchers (Caughley, 1976; Barnes, 1980; Weyerhaeser, 1985 and Barnes *et al.*, 1994) that the extent of damage decreases with the size of the tree. However, I still believe that their findings were also applicable to MNP. This was because the present study did not report the opposite of what they found but rather a different pattern, that young trees were not highly damaged as expected. Some youngest trees among the young size category were almost observed to be pristine. These youngest trees were assumed to have emerged when elephants had already reduced their use of baobabs. This was why damage to them was very low. Low level of damage to these youngest trees is assumed to have overcome damages to other young trees (in the same size category) making total damage to this group lower compared to medium sized trees.

There were variations among some transects as far as gauge and strip damages were concerned. However, total damaged area did not vary among transects (Table 6).

Table 6: Comparison of extent of damage (cm^2) among transects at Mikumi National Park, Tanzania

Transect	Gauge	Strip	Total
3	56.23 ± 44.37^{ac}	90.24 ± 0.06^{a}	822.31 ± 438.51^{a}
4	71.12 ± 9.87^{c}	2216.88 ± 481.68^{b}	914.68 ± 217.73^{a}
5	92.17 ± 40.50^{abc}	3690.28 ± 1175.16^{b}	231.47 ± 659.02^{a}
6	182.94 ± 43.07^{b}	0.00	162.56 ± 954.62^{a}
8	0.00	1859.52 ± 1107.13^{ab}	1336.10 ± 891.92^{a}
10	17.03 ± 40.50^{a}	0.00	618.69 ± 913.20^{a}
11	65.50 ± 39.37^{a}	0.00	179.85 ± 891.92^{a}

Means with the same letter are not significantly ($P<0.05$) different

NB: Means for gauges were very low compared to those for strips, this resulted into pooling means for total damages between the two.

Variation in total damage among transects could have been caused by distance to watering point from a particular transect. However, because the Mkata River and the two other water sources were dry, water would not have been a cause for variation and hence leave size of tree and duration of damage as course of variation.

4.2 Study of other woody vegetation

4.2.1 Proportion of woody vegetation damaged

A total of 724 trees were examined with 321 trees (44.6 %) showing elephant damage. The remainder (55.4 %) had damage caused by unknown agents. Four trees (0.6 %) were not browsed at all and were not included in statistical analysis due to the lower number of records. Generally the results show that elephants are not a threat to habitat in the study area as out of 44.6%, a large proportion (44.4%) were recorded in lightly damaged class.

Regarding the cause of damage, old elephant damage amounted to 39.7% while new elephant damage was only 4.9%. Old and new unknown damages accounted for 46.3 and 9.2% respectively.

Of all damaged woody vegetation, regardless of the causes of damage 386 plants (53.6%) were lightly browsed, 240 plants (33.3%) were intermediately damaged, and 94 plants (13.1%) were seriously damaged.

The type of data collected combined all easily noticeable utilization of wood material whether excessive or not, thus I recorded even very minimal browsing evidence. Therefore, out of the lightly browsed woody vegetation, a large proportion could have very low level of damage, which was rather a sign of browse than actual damage. This may indicate that the habitat is not threatened as far as elephant damage was concerned. If utilization categories were adapted from Tchamba (1995), much woody vegetation would have fallen into the undamaged class. These findings agree with those reported by Norton *et al.* (2001) and Maige (1990) in MNP, which did not find excessive use of the habitat by elephants. Similar results were reported by Nahonyo (1996) and Tchamba (1995) in different National Parks. Following the 2003 drought and due to a high density of elephants in MNP (1.96 elephants km^{-2}) (Norton *et al.*, 2001), a high percentage of elephant damage in the study area was expected. Based on previous findings, these results may have further indicated that the extent of damage was not related to elephant density in the study area. These results differed from findings by Ihde (1991) and Cumming *et al.* (1997) that when a habitat is overpopulated with elephants, there is a danger of excessive damage to such a habitat. However, the findings agree with those reported by Anderson and Walker (1974) and Eltrihgham (1980). The authors stated little relationship between densities and elephant damages. They reported this to be attributed by elephant density figures applying to too large an area. In MNP however, the population density seem to be highly applicable to the study area as most of population studies were done around that area (Norton *et al.*, 2001). The fact that, MNP elephants were able to freely range over an area greater than 55,000 km^2 (Stronach, 1998), with the possibility of movement throughout Mikumi–Selous ecosystem, which provide high protection to elephants (Norton *et al.*, 2001) may partly explain the results. On the other hand, the Mikumi elephants were evidently known to use the hilly heavily wooded areas of the park extensively in the dry season as their refuge (Norton *et al.*, 2001). This may have been the situation during the study period as elephants were rarely encountered during the process of data collection, although this study did not take account on presence of elephants in the study area.

A large percentage of old elephant damage to woody vegetation in the study area was also reported by Maige (1990), who recorded only one tree to be pushed over, along with a small number of normal fresh elephant browses in his investigation in the dry season. It is possible that, old damage has accumulated over a long period when compared with new damage that was assumed to have occurred only in that particular dry season. However, Maige (1990) urged that damage recorded on trees (particularly *C. abbreviata*) might have occurred both in the wet and dry season.

Many woody species were damaged by agents other than elephants (i.e. unknown agents). While it was reported by Eltrihgham, (1980) and White (1983) that, elephants might damage trees leaving them vulnerable to fire, wood borers and termites, it is important to note here that a considerable proportion of these woody vegetations might have been damaged by elephants before they were damaged by unknown agents. This may indicate linearity of relationship between these two kinds of damages.

4.2.2 Distribution and damage to woody vegetation based on size category

A total of 604 (84.2%) of the woody plants fall in the young class while 114 (15.8%) were in mature class. In the young class, 304 plants (50.2%) were lightly browsed, 220 plants (36.3 %) intermediately browsed and 82 plants (13.5 %) were over browsed. In the mature size, 82 plants (71.9 %) were lightly browsed, 20 plants (17.5 %) were intermediately browsed while only 12 plants (10.5 %) were over browsed. The results revealed that the Mikumi elephants damaged younger plants more than mature plants ($\chi^2 = 0.13$, df = 2). A correlation test also proved that regardless of the type of damage; young woody vegetation was damaged significantly higher than mature ones ($P < 0.01$).

Over-utilization of habitat in the past compared to the present might be related to elephant population density and composition that previously existed. It was assumed that, before poaching became a problem (1970's to early 1980's), the elephant population density in MNP was even higher than it is now. This was because, despite the fact that mature bulls were the prime target of poachers (Norton *et al.*, 2001), there must be a proportion of cows that were poached. It is hence assumed that the past population density had greater impact on the habitat compared to the current population density. But more important here was the population composition. The number of bulls in the population was higher before poaching became a problem. While it was suggested by some researchers (Barnes, 1982; Guy, 1976) that, because of high absolute food intake leading into more damage per individual plant, bulls may have greater impact to the habitat than equal number of cows and in MNP, bulls comprise of only 6.5% of the adult population (Ihde, 1991), there must be differences in impact to the habitat between the past and the present. The fact that the damaged woody parts are not easily replaced by individual plants (Barnes, 1982) makes it possible that, the above situation became stable even after reduction of the large number of bulls due to severe poaching pressure in the mid – late 1980's. The habit of elephants to kill mature trees and suppress regeneration (Barnes, 1980, 1983; Cumming *et al*; 1997), which were assumed to have happened in the past, might have also contributed to the prevalence of young individuals. This was why the effect was still pronounced during the study period. Increased recruitment of young males into mature bulls in MNP (Norton *et al.*, 2001) following the imposition of the ivory trade ban might re-ignite the problem.

The study revealed that the Mikumi elephants prefer to browse young woody vegetation to mature ones. Similar results were obtained by Van Wyk and Fairell (1969); Anderson and Walker (1974); Caughley (1976) and Nahonyo (1996) in other National Parks. They all revealed that, elephants selectively browse small woody vegetation in preference to the large ones. Young woody vegetation is generally more palatable compared to mature trees because the wood is softer than that of older trees. Jachmann and Bell (1985) reported mechanical properties of browse (such as softness) to determine its palatability. But another possible explanation for preference on young woody vegetation could be because the branches of these woody vegetations are within reach of an elephant's feeding range. It was reported by Caughley (1976); Guy (1976); and Jachmann and Bell (1985) that the preferred feeding height of trees by elephants is between 1 and 2m above ground level. Other researchers (Anderson and Walker, 1974; Jachmann and Bell, 1984 and Lewis, 1991) found similar results. Smallie and O'Connor (2000) reported this phenomenon of elephant feeding habit as "hedging". Jachmann and Bell (1984) defined "hedging" as the habit for elephants to prefer previously damaged trees, maintaining tree canopy within feeding range for a long period. The effect of "hedging" is an increase in density of short trees of selected species (Jachmann and Bell, 1985). However, it should be noted that, the habit of MNP elephants to browse young trees might be due to their availability than their preference by elephants.

Distribution of trees based on size category in the study area is summarized in Table 7.

Table 7: Counts and percentage frequency of woody species based on size category in the Mikumi National Park, Tanzania

Woody species	n	Size category	
		Young (%)	Mature (%)
Lonchocarpus capassa	84	92.9	7.1
Acacia spp	82	53.7	46.3
Diospyrus usambarensis	36	94.4	5.6
Securinega virosa	94	97.9	2.1
Dalbegia melanoxylon	48	100.0	0.0
Harrisonia abscinica	54	100.0	0.0
Makhamia spp	40	100.0	0.0
Commiphora africana	30	92.9	7.1
Croton spp.	24	100.0	0.0
Balanites aegyptiaca	38	47.4	52.6
Combretum Spp	104	71.2	28.8
Other species	86	-	-
Total	720	-	-

The mean heights of some woody species in the study area can be explained by the morphology of the tree species under optimum conditions. An example is *D. melanoxylon*, which when provided with optimum conditions; is of short stature (Mbuya *et al.*, 1994). This can be supported by results from the current study, that 100% of trees of this species were less than 3m tall. Further examples are the *Acacia spp.* and *B. aegyptiaca.* It seems that a large proportion of trees of these species had mature trees relative to other species. There are two possible reasons for average heights of these species. Provided with optimum conditions, individuals of these trees will grow to a height greater than 3m tall, and that, there was no hedging effect on these species. For *L. capassa*, however, 92.9% were young, and yet had highest percentage extent of damage. There was also evidence of regrowth in many of these trees, from the terminal parts of main stem that had been previously broken. These results differ from two reports about the tree's growth and their use by elephants. Mbuya *et al* (1994) reported that under optimum conditions, the average height of *L. capassa* tree is 4–10 m, and Njawa (1999) reported that in the Selous Game Reserve, *L. capassa* is a strong tree and that although elephants have a penchant for the leaves, a bull weighing 7 tonnes finds it impossible to push one down to get access to the leaves at the top of the tree. This is a clear indication that in MNP, there is hedging effect on *L. capassa* trees compared to the Selous Game Reserve.

4.2.3 Distribution and damage to individual woody species

The total sample of 720 plants comprised of 14.4% *Combretum spp*, 13.1% *Securinega virosa*, 11.7% *Lonchocarpus capassa*, 11.4% *Acacia spp.*, 7.5% *Harrisonia abiscinica*, 6.7% *Dalbegia melanoxylon*, 5.6% *Makhamia spp.*, 5.3% *Balanites aegyptiaca*, 5.0% *Diospyrus usambarensis*, 3.9% *Commiphora africana*, 3.3% *Croton spp.*, and 12% of other woody species. The latter group consisted of 12 woody species whose frequencies in the study area was less than 10 individuals for each species and hence were thought not to infer valid results if analysed individually. These species were *Xeroderris stuhlmannii, Carparis tomantosa, Tamarindus indica, Albizia robusta, Strychnos madagascariensis, Cassia abbreviata, Pseudolachnostylis maprouneifolia, Diospyrus cocci, Pteliopsis myrtifolia, Manilkara mochisia, Kigelia africana, Sclerocarya caffra* and one species that could not be identified.

Table 7 shows percentage of damage for each individual woody species based on cause of damage. The highest old elephant damage was observed in *L. capassa*, while *Croton spp*. had the lowest old elephant damage. For old damages caused by unknown agents *Makhamia spp*. had the highest while *L. capassa* had the lowest percentage. New elephant damages were higher in *Acacia spp*. and *C. africana* while *Makhamia spp*., *D. melanoxylon*, and *Croton spp*. had no damage. In new damages caused by unknown agents, *Croton spp*. had the highest damages while the lowest were recorded in *D. usambarensis* and *B. aegyptiaca*.

Table 8: Percentage frequency of damage in individuals of different woody species based on type of damage in the Mikumi National Park, Tanzania

Species	n	Percentage frequency of damage			
		Old damages		New damages	
		Elephant	Unknown	Elephant	Unknown
Lonchocarpus capassa	84	70.2	19.0	2.4	8.3
Acacia Spp	82	40.2	42.7	11.0	6.1
Diospyros usambarensis	36	41.7	52.8	5.6	0.0
Securinega virosa	94	33.0	50.0	5.3	11.7
Dalbegia melanoxylon	48	33.3	50.0	0.0	16.7
Harrisonia abiscinica	54	38.9	40.7	5.6	14.8
Makhamia spp	40	25.0	62.5	0.0	12.5
Commiphora africana	30	35.7	32.1	10.7	21.4
Croton spp	24	20.8	45.8	0.0	33.3
Balanites aegyptiaca	38	47.4	50.0	2.6	0.0
Combretum spp.	104	38.5	55.8	5.8	0.0
Other species	86	30.7	55.7	4.5	9.1
Total	720	-	-	-	-

Lonchocarpus capassa had the highest old elephant damage (70.2%). Anderson and Walker (1974) also reported high elephant damage (75.9%) for *L. capassa* in the Sengwa Research Area, Rhodesia. In a similar study, Jachmann and Bell (1985) reported *L. capassa* to be among the species selected by elephants in the Kasungu National Park. Two things might be possible as far as *L. capassa* damage was concerned in MNP. The high damage to *L. capassa* was probably related to seasonal variation in chemical composition of this species rather than their availability and physical properties such as softness and height. This was because most of the damage was bark stripping of these trees. Anderson and Walker (1974) reported 78.6% of *L. capassa* to be bark stripped. Many researchers reported bark stripping of trees to be related to variation in chemical content of trees (Croze, 1974; Anderson and Walker, 1974; Barnes, 1982). Secondly, the high old elephant damage reported in these trees might not have happened in previous season as was assumed in this study, but rather in the same dry season and hence could be regarded as new damage. This was because when data collection was starting (at the mid dry season of 2003), many trees of these species were observed to have serious new damage, mostly bark stripping. Then between October and December (2003), bush fires set by park authority covered these new damages and were hence observed as old damages in subsequent data collection. Later on, the study area was flooded following the short rains, and so data collection was impossible for a short period. This extended time period may have masked many damages as many trees and branches had new sprouts. This situation was observed particularly in *L. capassa* and not other species.

The *Acacia* trees also had considerable high old elephant damage, and indeed the highest new elephant damages. Several studies (e.g. Anderson and Walker, 1974; Tchamba, 1995; Nahonyo, 1996) have reported similar findings in other National Parks. Preference on *Acacias* by MNP elephants might be attributed to presence of thorns. Thorned trees are preferred by elephants because they have less inhibiting compounds (Barnes, 1982). However, all of these studies pinpointed specific species of *Acacia* that were highly damaged in relation to others. Anderson and Walker (1974) reported heavy damage (99.0%) on *A. robusta* while Nahonyo (1996) and Tchamba (1995) reported high damage in *A. tortilis* and *A. seyal* respectively. However, Nahonyo (1996) reported virtually no damage to *A. nigrescence*, *A. kirkii*, and *A. melifera*. It is possible that there were variations in extent of damages between different species of *Acacia* in MNP too. Although this study combined all *Acacias*, the damages were still high. If different species of *Acacia* were considered, it might be observed that some would have more damages than others. *Acacia* species had the highest new elephant damage; it is possible that, in MNP elephants use *Acacia* more extensively as their alternative food during drought conditions.

Commiphora africana was another species with a considerably high frequency (10.7 %) of elephant new damage relative to other species. Nahonyo (1996) reported severe elephant browse on *Commiphora spp.* in the Ruaha National Park. However, unlike in MNP, where foliage utilization was observed, Nahonyo (1996) reported elephants to have special preference of roots and bark of this species. A similar study by Hayashi (1992), reported high preference of the *Commiphora* in Kitui, Kenya, probably because of its soft wood and high water content. It is possible that, the new elephant damage on *Commiphora* species in MNP was also related to its soft wood and high moisture content. However, if this was the case, a higher extent of damage would have been expected on this species following shortage of water in the study area, than what was actually observed. Nevertheless, it is possible that MNP elephants preferred *Commiphora africana* despite low levels of damages. Smallie and O'Connor (2000) reported *Colophospermum mopane* to be a staple food item of elephants despite light utilization of individuals of this spicies (< 10% of biomass removed). So a woody species can be preferred regardless of its extent of damage. On the other hand, it is possible that low extent of damages on *Commiphora africana* is because the tree is poisonous (Mbuya *et al.*, 1994). Barnes (1982) reported that, for poisonous species elephants bulls were spending shorter time per species so as to avoid ingesting lethal dose of toxins.

Table 9 below shows proportion of individual woody species damaged in the various damage categories. In the lightly browsed category, *C. africana* had the highest damage while the lowest proportion was recorded in *L. capassa*. In the intermediately browsed class, the highest proportion was observed in *H. abscinica* and the lowest in *C. africana*. *L. capassa* recorded highest proportion in the over browsed class while the lowest proportion were observed in *C. africana*.

Overall, the proportions were tested by χ^2, which showed *L. capassa* ($\chi^2 = 0.05$, df=2) and *Acacia spp* ($\chi^2 = 0.04$, df = 2) had the highest elephant damage (new and old).

Table 9: Proportion of woody individuals damaged in the various damage categories at Mikumi National park, Tanzania

Woody species	n	Damage percentage		
		1 – 25%	26 – 50%	51 – 75%
Lonchocarpus capassa	84	19	42.9	38.1
Acacia spp.	82	46.3	34.1	19.5
Diospyrus usambarensis	36	55.6	33.3	11.1
Securinega virosa	94	80.9	17.0	2.1
Dalbegia melanoxylon	48	75.0	20.8	4.2
Harrisonia abscinica	54	44.4	51.9	3.7
Makhamia spp.	40	50.0	40.0	10.0
Commiphora africana	30	92.9	7.1	0.0
Croton spp.	24	50.0	25.0	25.0
Balanites aegyptiaca	38	47.4	47.4	5.3
Combretum Spp.	104	53.8	32.7	13.5
Other species	86	50.0	38.6	11.4
Total	720			

It seemed that regardless of the season, *L. capassa* and *Acacia spp* sustained the highest damage. Higher damages to *L. capassa* and *Acacia spp* in the study area indicate that, in the future, populations of these species may be highly reduced in the study area if their utilisation remained high.

4.2.5 Woody species preference ratio by elephant

Table 4.8 shows preference ratio for woody species by elephants. Woody species with PR > 1 were utilized proportionately more frequently than their proportion of availability while avoided species had PR <1. From the Table 4.8, *C. africana* had the highest PR (7.3). Other selected species included *Acacia spp.*, *D usambarensis*, *H. abscinica*, and *B. aegyptiaca*. Three species had PR = 0.

Table 10: Woody species preference ratio by elephants at Mikumi National Park, Tanzania.

Woody species	%Utilization	%Availability	Preference Ratio
Lonchocarpus. capassa	4.8	11.7	0.4
Acacia Spp.	12.2	11.4	1.1
Diospyros usambarensis	11.1	5.0	2.2
Securinega virosa	8.5	13.1	0.6
Dalbegia melanoxylon	0.0	6.7	0.0
Harrisonia abscinica	11.1	7.5	1.5
Makhamia Spp.	0.0	5.6	0.0
Commiphora africana	28.6	3.9	7.3
Croton spp.	0.0	3.3	0.0
Balanites aegyptiaca	5.3	5.3	1.0
Combretum spp.	9.6	14.5	0.7

It is better then to look at other factors governing woody species selectivity by elephants. These include mineral concentration, palatability and physical condition such as height, thickness and softness. *Acacia spp.* and *Commiphora africana*, were elephant food in the dry season in MNP as they showed both high new elephant damages, and their PR were greater than one.

For *Diospyros usambarensis* and *Harrsonia abscinica*, their selection might be due to their size relative to others. The majority of individuals of these species were in the young size category.

Three species had PR of zero. Sizes of these species were obviously small as all individuals of these woody species were in the young class category. *Dalbegia melanoxylon* wood is known to be extremely hard. This may have rendered its selection.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study did not reveal excessive damage to baobabs and other woody vegetation in the Mkata floodplain despite extended dry season in the year 2003. This was because the Mikumi elephant population comprised fewer numbers of bulls, which are primarily responsible for damaging the baobabs. However, it has been suggested that MNP elephants have other alternatives of acquiring water during the dry season other than baobabs.

The study revealed that, the Mikumi elephants selectively browse young woody vegetation over large ones. However, *Acacia spp.* and *Commiphora africana* were thought to be preferred species by the elephants in the dry season than the other species, regardless of their sizes and abundance.

5.2 Recommendations

It is recommended that a long-term study be conducted to:

- Compare the extent of elephant damage to the baobabs between successive dry seasons
- Monitor the rate of recruitment of bulls in relation to baobab damage
- Relate the extent of the elephant damage on other woody vegetation in the dry season to chemical composition and physical properties of the woody species.

REFERENCES CITED

Anderson, G.D: and Walker, B.H. (1974). Vegetation composition and elephant damage in the Sengwa wildlife research area, Rhodesia. *Journal of South African Wildlife Management* Ass. 4 (1) 1-14.

Anderson, K; Eltrihgham, S.K. (1997). Some preliminary observations on possible stress in the elephant of Mikumi National Park, Tanzania, *African Journal of Ecology*. 35: 278 – 282.

Balozi, J. (1989). Effect of poaching on Mikumi elephant population dynamics. MSc. Thesis, Agricultural University of Norway.

Barnes, R.F.W., (1980). The decline of baobab tree in Ruaha National Park, Tanzania; *African Journal of Ecology*. 18: 243-252.

Barnes, R.F.W., (1982). Elephant feeding behaviour in Ruaha National Park, Tanzania, *African Journal of Ecology*. 20: 123 – 136.

Barnes, R.F.W., (1983). Effects of elephant browsing on woodlands in Tanzanian National Park: Measurements, models and management, *Journal of Applied Ecology*. 20:521-540.

Barnes, R.F.W. (1985). Woodland changes in Ruaha National Park (Tanzania) between 1976 and 1982, *African Journal of Ecology*. 23: 215 – 221.

Barnes, R.F.W. and Kapela, E.B. (1991). Changes in Ruaha elephant population caused by poaching. *African Journal of Ecology*. 29: 289 – 294.

Barnes, R.F.W., Barnes, K.L; and Magombi, J.K. (1992) *The age structure of the Ruaha elephants in 1992*, Mimeograph 22pp.

Barnes, R.F.W., Barnes, K.L; Kapela, E. B. (1994) The long-term impact of elephant browsing on baobab trees at Msembe, Ruaha National Park, Tanzania, *African Journal of Ecology*. 32: 177 – 184.

Bax, P. Napier and Sheldrick, D.L.W. (1963). Some preliminary observations on the food of elephants in the Tsavo National Park (East) of Kenya. *East African Wildlife Journal*. 1:40 – 53.

Botkin, D.B. (1990). *Discordant Harmonies*. Oxford University Press, New York.

Caro, T.M. (1999). Conservation monitoring, estimating mammal densities in woodland habitats. *Animal Conservation*. 2: 205 – 315.

Caughley, G. (1976). The elephant problem: An alternative hypothesis, *East African Wildlife Journal*. 14: 265 – 283.

Conant, F., Rogers, P., Baumgadner, M., Mckell, C., Basman R. and Reining, P. (1984) *Resource inventory and Baseline Study Methods for Developing Countries*, American Association for the Advancement of Science, Washington D.C.

Croze, H. (1974). The Serenora bull problem. II. The trees. *East African Wildlife Journal*. 12. 29 – 49.

Cumming, D.H.M. (1994). WWF/EC. Study of land use trends, natural resource use and agro-ecosystem sustainability in the Zambezi Valley of Zimbabwe. In: *Proceeding of a Workshop to Coordinate Studies of Land Use Change in the Zambezi Valley of Zimbabwe*. eds. D.H.M. Cumming and I.M. Daniels. pp 30 – 40.

Cumming, D.H., Fenton, M.B., Rautenbach, I.L., Taylor, R.D., Cumming, G.S; Cumming, M.S., Dunlop, J.M., Ford, A.G.; Hovorka, M.D., Johnston, D.S; Kalcounis, M; Mahlangu, Z; Port forts, C.V. (1997). Elephants, Woodlands and biodiversity in Southern Africa, *South African Journal of Science* 93: 231 – 236.

Dougall, H.W. (1964). The chemical composition of a day's diet of an elephant. *East African Wildlife Journal*. 11:51 – 59.

Douglass – Hamilton, I. (1987). African elephants population study. *Pachyderm* 8: 1 – 10.

Douglas – Hamilton, I; Hirji, K; Mbano, O; Olivier, R; Tarimo, E; De Butts, H; (1986). Aerial census of wildlife in the Selous Game Reserve, Tanzania. Report to Ministry of Natural Resources and Tourism, Dar es Salaam.

Douglass, H.W; Drysdale, V.M. and Glover, P.E. (1964). The chemical composition of Kenya browse and pasture herbage. *East African Wildlife Journal*. 2. 86 – 121.

Eltrihgham, S.K. (1980). A quantitative assessment of range usage by large African mammals with particular reference to the effect of elephants on trees. *African Journal of Ecology*. 18: 53 – 71.

Eltringham, S.K., (1982). *Elephants*. Sterling Publishers Co., New York. 2621.

Ereckson, A. (2001). Population Structure and Ecology of the Mikumi National Park Elephant Population. M. phil. Dissertation, Department of Life Sciences, Anglia Polytechnic University, Cambridge UK.

Fenner, M. (1980). Some measurements on the water relations of baobab tree. *Biotropica* 12 (3): 205 – 209.

Field, C.R. (1971). Elephant ecology in Queen Elizabeth National Park, Uganda. *East African Wildlife Journal*. 9. 93 – 123.

Field, C.R. (1975). Climate and the food habits of ungulates on Galana Ranch. *East African Wildlife Journal*. 13:203 – 220.

Foley, C. A. H., (2002). High incidence of elephant twin births in Tarangire National Park, Tanzania. *African Journal of Ecology*. 32: 64-68.

Grizmek, B. (1975) *Animal Life Encyclopedia* Vol. 12 (iii), Van Nostrad Reinhold Company-New York.

Guy, P.R. (1976). The feeding behavior of elephant (*Loxodonta africana*) in the Sengwa wildlife area, Rhodesia. *South African Journal of Wildlife Research*. 6. 55 – 63.

Hall – Martin, A.J. (1992). Distribution and status of African elephant *Loxodonta africana* in South Africa, 1652 – 1992. *Koedoe* 35, 65 – 83.

Hanks, J. (1979). A Struggle for Survival: *The Elephant Problem*. Struik, Cape Town.

Hayashi, F. (1992). A preliminary experiment on vegetation recovery of drought deciduous woodland in Kitui, Kenya. *African Journal of Ecology*. 30: 1 –9.

Huston, M. (1993). Biological diversity, soils and economics, *Science* 262. 1676 – 1680.

Ihde, S. (1991). A study of the Elephant Population in Mikumi National Park, Tanzania. Msc. Thesis, University of Bielefeld, Germany.

IUCN (1980). Elephant numbers are falling heavily. International Union for Conservation of Nature and Natural Resource. *Bulletin*. 11:2,8.

IUCN (1993). The World Conservation and the World Wide Fund for Nature. Elephant Fact Sheet. IUCN-Gland.

Jachmann, H. (1991). Evolution of four survey methods for estimating elephant densities, *African Journal Ecology*. 29: 188 – 195.

Jachmann, H. and Bell, R.H.V. (1984). Why do elephants destroy woodlands? AERSG Newsletter, No. 3: 9 – 10.

Jachmann H, and Bell, R.H.V. (1985) Utilization by elephants of the *Brachystegia* woodlands of the Kasungu National Park, Malawi. *African Journal of Ecology*. 23; 245-258.

Kabigumila, J.D.L. (1993). Diunal activity of elephants in Ngorongoro Crater, Tanzania, *African Journal of Ecology*. 31: 75–80.

Kagwana, K. (1996). *Studying Elephants*: African Wildlife Foundation–Nairobi.

Kalemera, M.C. (1987). Dry season diurnal activity of elephants in Lake Manyara National Park, Tanzania, *African Journal of Ecology*. 25: 255 – 263.

Kent, M. and Coker, P. (1992) *Vegetation description and analysis. A Practical approach*, Belhaven Press-London.

Lamprey, H.F., Glover, P.E; Turner, M.I.M. and Bell, R.H.V. (1967). Invasion of the Serengeti National Park by elephants, *East African Wildlife Journal*. 5: 151 – 166.

Laws, R. M. (1981a). Experiences in the study of large mammals. In: Fowler, C. M. and T. D. Smith, eds. *Dynamics of Large Mammals Populations*. John Willey and Sons. New York. pp 19 – 45.

Laws, R. M. (1981b). Large mammals feeding strategies and related overabundance problems. In: Jewell, P. A. and S.A. Holt, eds. *Problem and Managemant of Locally Abundant Wild Animals*. Academic Press. New York. pp 217 – 232.

Lovett, J. C., and Norton, G. W. (1989). Afromontane Rainforest on Malundwe Hill in Mikumi National Park, Tanzania. *Biological Conservation*. 48: 13 – 19.

Maganga, S.L.S. (1985). Influence of elephants on woodlands of Tanzania: A social ecological analysis. MSc. Thesis, University of Idaho, USA.

Maige, M.K.S. (1990). Effect of Elephants (*Loxodonta africana*) on the woody vegetation in Mikumi National Park, Tanzania. MSc. Thesis. Agricultural University of Norway.

Malimbwi, R.E. (1997). Fundamentals of Forest Mensuration. A Compendium.

Martin, E.B. and Martin, C.B. (1982). *Run Rhino Run*. Chato and Windus, London.

Martin, R.B., Craig, C.G. and Booth, V.R. (eds.) (1989). Elephant Management in Zimbabwe. Depertment of National Parks and Wild Life Management in Harare.

Mbuya, L.P., Msanga, H.P., Ruffo, C.K., Ann Birnie and Bo Tengnas (1994). *Useful Trees and Shrubs for Tanzania. Identification, Propagation and Management for Agricultural and Pastoral Communities*. SIDA's Regional Soil Conservation Unit.

Mc Key, D. (1974). Adaptive patterns in alkaloid physiology. *American Naturalists* 108. 305 – 320.

Nahonyo, C.L. (1996). Impact of Elephant Browsing on vegetation in Ruaha National Park, Tanzania. MSc. Thesis. University of Dar es Salaam, Tanzania.

Norton, G.W. (1994). Rainfall in Mikumi National Park Part 1: Monthly and Annual Patterns 1964 – 1993, Report to Tanzania National Parks and Serengeti Wildlife Research Institute, Arusha, Tanzania.

Norton, G. W., Rhine, R. J., Wynn, G. W., Wynn, R. D. (1987). Baboon Diet: A five-year study of stability and variability in the Plant feeding and the Habitat of Yellow Baboons (*Papio cynocephalous*) of Mikumi National Park, Tanzania. *Folia Primatologica*. 48:78 – 120.

Norton, G.W; Ereckson, A.E; Hawkins, D.M. (2001). The Elephant Population in Mikumi National Park, Tanzania: Historical Issues, Current Status and Future Problems.

Okula, J.P. and Sise, W.R. (1986). Effects of elephants browsing on *Accasia seyal* in Waza National Park, Cameroon. *African Journal of. Ecology*. 24(1): 1-6.

Owen-Smith, N. (1988). *Mega herbivores*: *The Influence of very large Body Size on Ecology*. Cambridge University Press-Cambridge.

Pomeroy D and Service M.W., (1986). *Tropical Ecology*. Longman Inc – New York.

Poole, J. (1989). The effect of poaching on the age structures and social and reproductive patterns of selected East African elephant populations. In: *The Ivory Trade and the Future of the African Elephant*. Ed. S. Cobb. The Ivory Trade Review Group.

Pratt, D. J., and Gwynne, M. D. (1977). *Rangeland Management and Ecology in East Africa*. Hodder and Stoughton – London.

Redmond, I. (1993). *Elephant. Eyewitness Guides*. Dorling Kindersley-London

Russel, E. W. (1961). *Soil Conditions and Plant Growth*. Longmans – London.

SAS (1998) Statistical Analysis System. SAS/STAT User's guide. Satatistical analysis Institute. Inc. Nc. USA.

Shoshani, J; and Eisenberg, J.F. (1982). *Elephas maximus*, *Mammalian species*, No. 182, pp. 1 – 8. American Society of Mammologists. (Technical account of the taxonomy, biology and life history of the Asiatic or Indian elephant).

Sikes, S. (1971). *The Natural History of the African Elephant*. Weidenfeld and Nicolson-London. 397.

Smallie, J.J. and O'Connor, T.G. (2000). Elephant utilization of *Colophospermum mopane*: possible benefits of hedging. *African Journal of Ecology*. 38: 352 – 359.

Snelson, D. (1987). *Mikumi National Park Guide book.* Tanzania National Parks – Arusha.

Spinage, C.A. (1990). Botswana's problem elephants. *Pachyderm* 13, 14-19.

Strahler, A. N., and Strahler, A. H. (1987). *Modern Physical Geography.* 3rd Ed. John Willey and Sons-Singapore.

Stronach, N. (1998). The elephants of the Selous Game Reserve and their Management. Selous Convervation *Programme Discussion Paper.* 19. 2nd ed. Dar es Salaam

Swanepoel, C.M. (1993). Baobab phenology and growth in the Zambezi valley, Zimbabwe, *African Journal of Ecology,* 31: 84 – 86.

Swanepoel, C.M. (1993). Baobab damage in Mana Pools N. Park, Zimbabwe. *African Journal of Ecology.* 31:220-225.

Tchamba, M.N. (1995). The impact of the elephant browsing on the vegetation, in Waza National Park, Cameroon. *African Journal of Ecology.* 33: 184 – 193.

Van Wyk, P. (1972). *Trees of the Kruger National Park.* Vol. I Cape Town. Purnell.

Van Wyk, P. and Fairall, N. (1969). The influence of the African elephant on the vegetation of the Kruger National Park. *Koedoe.* 12. 57 – 89.

Vancuylenberg, B.W.B. (1977). Feeding behaviour of the Asiatic elephant in south – east Sir-Lanka in relation to conservation. *Biological Conservation.* 12. 33 – 54.

Western D. and Gichohi, H. (1993). Segregation effect and emprovement of savannah parks: the case study for ecosystem viability analysis. *African Journal of Ecology*. 31: 269 – 281.

Weyerhaeuser, F.J. (1985). Survey of elephants damage to baobabs in Tanzania's Lake Manyara National Park, *African Journal of Ecology*. 23: 235 – 243.

White, F. (1983). *The Vegetation of Africa*. UNESCO-Paris.

Wickens, G.E. (1982). The Baobab. Africa's upside – down Tree. *Kew Bulletin*. 37 (2). 173 – 209

Williamson, B.R. (1975). The condition and nutrition of elephant in Wankie National Park. *Arnorldia*. 7. 1 – 20.

Wyatt, J.R. and Eltringham, S.K. (1974). The daily activities of the elephants in Rwenzori National Park, Uganda. *East African Wildlife Journal*. 12, 273-289.

APPENDICES

Appendix 1: Data sheets

(a) Baobab data sheets

Transect No.	Tree No.	GBH (m)	Tree height (m)	Canopy width (m) max*perp.	Habitat type	Animal signs					Type and frequency of damage						Duration of damage						*Extent* of damage							
																							Recent damage				New damage			
						Dung	Tusk Mark	Foot print	Rub	Veg. dmg	gauge			strip			gauge			strip			gauge		strip		gauge		Strip	
											1	2	3	1	2	3	4	5	6	4	5	6	7	8	8	9	7	8	8	9

KEY:

1 = no damage
2 = single damage
3 = multiple damage
4 = old
5 = recent
6 = new
7 = depth
8 = width
9 = height

HABITAT CODES

1 = grassland
2 = wooded grassland
3 = open woodland
4 = woodland
5 = ravine thicket
6 = ravine forest
7 =waterhole
8 = korongo

(b) Baobab monitoring sheet

Date	Transect No.	Tree No.	New animal signs				Size of damage (for new damage)				Comments
			Dung	Foot print	Rub	Veg dmg	Gauge		Strip		
							Depth	Width	Width	Height	

(c) Woody vegetation data sheet

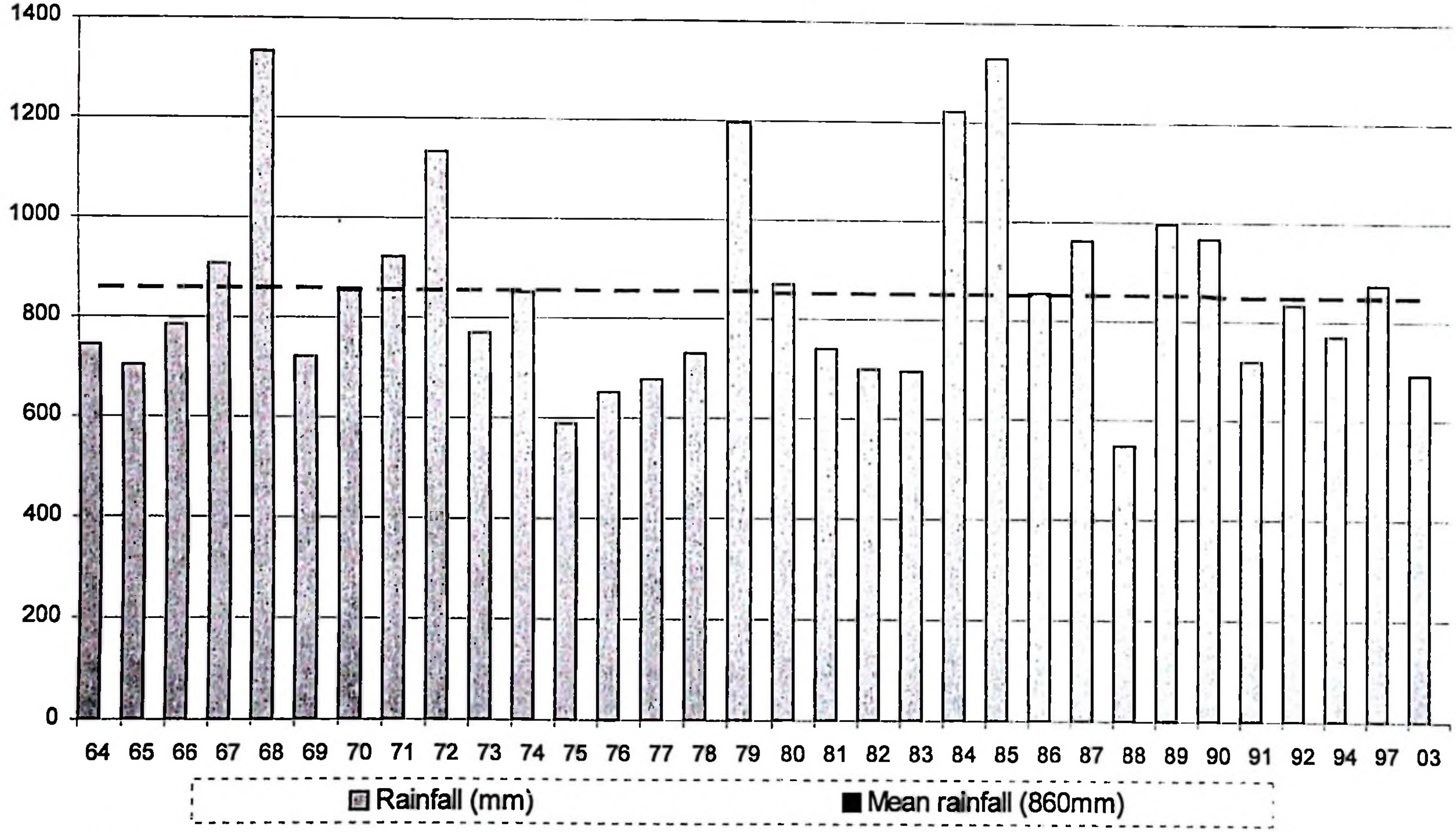
Transect No.	Plot No.	Tree species	Tree height	DBH	Damaged?	Damage type	%Damage

Key:

Damage types
1 = old elephant
2 = old unknown
3 = new elephant
4 = new unknown

% damage
1 = 1 – 25% of tree damaged
2 = 26 – 50% of tree damaged
3 = 51 – 75% of tree damaged
4 = 76 – 100% of tree damaged
0 = tree not damaged

Appendix 2: Mikumi National Park rainfall pattern



Source: Modified from Norton (1994).

Appendix 3: ANOVA Tables

(a) Dependent Variable: Damage gauge area

Source	DF	Sum of square	Mean square	F - Value	P - Value
TRANS	5	7.8929	1.5786	2.31	0.0498
PERIODS	1	13.5258	13.5258	19.77	0.0001
SIZE	2	4.5834	2.2917	3.35	0.0391
Error	100	68.4159	0.6842		
Corrected Total	108	85.3396			
R-Square		0.198310	CV	127.0067	

(b) Dependent Variable: Damage strip area

Source	DF	Sum of square	Mean square	F - Value	P – Value
TRANS	3	6146.4852	2048.8284	4.76	0.0047
PERIODS	1	117.1872	117.1872	0.27	0.6038
SIZE	2	12089.6304	6044.8152	14.03	0.0001
Error	65	28006.5021	430.8693		
Corrected Total	71	42772.9879			
R-Square		0.345229	CV	104.8541	

(c) Dependent Variable: Total damage area

Source	DF	Sum of square	Mean square	F - Value	P - Value
TRANS	6	982.9971	163.8328	0.46	0.8393
PERIODS	1	1647.6768	1647.6768	4.59	0.0339
SIZE	2	4421.8109	2210.9055	6.16	0.0027
Error	137	49153.0830	358.7816		
Corrected Total	146	56354.1931			
R-Square		0.127783	CV	186.0821	