FORAGE QUALITY AND BARK UTILISATION BY THE AFRICAN ELEPHANT (*Loxodonta africana*) IN SAMBURU AND BUFFALO SPRINGS NATIONAL RESERVES, KENYA

By

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university

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DEDICATION

I dedicate this thesis to my parents Francis Ihwagi and Beatrice Nyokabi, my dear wife Margaret and son Ben-Gurion

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ABSTRACT

Foraging behavior of elephants with respect to debarking of woody species was investigated in Samburu and Buffalo Springs National Reserves, Kenya. *Acacia elatior* was the most preferred species followed by *Acacia tortilis*. Both *A. elatior* and *A. tortilis* dominate the woody vegetation accounting for over 80% of all woody plants. Debarking levels varied in different parts of the reserves and this was attributed to elephants' densities and the ultimate influence of endaphic factors on species assemblages. Species diversity indices were negatively correlated with salinity indicating a direct influence of salinity on plant community structure. Both *Acacia tortilis* and *A. elatior* have the highest tolerance to salinity and occur almost exclusively in saline areas. Debarking was highest during the dry months just before the rains.

Through chemical analysis of bark samples collected from trees utilized at various intensities, the influence of bark mineral content on elephant's debarking behavior was assessed. Samples were analysed for Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Iron (Fe), Manganese (Mn), Zinc (Zn) and Copper (Cu). The most preferred and abundant species, *A. elatior* had significantly higher nutrient elements than *A. tortilis*, the second most abundant. Debarking was positively correlated with levels of N, P, K, and Zn. Of these, crude protein (N) had the greatest influence on debarking behavior. Soil samples were collected in the sites and analyzed for physical properties and content of the above elements as well. Site differences in soil mineralogical content influenced bark nutrient content significantly in this study as there was significant positive correlation between nutrient content in bark and in soil samples from each plot. Phosphorus content was found to be high in soil but remarkably low in bark despite its significant correlation with debarking behavior. Aridity of the area, high soil pH and coarse soil texture contributed to generally low nutrient content of soil and subsequent unavailability of the nutrients to plants.

Key words: elephants, foraging, debarking, preference, soil, nutrient

CHAPTER ONE

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The African elephants (*Loxodonta africana*) in East Africa comprised of 80-100 discreet units of geographical populations each with seasonal range in the order of 130-260 km^2 before the 1970s (Laws, 1970). Their numbers were dramatically reduced by the upsurge in ivory poaching in the 1970s and early 1980s (Douglas-Hamilton, 1989). The coalitions that formed during the late 1980s and their respective banning of ivory trade has helped in the recovery of most populations (CITES, 2002). The Laikipia-Samburu region is one of the MIKE (Monitoring of Illegal Killing of Elephants) sites in Africa. The implementation of MIKE started in 1999 as a CITES initiative and is critical to developing a rational approach to elephant management in Africa (CITES, 2002). The Laikipia-Samburu region had over 5,000 elephants in 2002 with an estimated average annual increase rate of 3.5% (Omondi *et al.*, 2002). Save the Elephants and Kenya Wildlife Service implement the MIKE program in the Laikipia-Samburu MIKE site in Kenya.

Elephants in Samburu National Reserve (SNR) and Buffalo Springs National Reserve (BSNR) are part of a bigger subpopulation whose range extends south to Laikipia District and further up to the north of the reserves in Samburu District (Thouless, 1995). The adult elephant population in the reserves is highly skewed in favor of females and the reserves are a focal calving area (Wittemyer, 2001). The resulting population dominated by young-ones and lactating cows would be expected to forage diversely on the community of woody species. The preferred habitats of the African elephant are forest edge, woodland, bush-land and wooded bush-land or bushed grassland (Laws, 1970). The riverine vegetation in both SNR and BSNR is a critical support for elephants when resources outside the reserves are depleted or in escape from human competition (Wittemyer, 2001).

1.2 Literature review

At the root of all elephant problems is their effect on the habitat (Douglas-Hamilton, 1972). Attention in East Africa is invariably drawn to woodland change to open grasslands in the presence of elephants (Buechner and Dawkins, 1961; Croze, 1974; Barnes, 1982). Dramatic changes in vegetation were brought about by elephants, often in combination with other factors such as fire, incurring elevated mortality of mature trees and suppressing recruitment and regeneration. The problem is precipitated by compression of elephant populations into parks and in response to expanding human settlement (Cumming, 1982). Larger group sizes have a greater impact on the habitat than the actual densities might imply (Laws, 1970), and the impact may vary considerably over distances of a few kilometers depending on the distribution of water supplies (Ben-Shahar, 1993). When trees and shrubs are debarked by elephants, they become far more vulnerable to fires, especially during the dry season when most damage occurs (Buss, 1961; Laws, 1970).

Elephants were largely responsible for substantial decline in the *Acacia tortilis* woodland in the Seronera woodlands through destruction of mature trees and subsequent suppression of the regenerating shoots due to browsing by giraffe (Pellew, 1983). Mature *A. tortilis* trees were considerably damaged by elephants in Lake Manyara and the damage consisted of bark stripping whereby the ring barked trees eventually died (Vesey-FitzGerald, 1973). In the Sahelo-Soudanian region, elephants are implicated with vegetation change in structure and composition through their varied seasonal choice of food items that include debarking in the dry season (Pamo and Tchamba, 2001). The density of *Acacia xanthophloea* trees in Seronera river valley, and the frequency of the species' large trees along the Seronera river terrace declined by approximately 30% due to destructive impacts of elephants (Ruess and Halter, 1990).

One aspect of elephant feeding behavior that concerns wildlife managers of national parks in savannah ecosystems is their habit of stripping bark from trees (Ruess and Halter, 1990). Several theories have been proposed suggesting that it is a consequence of physiological changes in the elephants and the trees (Barnes, 1982). The factors underlying differences in species utilization have not been investigated (Holdo, 2003). Riparian habitats serve as key habitats for elephant by providing forage of adequate quality at the height of the dry season (Buss, 1961). The fibrous bark of *A. elatior* has a high tensile strength and tends to be ripped off in strips by the elephants (Douglas -Hamilton, 1972). Buechner and Dawkins (1961) noted that the most severely damaged trees are the ones for which elephants have developed a predilection; consequently elephants seek out these trees until they become completely girdled and die within two years.

The elephant is an intermediate feeder, consuming both grass and browse in different proportions at different times of the year (Beekman and Prins, 1989). The use of different plant species by elephants falls into four broad categories in terms of how they are utilized, (i) those that are selected, (ii) those that are utilized in proportion to their occurrence, (iii) those used infrequently, and (iv) those not used at all, or rejected (Page, 1995). The utilization may be via foraging on leaves, twigs, roots or the bark (Holdo, 2003). The daily food intake of elephant averages 1.0 - 1.2% of body mass for males and non-lactating females and about 1.2-1.5% for lactating females (Owen-Smith, 1988). The intake increases when food quality declines (Meissner and Spreeth, 1990).

The ultimate importance of nutritional balance to individual fitness provides a strong argument for viewing landscape and regional herbivore distributions from a forage nutrition stance (Seagle and McNaughton, 1992). In the African savannas, there are seasonal fluctuations in plant biomass, nutrient content and digestibility (Pamo and Tchamba, 2001). Past studies on food selection by elephants have focused on leaves rather than other parts (e.g. Jachmann, 1989; Holdo, 2003). Holdo (2003) noted that elephants feed extensively on the bark of woody plants. Elephants have been recorded to use their tusks to gouge trees and then use their trunks to peel the stringy cortex of the bark off (Vesey-Fitzgerald, 1973).

Elephants selectively suppress the regeneration of desirable species when they occur in gaps created by falling trees, as they preferentially forage on their saplings (Jachmann and Bell 1985). *A. tortilis* is easily killed by moderately high debarking or branch removal (Page, 1995). Selective feeding by mammalian herbivores on the more palatable woody species can result in domination of the vegetation by the chemically defended woody species (Bryant *et al.*, 1992). Due to the constant hedging of preferred species, an area heavily foraged by elephants will show a change in composition with an increase in stem density of small trees of some species (Jachmann and Bell, 1985). The impact of elephants on woody vegetation has led to concern about possible extirpation of plant species and of animal species whose persistence is dependent on forest or woodland habitat (Lombard *et al*., 2001). The influence of large body size on foraging ecology has the potential to affect the success of some woody species and possibly lead to extirpation of some preferred species (O'Connor *et. al*. 2007).

The percentage of browse in the diet of an elephant is high during the late-dry season and drops off rapidly in the wet season (Osborn, 2004). The quality of food eaten is higher in the wet season than in the dry season, and browse contains higher concentrations of proteins and fatty acids than are found in grasses (Barnes, 1982). Elephants should favor food types that permit a rapid rate of nutrient intake; foods from which the greatest amount of digestible protein can be sequestered per unit time (O'Connor *et al.,* 2007). Woody forage takes a longer handling time than herbaceous forage leading to fewer mouthfuls per minute, 2.7±0.5, compared to 5.3±0.5 on herbs, but it constitutes twice the biomass of the herbs (Croze, 1974). Ingestion rates of bark or woody roots are the slowest because of the time taken to harvest and chew (O'Connor *et al*., 2007). Protein concentration of browse can be up to twice that of grass during the growing season and is more constant over the annual cycle (Dougall *et al*., 1964). The protein content in browse materials selected by elephants ranges from 6.7% in the dry season to 10.7% in the wet season (Meissner and Spreeth, 1990). An elephant's size and digestive system result in a hierarchy of selection for plant types, species and plant parts in response to seasonal changes. The populations in which the expected seasonal pattern shows an increasing proportion of bark and roots being consumed during the early dry or even wet seasons are likely to be experiencing nutritional stress (O'Connor *et al.*, 2007).

Elephants in East Africa prefer grasses in the wet season turning to browse in the dry season when grass has withered (Barnes, 1982). The crude protein and fibre content in the browse fluctuates less than that of grass (Field, 1971). Woody parts dominate the diet in dry season but leaves and shrubs are eaten throughout the year (Barnes, 1982). When green grass is less available during drought years, elephant are forced to increase consumption of bark earlier in the season when they are relatively the most palatable (Styles and Skinner, 2000). This results in increased impact on woody plants (Osborn, 2004). Oliver (1978) argued that elephants are dentally specialized towards grass feeding but because of changes in the grass' seasonal availability; they must be able to switch to alternate foods such as browse. Despite its higher lignin levels, browse offers higher levels and diversity of nutrients (Jachmann, 1989). Large-bodied herbivorous mammals survive on food of lower quality owing to their higher absolute metabolic needs, higher digestive efficiency, and lower specific metabolic rate (Belovsky, 1997). Edaphic factors influence diet quality since plants derive nutrients from the soil (Scholes and Walker, 1993).

Elephants' utilization of trees entails switching to bark stripping as tree height increases (Smallie and O'Connor, 2000). Tree breaking is consistent with the elephant's diet (Ben-Shahar, 1993). Elephants consume considerable amounts of bark and roots of the felled trees to supplement their grass intake (Barnes, 1982). Large *Acacia* spp. trees are uprooted by bull elephants for nutritional rather than social reasons as it is the younger low ranking bulls that are often involved (Croze, 1974). In Ruaha National Park, elephant bulls were recorded to feed on the bark throughout the year but more intensively in the early and late dry season (Barnes, 1982). Barnes (1982) and Owen-Smith (1988) suggested that bark is consumed mainly for its sugar-containing phloem tissue, as it is most consistently utilized during early spring when sap flow through phloem is most active for flowering or leaf flush.

Elephants have been observed to gouge small bits of the bark of marura tree *Sclerocarya birrea*, smell or taste it first before deciding on whether to abandon the tree or peel bigger strips and eat (Gadd, 2002). Likewise they have been observed to fell trees, sample them for less than five minutes then proceed to fell another of similar species and size nearby which they devour for hours (Croze, 1974). Such observations suggest that there exist differences between species and amongst trees of the same species. A mammal's avoidance of a plant is based upon some fundamental nutritional deficiency in the plant's tissues or the presence of specific phytochemicals which are unpalatable or adversely affect the mammal's physiology (Bryant *et al*., 1992). Mature bark of different species differs largely in chemical and structural composition but the physical structure alone can not explain preference (Malan and Van Wyke, 1993).

Relations between bark consumption and other nutrients in different studies have been inconsistent with some studies showing high debarking intensity to be positively correlated with crude protein, calcium or magnesium (Croze, 1974; Hiscocks, 1999). Jachmann and Bell (1985) found leaf sodium and protein concentration to be major factors determining browse quality for elephants, with the concentration of sodium being related to that of magnesium. Holdo *et al.*, (2002) reported that elephants compensate for the low sodium levels in the Kalahari Desert woody vegetation and water sources by geophagy where elephants selectively consume soils rich in sodium.

Female elephants have different physiological needs from males (Stokke and Du Toit, 2000). They have been recorded to spend a greater proportion of their time on salt licks consuming more soil to compensate for low sodium levels in their diet (Holdo *et al*., 2002). Female elephants and their families are more selective feeders and feed more on woody species than adult males (Stokke and Du Toit, 2000). Barnes (1982) noted significant differences between bulls and cows in the time spent feeding on individual baobab trees, *Adansonia digitata*.

Macronutrients for both plants and animals are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), chlorine (Cl) and sulphur (S) (Whitehead, 2000). The N: S ratio in soils is rather constant, typically 7.7: 1, indicating that the stabilization of S in organic matter (OM) is similar to that of N (Nguyen and Goh, 1994). Sodium and Chlorine are micronutrients for plants but macronutrients for animals. While Cl may accumulate as salts of Na and K in arid areas, it is barely retained for long by soil constituents and hardly any is observed in senescent herbage and was omitted on this basis. Iron (Fe) is a macronutrient for plants and is on the borderline between micro and macronutrients for animals while Manganese (Mn), Zinc (Zn), Copper (Cu), Molybdenum (Mo) and Cobalt (Co) are micronutrients for both plants and animals (Whitehead, 2000). The amount of Mo is low in sandy soils and its adsorption is very low under conditions of high pH ($\geq$5) (Whitehead, 2000); conditions that are characteristic of the reserves according to Young (1976). Cobalt after being released by weathering is adsorbed by Mn and Fe oxides or is complexed by OM (Whitehead, 2000). The adsorption and complexation with some of the oxides reduces cobalt’s solubility and availability (Whitehead, 2000). Cobalt’s availability is increased when the drainage is very poor (Berrow *et al*., 1983), which is converse of soils in the study area that have been reported to be well drained (Barkham and Rainy, 1976).

Phosphorus plays an important role in animal reproduction and lactation (Groenewald and Boyazoglu, 1980). N, P, Ca and Fe are major constituents of animal body tissues. Na, K and Mg are important for buffering pH and osmoregulation, while the micronutrients Mn, Zn and Cu are major constituents of enzymes (Groenewald and Boyazoglu, 1980).

1.3 Justification

Since not all nutrient elements could be analysed within the scope of this study, the decision on what to analyze was made based on the existing knowledge of elements' co-occurrence in soil, their availability to plants and ultimate importance in animal nutrition. All of the elements discussed above may have more than one function. Following the above considerations, a list of elements to analyze for in soil and bark samples was drawn as follows; N, P, K, Ca, Mg, Na, Fe, Mn, Zn and Cu. Particular bark samples were also analysed for neutral detergent fibre as an indication of total indigestible fraction of the bark. In addition to these elements, soil samples were analysed for total organic carbon as an indication of organic matter decomposition. The existing knowledge of tree-elephant relationships is largely on studies conducted in closed parks whereby within such systems, there is the potential of tree populations going to near extinction as a result of elephant browsing (Barnes 1982). Though the reserves support the bulk of elephant population in the area (Thouless, 1995; Wittemyer, 2001), it is yet to be shown that the observed debarking and subsequent death of some woody plants occurs as a result of elephant having a distinct preference for some species, and not simply as a result of excessive concentration of elephants.

Despite the knowledge that elephants feed on tree barks in East Africa and elsewhere, (e.g. Douglas-Hamilton, 1972, Gadd, 2002), studies on chemical composition of bark as part of elephant's diet are few for most African trees (e.g. Malan and Van Wyke, 1993; Smallie and O'Connor, 2000). No study has been carried out to show how the observed elephant debarking relates to the trees dietary content in Samburu and Buffalo Springs National Reserves. Since not all dietary components could be analyzed in this study, neutral detergent fibre (NDF) was analyzed in samples collected at the height of debarking behavior as a measure of total indigestible content of bark. Neutral detergent fibre comprises of both hemicelluloses and the fibre fraction, the portion with low digestibility in non-ruminants.

1.4 Hypothesis

The hypothesis of this study was that African elephants in Samburu and Buffalo Springs National Reserves have a preference of bark of some trees/species due to the species differences in nutritional content, and that the soil directly influences the forage quality.

1.5 Objectives

The Main objective was to determine whether elephant's debarking behavior on the different woody species is preferential in relation to nutrient content.

The specific objectives of this study were:

1. To determine whether elephants have a preference of bark from the different woody species in Samburu and Buffalo Springs National Reserves.
2. To determine nutrient element concentrations in soil and bark tissues.
3. To determine whether debarking of trees by elephants is particularly driven by quest for particular nutritional elements.

CHAPTER TWO

2.0 STUDY AREA, MATERIALS AND METHODS

2.1 Study area

Samburu and Buffalo Springs National Reserves were established in 1948 initially as the Samburu-Isiolo Game Reserve and formally separated as Samburu National Reserve (SNR) and Buffalo Springs National Reserve (BSNR) in 1963 (Wilson, 1989). The reserves lie opposite each other at 0°30´ N, 37°30´ E, 862 m above sea level and are separated by Ewaso Nyiro River (Figure 1). Both reserves have a combined area of 336 km^2.

2.1.1 Climate

The reserves lie in an area that is typically dry savanna, hot and dry for most of the year with highly variable bimodal rainfall (Figure 2) (Jaetzold, 1983). The rainfall is highly variable and is usually less than 400mm per annum (Figure 3). Jaetzold (1983) classified the area under the Lower Midland Agro-Ecological Zone. About 90% of the mean annual rainfall occurs in the peak months of April-May and November-December (Barkham and Rainy, 1976). The average rainfall during the peak months is normally exceeded at least in 6 out of 10 years (Jaetzold, 1983). During the long dry season usually lasting from late May till early October, large migrant animals congregate in the reserves due to permanent availability of green riverine vegetation along Ewaso Nyiro River (Barkham and Rainy, 1976).

2.1.2 Geology and soils

To the north of the river, (SNR), surface geology is dominated by ancient basement complex rocks which consist of horn-blend gneisses and schists, and banded biotite gneisses (Jennings, 1966 cited in Barkham and Rainy, 1976; Wilson, 1989). Between these are the more or less gently sloping pediments covered with recent deposits of red sand (Barkham and Rainy, 1976). South of the river, (BSNR), the landscape and geology are different, with the area dominated by tertiary and more recent flows of olivine basalt giving rise to a plateau of poorly structured and excessively drained volcanic soils. On the eastern side, addition of calcium carbonate to the sediments by the evaporation of percolating ground water and re-crystallization of limestone in the sediments often forms a thick superficial calcite deposit which masks the underlying rocks (Jennings, 1966 cited in Barkham and Rainy, 1976).

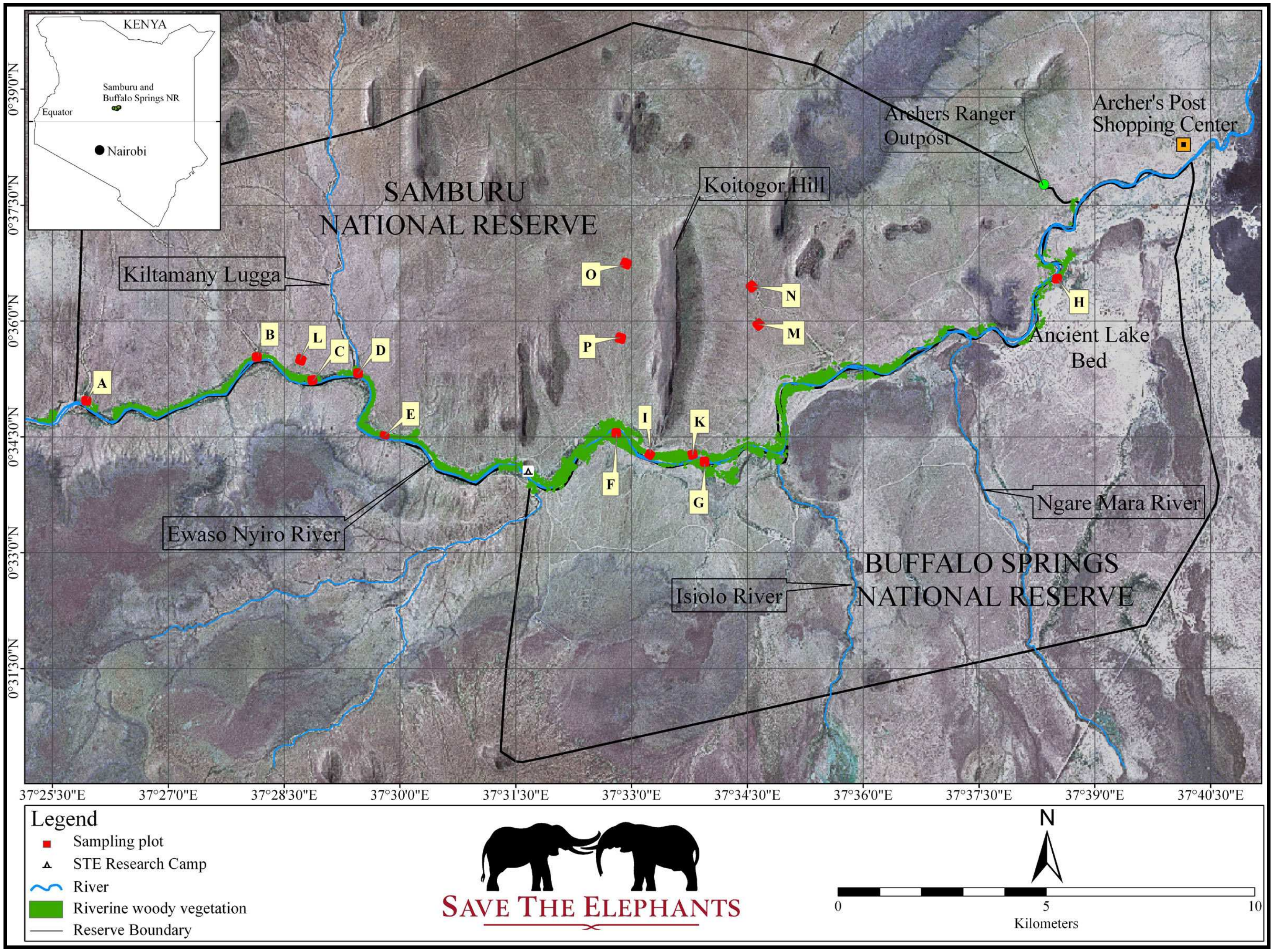

Figure 1. Locations of study sites in Samburu and Buffalo Springs National Reserves on a LandSat image overlain on a digital elevation model (DEM) of the area. The riverine forest in green was mapped by Save the Elephants in 2003.

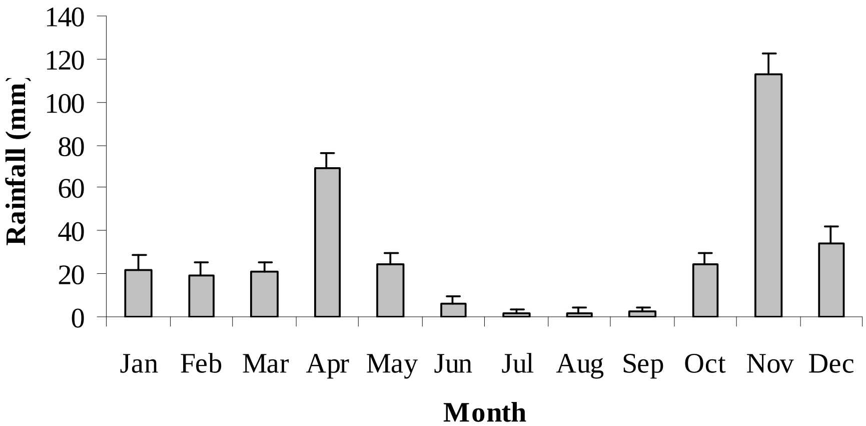

Figure 2. Mean monthly rainfall (±SEM) recorded at Archer's Post weather station for eight years showing the bimodal pattern (1994 to 2002).

The soils are markedly influenced by the geomorphology of the area (Barkham and Rainy, 1976). The riverine belt soil is eutritic legosol with rock out crops and calcic cambisols that are excessively drained, shallow, reddish brown, friable, rocky or stony sandy-clay-loam (Jaetzold, 1983). The isolated steep-sided basement complex hills have been weathered and the regolith moved down slope leaving behind skeletal gravely soils on these hills. Considerable depths of gravel, sand and silt accumulate as terraces associated with seasonal drainages, which flow mainly southwards to Ewaso Nyiro. These provide soils which may exceed six meters in depth and which may remain permanently below the top soil layer (Barkham and Rainy, 1976). In the Ewaso Nyiro River Valley, the water table is within the capillary range of the profile and in this part of the reserves, soluble salts accumulate in the profile to produce halomorphic solonetz soils (Young, 1976).

Calcareous and calcrete soils with high calcium carbonate contents are characteristic of BSNR. Soils of the lava are young and generally shallow with low water holding capacity though other superficial materials may overlie the olivine basalt to give deep almost structure less soils of a brown calcimorphic type (Young, 1976).

2.1.3 Landscape and hydrology

Buffalo Springs National Reserve (BSNR) is a gently rolling lowland plain, the main topographical feature being the ancient lava-terrace which forms Champagne Ridge in the south-east (Barkham and Rainy, 1976; Wilson 1989). Samburu National Reserve (SNR) is marked by Koitogor hill that prominently rises above the general terrain. The Ewaso Nyiro

River drains into the Lorien Swamp, formerly a dry season refuge for elephants before the intensive elephant poaching in the 1970's and 80s and the onset of periodic droughts (Wilson 1989). The river basin comprises of tributaries from Mt. Kenya and Aberdare Ranges (Barkham and Rainy, 1976). On the Eastern side of BSNR are perennial streams that include Isiolo and Ngare Mara flowing from Mt. Kenya across the ancient alkaline lakebed before draining into Ewaso Nyiro River. In the past, lava flows from Mt. Kenya blocked the eastward progression of Ewaso Nyiro River deriving a Quaternary lake whose sedimentary deposits are evident as white calcrete soils west of BSNR (Wilson, 1989). Sudden torrential rainstorms that are a common occurrence make the area a country of sandy perennial river beds known as *luggas* (Wilson, 1989). Buffalo Springs National Reserve is characterized by springs and swamps that provide a permanent water source for wildlife.

2.1.4 Vegetation

According to classification by Pratt *et al.* (1966), most of the vegetation communities fall under the 'ecological zone V' consisting largely of wooded grassland and bush grassland. Barkham and Rainy (1976) identified 17 communities. These communities are made complex by the intervening mixture of riverine strip communities. The 17 communities comprise of the following dominant species: *Commiphora* spp. – *A. tortilis, A. Senegal;* Mixed *A. tortilis* - *A. Senegal-Commiphora* spp. - *Ipomea cicatricosa*; *A. tortilis – Pupalia lappacea - Barleria acanthoides*; *A. tortilis* open-grassland; *A. tortilis – Lippia somalensis – Sericocomopsis hildebrandtii*; a disturbed community comprising the latter three communities; *Acacia reficiens*; *Acacia horrida – A. paolli – A. reficiens*; *A. reficiens – A. tortilis – Salvadora persica – Salsola dendroides* intermediate community; *S. dendroides*; *Salvadora persica*; *Hyphaene coriacea*; *A. elatior*; *A. elatior – S. persica – A. Senegal – A. tortilis* intermediate community; *Cynodon dactylon* grassland; and *Sporobolus spicatus* grassland. Most of these plant species are ephemeral or shed their leaves during the dry season.

The Ewaso River and its tributaries support a band of riverine vegetation which serves as a lifeline for wildlife by providing dry season food resources long after plants elsewhere have dried (Wilson, 1989). The salt-tolerant *S. persica* bushes dominate the eastern end of the reserves that is devoid of trees (Barkham and Rainy, 1976). *A. elatior* and *Hyphaene coriacea* dominate the riverine woodland, the latter being confined to the eastern side. Much of the woody vegetation grows on the inner bends of river meanders (Barkham and Rainy (1976). *A. elatior* grows mostly on the deep alluvial deposition curves of the river meanders and is often absent from the eroding outer bank of the river where possible bank collapse may occur. Low lying pans adjacent to the river become seasonally water logged and minerals dissolved in the shallow water table percolate yielding saline soils that support the halophytic salt bush (*Sansola dendroides*) and the grass *Sporobolus spicatus* grass (Barkham and Rainy, 1976; Wilson, 1989).

The most extensive vegetation community is the thorny *Acacia-Commiphora* scrubland dominated by short thorny bushes no more than a meter high or small trees and ephemeral grasses (Barkham and Rainy, 1976). Throughout the area, desert roses, *Adenium obesum, Helicotropium* spp. and morning glory, *Ipomea* spp. are common. Large areas of *Acacia tortilis* wooded grasslands with a ground cover of perennial and annual grasses are found in BSNR.

2.1.5 Fauna

The reserves' diverse vegetation communities and water availability attracts many wildlife species. When rain falls, many herbivores disperse into the surrounding countryside and this happens several times a year due to the high rainfall variability. Over 900 elephants use the two reserves (Wittemyer *et al.*, 2005). Reticulated giraffe *Girrafa camelopardalis*, is found in the reserves and throughout northern Kenya. Plains zebra *Equus burchelli*, are restricted to the south of the river in BSNR. The Grevy zebra *Equus grevyi*, are however less restricted and are present even in SNR owing to their better adaptation to arid conditions (Wilson, 1989). Cape buffaloes (*Syncerus caffer*), impalas (*Aepycerios melampus*), defassa waterbuck (*Kobus defassa*), and common waterbuck (*Kobus ellipsiprymnus*) favor heavily bushed areas. Both Kirk's dikdik (*Madokua kirkii*) and Gunther's dikdik, (*M. guantheri*) occur in the reserves especially in the *Salvadora* spp. thickets. The greater kudu (*Tragelaphus strepsiceros*), and lesser kudu (*T. imberbis)* are found in low numbers. Other large ungulate species found in the reserves are the beisa oryx (O*ryx beisa*), the eland (*Taurotragus oryx*) and the gerenuk (*Litocranius walleri*). Small ungulates include Klipspringer (*Oreotragus oreotragus*), grey duiker (*Sylvicapra grimmia*), African hare (*Lepus capensis*) and warthog (*Phacochoerus aethiopicus*).

The predators present in the reserves include lion (*Panthera leo*), leopard (*P. pardus*), cheetah (*Acynonyx jubatus*), caracal (C*aracal caracal*), serval (*Felis serval*), civet (*Civettictis civetta*), genet cat (*Geneta geneta*) wild cat (*Felis silvestris*), wild dog (*Lycaon pictus*), spotted hyena (*Crocuta crocuta*) and stripped hyena (*Hyaena hyena*). The smaller predators include the bat eared fox (*Otocyon megalotis*), golden-backed jackal (*Canis aureus*), *b*lack-backed jackal (*C. mesomelas*), serval cat (*Felis serval*), caracal (*F. caracal*), common genet (*Genetta genetta*), aardvark (*Orycteropus afer*), dwarf mongoose (*Helogale parvula)* and banded mongoose (*Mungos mungo*).

Primates found in the reserve are the vervet monkey (*Cercopithecus aethiops*) and olive baboon (*Papio anubis*). The Nile crocodile, *Crocodilus niloticus,* is found in Ewaso Nyiro River and up the main tributaries in BSNR. Almost 400 species of birds have been recorded in the area (Wilson, 1989). Birds of prey abound in the reserves notably the martial eagle (*Polemaetus bellicosus)*, bataluer (*Terathopius ecaudatus)*, eastern pale chanting goshawk (*Melierax poliopterus)* and augur buzzard (*Buteo augur)*.

2.2 Materials and Methods

The study was conducted from October 2006 to March 2007. This coincided with both wet and dry periods. The riparian zone was chosen for detailed study because co-occurrence of different woody species necessitated studies on preferential foraging. The study sites were visited fortnightly except during the rains in November and December 2007 that rendered much of the riparian zone inaccessible due to flooding and subsequently the sites were visited once a month.

2.2.1 Marking field study plots

Fifteen 100 x 100 meters plots were randomly established and permanently marked on both reserves (Figure 1). Ten of these were riverine plots and labeled A to K. Caution was taken to exclude areas exclusively under doum palm (*Hyphaene compressa*). The other five plots labeled L to P were situated at least 900m away from the river. A GPS (model Garmin 3.2) was used to map the plots with the corners georeferenced as waypoints. These waypoints were downloaded in ArcGIS 9.0 and stored as a shape-file. The waypoints aided in locating the plots during subsequent field visits by navigating to each. Plot dimensions were measured and demarcated by walking a 100m path guided by a GPS enabled HP PDA (Personal Digital Assistant) (h2200 series) and navigating to its consecutive corners. The GPS enabled PDA offered higher accuracy needed to guide a straight path often under vegetation. The plots away from the river were sampled to compare the woody vegetation community structure and elephant debarking intensities with plots along the river.

2.2.2 Assessment of woody plant community structure and debarking intensities

The initial survey involved mapping out of individual woody plants within the randomly selected plots using a Garmin 3.2 Global Positioning System (GPS) unit for which Horizontal Position Error (accuracy) ranged from 5.5m to 7.5m. A GPS enabled HP PDA (h2200 series) with a BC-337 receiver and external AT-65 GPS antenna was used for increased accuracy approximately two meters where trees were very close to each other.

Each tree was assessed for fresh and old elephant debark which was recorded on a scale of 0 to 5 corresponding to various proportions of the debarked part of stem (Table 1) (Walker, 1976; Smallie and O'Connor, 2000). Old elephant debarking marks were defined as those whose sap and loosened fibers had dried up. During the initial bark damage assessment and sampling conducted in October, existing fresh and old debarking marks were recorded as individual trees were georeferenced. The circumference of each tree at breast height was measured with a tape measure. Bark damage by elephants was assessed as elephant tusk marks and associated injuries on the stems and main branches. Subsequent regular assessments of debarking involved recording additional fresh elephant debarking which gave cumulative data on woody plants debarking at the end of the study period. In the case of bark utilization from main branches, estimates of the percentages of damage on each the branches' circumference were averaged to yield a value taken as a representative of how much damage it would be were it on the main stem. The resulting average was thus allocated to a utilization class as if it was on the main stem. A fully utilized tree, with a score of 5 was a tree with complete ring debarking.

To avoid bias in calculation of species preferences where trees were utilized to different degrees, the number of trees of a species within each utilization score was multiplied by a weighting factor ranging from 0 to 1 corresponding to damage levels of between 0 and 5, (Table 1), to yield a debarking index. Each weighting factor was taken as the midpoint of the utilization class. The number of fully utilized trees was later calculated as the weighting factor multiplied by the frequency of individuals within the utilization class (Barnes, 1976, Walker 1976). Multiplication with a weighting factor to get fully utilized trees was also necessary because different classes covered a different range of values. Mean debarking indices of trees in the same plot as well as trees sampled in a month were calculated by averaging the indices of the individual tree damage scored as above.

Category	Class (Proportion of debarked stem)	Weighting factor
0	0%	0.00
1	1 - 25%	0.13
2	26- 74%	0.50
3	75%	0.75
4	76 -99%	0.88
5	100%	1.00

Table 1. Utilization classes of trees as a percentage of damaged portion of tree circumference at the height of worst damage, and the corresponding weighting factors for each utilization class.

Preference ratio (PR) of each woody species was then calculated for each species as described by Viljoen (1989);

$PR = PA / PU$,

Where PU = percent utilization, PA = Percent availability.

$PA = 100 \times (n_{sp}/ N_{sp})$,

$PU = 100 \times n_u / N_u$

Where, n_{sp} = number of trees of a species in a plot,

N_{sp} = total number of all species in the plot

n_u = number of fully utilized trees of a species, and

N_u = number of fully utilized trees of all species in the plot

A preferred species was defined as one that was utilized proportionately more frequently by elephants than its proportion of available trees, PR > 1. A preference ratio (PR) of less than 1 showed avoided species of less preferred species.

2.2.3 Bark sampling

For the purpose of bark sampling, three levels of debarking were distinguished as follows based on the definitions in Table 1.

1. the less debarked or avoided corresponding to the categories 0 and 1;
2. moderately debarked corresponding to the categories 2 and 3; and
3. heavily debarked corresponding to the categories 4 and 5.

A bark sample of approximately 15 grams was collected from each identified tree on the main stem and when the sample tree was debarked, the sample was taken from the remains of the elephant stripping with a knife. To collect a sample from a non debarked tree, a sharpened 2.5 cm square metal tube was hammered onto the stem and two or three pieces removed vertically next to each other. Vertical orientation was chosen to minimise interference with tree sap flow which would have lead to much water loss by plant. Samples from each tree were air dried in the field inside brown 'sugar papers' and latter transported to the laboratory for analysis of nutritional content. The sampling regime targeted to collect six samples from each of the three debarking levels defined above every month. The target of six samples was not attained in all months as the number of debarking incidences and their intensities varied in time, with no incidences of debarking observed in some months. A total of 67 bark samples were collected. These comprised of 34 samples from less debarked, 16 from moderately debarked and 17 from heavily debarked trees.

2.2.4 Analysis of bark samples dietary content

Laboratory analysis was done at Kenya Agricultural Research Institute (KARI) laboratory. Each of the 67 bark samples was analyzed for total calcium (Ca), sodium (Na), Phosphorus (P), Magnesium (Mg), Potassium (K), Nitrogen (N), Iron (Fe), Copper (Cu), Manganese (Mn), and Zinc (Zn). In addition to these analyses, eighteen bark samples collected in March were analysed for Nutrient Detergent Fibre (NDF) as an indication of the overall indigestible proportion content of the samples. Bark samples were first digested with a mixture of hydrogen peroxide, sulphuric acid, selenium and salicylic acid. The content of each of the elements N, P, K, Ca, Mg, Mn, Cu, Zn, Fe was determined in the acid digest using standard methods described by Anderson and Ingram (1989). A bark portion weighing 0.3grams from each sample was put in a dry digestion tube and labeled. Then 2.5 ml of freshly prepared digestion mixture (3.2 grams salicylic acid in 100ml sulphuric acid-selenium mixture) was added into each tube and the reagent blanks for each batch of samples. Samples were digested at 110^{O}C for one hour. They were then removed, cooled and three successive 1 ml portions of hydrogen peroxide added to each tube. Temperature was then raised to 330^{O}C and heating continued till the color cleared, and the contents were then allowed to cool. Then 25 ml of distilled water was added and mixed until it was saturated with hydrogen peroxide. The contents were cooled, topped up to 50ml with water and allowed to settle before taking clear solutions from the tube for analysis.

Total N was determined calorimetrically. The acid digest was diluted to a ratio of 1:9 (v/v) with distilled water to match the standard solution. Using a micropipette, 0.2ml of each of the sample's digest was drawn into labeled test tubes. Some 0.5 ml of reagent N1 was added and vortexed. Reagent N1 was prepared as follows: 34g sodium salicylate, 25g sodium citrate and 25g sodium tartrate dissolved in 750 ml water; to the solution was added 0.12 g sodium nitroprusside. To these, 0.5 ml. of reagent N2 was added. Reagent N2 was prepared as follows: 30g of sodium hydroxide dissolved in 750 ml water; cooled, 10 ml of sodium hypochlorite added. The contents were topped up to one liter with water and vortexed. The mixture was allowed to stand for 2 hours and its absorbency measured at 650 nm, for total nitrogen.

Total P was determined by pH adjustment using Ascorbic acid method. Some 5 ml of each of the clear digested samples' solution was drawn using a pipette in to 50ml volumetric flasks. About 20ml of distilled water was added to each flask. Ten milliliters of ascorbic acid reducing agent was added accordingly. The contents were made to 50ml by adding water, closed using a stopper and shaken thoroughly. These were stood for one hour for full color development and concentration of phosphorus in sample read from absorbance measured at 880 nm wavelength in a calorimeter.

For the determination of K, some 2 ml of the digested sample's solution was put in a 50 ml volumetric flask and distilled water added to 50ml. Starting with the standards, each of the solutions was sprayed into atomic absorption spectrophotometer flame at wavelength 766.5 nm and the amount of K was recorded from the absorbance noted. To determine Ca content in the sample digests, 10 ml from each of the digested sample's solution was put in 50ml volumetric flasks. Then 10 ml of 0.15% lanthanum chloride were added to each flask and topped the 50ml mark with distilled water. The flask was shaken thoroughly and the solution sprayed onto the atomic absorption spectrophotometer flame at wavelength 422.7 nm. The concentration of calcium was recorded on the spectrophotometer as indicated by absorbance.

Five milliliters of each of the digested sample solutions was put in 50ml volumetric flasks for determination of Mg and made to the 50ml mark with distilled water. Magnesium standard series, the blank and sample solutions were sprayed on to the flame of atomic absorption spectrophotometer and Magnesium concentration read. For the determination of Mn, Fe, Cu and Zn, the sample digests were aspirated into the atomic absorption spectrophotometer calibrated for 279.5nm 248.3nm 324.7nm and 213.9nm respectively. Their absorbencies were measured for inference of the elements concentration in the acid digest.

The proportion of Neutral detergent Fiber (NDF) in bark was analyzed in 18 samples all taken in March when debarking was most intense to determine the indigestible proportion of bark. These comprised of six samples from each of the three debarking categories. The reagents used were; Neutral Detergent Solution (NDS) prepared by adding 30.0 g sodium lauryl sulfate, 18.61 g of ethylenediaminetetraacetic Disodium Salt (EDTA, Dihydrate), 6.81 g sodium tetraborate decahydrate; 4.56 g sodium phosphate dibasic, anhydrous and 10.0 ml triethylene glycol in 1000 ml distilled water. These were agitated and heated to facilitate solubility. The resultant pH values ranged from 6.9 to 7.1 as preferred. Some 0.5 g (± 0.05 g) of air-dried sample was weighed, (W2), into a beaker. 100 ml of NDS, 0.5 g of sodium sulfite and 2 ml of Decahydronaphthalene were added and the contents refluxed for 60 minute after boiling. The sample was filtered and put in a pre weighed crucible, (W1), and rinsed with hot water. The liquid was filtered and repeatedly washed 5 times. The sample was washed twice with acetone and sucked dry. The acetone was allowed to evaporate and after drying, it was dried completely in oven at 105° C for 8 hours and weighed (W3). The entire sample was ashed for 2 hours at 550°C, cooled in a desiccator and weighed (W4). NDF was calculated as follows:

NDF (%) = (W3-W2)/2 × 100

NDF_{OM} (DM basis) % = (W4 - W1)/W2 × 100

Where

W1 = Empty crucible weight.

W2 = Sample weight.

W3 = Weight after extraction process.

W4 = Weight of Organic Matter (OM) - loss of weight on ignition.

2.2.5 Soil sampling

Soil samples were collected during the dry month of February 2007 from nine riverine plots using a soil augur. Each plot was subdivided into ten squares that constituted sampling locations. The coordinates of the center of each square was fed into a Geographical Position System (GPS). The locations of these points were entered into a GPS as WGS_84_UTM_Zone37N waypoints and navigated to in the field, but the accuracy varied by 4 to 5 meters due to GPS' Horizontal Position Error. Not all stored points were accessible for sampling due to dense vegetation or extremely deep silt deposits or rock outcrop in some plots. Eight to ten points were sampled in each plot to a depth of 30 centimeters. Attempts were made to dig through the fresh silt deposition to the underlying soil using a shovel and a hoe. The core of soil in augur was removed from each sampling point and all sub samples from each plot were put in the same plastic bucket. These were then mixed by hand and approximately 1 kilogram composite sample taken as a representative of the plot. The samples were air dried in the field and stored in labeled 'sugar papers' awaiting chemical analysis at Kenya Agricultural Research Institute (KARI) laboratory in Muguga.

2.2.6 Analyses of soil nutrients content

Each of the soil samples was analysed for total calcium (Ca), sodium (Na), Phosphorus (P), Magnesium (Mg), Potassium (K), Nitrogen (N), Iron (Fe), Copper (Cu), Manganese (Mn), and Zinc (Zn). The pH of each sample was measured too. Total nitrogen and phosphorus in the samples were determined using the same methods described above in section 2.2.4 for bark samples. For the exchangeable cations, Na^{+}, K^{+}, Ca^{2+} and Mg^{2+}, these were first extracted from soil with an excess of ammonium acetate. Five grams of each of the air dried soil samples were weighed into plastic bottles. Blanks and repeat samples were included in the batch of soil samples. Then 100 ml of 1 mole ammonium acetate solution of pH 7 was added. The contents were shaken for 30 minutes and filtered through number 42

Whatman paper. The filtrate of the soil extract was used in determination of the content of Na, K, Ca and Mg. For determination of sodium, potassium and calcium, each of the extracts was diluted ten times (solution '*A*'). Five milliliters from each of the diluted soil extract solution was drawn using a pipette into 50ml volumetric flasks. To it was added 1ml of 26.8% lanthanum chloride solution. The contents were diluted to the 50ml mark with 1 mole ammonium acetate extraction solution. The solution was sprayed into the atomic absorption spectrophotometer flame for determination of Na and K. Absorbencies were measured as described in section 2.2.4.1 above to determine the amounts of each element. The standard working solutions with known quantities were measured first to calibrate the instrument.

For determination of magnesium, the extract solution '*A*' above was first diluted 25-fold. To make this dilution, 2ml of soil extract solution '*A*' was drawn using a pipette into a 50ml volumetric flask. Then 5ml of 5000 parts per million (ppm) were added and I mole ammonium acetate used to fill the contents to 50ml mark. The solution was sprayed into atomic absorption spectrophotometer. The content of K, Na, Mg and Ca in soil was expressed in ppm.

Chelating agent ethylenediaminetetraacetic acid (EDTA) was used in determination of soluble Cu, Zn, Fe and Mn. Air dried soil samples were first extracted in 1% EDTA. To achieve this, 5 grams of each air dried soil samples was placed in 50ml EDTA, shaken for one hour and then filtered. The filtrate and standard samples were aspired into an air-acetylene flame of atomic absorption spectrophotometer. Copper, zinc, iron and manganese concentrations were read at 324.7nm, 213.9nm 248.3nm and 479.5nm respectively.

Soil particle size was analysed by the Hydrometer Method (Bouyoucos, 1927). One hundred grams of each of the air dried soil samples was weighted into 400ml beakers. These were saturated with distilled water and to each was added 10ml of 10% calgon solution (sodium hexametaphosphate). The contents were allowed to stand for 10minutes. The dispersion was transferred to a dispersing cup and 300ml of tap water added. The suspension was then mixed for 2 minutes with a high speed electric stirrer. The suspension was transferred to a graduated cylinder and the remaining soil rinsed into the cylinder with distilled water. A hydrometer was inserted into the suspension and water added to the 1130ml mark, after which the hydrometer was removed. The cylinder was covered with a tight fitting rubber bung and the suspension mixed gently by inverting the cylinder carefully ten times. 2-3 drops of amyl alcohol were quickly added to remove the froth and hydrometer placed gently into the column after 20 seconds. At 40 seconds, the hydrometer and temperature readings of the suspension were taken. After the 40 seconds, the sand had settled and the reading reflected the grams of silt and clay in one liter of the suspension. The cylinder was covered again with a tight fitting rubber bung and the suspension mixed gently by inverting the cylinder carefully ten times and the cylinder allowed to stand again for two hours when both hydrometer and temperature readings were taken again. The temperature corrections were made as described by Bouyoucos (1962). In the two hours time, the silt had settled and the hydrometer reading reflected the clay content of the original suspension. Assumption is that organic matter is negligible and the proportions of sand silt and clay were calculated by subtractions from the original sample weight.

Soil pH was measured on a 2.5:1 water to soil suspension as described by Rhoades (1982). Some 50ml of de-ionized water was added to 20g soil the mixture was stirred for 10 minutes, allowed to stand for 30 minutes and stirred again for 2 minutes. The pH of the suspension was measured using a pH meter. Soil samples were analysed for total organic carbon as an indicator of litter decomposition rates. The Walkley and Black (WB) method was used as described by Walkley and Black in 1934. Concentrated sulphuric acid (H_2SO_4) was added to a mixture of soil and aqueous potassium dichromate ($K_2Cr_2O_7$). The heat of dilution raised the temperature to induce a substantial, but not complete, oxidation by the acidified dichromate. Residual dichromate was back titrated using ferrous sulphate. The difference in the added iron sulfate ($FeSO_4$) was compared with a blank titration to determine the amount of easy oxidizable organic carbon. The percentage WB carbon (WBC) was calculated by the formula:

$$WBC = M \times (V_1 - V_2)/W \times 0.30 \times CF$$

where M is the molarity of the $FeSO_4$ solution (from blank titration),

V_1 is the volume (ml) of $FeSO_4$ required in blank titration,

V_2 is the volume (ml) of $FeSO_4$ required in actual titration,

W is the weight (g) of the oven-dried soil sample, and

CF is the correction factor which is a compensation for the incomplete oxidation and is the inverse of the recovery set by Walkley and Black (1934) to 1.32 (recovery of 76%).

2.2.7 Statistical analysis

Data was analyzed in SPSS'-SYSTAT 9.0 (SYSTAT, 1998). The laboratory analysis data were normalized by log transformation [X' = log(X+1)] before applying parametric analysis tests because some of the values were very small or even zero. All hypotheses were tested at $\alpha = 0.05$. Homogeneity of soils sampled in different plots with respect to mineralogical composition was tested using a single-factor Analysis of Variance (ANOVA) (Zar, 1996). Pearson's correlation was used to test whether bark nutrient content varied with the site's soil composition. Student's *t*-test was used to test the significance of the correlation coefficient.

ANOVA was used to test whether there were significant differences in the debarking intensities between the months and Bonferroni adjustment used to determine the sources of differences. The *log-likelihood ratio* G-test was used to test whether different woody species were utilized in proportion to their availability, a measure of species selection. One way ANOVA test was used to test whether there were significant differences in the level of debarking of the woody species in different plots. The Shannon-Wiener diversity index *H*', (Shannon, 1948) was calculated and used as a measure of species diversity in each riverine plot and for all riverine plots merged.

The sampled population of trees exhibited a negatively skewed frequency distribution of circumferences and these measures were log transformed as $Y' = \log(Y+1)$ to conform to normal distribution before regression analysis (Zar, 1996). Linear regression was used to test the relationship between elephants' debarking intensity and tree circumference.

The non Parametric, Mann-Whitney, test was used to determine if there existed differences between the two most abundant species, *Acacia elatior* and *A. tortilis* with respect to each of the four nutrient elements that had significant positive correlation with debarking intensity. The non parametric test was preferred because the differences between the two samples' sizes was over 10 % (=28.9%), and the smaller variances were associated with the larger sample; the latter of which would compromise robustness of *t*-test (Ramsey, 1980). Mann-Whitney test with tied ranks was used to test for the null hypothesis that *A. elatior* had greater than or equal amounts of each of the four dietary elements N, P, K and Zn than *A. tortilis*. Considering that the smaller sample size exceeded twenty, the normal approximation to the Mann-Whitney Test was employed in this analysis and the *Z*-statistic calculated (Zar, 1996). The differences between means of the circumferences of the species dominant in the riverine and those away from the river were tested using student's *t*-test. Anova was used to test for variations in numbers of debarking incidences with stem circumferences.

Pearson's correlation was used to test whether debarking intensity was correlated with each of the mineral elements analysed in the bark samples. Student's *t*-test was used in evaluating the significance of the correlation coefficient *r* at $\alpha \leq 0.05$ (Zar, 1996). One way

ANOVA was used to test whether the proportion of NDF in bark samples varied in the three sets of six bark samples collected for each of the three debarking level categories. ANOVA was used to test for monthly fluctuations in the content of the various mineral elements in the bark.

CHAPTER THREE

3.0 RESULTS

3.1 Woody vegetation structure and composition

A total of 1,602 woody plants were recorded, assessed for elephant damage and georeferenced (Appendix 1). Of these, 1373 individuals comprising of fourteen species were recorded within the ten riverine plots labeled A to K (Figure 1). Some 229 individuals were recorded in the plots situated away from the river where only three species were encountered. There was a higher density of trees along the river than away from it (Appendix 2). Elephants' utilization of the woody vegetation comprised of tree felling, foraging on the branches and twigs of the felled trees and debarking, but this study focused on debarking alone. The number of plants of each species recorded in each debarking class in the fifteen plots is tabulated in appendix 2. It was not possible to measure circumferences of some 23 riverine trees due to inaccessibility rendered by thick *Salvadora persica* bush around them. The scars on the bark varied from occasional single gouges caused by the action of one or more strokes of an elephant's tusk to large patches where the bark had been stripped for up to approximately 3 to 4 meters up the stem.

Acacia elatior and *A. tortilis* were the most abundant trees in the riparian zone both accounting for 85% of all woody plants recorded (Figure 3). Of these two species the bark of *A. elatior* was the most preferred with a preference ratio of 1.27.

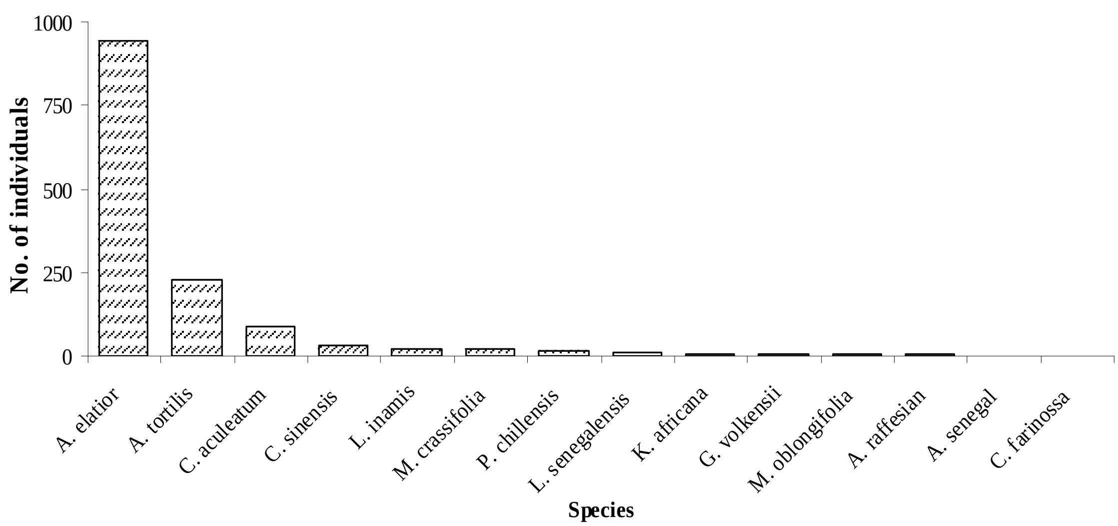

Figure 3. The numbers of woody plants of various species in the riverine plots.

While both *A. elatior* and *A. tortilis* were recorded in the riverine zone, the former was absent in the plots situated away from the river. In the riverine zone, *A. elatior* was apparently in higher density of 91 ± 20.5 (SE) trees per hectare while that of *A. tortilis* was appreciably low at a density of 22 ±12.3 (SE). Comparison was made between the population structures of *A. tortilis* trees along the river and away from the river. The two populations were significantly different with respect to tree circumferences ($t_{0.05\ (2),\ 240} = 6.42$, $p < 0.05$). The *A. tortilis* trees in the plots located to the away from the river had higher frequencies for each circumference class and remarkably more saplings (Figure 4).

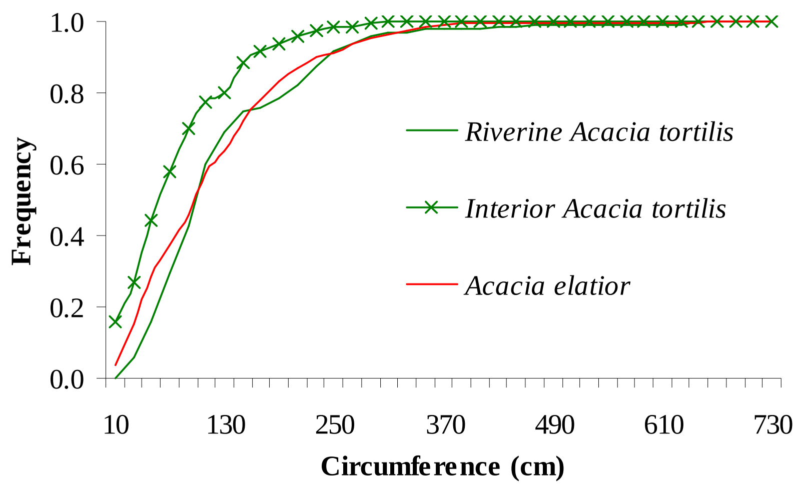

Figure 4. Cumulative relative frequency distribution of circumferences of *Acacia tortilis* trees along the river and away from the river.

Each of the riverine plots exhibited low diversity of woody species ($0.132 \leq H' \geq 0.517$). Diversity indices were calculated by pooling all riverine plots except plot A that was entirely composed of *A. elatior.* The overall diversity index *(H')* for the riparian woody community was 0.488.

3.2 Elephant foraging behavior with respect to debarking

The level of debarking varied significantly from October 2006 to March 2007 ($F_{0.05, (2) 5, 60} = 4.13$, $p < 0.05$) (Figure 5). The months of November and December varied greatly from the others, exhibiting the lowest mean debarking indices.

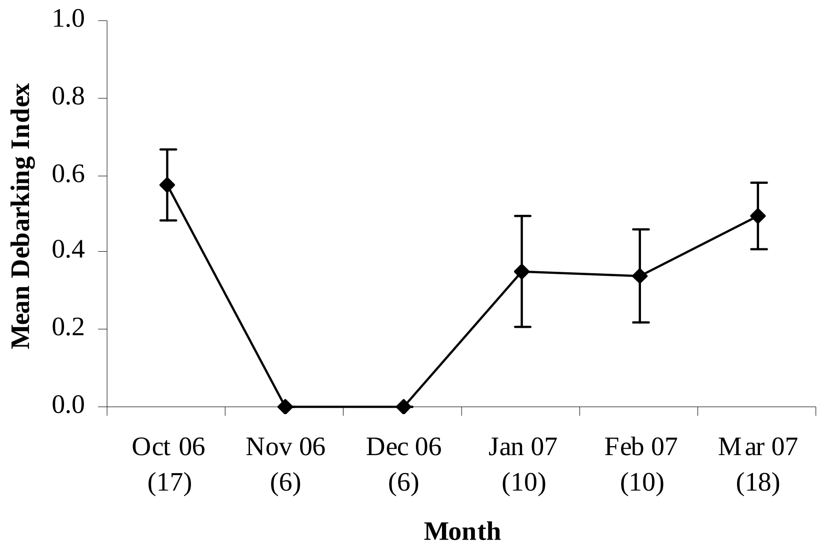

Figure 5. Monthly mean debarking indices (± SE) of trees in Samburu and Buffalo Springs National reserves. Number of samples collected and analysed every month (n) in parenthesis.

The plots situated away from the river were excluded in analysis of selective debarking behavior because of the notably few species present in them. These would have biased the tests by having offered the elephants little or no choice. All the 1373 riverine woody plants were considered available for utilization by elephants through debarking of which an equivalent of 431 were fully utilized. Individual species were not utilized in proportion to their availability, indicating selection between species (G_{adj} 29.5, df, 13; $p < 0.05$). Elephant preference of various species varied from 0 to 3.19 (Table 2). There were significant differences in debarking indices of plants in the different plots ($F_{0.05(1)15,\ 1602} = 16.124$, $p < 0.05$). Trees in the plots away from the river were least debarked (Figure 6).

A. elatior had approximately 42% of trees with more than three quarters of their circumference debarked (Figure 7a). Figure 7b shows the theoretical equivalent of the fully utilized portion of *A. elatior* trees using the weighting factor as a measure of debarking intensity.

Species	Number of trees (n)	Expected proportion of utilized trees (Pi)	Observed proportion of utilized trees	Preference ratio (PR)
Acacia elatior	941	68.44	86.65	1.27
Acacia raffesian	4	0.29	0.46	1.60
Acacia senegal	2	0.15	0.46	3.19
Acacia tortilis	226	16.44	10.15	0.62
Cadaba farinossa	2	0.15	0.00	0.00
Combretum aculeatum	84	6.25	0.00	0.00
Cordia sinensis	31	2.25	0.64	0.28
Gardenia volkensii	6	0.44	0.00	0.00
Kigelia africana	7	0.51	0.35	0.69
Lawsonia inamis	23	1.67	0.00	0.00
Lepisanthes senegalensis	8	0.58	0.70	1.20
Maerua crassifolia	21	1.53	0.20	0.13
Maerua oblongifolia	5	0.36	0.00	0.00
Prosopsis chillensis	13	0.95	0.38	0.40

Table 2. Preferential utilization of the different woody species expected and observed proportion of trees utilized (n =1373) and preference ratios.

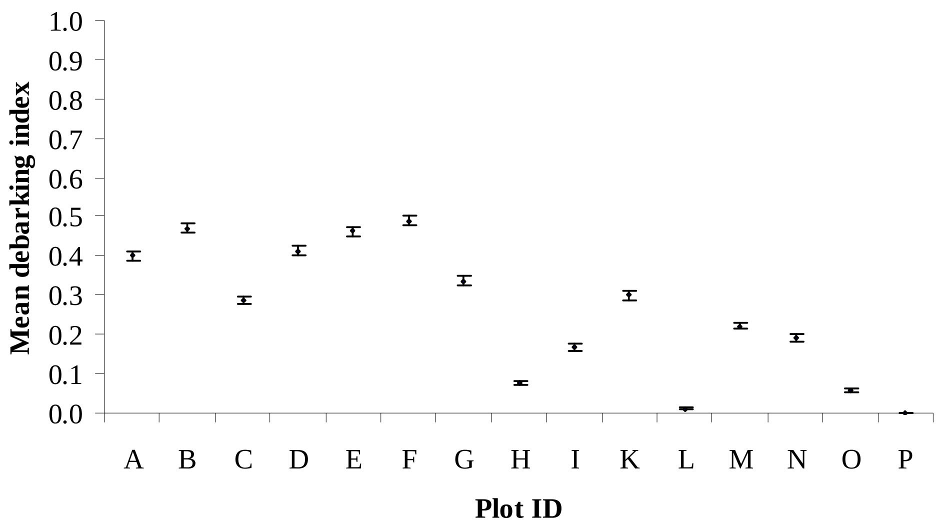

Figure 6. The mean debarking indices (± SE) of woody plants in riverine plots (A to K) and those away from the river (L to P).

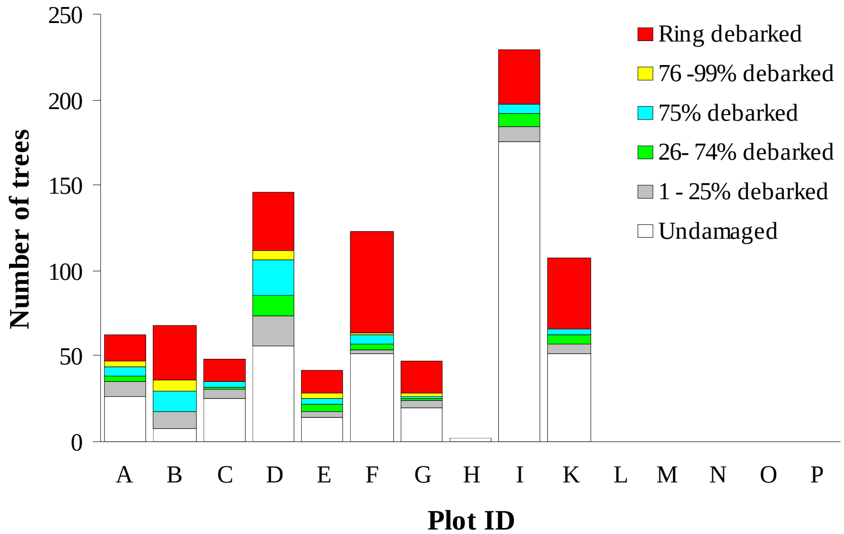

Figure 7a. Elephant stem debarking on *Acacia elatior* in the riverine plots, the most abundant tree in the riparian zone of Samburu and Buffalo Springs National Reserves.

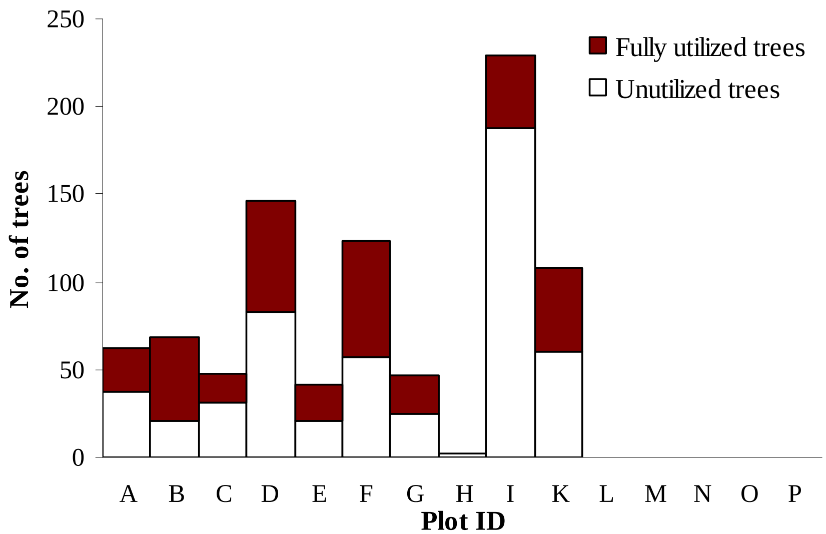

Figure 7b. The equivalent number of ring barked (fully utilized) and non utilized *A. elatior* trees calculated using a weighting factor of 0 to 1 showing the general impact of elephants on the species.

Few individuals of riverine *A. tortilis* trees, approximately 25%, were recorded with over three quarters debarking. Only 5% *A. tortilis* trees away from the river suffered over three quarters damage to stem circumferences (Figure 8a). Figure 8b shows the theoretical equivalent of the fully utilized portion of *A. tortilis* as calculated using the weighting factor. Fully utilized portion refers to the general impact of elephants debarking behavior on trees in the particular plots.

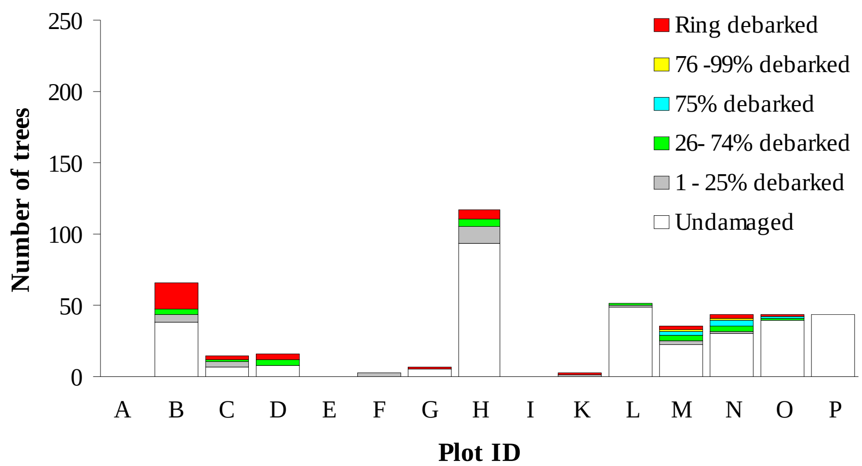

Figure 8a. Elephant stem debarking on *Acacia tortilis* trees along the riverine plots, A to K, and away from the river in Samburu National Reserve, plots L to P.

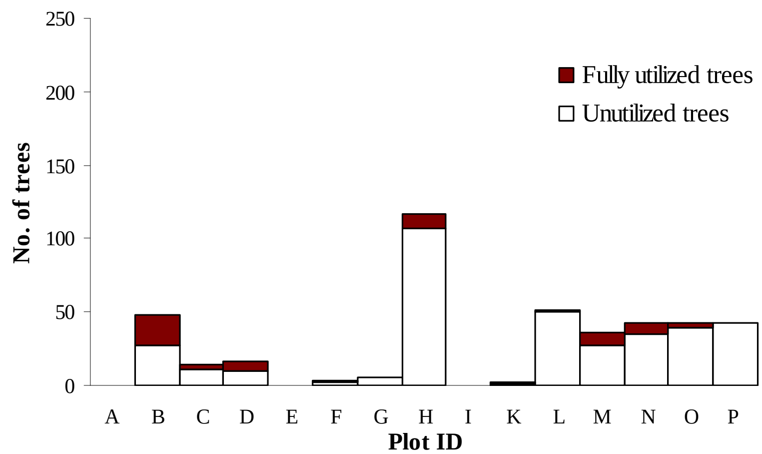

Figure 8b. The equivalent number of ring barked (fully utilized) and non utilized *Acacia tortilis* trees calculated using a weighting factor of 0 to 1 showing the general impact of elephants on the species.

Linear regression was used to determine the influence of stem circumference on debarking behavior. There was significant but weak dependence of the number of debarking incidences on stem circumference for all 1579 trees of all woody species whose circumferences were measured (r^2 = 0.073, $F_{0.5\ (1)\ 1,\ 1579}$= 137.5, $p < 0.05$). Further regression done on trees of the two most abundant and preferentially debarked species, *A. elatior* and *A. tortilis* showed significant dependence of debarking behavior on circumference (r^2 = 0.2, $F_{0.5\ (1)\ 1,\ 1166}$ = 237.9, $p < 0.05$). The trees sampled from each species were then grouped into circumference classes of 40cm per class and ANOVA with Bonferroni post hoc tests was carried out to determine which size class was most sought by elephants. There were significant differences in the debarking of different circumference classes of *A. elatior* ($F_{0.05(1)1,9}$ = 24.33, $p < 0.05$). Trees in the circumference class of 121-160 cm were significantly more debarked than trees in other circumferences. There were significant differences in the debarking of different circumference classes of *A. tortilis* ($F_{0.05(1)1,16}$ = 21.02, $p < 0.05$). Trees in the circumference class of 81-120cm were significantly more debarked than trees in other circumferences. Figures 9a and 9b show the levels of debarking of *A. elatior* and *A. tortilis* trees in different circumference classes.

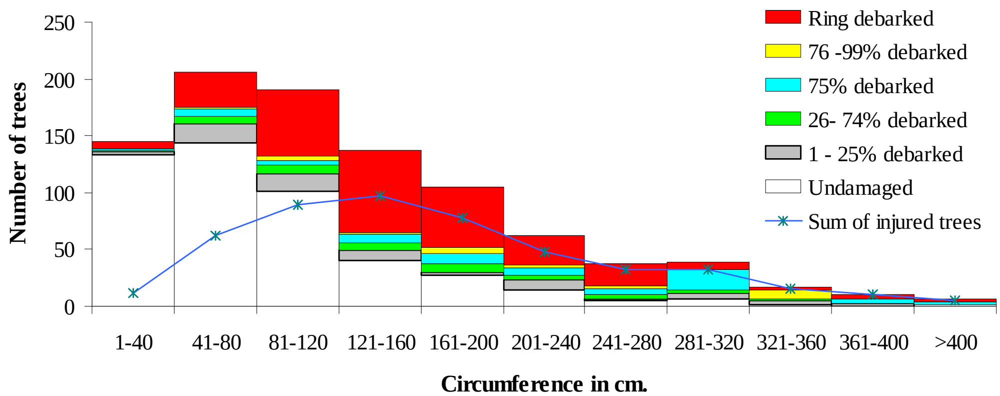

Figure 9a. Elephants' utilization pattern for different sizes of *A. elatior* trees (n = 955) (bars) and the sum of injured trees per circumference size class (line).

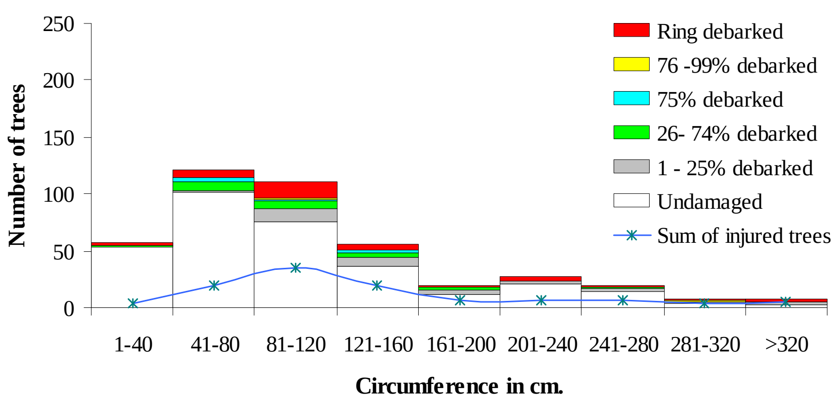

Figure 9b. Elephants' utilization of different sizes of *A. tortilis* trees (n = 429) (bars) and the sum of injured trees per circumference size class (line).

3.3 Bark dietary content

There were significant monthly variations in mineral elements content of bark samples ($F_{0.05\ (1)5,\ 61} = 2.94$, $p = 0.02$) (Figure 10). The samples had relatively high quantities of N (Crude Protein) and Ca. Correlation coefficients between debarking index and each of the mineral element content of bark ranged from -3.91 to 0.575 (Table 3). A significant positive correlation was found between debarking intensity and N (crude protein), P, K and Zn as tabulated in Table 3. *A. elatior,* apparently the most preferred of the two *Acacia* spp., had significantly higher quantities of each of the four elements N, P, K, and Zn than *A. tortilis* ($0.81223 \leq Z_{0.05\ (1)} \geq 0.83139$, $p < 0.05$).

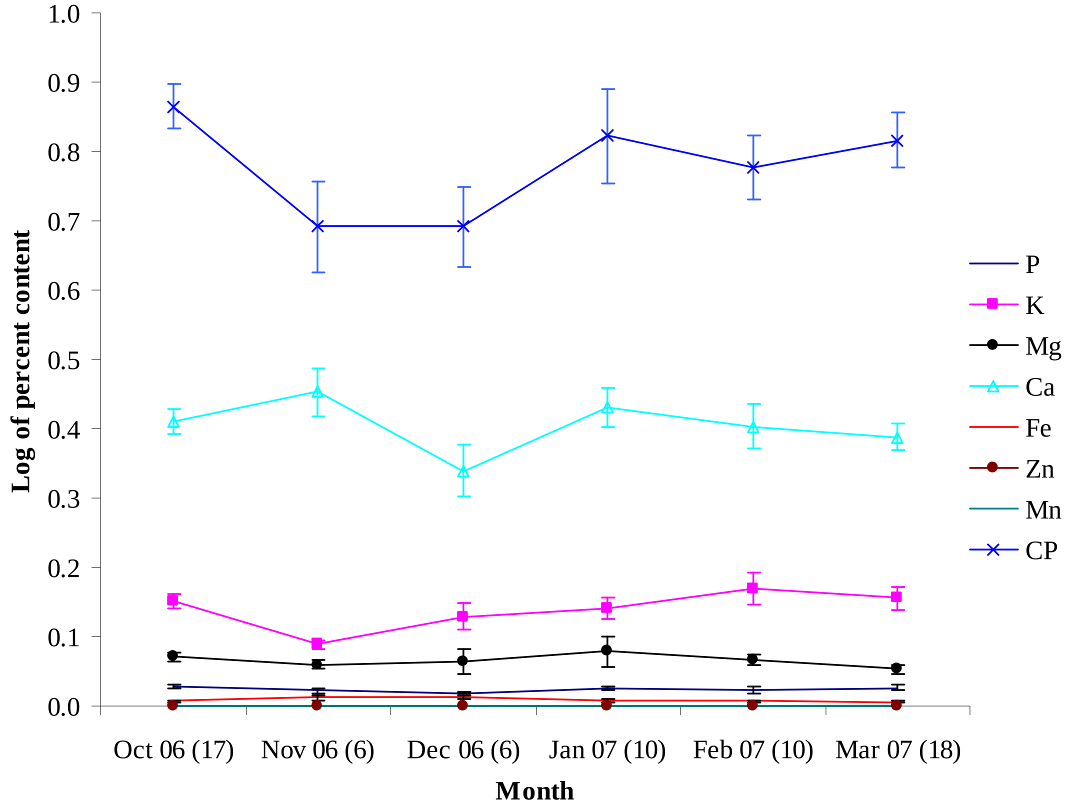

Figure 10. Mean monthly content of various dietary components (± SE) of bark samples (the number of samples, *n,* for each month in parenthesis).

There was no significant difference in Neutral Detergent Fibre (NDF) content in the 18 bark samples collected for the three utilization categories ($F_{0.05\ (1),\ 2,\ 15} = 0.841$. $p = 0.451$). The proportion of NDF in the samples varied from 60.0% to 80.14% with a mean of 67.42 ±1.57 (SE)% (Figure 11). The level of crude protein (CP) was calculated from total nitrogen by multiplying by 6.25. The mean CP content in the samples was 5.7± 0.33 (SE) %. Monthly variations in CP for the 67 samples collected were not significant ($F_{0.05\ (1)\ 5,\ 61} = 1.763$, $p = 0.134$).

	Correlation coefficient (r)	r^2	Hypothesis test result (t-test, $\alpha \leq 0.05$)
N	0.575	0.331	Significant positive correlation
Na	0.067	0.004	No significant correlation
P	0.31	0.096	Significant positive correlation
K	0.336	0.113	Significant positive correlation
Mg	-0.143	0.020	No significant correlation
Ca	-0.071	0.005	No significant correlation
Fe	-0.391	0.153	Significant negative correlation
Zn	0.445	0.198	Significant positive correlation
Mn	-0.06	0.004	No significant correlation

Table 3. Coefficients of correlation between debarking intensity and the content of various mineral elements in bark samples

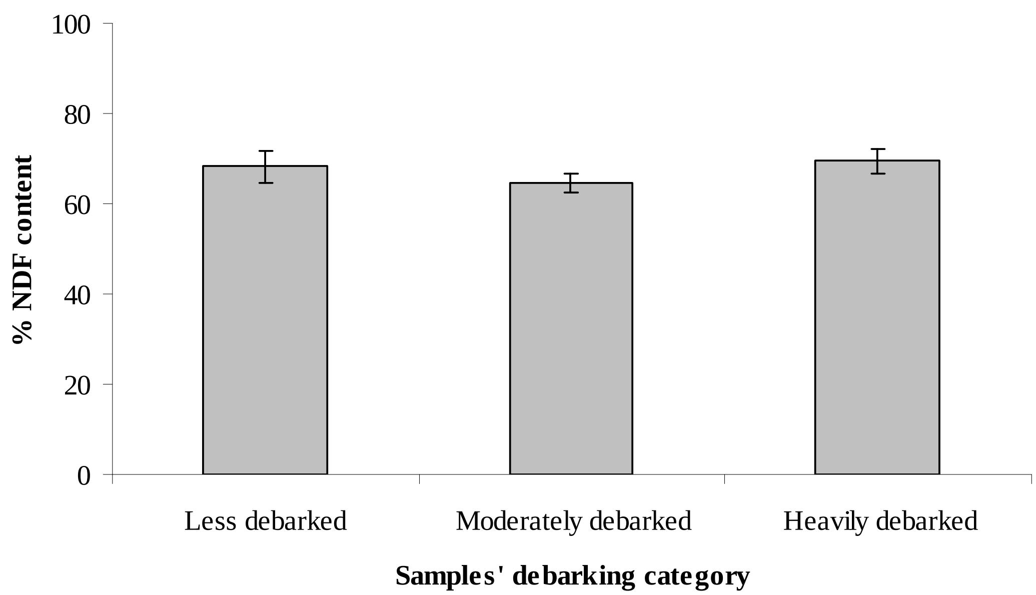

Figure 11. The percent content of NDF (± SE) fibre and hemicelluloses (n=18) for three categories of debarking in March 2007.

3.4 Soil structural composition and nutrient content

The soils in the sampled area were slightly alkaline with pH ranging between 7.63 and 8.40 (Table 4). Sand was a major component accounting for 47.5 (±6.4 SEM)% of most soil samples taken resulting in mainly coarse textures of soils sampled (Figure 12). Silt and clay accounted for 27.7 (±4.9 SEM)% and 24.2 (±2 SEM)% respectively, n = 9. The quantities of the individual mineral elements varied significantly between the riverine plots ($F_{0.05\ (1),\ 8,\ 90}$ = 2.43, $p < 0.05$). The soils from the different plots were assigned textural classes based on particle size distribution using the textural triangle (Table 4). Total organic carbon ranged from 0.75% to 2.01%. The mean value was 1.26 ± 0.15% (SE).

The total N content of the nine soil samples ranged between 0.01% and 0.14% averaging 0.07 ± 0.02 % (SE). Soil phosphorus ranged from 174 ppm to 437 ppm in the plots, a mean of 301 ± 28.24 (SE) ppm (n=9). Total amounts of elements in soil samples varied with changes in soil texture with more clayey soils having the highest elemental content than sandy soils (Figure 13a and 13b). Plots A, D and H had high electrical conductivity (EC) values, which tallies with their associated high amounts of Na, Ca, Mg and K (Figure 14). The total organic carbon varied between 0.68 % and 2.01%.

There was significant positive correlation between electrical conductivity and the sum of the bases Ca, Mg, Na and K ($t_{0.05\ (2),\ 8}$ = 1.63). Soils in areas of relatively high flooding frequencies, i.e. at junctions of water courses and next to permanent springs had high EC values, which is owed to accumulation of salts after evaporation. Overall, the plots varied significantly with respect to each element analysed ($3.38 \leq t_{0.05\ (2),8} \geq 10.66$, p =0.05). There was a negative correlation between diversity of the woody species, *H'*, and the electrical conductivity of the nine plots, r = -0.429. While the plots differed in soil mineralogical composition, there was significant positive correlation between the bark nutrient content and soil content of each of the nutrient elements in the nine plots ($6.03 \leq t_{0.05\ (2),8} \geq 13.34$).

Plot	*% OC*	*% N*	*ppm P*	*ppm K*	*ppm Ca*	*ppm Mg*	*Ppm Na*	*ppm Fe*	*ppm Cu*	*ppm Zn*	*ppm Mn*	*Structural class*	*pH*	*EC*
A	0.75	0.01	227.36	695.03	4524.84	1051.13	651.50	919.18	15.22	32.85	1307.89	Loam	7.95	4.00
B	0.75	0.01	359.33	643.94	2384.81	731.43	1021.20	117.04	7.21	29.64	702.43	Sandy clay loam	8.40	2.00
C	1.68	0.09	436.73	516.21	3219.94	783.11	384.84	276.02	6.41	60.08	841.35	Sandy clay loam	7.63	0.20
D	0.93	0.13	253.90	567.30	5098.99	1110.47	1712.10	203.76	11.22	28.84	1216.16	Loam	7.88	5.00
F	0.93	0.04	174.28	516.21	3011.16	677.82	448.48	528.95	8.81	32.04	883.29	Sandy loam	8.14	0.20
G	1.23	0.06	242.84	771.67	3376.53	771.63	639.39	254.34	9.61	39.25	964.54	Sandy clay loam	7.98	0.20
H	1.23	0.05	357.85	1512.51	5359.97	1550.78	1499.95	23.30	5.61	24.83	490.13	Clay loam	8.06	5.00
I	2.01	0.14	371.86	1384.78	5203.38	1187.05	1021.20	630.12	16.82	57.68	1714.15	Clay loam	7.96	0.40
K	1.83	0.13	284.87	1052.68	5673.15	1175.56	893.93	66.45	17.62	42.46	1412.73	Clay loam	7.96	0.30

Table 4. The content of various mineral elements, textural composition, pH, electrical conductivity for each of the nine riverine soil samples.

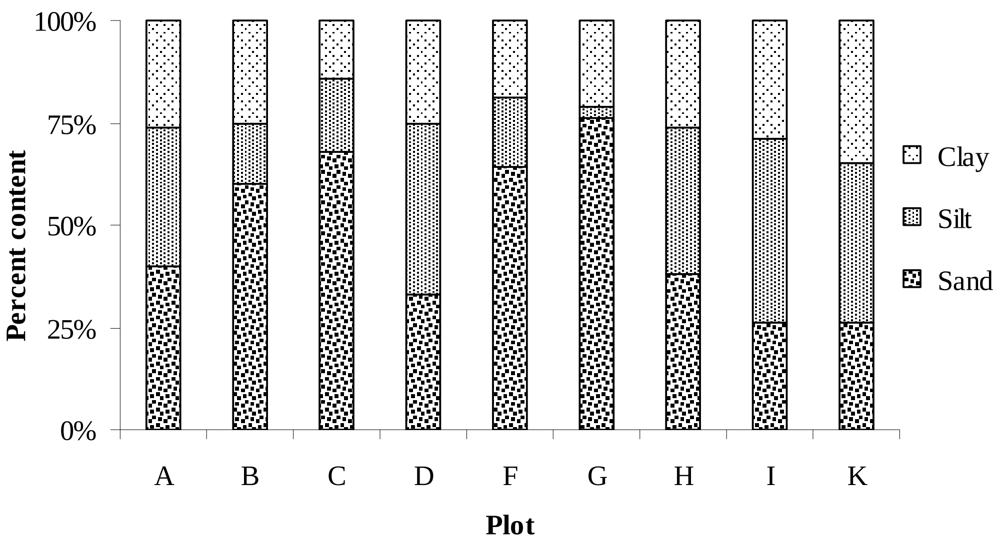

Figure 12. Soil textural composition: percent sand, silt and clay in the nine composite riverine samples.

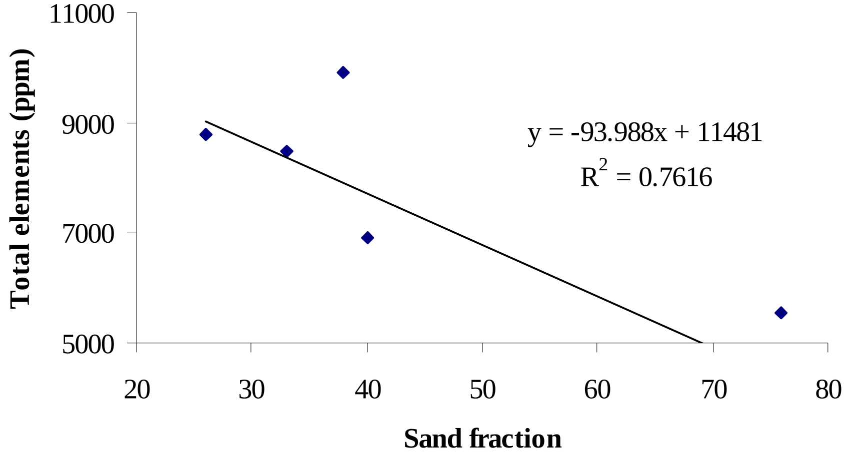

Figure 13a. Inverse relationship between sum of mineral elements and the proportion of sand content of soil. The total mineral content was inversely proportional to sand fraction.

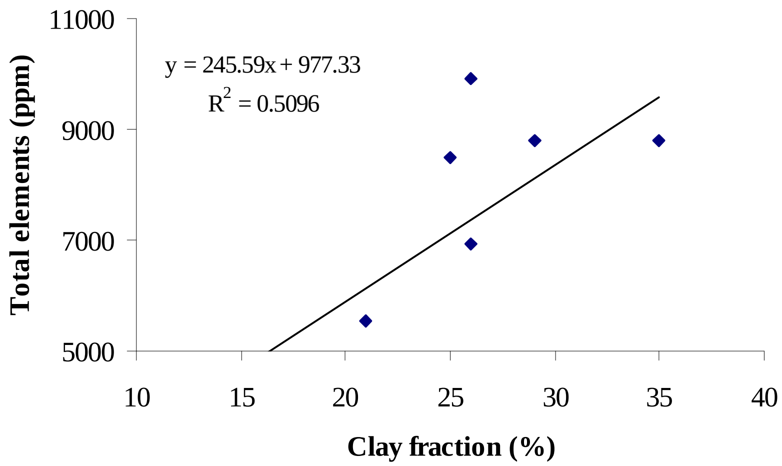

Figure 13b. Direct relationship between sum of mineral elements and the proportion of clay content of soil. The total mineral content was directly proportional to clay fraction.

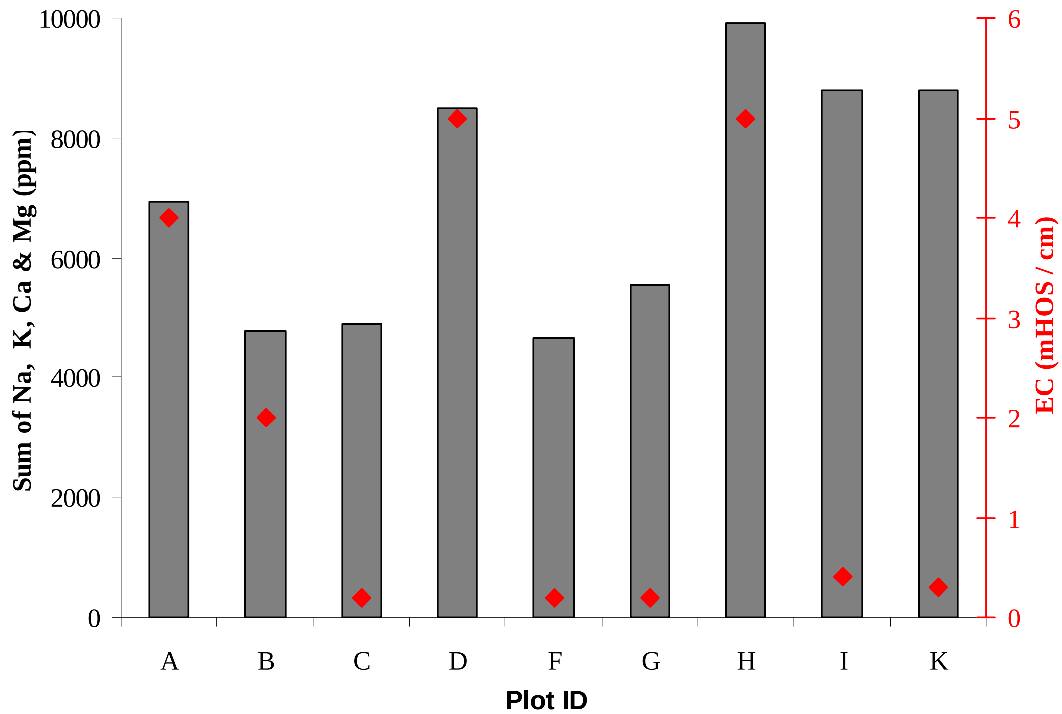

Figure 14. The total content of bases Na, K, Ca and Mg (bars) and Electrical Conductivity (EC) measures (diamonds on secondary axis) of soil samples from each of the riverine plots.

CHAPTER FOUR

4.0 DISCUSSIONS, CONCLUSIONS AND RECOMENDATIONS

The salient findings of this study are that bark chemistry influences debarking behavior of elephants in Samburu and Buffalo Springs National Reserves. Soil mineralogical composition exerts an indirect effect on debarking behavior through its influence in plant mineral content. Elephants have a preference for some species over others with respect to debarking behavior. The soils in the reserves have minimal amounts of nutrient elements compared to the general ranges of nutrient in the earths crust documented in literature and the availability of some of these elements to the plants may be hampered by high soil pH.

Species selection in elephants' foraging behavior has been observed elsewhere in the past by Smallie and O'Connor (2000), and Holdo (2003). The selected species are not always used in a similar manner (Van Wyk and Fairall, 1969). Elephants in SNR and BSNR have the highest preference for *Acacia elatior* with respect to debarking. *Acacia* spp. topped in the list of preferred species in the Sahelo-Soudanian region of Congo (Pamo and Tchamba, 2001). This study allows comparison of two acacia species and reveals that such differences in species preference with respect to debarking do exist even in closely related plants of the same genus. In the Seronera woodlands; bark damage was reported to be highest on the *Acacia* spp. component of the tree population (Ruess and Halter, 1990). Debarking of potentially utilizable species depends on the ease with which bark can be separated from the stem (Douglas-Hamilton, 1972; O'Connor *et al.* 2007).

Trees with circumferences 80-160cm were attacked most by elephants via debarking. Smaller trees would possibly have been sub-optimal for an elephant to spend time on as they contribute smaller quantities of forage intake and are not firm enough to pierce with the tusks as elephants often do to initiate debarking. Larger trees may have been avoided primarily due to their tough collenchymatous tissue rendering them hard to pierce through and strip. It was observed that whenever an elephant managed to gorge out and strip bark from older and bigger trees, it would skillfully peel the inner cortex leaving a heap of dry collenchyma tissue at the base of the tree. The medium trees may also have provided a more optimal source of forage, possibly even more nutritious diet as the trees at the stage are actively growing and thus have more sap flowing in them. A study focusing on dietary differences between trees of different circumferences and age is worth conducting to quantify the dietary differences that may possibly influence elephants foraging behavior.

Large generalist herbivores face a limit on how much material they can digest (Westoby, 1974). If their diet selection is largely driven by the necessity to meet a nutritional need, their response to availability of particular foods should not be continuous but take the form of a cutoff at very low availability. This implies that as a food becomes rarer in a plant community, grazing pressure on it will increase, at least until the cutoff is reached. This is typically what elephants did in the reserves during the study period. The debarking pressure increased on *A. elatior* until other forage items were available in the wet season and elephants decreased debarking intensity. Foraging opportunities for elephants are compromised at a critical time of the year, which should force them to rely on dry land browse earlier in the season and for a greater duration (O’Connor *et al.*, 2007). A possible factor contributing to dispersal of elephants away from the riparian zone after rains is availability of alternative sources of water as temporally pools as well as food. The most important spatial refuge from elephant is distance from water as elephants drink on a near daily basis which restricts foraging to within about 15 km from water (Conybeare, 2004 cited in O’Connor, *et. al.* 2007).

A notable aspect of the woody species composition in the plots was the absence of *A. elatior* in plots away from the riverine zone, and the species domination of the riverine zone. However, *A. tortilis* occurred along the Ewaso River and away from it. *A. tortilis* trees’ age structure as inferred from their circumferences showed that there is a higher recruitment rate or possibly higher saplings survival away from the riverine zone. Differences in recruitment rates may be due to endaphic factors or other environmental factors such as intensity of herbivory by smaller herbivores and trampling by elephants. Browsing by the impalas (*Aepyceros melampus*) has been shown to play a great role in reducing survival rate of the *A. tortilis* saplings elsewhere (Belsky, 1984). O’Connor *et al.*, (2007) noted that the weak coppice growth of *A. tortilis* in a South African rangeland usually dies within a year. Plants occurring away from the river enjoyed a partial refuge from impalas and also from extensive trampling by elephants. In addition to trampling, elephants damage saplings in a bid to rid themselves of ecto-parasites at the base of their trunks (Buss, 1961). In the Seronera woodlands where *A. tortilis* dominated, its population structure changed drastically under the impact of elephants when the mature class reduced from 48% to 3% in a span of seven years (Pellew, 1983).

Time of the year is an important factor in determining debarking intensity as documented in past studies that much debarking takes place towards the end of the dry season (Viljoen, 1989; Osborn, 2004). This is harmonious with observations in this study as October, February and March in which high debarking was observed were the dry months. Elephants moved out of the reserves soon after the rains easing the foraging pressure on the riparian zone and this contributed to the observed low debarking in November and December. Even at the periods of intense debarking in October, February and March, there were differences between the plots and this is largely attributed to plant species composition and elephant densities in different parts of the reserves. Plots with a high proportion of *Acacia elatior* in the species assemblage had higher numbers of heavily debarked trees.

The different debarking intensities between plots are a factor of the species assemblage since different species are preferred variously. The locations of plots in the reserve in relation to elephants' distribution also lead to different debarking intensities because elephants spend more time in some areas than in others. The riverine zone is the core elephant habitat in the reserves as revealed by Save the Elephants long term elephant tracking data accumulated for ten years (Appendix 3). Plots away from the river experienced lower debarking intensities, as well as one riverine plot in BSNR. Plot *H* experienced low debarking intensities. This is partly explained by its location away from the core elephant concentration areas and partly by its domination by the less preferred A. *tortilis*. The plot lies on the ancient lake bed and the soil sub-sample from the plot was remarkably low in iron, copper, zinc and manganese. While a conclusion can not be reached by the findings from only one site on the ancient lake bed, the finding validates a future study to compare the vegetation on different geological areas with respect to nutrient content and elephant densities. Low elephant densities on the site coupled with low soil micronutrient is perhaps an indication that geology has an effect on elephants' distribution either as the template on which elephants walk on or by effects on forage dietary quality which warrants further study. Georgiadis and McNaughton (1990) found marked differences in element contents of savanna grasses between samples from different soil types elsewhere in Kenya. Site differences in soil mineralogical content influenced bark nutrient content significantly in this study.

The nitrogen content of a plant is only one of the many plant characteristics that are vitally important to herbivores (Mattson, 1980). Protein concentration of browse can be up to twice that of grass during the growing season and is more constant over the annual cycle (Dougall *et al.*, 1964; Field, 1971). The results of this study are consistent with the literature as crude protein did not vary significantly during the six month study period that spun through both wet and dry seasons. Total nitrogen had the strongest positive correlation with elephants debarking behavior. The bark offers a diet that is less variable in quality as the results of this study show. Food quality is affected by the density of nutrients, amongst other factors (Georgiadis and McNaughton, 1990). Large grazing mammals must exploit a nutritional environment that is complex in composition and varies temporally and spatially (McNaughton and Georgiadis 1986). The less variations in bark quality make it an ideal source of nutrition for the elephants, at least in the dry season when grass senesces. The nutritional value of grass declines steadily as leaves age over the growing season (Georgiadis and McNaughton, 1990).

McCullagh (1969) found that the percent crude protein (CP) in the stomach contents of elephants sampled during the dry season to be less than half that of the wet season value and suggested that the diet may be deficient in protein in the dry season. Malpas (1977) recorded 4.9% CP in the stomach contents of elephants during dry season and 14% in the wet season showing high seasonal variations in diet quality. McCullagh (1969) had estimated the daily digestible protein requirement for a young growing elephant with a body weight of 1,000 kg to be approximately 0.3 kg and that would require a mean of 6% CP in the food eaten. This was what the bark of *Acacia* spp. trees sampled in this study contained, 5.8 ± 2.64% protein. This places the bark of *Acacia elatior* and *A. tortilis* among the richest sources of CP for elephants in the dry season. Dougall (1964) had found bark samples of *A. elatior* to comprise 6.69% CP which is quite consistent with the results of this study.

Phosphorus is a constituent of the plant cell nucleus and plays an important part in cell division and development of meristematic tissues (Wilde, 1958). Bark samples collected in this study had twice the amount of phosphorus found in *A. elatior* sampled elsewhere in Kenya by Dougall (1964). The data on debarking index versus phosphorus content in bark of various species recorded by Owen-Smith (1988) show a negative correlation, which is contrary to the results of this study that found a significant positive correlation. From Dougall’s (1964) detailed analysis of Kenyan forage items, the average phosphorus content of leguminous browse was less than that of grasses. Sixty five, 68 and 67 per cent of the records of grasses, leguminous browse and non leguminous browse respectively are distributed between 0.5% and 0.25% phosphorus while for the non browse legumes, over 70% of the records are distributed between 0.15 and 0.35% phosphorus in the dry matter. This places the recorded mean of 0.06% in this study on the lower level of other forage items dietary content. It shows that the bark of *Acacia* spp. is not a rich source of phosphorus for the elephants, just like the records above show for other leguminous browse. This begs the question; are elephants limited in dietary phosphorus supply in the study area, to an extent of seeking the little they can find from nutrient poor sources like the bark of *Acacia* spp.? The observation that bark is not a rich source of phosphorus yet elephants seek for it from bark, as this study shows, indicates that elephants in the ecosystem are most likely under nutritional stress with respect to supply of phosphorus. The same might apply to other herbivores in the ecosystem and this warrants further studies on the nutritional ecology of the herbivores in the ecosystem. There is a need for a study on nutrient content of other forage items in the diet of elephants in the reserves.

As the nutritive value of the food supply is a function of environmental variables, such as soil fertility, texture and moisture, environmental heterogeneity is an important parameter of habitat quality. The soils in the study area are slightly alkaline with minimal quantities of most of the nutrients implying that the plants are bound to have a lower than normal range of concentrations of the different nutrient elements. Sandy soils have low cation exchange capacity, which explains the generally minimal nutrient element content (Barden, 1987).

The river terrace has a flat-gently undulating slope and plots A, B, and G had an over wash deposition after the November rains. The surface of plot *A* was broken by intermittent rock outcrops, while B, F, I and K exhibited heavy compaction. Those plots that were under flooding in November and early December had crusting at least in some parts. The soil on the riverine terrace is imperfectly drained and it remained wet late November to December after the short rains in October and November of 2006.

The content of total N in the top layer of virgin forest soil varies from about 0.1 to 0.3% and a total N of 0.2 % is enough for most tree species (Wilde, 1958). The soils sampled had N content below the range of tropical soils recorded in Landon (1984); from 0.01% to 0.14% which is rated very low to low by the author. According to the author, Nitrogen is arguably higher in the soil after a dry spell in form of NO_3. The fact that the measured amounts were still low despite sampling after a dry spell further indicates the soil's deficiency in N. Phosphorus deficiency is seldom strikingly manifested in trees (Wilde, 1958). Phosphorus content varies from 10 to 220 ppm in forest soils (Wilde, 1958) and the study area had as much as twice this value, 174 to 437 ppm. Phosphorus levels of over 15 ppm in tropical soils are rated as high. This shows that the soils are rich in P but its availability to plants is reduced by the high pH. Availability of phosphorus to plants is reduced at high soil pH and possibly at Ca: Mg ratios of < 3: 1 (Barden, 1987). However the Ca: Mg ratios in the sites were above this threshold ratio thus not a possible source of P inhibition. Ratios of Ca: Mg of 3.26 – 4.83: 1, as observed in the nine study sites, are considered normal. The recorded high pH values of 7.63 to 8.40 is a potential cause of nutritional stress to the plants in the area and ultimately to herbivores. Also, in presence of Ca, phosphate tends to be converted to calcium phosphate further reducing phosphorus's availability (Landon, 1984). Phosphorus levels tend to decrease in high pH soils sampled when dry (Hesse, 1971). The amount of phosphorus measured in this study may thus actually be the lower side since the samples were taken when the soil was dry.

Calcium in soil aids in absorption of water and nutrients by favoring adequate permeability of the cell walls and aids in overcoming the toxicity of excessive amounts of Na, K, Mg, and Mn in soil (Wilde 1958). The amount of available Ca varies in forest soils from 200 to several thousand parts per million (Wilde 1958). The soils in the reserves with a mean of over 4200 ppm of Ca are thus within the normal range. Magnesium is depleted quickly in sandy soils (Barden, 1987). The content of available Mg in forest soils is usually from one-fifth to one-third that of calcium (Wilde 1958). Calcium levels above 60 ppm in tropical soils are considered high (Landon, 1984).

The average concentration of copper on the earth's crust is 55 ppm, and is very strongly complexed by both soluble and insoluble organic compounds leading to its deficiency to plants (Whitehead, 2000). The threshold 'low levels' of Cu in tropical soils is 6 ppm (Landon, 1984). Plot H had less than the threshold, 5.61 ppm. The author also points out that sandy texture, high pH, and high phosphorus in soil contribute to copper deficiency in plants. The soils sampled had these attributes which explains the deficiency in plants inferred from the lack of Cu in the bark samples. Only traces of the element were prevalent in the bark samples and this could be attributed to its complexation.

Iron is essential in the formation of chlorophyll and is widely distributed in nature. The iron content of soils varies 10,000 to 100,000 ppm (Whitehead, 2000). The soils sampled in the reserves had much lower amounts of Fe, ranging from 23.3 ppm to 919.2 ppm. High temperatures, moisture extremes, high soil P and low organic matter may contribute to Fe deficiency in plants (Landon, 1984). These factors characterize the study area showing a potential for its deficiency to plants. The average concentration of Mn on earth's crust is 1000 ppm (Whitehead, 2000). The recorded values of Mn in the nine sites range from 490.13 ppm to 1714.15 ppm, a mean of 1059.19 ppm. Manganese content in the sites is thus within the normal range. Its availability to plants can however be reduced by the high pH and dry weather in the semi arid study area. Low zinc content is attributed to the calcareous nature of soils, low organic matter as indicated by OC measures and soil compaction (Landon, 1984).

Organic carbon (OC) measures in the nine samples ranged from 0.75% to 2.01%. These are very low measures according to the general rating for tropical soils' threshold of < 2% for very low OC. Likewise, the measures of total nitrogen were low, ranging from 0.01% to 0.14%. The low OC and total N values indicate low degree of humification, which is nevertheless expected in semi arid regions. High soil pH decreases bacterial activity and hence nitrification of organic matter (Landon, 1984).

Electrical conductivity (EC) measures are useful as indicators of total quantities of soluble salts in soils. The EC measures of between 0.2dS/m and 5dS/m characterize the soils as salt free to slightly saline. Plots A, D and H had the highest EC values, 4dS/m, 5dS/m, and 5dS/m respectively. One thing in common with the three plots is their location in relation to drainage; plots A and D are situated on the confluence of Ewaso River and seasonal *luggas* while H is situated between Ewaso River and a permanent spring. The three plots thus experience more evaporation which concentrates salts yielding higher EC values. Soil salinity has a negative impact on the woody species diversity indices diversity as the diversity decreased with increasing salinity. This is shown by the negative correlation between species diversity and EC values. Soil type through its influence on species assemblage on debarking ultimately explains differential debarking intensities in different parts of the reserves. Different species have varied tolerance to salinity; *A. tortilis* dominates plots D and H which apparently have the highest EC of 5dS/m in each, accounting for 87.31% and 88% of individual woody plants respectively. This shows that the species have a high tolerance to salinity contributing to their high abundances in the study area. Plot A with the third highest

EC value of 4dS/m exclusively supports *A. elatior*. These results show that both species tolerate high salinities more that other woody species, this, contributing to their abundance in the in the reserves and partially or totally excluding the other less tolerant species. Consistent with this is the observation that the highest species diversity, *H'* = 5.17, of woody species was recorded in plot B which is salt free with EC of 2.0dS/m.

The environmental conditions comprising of high pH, aridity and soil textural composition impact negatively on nutrient availability to plants in the study area. Low nutrient elemental composition of soils observed in this study is not uncommon since the concentrations of most nutrient elements are known to be lower in sandy than in clay soils, with loam and silt being intermediate (Whitehead, 2000). Some clay minerals incorporate small amounts of other metallic elements, such as Mn^{2+} and Zn^{2+} through the isomorphous replacement of Al^{3+} (West, 1981). Apparently the clay portion was minimal in most soils thus reducing the above mentioned incorporation of other metallic elements.

Low OC indicates low rates of mineralization in the study area. This is attributed partly to high aridity of the area that reduces the numbers and activity of soil micro and macro-organisms and partly due to less amount of litter potentially available from the sparse vegetation cover on most plots. Very low soil OC content and high pH decreases bacteria activity. The plots I and K that had the highest of OC amounts are situated in sheltered inner bends of the river characterized by clayey soil, dense undergrowth and frequent visitation by wildlife contributing to relatively higher amounts of falling litter and dung. On the other hand, plots A and B that had the lowest OC content were characterized by sandy texture and boulders. The sandy texture on plot B has resulted in scanty vegetation cover hence low OC. Despite plot A having a loamy texture, the huge boulders in it leave relatively little space for undergrowth vegetation. High dispersion in soils leads to low organic matter content (Landon, 1984). The low OC content contributes to the soils poor nutrient content.

The barks consumed at the study area were not very rich in most nutrient elements compared to other forage items documented elsewhere. Elephants' efforts in search of specific dietary elements from bark imply they were under nutritional stress at least during the dry season. Bark chemistry influenced debarking behavior of elephants in SNR and BSNR as elephants sought for bark with high amounts of crude protein, P, K and Zn. Elephants had a preference for bark of *A. elatior* over other woody species in the reserves. This highly preferred species was significantly richer in nutrients than *A. tortilis* the second most abundant and preferred species. This relationship possibly applies for other herbivores in the ecosystem and this warrants further studies on the nutritional ecology of the herbivores in the ecosystem.

The soils in the study area are generally nutrient deficient. Soil mineralogical composition determines the nutritional content of the bark with the content of mineral elements in both being positively correlated. High pH and aridity in the study area are bound to reduce availability of some of these elements to plants. The influence of geology on elephant distribution through its direct effect on plant nutritive value needs to be explored at a wider geographical scope than was covered in this study. The study showed that soil mineral content particularly the amount of bases influenced species diversity. Understanding the ultimate consequences of elephant utilization on dynamics of *A. elatior* awaits a plant centered study focusing on survivorship of recruits and the progress of individual established plants after they have been injured. These will enable understanding of how disturbances influence the tree community composition and structure in the reserves.

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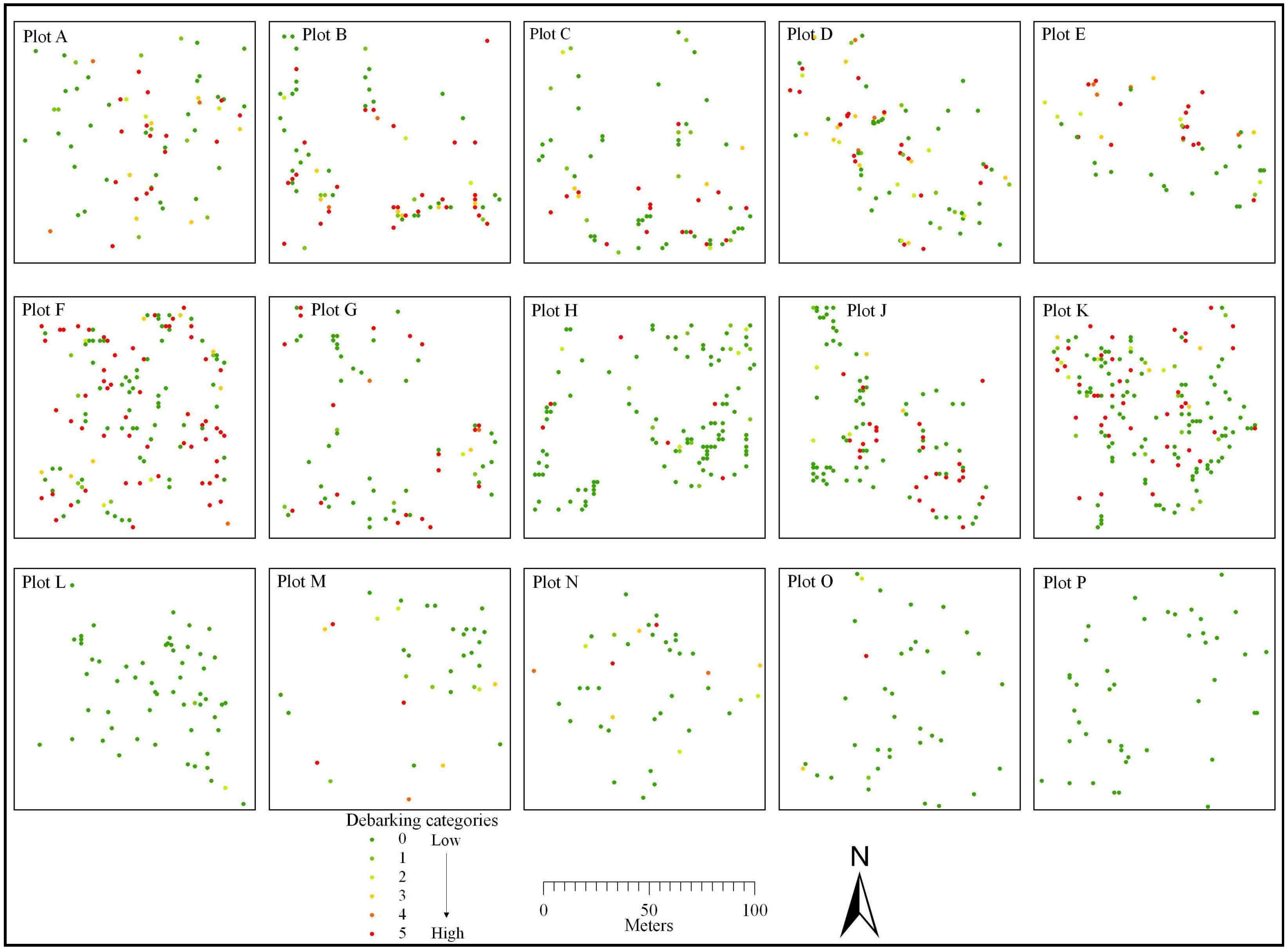
APPENDICES



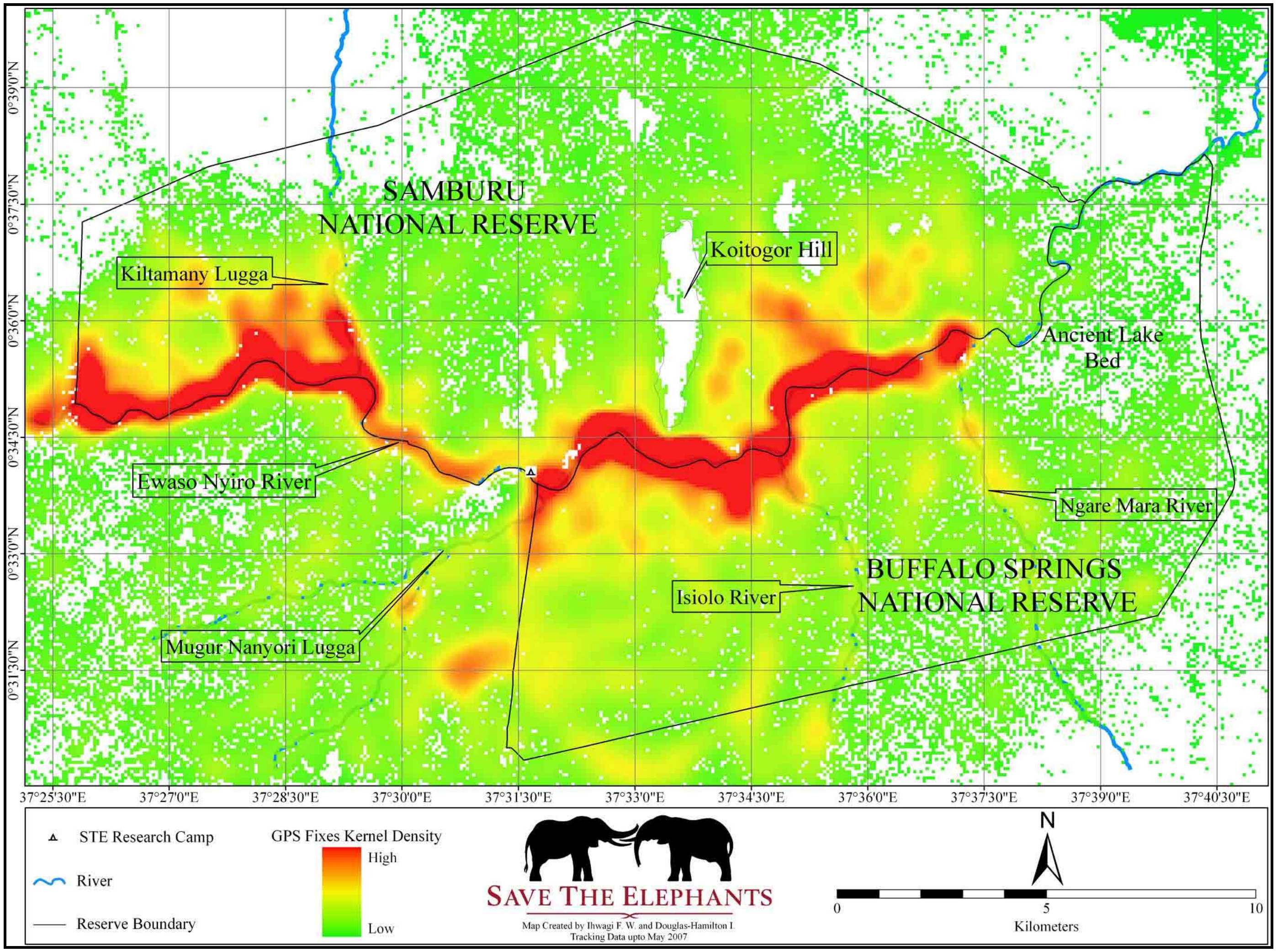
Appendix 1. Debarking intensities on each of the woody plants assessed in fifteen plots in Samburu and Buffalo Springs National Reserves.

Appendix 2. The number of plants of each species recorded in each debarking class in the fifteen plots

Plot	*Species*	*Non damaged*	*1 - 25% debarked*	*26- 74% debarked*	*75% debarked*	*76 -99% debarked*	*Ring debarked*
A	*Acacia elatior*	26	9	3	6	3	15
B	*Acacia elatior*	8	10	0	12	6	32
	Acacia raffesian	2	0	0	0	0	2
	Acacia senegal		0	0	0	0	2
	Acacia tortilis	38	6	4	0	0	18
	Combretum aculeatum	4	0	0	0	0	0
	Lawsonia inamis	4	0	0	0	0	0
	Maerua crassifolia	6	0	0	0	0	0
C	*Acacia elatior*	25	6	1	3	0	13
	Acacia tortilis	6	5	1	0	0	2
	Cadaba farinossa	1	0	0	0	0	0
	Cordia sinensis	9	2	0	2	0	1
	Lepisanthes senegalensis	1	0	0	0	0	0
D	*Acacia elatior*	56	18	12	20	6	34
	Acacia tortilis	8	0	4	0	0	4
	Cordia sinensis	2	0	0	0	0	0
	Maerua crassifolia	2	0	0	0	0	0
E	*Acacia elatior*	14	3	5	3	4	13
	Lawsonia inamis	1	0	0	0	0	0
	Lepisanthes senegalensis	4	0	0	0	0	1
	Maerua crassifolia	1	0	0	0	0	0
F	*Acacia elatior*	51	3	3	6	1	59
	Acacia tortilis		2	0	0	0	1
	Combretum aculeatum	9	0	0	0	0	0
	Gardenia volkensii	3	0	0	0	0	0
	Kigelia africana		1	0	1	0	0
	Lepisanthes senegalensis		0	0	0	0	2
	Maerua crassifolia	2	0	0	0	0	0
G	*Acacia elatior*	20	4	1	1	2	19
	Acacia tortilis	5	0	0	0	0	1
	Combretum aculeatum	10	0	0	0	0	0
	Cordia sinensis	6	0	0	0	0	0
	Maerua crassifolia	1	0	0	0	0	0
H	*Acacia elatior*	2	0	0	0	0	0
	Acacia tortilis	94	11	6	0	0	6
	Cordia sinensis	2	0	0	0	0	0
	Lawsonia inamis	8	0	0	0	0	0
	Maerua oblongifolia	5	0	0	0	0	0

Appendix 2 continued

Plot	*Species*	*Non damaged*	*1 - 25% debarked*	*26- 74% debarked*	*75% debarked*	*76 -99% debarked*	*Ring debarked*
I	*Acacia elatior*	175	9	8	5	0	32
	Combretum aculeatum	6	0	0	0	0	0
	Cordia sinensis	1	0	0	0	0	0
	Gardenia volkensii	2	0	0	0	0	0
	Kigelia africana	1	1	0	0	0	0
	Maerua crassifolia	3	0	0	0	0	0
K	*Acacia elatior*	52	5	6	3	0	42
	Acacia tortilis		1	0	0	0	1
	Combretum aculeatum	33	0	0	0	0	0
	Cordia sinensis	3	0	0	0	0	0
	Lawsonia inamis	8	0	0	0	0	0
	Maerua crassifolia	3	1	0	1	0	0
	Prosopsis chillensis	7	5	0	0	0	1
L	*Acacia tortilis*	49	1	1	0	0	0
	Commiphora sp.	7	0	0	0	0	0
	Maerua crassifolia	3	0	0	0	0	0
M	*Acacia tortilis*	22	3	4	3	1	3
	Maerua crassifolia	2	1	0	0	0	0
N	*Acacia tortilis*	30	2	4	3	2	2
O	*Acacia tortilis*	39	1	1	1	0	1
P	*Acacia tortilis*	43	0	0	0	0	0



Appendix 3. Kernel density distribution of cumulative elephant fixes from long tem GPS and GSM tracking data of 48 elephants that use the reserves.