EFFECTS OF ELEPHANT FEEDING ON SPECIES OF *ACACIA* ALONG THE GREAT RUAHA RIVER IN RUAHA NATIONAL PARK, TANZANIA

BY

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ABSTRACT

This study compared the effects of elephant browsing and response between *Acacia tortilis* and *A. kirkii* in Ruaha National Park. A total of 30 belt transects were randomly placed in an area of 38.8 km^2 on the northern bank of the Great Ruaha River, where 1007 *Acacia* trees were assessed for elephant damage. Damage was assessed basing on six browsing categories and four debarking classes. There was no significant difference in browsing ($F_{1, 10} = 0.6$, $p>0.05$) and debarking ($F_{1, 6} = 0.16$, $p > 0.05$) between *A. kirkii* and *A. tortilis*. Trees were classified into three height classes and twelve diameter classes to determine population structure. A total of 3613 trees < 1 m in height were recorded to represent response in addition to coppices; and a significant difference between the two species was observed only in regeneration potential ($F_{1,58} = 41.4$, $p < 0.05$). Significant difference was also observed in population structures ($F_{1, 58} = 42.08$, $p < 0.05$). However, the low regeneration potential, relatively high proportion of severely browsed trees and restricted distribution of *A. kirkii* in the study area could make it vulnerable to elephant feeding than *A. tortilis*. The high *A. tortilis* regeneration potential suggests the likelihood that the area between Msembe and Lunda could become an *Acacia* bush or woodland if fire is controlled. The study concludes with recommendations for further studies on the variation in vegetation utilisation by elephant along the Great Ruaha River, suppressed regeneration of *Acacia* trees at Msembe, effects of fire and small browsers on *Acacia* species as well as continuous monitoring of vegetation and animal trends.

DECLARATION

I, Stephano Niima Qolli**,** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

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The above declaration is confirmed

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LIST OF ABBREVIATIONS AND SYMBOLS

<	less than

>	greater than
≤	less or equal to
a. s.l	above sea level
ANOVA	Analysis of variance
cm	centimetre
DBH	Diameter at breast height
df	degree of freedom
GPS	Global positioning system
K	Potassium
km	kilometre
m	metre
N	Nitrogen
P	Phosphorus
RNP	Ruaha National Park
SI	sampling intensity
TANAPA	Tanzania National Parks
TAWIRI	Tanzania Wildlife Research Institute
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The African elephant *Loxodonta africana* Blumenbach has been reported to cause damage to different species of trees in various protected areas in Africa when feeding (Nahonyo, 1996). Studies indicated that, some tree species affected by elephant feeding include *Adansonia digitata*, *Faidherbia albida* and *Commiphora ugogoensis* (Barnes, 1985), *Acacia tortilis* (Mwalyosi, 1990), *Colophospermum mopane* (Lewis, 1991), *Acacia xanthophloea* (Kabigumila, 1993), *Acacia seyal* (Tchamba, 1995), *Sclerocarya birrea* (Gadd, 2002), and *Acacia elatior* (Ihwagi *et al.*, 2009).

Elephants affect trees by causing physical damages, such as debarking, breaking branches, felling, pushing over or uprooting young trees and seedlings during browsing, or when young bulls engage in social displays (Guy, 1976 cited by Smallie and O’Connor, 2000). Such damages result into reduced tree species diversity, mortality and stunted growth (Chira and Kinyamario, 2009). Tree damages are intense in areas with high densities of elephants (Tchamba, 1995; Wahungu *et al.*, 2011), especially in small isolated protected areas, where corridors and dispersal areas are occupied by human settlements (Ngene *et al.*, 2009; Hema *et al.*, 2010; Wahungu *et al.*, 2011), or around permanent water sources (Guldemond and van Aarde, 2009).

Scarcity of water during dry season also contributes to concentration of elephant activities around permanent water sources resulting into more destruction (Gaugris and van Rooyen, 2009). This damage may have negative impacts on habitats and some of the associated fauna. On the other hand, presence of elephants is beneficial to some animals as they open closed woodland thereby creating diversity of habitats and/or increase accessibility to resources such as browse and water (Kerley *et al.,* 2008) and seed dispersal (Blake *et al*., 2009; Majid *et al*., 2010). For example, opening of the closed forest may result into grassland that favours grazers such as warthogs (Kerley *et al.,* 2008).

Studies on the impact of elephant browsing on vegetation in Tanzania were done in four protected areas, namely Ruaha (Barnes, 1985; Nahonyo, 1996), Lake Manyara (Mwalyosi, 1990), and Serengeti (Ruess and Halter, 1990) National Parks, and Ngorongoro Conservation Area Authority (Kabigumila, 1993). However, all studies focused on the impact of elephant browsing on selected tree or shrub species and little was done to compare the browsing effects and responses to damage between tree or shrub species. Response to elephant browsing varies from species to species, but generally include; coppicing (re-growth of shoots), reduced or increased production of fruits and regeneration, increased density of spines and production of concentrated chemical compounds such as tannin as a defense to herbivory (Morgan, 2007).

1.2 Problem Statement and Justification

Two studies on impacts of elephant browsing on trees were done in Ruaha National Park (RNP), where three vegetation zones namely *Combretum*, *Acacia* and miombo were sampled. The first study was done in the *Combretum* zone only (Barnes, 1985), while the second covered all the three zones (Nahonyo, 1996). *Faidherbia albida* was the only species assessed along the Great Ruaha River in both studies. However, both studies focused on the impact of elephant browsing on selected tree or shrub species. No attempt was made to compare the effects of elephant browsing and responses between tree species damaged by elephants, including *Acacia*. This study, therefore, investigated the effects of elephant browsing and responses after damage between two dominant species of *Acacia* along the Great Ruaha River between Msembe (Park Headquarters) and Lunda Ranger Post.

The area along the Great Ruaha River is the main water source which supports a high concentration of animals, including elephants in the dry season. This high seasonal concentration of elephants may have a greater impact on *Acacia* species than in areas away from the Ruaha River. *Acacia* trees, which contain high crude protein levels than many other trees (Sauer *et al*., 1982 cited by Zinn *et al*., 2007), are an important source of food for elephants in the area when most of the remaining tree species have shed leaves. As a result of high nutritive value, some *Acacia* trees are more favoured by elephants than most of the other tree species (Milewski *et al*., 1991 cited by Zinn *et al*., 2007), thus may be highly impacted. Furthermore, the presence of *Acacia* trees contributes to aesthetic value (Dharani *et al.,* 2008) of the area, which is one of important factors in wildlife-based tourism. Intensity of damage to *Acacia* trees depends on elephant population in an area, which in RNP has indicated an upward trend from about 5890 in 1993 (Farm and Woodworth, 1994 cited by Nahonyo, 1996) to 6288 ± I544 in 2006 dry season (TAWIRI, 2009).

In efforts to achieve the aim of the study, coppicing and regeneration potential were used to represent response. Browsing included breaking of branches and bole (Okula and Sise, 1986). Furthermore, Chira and Kinyamario (2009) defined coppices as plant shoot that grow from tree stumps, which results from foraging. In addition to this definition, in this study coppices also included re-growth from stems and branches broken by elephants.

This study gives an insight on how two dominant *Acacia* species are affected and respond to elephant browsing in the study area. Understanding the effects and responses of these

Acacia species could facilitate prediction of possible habitat changes that could occur, which is important in conservation and management of habitats (Scogings and Macanda, 2005). Such information could be used by park management in making decisions on habitat management.

1.3 Objectives

1.3.1 Main objective

The main objective of the study was to compare effects of elephant damage to the two dominant species of *Acacia* and tree responses along the section of Great Ruaha River in the RNP.

1.3.2 Specific objectives

a) To assess type, extent of damage and the response to damage by elephants for the two dominant *Acacia* species

b) To determine variations in densities of the two dominant *Acacia* trees with increasing distance from the river and assess population structure of the two dominant *Acacia* species

1.4 Research Hypotheses

The following hypotheses were tested in this study:

H_0: The two dominant *Acacia* species are equally damaged and respond equally to elephant damage

H_1: The two dominant *Acacia* species are not equally damaged and do not respond equally to elephant damage

H_o: The two dominant *Acacia* species tree densities do not vary with distance from the river and population structures are the same

H_1: The two dominant *Acacia* species tree densities vary with the distance from the river and their population structures are different

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 *Acacia* Species and Wildlife

There are more than 1342 species of *Acacia* species worldwide, of which about 132 species are found in Africa (Dharani, 2006). Out of 132, 62 species are found in East Africa, of which eight are endemic to Tanzania and four to Kenya (Dharani, 2006). Those endemic to Tanzania include *A. bullukii*, *A. burttii. A. erythrphloeae*, *A. fischeri*, *A. malacocephala*, *A. mbuluënsis*, *A. pseudofistula* and *A. tanganyikensis*. Most *Acacia* species are found in hot arid and semi-arid savannah areas of Africa, while few grow in montane forest or wet areas or in coastal areas (Dharani, 2006). Therefore, *Acacia* species growing under various environmental conditions contribute to diverse habitats that result into diverse flora and fauna species in Africa (Dharani, 2006). Many *Acacia* species have evolved various ways to survive, including; ability to grow in different environmental conditions and habitats, reduced loss of moisture through transpiration, development of deep root systems or shallow root systems depending on ground water table (Dharani, 2006).

Acacia trees provide browse (leaves, pods, flowers and bark) for mammals such as greater kudu *Tragelaphus strepsiceros* Pallas, gerenuk *Litocranius walleri* Brooke, impala *Aepyceros melampus* Lichtenstein, giraffe *Giraffa camelopardalis* Lesson, eland *Tragelaphus oryx* Pallas and elephants *Loxodonta africana* Blumenbach (Or and Ward, 2003) and shelter, especially in the dry season. Vervet monkeys *Cercopithecus aethiops* and baboons *Papio anubis* feed on stem sap, while bees and butterflies use nectar (Dharani, 2006; Dharani *et al.*, 2008). Seeds are also consumed by birds, for example ostrich *Struthio camelus* Linnaeus and rodents such as maltimammate mouse *Praomys*

(*Mastomys*) *natalensis* Smith (Or and Ward, 2003). *Acacia* species also provide habitat for various organisms including tree climbing lions, for example *Acacia tortilis,* contribute to aesthetic quality (Mwalyosi, 1990; Dharani *et al*., 2008) which is one of the important aspects in wildlife-based tourism.

2.2 Elephant Feeding Behaviour and Impact on Trees

The African elephant is the largest extant terrestrial herbivore, with female reaching a maximum weight of about three tonnes, and males about six tonnes (Kerley *et al.*, 2008). They have fairly simple digestive system, with relatively rapid throughput (Morgan, 2007) and low digestive efficiency, as only 40% of ingested food is assimilated. Due to their low metabolic rate per unit of body mass, elephants are able utilise plant materials with low nutrient contents (Woolley *et al*., 2010). The daily food intake ranges between 1 and 1.5% of the body mass. Elephants feed on both leaves and grass (Kerley *et al.*, 2008) tending to select some plant species (Parker and Bernard, 2009). For example, 40-70% of elephants' browse intake in Chobe River Front Region in Botswana came from only three species of shrubs (Kerley *et al.*, 2008), reflecting high browsing pressure on these species.

Elephants, unlike other herbivores, are adapted to use a wide range of plant species and various parts of these plants (Kerley *et al.*, 2008). These adaptations include; use of the trunk, the high shoulder height reaching over 3 m (Stokke and du Toit, 2000), capability to adopt bipedal stance (Kerley *et al.*, 2008), as well as use of tusks to strip bark off trees and gouge in soft stemmed trees, such as baobab *Adansonia digitata* or dig some woody and succulent species (Barnes, 1982). The combination of high shoulders and the trunk enables elephants to browse up to the height of 8 m (Croze, 1974 cited by Kerley *et al.*, 2008). However, elephants' preferred browsing level ranges between 2 and 4 m (Smallie and O'Connor, 2000; Mtui and Owen–Smith, 2006). Trees higher than the preferred level are in most cases pushed over or uprooted so as to increase browse availability within the preferred level (Jachmann and Bell, 1985). Furthermore, elephants dig out geophytes or grass tussocks using their feet (Owen-Smith, 1988 cited by Kerley *et al*., 2008).

The above adaptations and the large body size make elephants to have greater effect on habitats than other herbivores, as they modify vegetation through breaking, felling or uprooting trees (Kerley *et al.,* 2008). Species of plants or type of food taken by elephant depend on vegetation cover and composition, water availability and season (van Aarde *et al.,* 2008). Grasses and herbs are mainly consumed during the wet season (Kabigumila, 1993) while in the dry season elephants mainly browse on trees and shrubs (Barnes, 1982).

2.3 Plant Defence Mechanism Against Herbivory

Herbivores food selection is based on plant palatability which is reflected in nutrients concentrations (Zinn *et al*., 2007). Nutritious tree species such as most of *Acaci*a trees are favoured by many herbivores than other tree species (Fornara and du Toit, 2007). This causes intensive browsing on such trees which can affect population of trees negatively through increased mortality, decreased reproduction and recruitment (Young and Augustine, 2007). Some of the trees cope with browsing pressure by developing defensive mechanisms, mainly chemical and physical defenses as well as growth responses (Kohi *et al*., 2010). Growth response includes massive compensations or change in plant phenology that reduce impact of herbivory (Fornara and du Toit, 2007). Physical defense mechanisms are aimed at reducing accessibility of leaves by increasing spine length and densities and reducing size of leaves (Zinn *et al*., 2007). Thorns/spines/prickles protect *Acacia* trees from browsing by large herbivores, such as giraffe, impala gerenuk and elephant (Dharani, 2006). However, these structures do not prevent animals to feed on *Acacia* trees, but only slow down the rate of feeding of browsers (Dharani, 2006) and increase time spent on food handling (Madden and Young, 1992). Other *Acacia* species form symbiotic association, for example, *Acacia drepanolobium* have developed swollen galls in which aggressive ants *Crematogaster mimosae* and *C. nigriceps* colonies inhabit (Dino, 2010). The symbiotic ants help in protection by deterring large herbivores from browsing (Milewski and Madden, 2006) by attacking and causing irritation on their muzzles when browsing (Dino, 2010).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Study Area

Ruaha National Park is situated in south-central Tanzania within Iringa and Mbeya regions, located between 33^0 49’ E and 53^0 24’ E and 6^0 52’ S and 7^0 57’ S (Fig. 1). It has an area of about 10 300 km^2 excluding the newly annexed Usangu area (of about 9240 km^2). It is part of the Greater Ruaha-Rungwa Ecosystem which includes; Rungwa-Kizigo-Muhesi Game Reserves (Nahonyo, 1996). The altitude in RNP (excluding the newly annexed area) ranges from 750 to 1863 m above sea level (asl.), (TANAPA, 2008). However, the altitude in the study area is between 750 m and 900 m above sea level.

Geologically, the eastern part of the Park (where the study area is located) consists of Precambrian gneissic rocks with migmatitic biotites and hornblende gneisses which belong to Dodoman system. The Park consists of undulating terrain with hills that consist of igneous rocks and a few hills that originated from volcanic activities. The large part of RNP has red brown well drained sandy soil and in some areas poorly drained black cotton soils (vertisols) are found. In major river valleys and their tributaries alluvial deposits are common (Bjørnstad, 1976).

Ruaha National Park can be divided into three eco-climatic zones namely; the north–eastern part (arid), the central portion (semi-arid) and the south-western part (semi-arid to sub-humid zones) (Pratt and Gwynne, 1977).

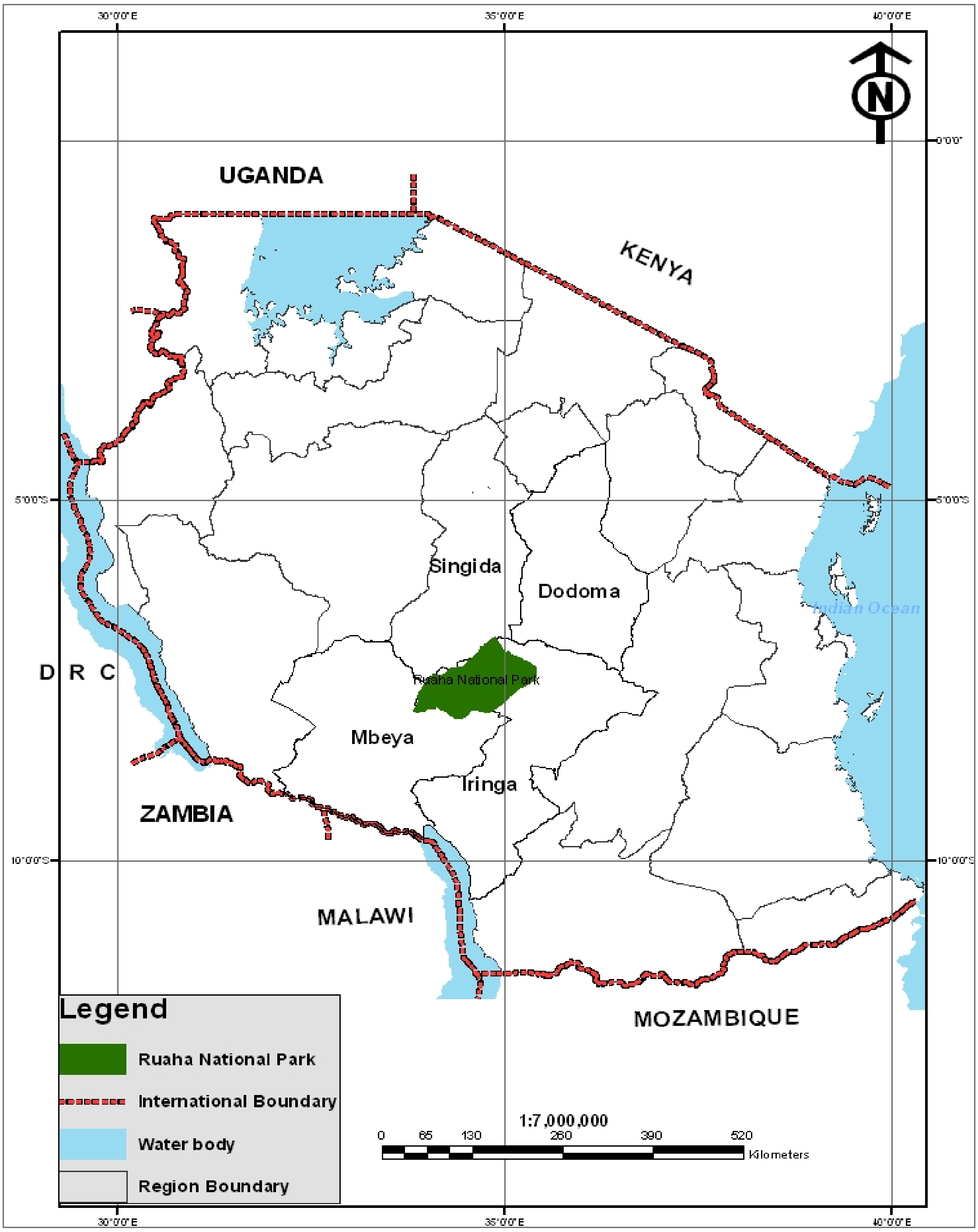

Figure 1: Location of Ruaha National Park.

Source: TANAPA (2008)

The rainfall is unimodal with an average of 650 mm per annum, which increases with altitude towards Isonkavyola Plateau (Bjørnstad, 1976). There is a long dry season from May to November and water becomes scarce when the Great Ruaha River flow ceases towards the end of September, virtually, every year since 1993. The mean annual temperature at Msembe is 24^0C (Bjørnstad, 1976).

The Park falls in the Sudano-Zambezian phytogeographical region (Bjørnstad, 1976), where two vegetation types, the dry East African savannah and the Southern African (Zambezian) miombo woodland meet (TANAPA, 2008). Therefore, the Park has plants and animal species that belong to the two phytogeographical regions, for example trees such as *Cadaba farinosa* (Sudanian) and *Tephrosia nyikensis* (Zambezian) (Bjørnstad, 1976). Ruaha National Park consists of different vegetation types which include; open grasslands, swamps, bushed grassland, deciduous wooded grassland, woodlands and evergreen forests (Bjørnstad, 1976). The Park has four zones of woody vegetation, which include; *Acacia*, miombo *(Brachystegia)*, *Drypetes* and *Combretum* (Bjørnstad, 1976; Nahonyo, 1996).

3.2 Methodology

3.2.1 Sampling Procedure

The sampled study area lies between Msembe and the Lunda Ranger Post, with a length of about 37 km starting about 1 km from Park headquarters along the Great Ruaha River, with an area of approximately 38.8 km^2. The study area extended for 1 km from the northern bank of the Great Ruaha River (Fig. 2 and 3).

The belt (strip) transect method by Okula and Sise (1986) was used in this study. Thirty belt transects each 20 m wide and 1000 m long, were divided into twenty 50 m x 20 m plots as described by White and Edwards, (2000). Belt transects were located randomly perpendicular to baseline (Mueller-Dombois and Ellenberg, 1974), the northern bank of the Great Ruaha River (Fig. 3), with distances between transects ranging from 1200 to 1600 m obtained using random numbers. A 50 m long perpendicular line to the northern bank of the river was established using a predetermined 50 m string with knots (White and Edwards, 2000).

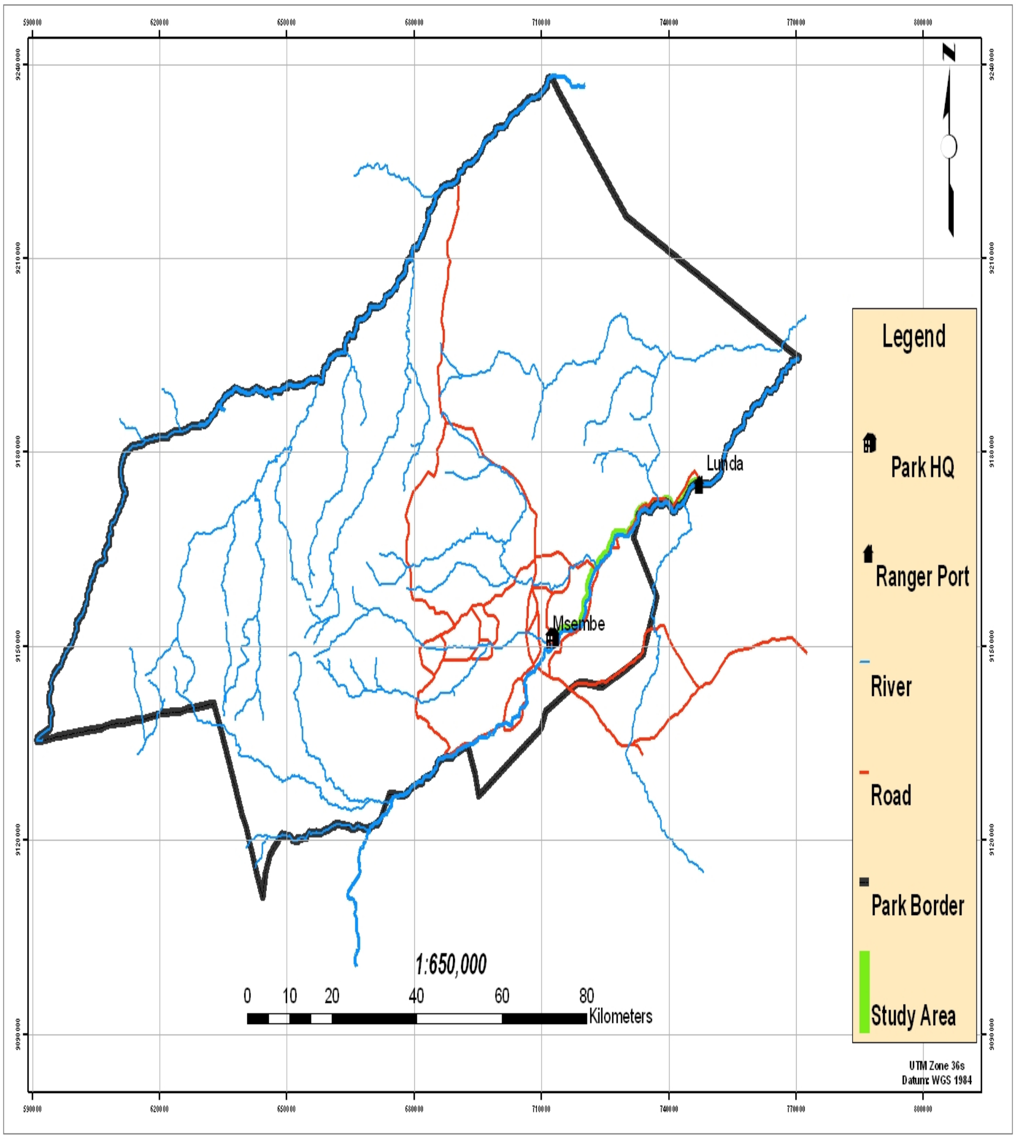

Figure 2: Location of the study area in Ruaha National Park.

Source: TANAPA (2008)

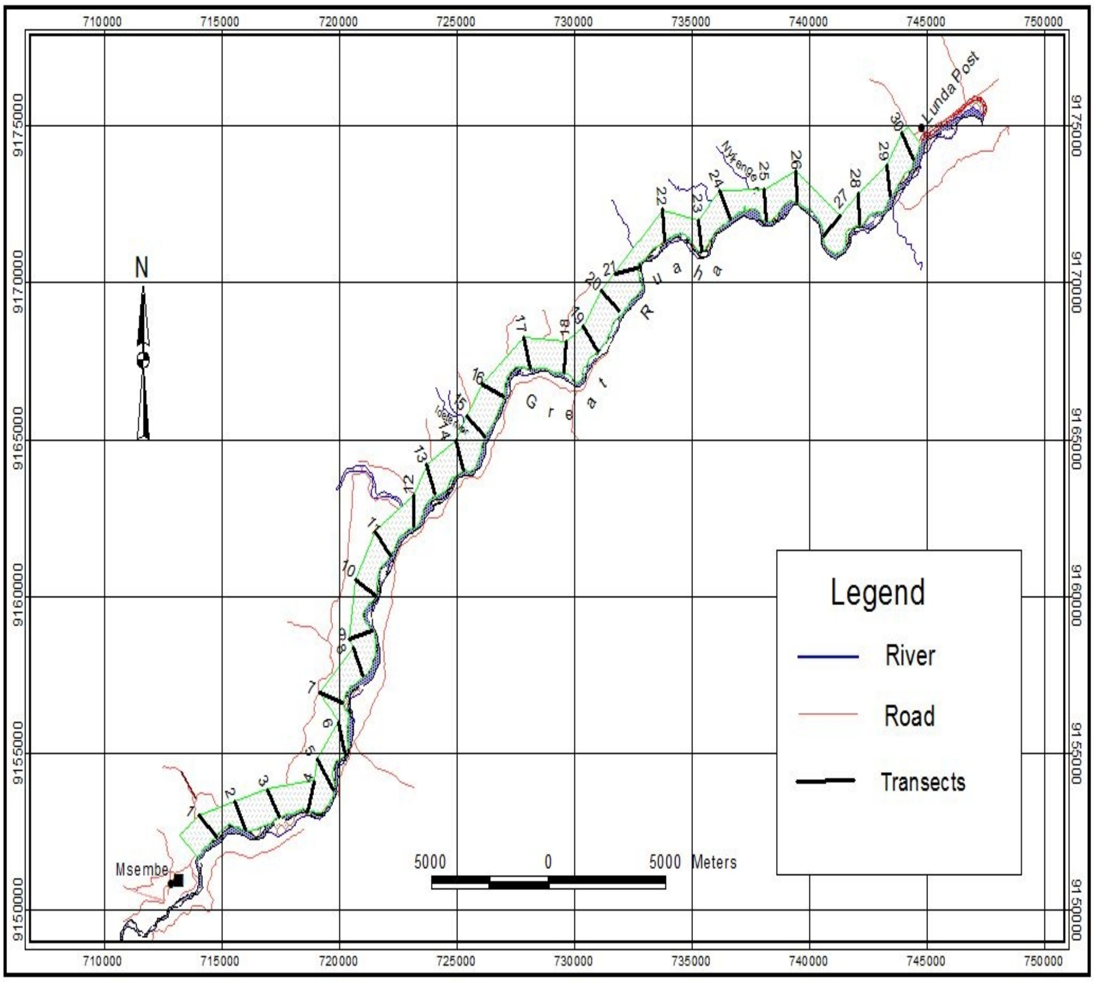

Figure 3: Locations of transects in the study area in Ruaha National Park.

Source: Mapping and Survey Division (1972)

A predetermined 20 m string with knots was then laid perpendicular to the 50 m (at the starting point) string extending 10 m on each side, more or less parallel to the northern river bank. The end points of the 20 m string were marked using flagging before moving it to the 50 m mark to complete a 50 m x 20 m plot. This formed the width of the transect, the first and subsequent plots. After collecting data, a 50 m string was moved with new starting point at the 50 m point, then the 20 m string was moved to new 50 m point to demarcate the second plot. The above procedure was repeated until the transect of 1000 m was completed. The direction of transect was maintained using global positioning system (GPS), Garmin Etrex 12 channel (1999-2002). Coordinates were recorded at the beginning and at the end of each transect line using GPS so as to facilitate plotting of transects on the map as well as for future use (Appendix 2).

3.2.2 Sample Size

Sample size (n), was computed using the formula from Participatory Forest Resource Assessment and Management Planning (Forestry and Beekeeping Division, 2005). Sampling intensity of 1.5% which is greater than 0.5-0.7% recommended for tropical natural forest (Synnoth, 1979 cited by Njana, 2008) was used to calculate the sample size (n) as follows;

$$n = \frac{\text{A x SI}}{a} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

where: A is total area of study in km^2

SI is sampling intensity (%)

a is sample plot area (size) in km^2

Therefore, the sample size (n) for 38.8 km^2 study area (A) and 0.02 km^2 sample plot area (a) and 1.5% sampling intensity (SI) was ⇨ 38.8 km^2 x 0.012/0.02 km^2 = 29.9 plots (approximately 30 belt transects/plots). Study area size (38.8 km^2) was calculated using geographical information system (GIS) after coordinates were recorded during the field work.

3.2.3 Data collection

In each transect measurements and records were taken and recorded (Appendix 1). *Acacia* tree species were identified in the field with a help from an experienced field assistant.

Specimens for unidentified *Acacia* species were also collected and identified at the Park's Herbarium at Msembe using Beetje (1994) and Dharani (2006) field guide books.

Six browsing categories adapted from Okula and Sise (1986) and four debarking classes (Ihwagi *et al.*, 2009) were used in recording type and extent of *Acacia* tree damages by elephants. Browsing classes were; (a) not or slightly browsed, (b) a quarter of the tree crown browsed, (c) half of tree crown browsed, (d) three quarters of tree crown browsed, (e) whole tree crown browsed and (f) tree uprooted. Tree crown was divided into four parts (quarters) and the portion damaged in each quarter was visually estimated and then added up to obtain the total damage for crown of a given tree.

Debarked trees were categorised as; (g_0) stem not debarked, (g_1) less than half of stem circumference debarked, (g_2) half to three quarters of stem circumference debarked and (g_3) stem completely debarked. The portion of the stem circumference debarked was estimated visually. The assessment of debarking was done on individual stem and not the whole tree as in browsing. Only browsing and debarking that occurred in the wet season and dry season of 2010 were recorded. Branches or stems broken before the wet season were identified by grayish colour (Chira and Kinyamario, 2009).

Acacia trees with coppices and regeneration potential (trees <1 m in height) were recorded as an indication of response by trees damaged by elephants. Trees that appeared to have been killed as a result of elephant browsing and/or debarking were enumerated to see if there was relationship between regeneration potential and trees killed by elephants. *Acacia* species in each of the 50 m x 20 m sub-plot in transects were recorded so as facilitate calculation of mean densities in the 30 plots across the 30 transects, which were later used in determining variations in the two dominant *Acacia* species densities with increasing distance along transects. The aim of determining variation was to see if elephants influence the distribution of *Acacia* trees.

Diameter at breast height (DBH) and tree height were measured so as to determine population structure for each of the two dominant *Acacia* species. Tree height was measured using a Suunto hypsometer, graduated stick and tape measure (for tree < 1 m). Trees were later grouped following Vesey-Fitzgerald (1973) and Okula and Sise (1986) classes; (a) young trees < 1 m height were classified as regeneration potential (a class that was vulnerable to dry season wild fires and contributes little to elephant browse), (b) trees between 1-3 m as recruitment potential (category that was in shrub layer and contributes to browse for elephant and other browsers) and (c) trees > 3 m as mature trees (browsed by elephants and giraffes). DBH was measured for all *Acacia* trees at 130 cm from ground level, a height generally accepted as a standard (Philip, 1994), using a caliper. For multi-stemmed trees forking below 130 cm from the ground level, diameter for each stem was measured and recorded separately (Philip, 1994). Trees were later grouped in twelve diameter classes (Alelign *et al.*, 2007).

3.3 Data Analysis and Presentation

3.3.1 Types and extent of elephant damages

All *Acacia* species encountered in the study area were listed and only two dominant *Acacia* species, namely *A. tortilis* and *A. kirkii,* were selected for comparison basing on their densities, number of individual trees and distributions in the study area. *Acacia* tree damages were tabulated according to six browsing classes and four debarking categories so as to evaluate the extent of damage. ANOVA was used to test differences in mean counts between damage classes/categories and between two dominant *Acacia* species. Microsoft-excel was used in data analysis.

3.3.2 *Acacia* species responses

Frequencies of trees <1 m (regeneration potential) and those with coppices were tabulated for the two dominant species, *Acacia tortilis* and *Acacia kirkii.* The differences between mean frequencies of these species were tested using ANOVA. Data on trees with coppices were not subjected to statistical test due to their low numbers. Regeneration potential frequencies were also tested with frequencies of dead trees between two dominant *Acacia* species in the transects for any relationship.

3.3.3 Variations in *Acacia* tree densities

Densities of *Acacia* trees were calculated as number of trees per ha for each of the two dominant *Acacia* species in 30 sub-plots across transects, tabulated and tested for any variation in densities with increase in distance from the Great Ruaha River along the transects using regression. The following formula by Philip (1994) was used to compute tree densities;

$N = n/a$ ………………………………………………………………………………. (ii)

Where, N = number of stems/trees per hectare,

n = average of the count, and
a = plot area

3.3.4 Population structure composition

In order to determine the population structure of *A. tortilis* and *A. kirkii,* basal area for each sampled *Acacia* tree was computed using the formula by Philip (1994);

$g = \pi/4 * d^2$ ……………………………………………………………………….. (iii)

where; d = diameter in metres

g = basal or cross-sectional area estimated at breast height in m^2

π = Pie

Basal area for each stem was computed separately (for multi-stemmed tree) using DBH (diameter at breast height) measured at 130 cm from the ground level (Philip, 1994). Total basal area for multi-stemmed trees was then obtained by adding basal areas of all stems. To facilitate diameter classification, average diameters for multi-stemmed trees were computed. Before data analysis, diameters were categorised into twelve diameter classes in cm for trees with height above 1.30 m; (a) ≤ 1 (b) 1.01–10 (c) 10.01–20 (d) 20.01–30 (e) 30.01– 40 (f) 40.01–50 (g) 50.01–60 (h) 60.01–70 (i) 70.01–80 (j) 80.1–90 (k) 90.01-100 and (l) > 100. Basal areas were then tabulated in diameter class distribution and compared between two dominant *Acacia* species, *A. tortilis* and *A. kirkii*. Tree volumes were not calculated as most of *Acacia* trees were multi-stemmed with different heights; hence it was not possible to measure the height for each stem. Therefore, the use of general tree height measured would have resulted into unrealistic estimation of stock volumes.

Tree frequencies were presented in height class distribution for the two selected *Acacia* species and mean frequencies were compared. The three heights categories representing regeneration potential (trees < 1 m), recruitment potential (trees between 1 and 3 m) and mature trees (trees > 3 m) were presented in a chart to depict the composition of population. Since basal areas for regeneration potential and trees between 1 m and 1.3 m were not calculated because diameter measurements were not taken, the use of basal areas as means of showing population structure was limited to trees in the two height classes, recruitment potential and mature trees. In this case tree height classes were used to represent tree sizes to fill the gap.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 *Acacia* Species

A total of eight (one unidentified) out of seventeen *Acacia* species previously recorded in the Park by Bjørnstad (1976), were encountered in the sampled area. These species include; *A. tortilis* (Forsk) Hayne, *A. kirkii* Oliv (Brenan), *A. senegal* (Willd) Brenan, *A. mellifera* (Vahal) Benth, *A. tanganyikensis* Brenan, *A. robusta* (Burch) Brenan, *A. nilotica* Willd and *Acacia* species that could not be identified because pods, flowers or leaves were not available.

The most common species in the sampled area was *A. tortilis* with 4131 (89.4%) individual trees, mean density of 69 ± 6 trees/ha, followed by *A. kirkii* with 395 trees (8.5 %) and mean density of 7 ± 1 trees/ha. The remaining *Acacia* species accounted for only 2.0% (94 trees) and 2 trees/ha as mean density (Fig. 4). Therefore, for comparison purposes of this study *A. tortilis* and *A. kirkii* were selected basing on the number of individual trees, distribution (*A. tortilis* was recorded in 249 plots while *A. kirkii* occurred in 66 plots out of 600 plots) and mean densities of the species.

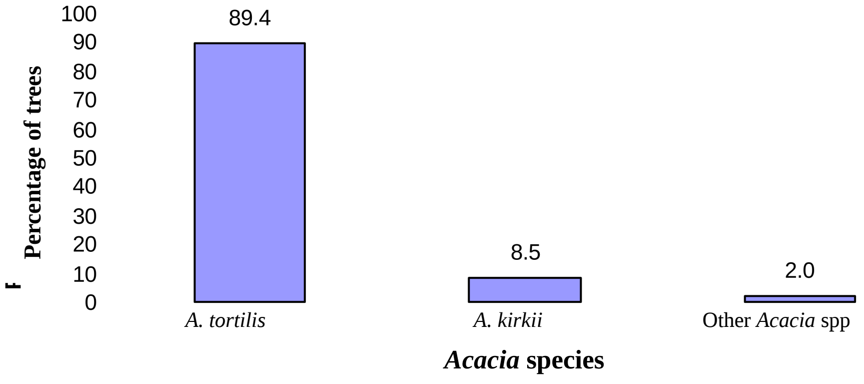

Figure 4: *Acacia* species composition in the study area in Ruaha National Park.

4.2 Extent of Damage by Elephant

4.2.1 Browsing

4.2.1.1 Overall Effect of Elephant Browsing on *Acacia* Trees

A total of 1007 trees from recruitment potential to mature trees were assessed for elephant damage. Regeneration potential class (trees < 1 m) were not assessed for elephant damage since elephants tend to uproot them, therefore, clear signs of elephant browsing could not be observed. Of the 1007 sampled *Acacia* trees, 79.3% of trees were not browsed or slightly browsed, 8.9% had ¼ of the crown browsed, 3.7% with 1/2 of crown browsed, 2.3% had 3/4 of the crown browsed, 5.1% with whole crown browsed and 0.7% of all trees were uprooted or pushed (Fig. 5). The last three browsing categories, 3/4 of crown, whole crown browsed and uprooted/pushed which were considered to be severely damaged accounted for only 8.0% of sampled trees. These three browsing categories are considered to be severe because trees are likely to die.

The large percentage (79.3%) of *Acacia* trees not browsed/slightly browsed and low proportion (8.0%) of severely browsed trees suggest that browsing by elephant was not a threat to *Acacia* trees in the study area. A study done by Nahonyo (1996) on vegetation utilisation by elephants and other browsers (giraffe, eland, impala and kudu) in three different vegetation zones in RNP found that 79.7% of sampled woody plants were not browsed. However, in the *Acacia* zone he observed that *A. tortilis* which was most common species had 45.8% of trees (out of 1081 trees) browsed, of which 24.9% were browsed by elephant. He attributed the overall low utilisation of woody vegetation to the fact that herbivore population was below carrying capacity of the Park. The elephant population in RNP was about 5890 in 1993 (Farm and Woodworth, 1994 cited by Nahonyo, 1996) and increased to 6228 ± 1544 in 2006 (TAWIRI, 2009). This increase was probably not large enough to cause significant browsing pressure on

Acacia trees. This means that elephant population was still below the carrying capacity of the Park at the time of this study.

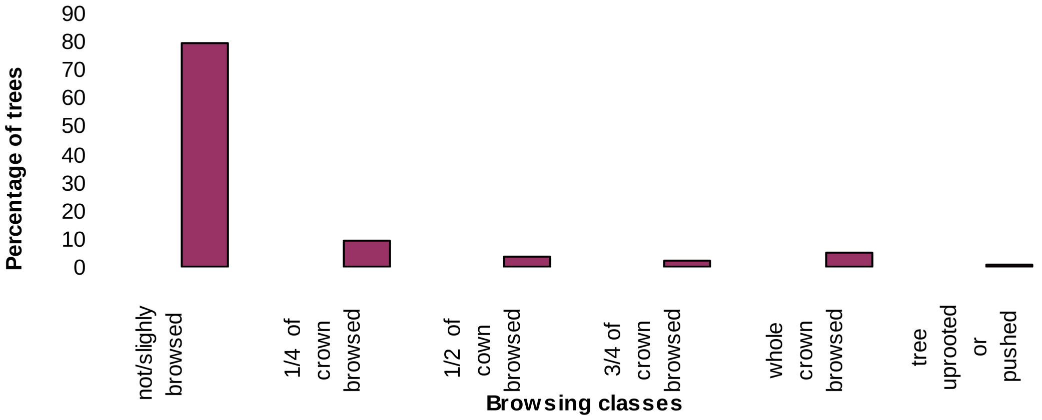

Figure 5: Browsing classes for all *Acacia* trees in the study area in Ruaha National Park.

The low elephant browsing damage could also be explained by the resultant increase in size and improved protection of the area bordering RNP after its gazettement to Usangu Game Reserve in 1998. The Game Reserve and the area outside the two protected areas were later annexed into RNP in 2008. The annexation increased the RNP size from 10 228 km^2 to about 20 000 km^2. These changes could have helped to reduce intensity of elephant activities in some areas, especially around permanent water points including the Great Ruaha River as elephants dispersed in the bigger area. A study by Wahungu *et al.* (2011) reported increased survival of *A. drepanolobium* following the expansion of the reserve and the opening of corridors and thus reducing the browsing intensity. Drying up of the Great Ruaha River during the dry season every year since 1993 could have influenced elephant browsing, particularly elephant family units which tend to feed near water points (van Aarde *et al.*, 2008).

Virtually every year, the Great Ruaha River stops flowing and only few pools of water remain. This could lead to variations in intensities of utilisation of *Acacia* trees in different areas along the Great Ruaha River, with areas near pools that retain water throughout the dry season facing more damage.

Visual observation to *Acacia* trees planted around the office and staff houses at Msembe just outside the study area indicated severe damage and regeneration seem to be suppressed. Nahonyo (1996) reported suppressed regeneration and slow recovery of vegetation in the Msembe area as a result of browsing pressure. A study on RNP vegetation by Bjørnstard (1976) showed that there was *Acacia tanganyikensis* woodland in Msembe area. However, visual observation around the Headquarters indicated the presence of *A. tortilis* regeneration potential more than *A. tanganyikensis.* It is likely that browsing pressure was still suppressing regeneration of trees since the area is protected from wild fires, but has water throughout the dry season. Furthermore, during the study, two elephant dung boli with plastic bags (Plate1) were seen in the Msembe area which was an indication that elephants were feeding from trash pits. This could have an influence on elephant activities in the area, especially if elephants develop a habit of visiting trash pits every day. This habit could result into high browsing pressure on planted *Acacia* trees and other woody species around staff quarters and the office.

4.2.1.2 Effects of Elephant Browsing on *A. tortilis* and *A. kirkii*

Elephant browsing intensity on *A. tortilis* did not differ much from the overall trend above, with 80.9% of trees not or slightly browsed, 4.3% was severely browsed and 1.0% was uprooted/ pushed. *Acacia kirkii* had 75.8% of trees not or slightly browsed and 12.1% with whole crown browsed, while all severely browsed *A. kirkii* trees accounted for 16.1% (Fig. 6). However, the difference in browsing between the two species, *A. tortilis* and

A. kirkii was not significant ($F_{1, 10} = 0.6$, $p>0.05$), except for the browsing classes ($F_{5, 6} = 7.54$, $p<0.05$). This could perhaps be attributed to small number of trees (above 1 m) enumerated for two species in the study area, i.e. 624 *A. tortilis* and 330 *A. kirkii* trees. *Acacia kirkii* had relatively more severely browsed trees, particularly trees with whole crown browsed than A. *tortilis*.

Plate 1: Elephant dung bolus with plastic bag in Msembe Area in Ruaha National Park.

The relatively high proportion of severely damaged *A. kirkii* trees (16.1%) might be due to the ease with which elephant would reach individual trees since they were clumped. This suggests that elephant browsing might have adverse effects on the species due to its patchy and clumped distribution in the study area, if the same browsing trend continues. Out of 600 plots, *A. kirkii* was recorded in 66 plots, while *A. tortilis* was enumerated in 249 plots. *Acacia kirkii* grows in seasonally flooded areas (Dharani, 2006) hence its population tends to aggregate in such areas, while

A. tortilis is widely distributed. This aggregation supports predictions from optimal foraging theories, that herbivores tend to browse more on resource-rich areas (Wahungu *et al*., 2011). Elephant browsing on marula trees *Sclerocarya birrea* in South Africa also indicated a similar tendency (Gadd, 2002). The localised browsing pressure coupled with low regeneration potential could eliminate *A. kirkii* in some areas, if elephants develop preference for these trees.

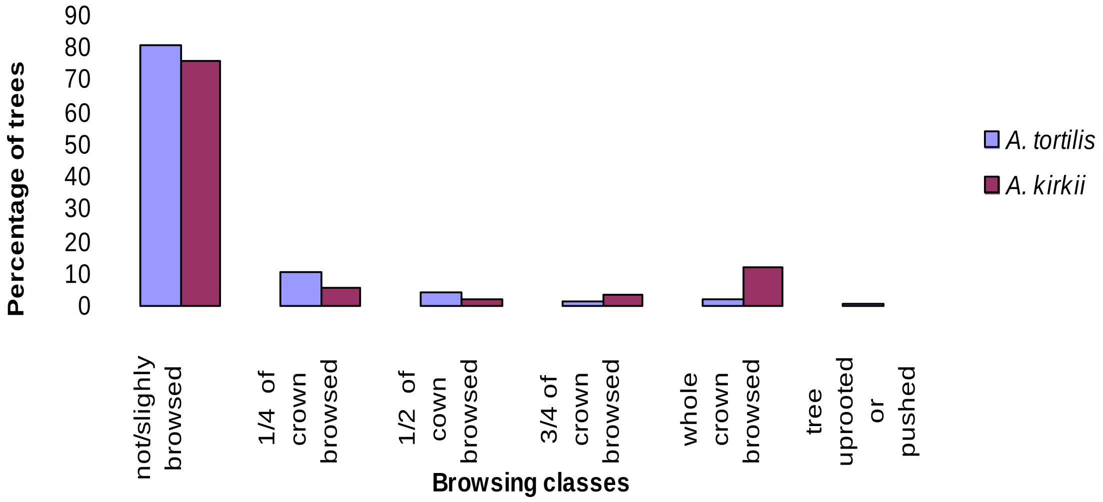

Figure 6*:* *Acacia tortilis* and *A. kirkii* browsing classes in the study area in Ruaha National Park.

Almost all *A. kirkii* trees encountered were multi-stemmed shrubs branching near the base (Dharani, 2006); (Plates 2 and 3). This made it easier for elephants to access and break branches than single stemmed *A. tortilis* trees which could be pushed to reach branches (Plate 4).

4.2.2 Debarking

A total of 4560 stems, that is, 1626 of *A. tortilis* and 2934 of *A. kirkii* were assessed for damage resulting from debarking by elephant. Individual stems were examined since only one or few stems in multi-stemmed trees were debarked by elephants. Out of all stems, 98.3 % were not debarked and only 0.5% of the stems were severely damaged (over half of stem circumference debarked), indicating the overall low level of elephant damage (Table 1). However, *A. tortilis* had 1.2 % of stems severely debarked compared to only 0.03% of *A. kirkii* stems and no stems were ring-barked, but the difference in debarking between the two species was not significant ($F_{1, 6} = 0.157$, $p > 0.05$). This could be attributed to low numbers of debarked stems enumerated for both species in the study area.

Plate 2: *Acacia kirkii* trees in the study area in Ruaha National Park.

Plate 3: ***Acacia kirkii*** **with whole crown browsed in the study area in Ruaha National Park.**

Plate 4: ***Acacia tortilis*** **old damage by elephant in one of the transects in study area in Ruaha National Park**

Table 1: *Acacia. tortilis* and *A. kirkii* trees damage in debarking classes in the study area in Ruaha National Park

Debarking classes	Number of stems	
	A. tortilis	*A. kirkii*
Not debarked	1563	2920
< 1/2 debarked	42	13
1/2 - 3/4 debarked	15	1
Completely debarked	6	0

The slightly higher percentage (1.2%) of severely damaged stems for *A. tortilis* compared to *A. kirkii* (0.03%) was due to the fact that *A. tortilis* had more trees with single stem and greater diameter (mean 17.9 ± 0.7 cm), while virtually all *A. kirkii* trees were multi-stemmed with smaller diameter (mean 4.1 ± 0.12 cm). Multi-stem growth protect trees from debarking since it makes ring-barking difficult, while the smaller branches provide little amount of forage and are difficult to debark than larger stems (Wanderi, 2007) resulting into less severe debarking by elephant. Elephants are also known to prefer some tree species over others (Wanderi, 2007; Chira and Kinyamario, 2009). This could also be the reason for slightly high debarking of *A. tortilis* compared to *A. kirkii*. A study on debarking of *Acacia elatior* and *A. tortilis* in Samburu and Buffalo Springs National Reserves, Kenya, showed that elephant preferred *A. elatior* to *A. tortilis* because of higher levels of nutrients such as N, P, K and Zn compared to *A. tortilis* (Wanderi, 2007).

The distribution of debarking by diameter classes for the two dominant species indicates that the 20.01-30 cm diameter class had 46.8% of debarked stems followed by 10.01-20 cm class with 31.2% (Fig. 7).

Figure 7: Distribution of debarking by diameter classes of combined *Acacia tortilis* and *Acacia kirkii* in the study area in Ruaha National Park.

Wanderi (2007) observed that *A. elatior* and *A. tortilis* trees with circumference between 80 and 160 cm or diameters ranging from 25.5 to 51 cm were the most debarked, which is close to the observed findings in this study. This could be due to the fact that, there were more stems in these diameter classes than in classes with larger diameters and stems with smaller diameters were difficult to debark.

The above observations indicate low damage resulting from elephant browsing and debarking as well as insignificant difference in damage between the two most dominant species, *A. tortilis* and *A. kirkii*. Nonetheless, patchy and clumped distribution and multi-stem growth form make *A. kirkii* more vulnerable to elephant browsing than *A. tortilis*, while debarking and uprooting/ pushing might affect *A. tortilis*.

4.3 *Acacia* Species Responses

4.3.1 Coppices

A total of 23 trees out of 1007 trees resprouted after damage by elephants. Most of the resprouted trees were *A. tortilis* (87%), three other *Acacia* species (13%) and none of *A. kirkii* had coppices. Since a very small proportion of *A. tortilis* and none of *A. kirkii* trees had coppices, no statistical test was done. The low proportion of *Acacia* trees with coppices could be a result of drought since the study was conducted at the end of the prolonged dry season (from November 2010 to January 2011). Soil moisture is one of the environmental factors that influence the ability of trees to resprout after damage (Sennerby-Forsse and Zsuffa, 1993; Stave *et al.*, 2006). Apart from drought, which affected all species of *Acacia*, genotypic differences between species (Sennerby-Forsse and Zsuffa, 1993) could be another reason for absence of *A. kirkii* trees with coppices after damage by elephants. *Acacia kirkii* is adapted to seasonally flooded soils, while *A. tortilis* grows in a wide range of soil types with roots growing deeper (depending on soil type) into the soil leading to differences in abilities to access soil water.

Other studies have shown that, *Acacia* species have little or no coppicing ability when mature (Kerley *et al.*, 2008); hence some of the sampled trees were mature and could not resprout after damage. Furthermore, *Acacia* trees might need more than two seasons to coppice, but this study was restricted to trees damaged in the 2010 wet and dry seasons. Contrary to these findings, Chira and Kinyamario (2009) reported that five woody plants (*Acacia ataxacantha, A. brevispica, Grewia bicolor, G. tembensis* and *G. virosa*) coppiced in a very short time after browsing by elephants in Mwea National Reserve, Kenya. This warrants a future study to be done in a bigger area so as to include more *A. kirkii* trees and observe *Acacia* trees damaged by elephant for more than two seasons.

4.3.2 Regeneration Potential

A total of 3613 trees with height under 1 m and mean height of 0.25 ± 0.003 m were enumerated. *Acacia tortilis* had a large proportion (97.1%) of total regeneration potential and only 1.8% was *A. kirkii* (Fig. 8). There was a significant difference in regeneration potential between A. *tortilis* and *A. kirkii*, ($F_{1,\ 58} = 41.4$, $p < 0.05$). *Acacia* species are known to have a capacity to regenerate rapidly from seedlings (Western and Maitumo, 2004), but their survival is determined by other environmental factors such as soil, fire, herbivory and climatic variations (Mwalyosi, 1990; Stave *et al*., 2006; Wahungu *et al*., 2011). Thus, one of the reasons for differences between *A. tortilis* and A. *kirkii* regeneration potential could be due to soil types to which the two species are adapted.

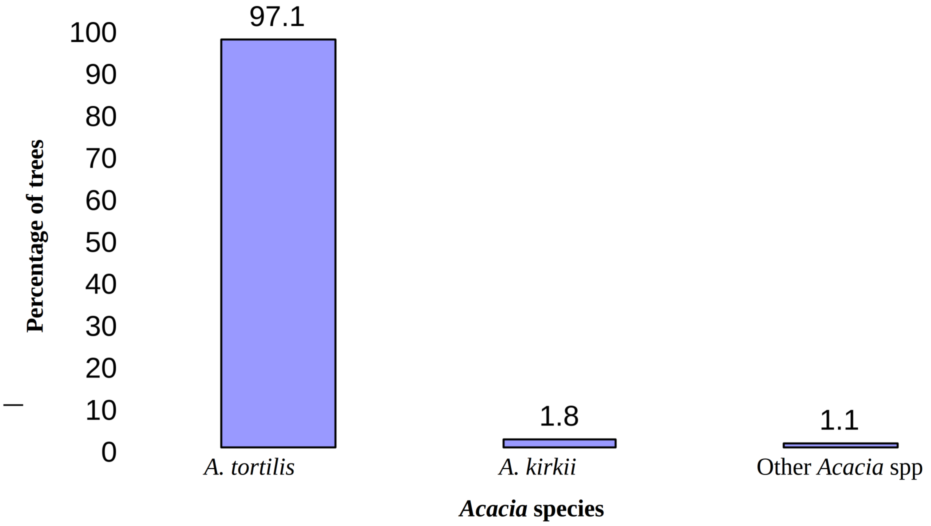

Figure 8: ***Acacia* species regeneration potential in the study area in Ruaha National Park.**

Acacia tortilis grows in a wide range of soils while *A. kirkii* is restricted to seasonally flooded areas (Dharani, 2006). Dispersal of seeds by elephant and other agents of the two species is likely to favour *A. tortilis* than *A. kirkii* due to its adaptation to different types of soils. Most of the trees < 1 m (94.1%) were under 0.3 m in height, 3.7% were between 0.3 m and 0.5 m, while only 2.2% were between 0.5 m and 1 m, and most of them were resprouts after damage by fire and small browsers. The large proportion (94.1%) of trees less than 0.3 m in height suggests probable annual suppression of seedling growth. Barnes (2001) reported that, smaller browsers such as impala and kudu reduced increase in *Acacia erioloba* seedlings mean height but did not reverse growth to ground level, while fire and elephant reversed the growth of seedlings to ground level. However, there are contradicting findings with regard to elephant feeding on trees with height less than 1 m. Pellew (1983) reported that, elephants in Serengeti National Park ignored trees less than 1 m; also Boundja and Midgley (2007) found that elephants had little effect on trees of same height (< 1 m) in Hluhluwe-Imfolozi Park. To the contrary, Jachman and Bell (1985) observed that elephants frequently browsed on seedlings less than 1 m in height, hence it was difficult to know if elephants fed on or ignored regeneration potential in RNP. Therefore, fire and small browsers were the likely factors influencing growth of *Acacia* seedlings in the study area apart from climatic variations.

The relationship between regeneration potential and dead *A. tortilis* and *A. kirkii* trees killed as a result of elephant browsing did not show a strong relationship (R = 0.16, n =30, p = 0.41 for *A. tortilis* and R = 0.01, n = 30 , p = 0.94 for *A. kirkii*). This indicates that the distribution of regeneration potential was probably not influenced by trees killed as a result of elephant browsing. *Acacia tortilis* seedlings were observed in open grassland where there were no mature trees or trees killed by elephants, and in some transects trees killed by elephants were enumerated but *Acacia* seedlings were absent. This could be an indication that re-establishment of regeneration potential in areas where trees were killed take time. Since the study area is not a forest with closed canopy (except in few areas near the riverbank), killing of mature trees by elephants might not have immediate influence on regeneration potential. In addition, *A. tortilis* young saplings are known to be unable to survive under mature parent trees (Mwalyosi 1990). Noumi *et al.* (2011) also reported that, *Acacia* species can have inhibitory effect on germination of *Acacia* seeds, thus death of mature trees would be expected to allow germination and regeneration of seedlings. Nevertheless, in this study A. *nilotica* seedlings were observed to grow under their mature parent trees or *A. tortilis* mature tree crowns

4.4 Variations of *Acacia* Tree Densities Along Transects

Examination of the relationship between distance from the river along transects and tree densities indicated a weak relationship for *A. tortilis* (R = 0.06, n = 20, p = 0.79), but a strong relationship for *A. kirkii* (R = 0.75, n = 20, p = 0.0002). With regard to regeneration potential, there was a weak relationship between the distance from the river and regeneration of *A. tortilis* (R = 0.35, n = 20, p = 0.13), but not for *A. kirkii* (R = 0.1, n = 20, p = 0.68) (Table 2). These results suggest that the variation of *A. tortilis* trees and regeneration potential of both species are influenced by factors other than distance from the river. This variation cannot be attributed to elephant feeding since a distance of 1 km (length of transects) was too short to detect variations caused by elephant feeding given the low level of damage resulting from elephant browsing and debarking. The relationship observed was probably due to the influence of the soils. Since areas close to riverbanks are well drained (in sampled area) and seasonal flooding is not common (except for small patches) within100 m from the riverbank, more *A. kirkii* trees were recorded with the increasing distance into areas with seasonal shallow water channels and temporary flooding. Furthermore, *A. tortilis* is adapted to a wide range of soil types (except seasonally waterlogged), hence widely distributed in the study area.

Table 2: **Relationship between distance from the river and *Acacia* trees densities in the study area in Ruaha National Park**

Trees > 1 m	R	R2	Equations	n	p
A. tortilis	0.063	0.004	$Y = -0.0006x + 10.7368$	20	0.791
A. kirkii	0.746	0.557	$Y = 0.0086x + 0.9789$	20	0.0002
Trees < 1 m					
A. tortilis	0.349	0.122	$Y = 0.0315x + 41.9315$	20	0.131
A. kirkii	0.099	0.010	$Y = 0.0004x + 0.8718$	20	0.677

However, in areas with dense bush especially of *Cordia gharaf*, *Maytenus* and *Vernonia* species near the riverbank and on ridges with *Combretum* trees where most of transects ended, there were fewer *A. tortilis* trees. *Acacia tortilis* being a shade intolerant species (Mwalyosi, 1990) could not grow in thick bush, while in the *Combretum* area, fire could have played a role in limiting regeneration and growth in addition to soils.

4.5 Population Structure and Composition

Basal area, trees height and tree diameter were used to classify *Acacia* trees in different sizes since it was not possible to age them using other methods. Mean diameters for *A. tortilis* and *A. kirkii* were 17.9 ± 0.7 cm and 4.1 ± 0.2 cm, respectively and the overall mean diameter was 12.9 ± 0.5 cm. There was a significant difference between *A. tortilis* and *A. kirkii* in basal areas ($F_{1, 22} = 11.8$, $p < 0.05$) and no significant difference was observed between diameter classes ($F_{11, 12}$, $p > 0.05$). Significant difference was also observed between *A. tortilis* and *A. kirkii* in trees < 1 m ($F_{1, 58} = 41.36$, $n = 30$, $p < 0.05$) and the combined height classes ($F_{1, 58} = 42.08$, $n = 30$, $p < 0.05$), but not in other height classes ($F_{1, 58} = 2.54$, $n = 30$, $p > 0.05$). The difference in basal areas between the two species was mainly due to the fact that most of *A. kirkii* trees were multi-stemmed shrubs with smaller stem diameters, while *A. tortilis* had relatively fewer stems but with larger diameters, thus accounting for larger basal area. Distribution of basal area by diameter classes representing population structure of *A. tortilis* and *A. kirkii* for trees above 1.30 m in height are shown in Fig. 9. *Acacia tortilis* had trees distributed in all diameter classes with 20.01-30 cm and 30.01-40 cm having high basal area and the higher diameter classes had low basal area, showing decrease in number of bigger trees. The 0-1 cm class had the lowest basal area. The shape of the chart is not a negative exponential or inverted J-curve shape. Negative exponential curve or inverted J-shape curve is considered as an indication of healthy regeneration of a woodland or forest (Alelign *et al.*, 2007; Tsingalia, 2010; Nacoulma, *et al*., 2011). *Acacia kirkii* chart is also different from an inverted J-shaped curve, with a high basal area in one diameter class (1.01-10 cm), lower in 20.01-30, lowest in 40.01- 40 cm and none in the remaining classes (Fig. 9).

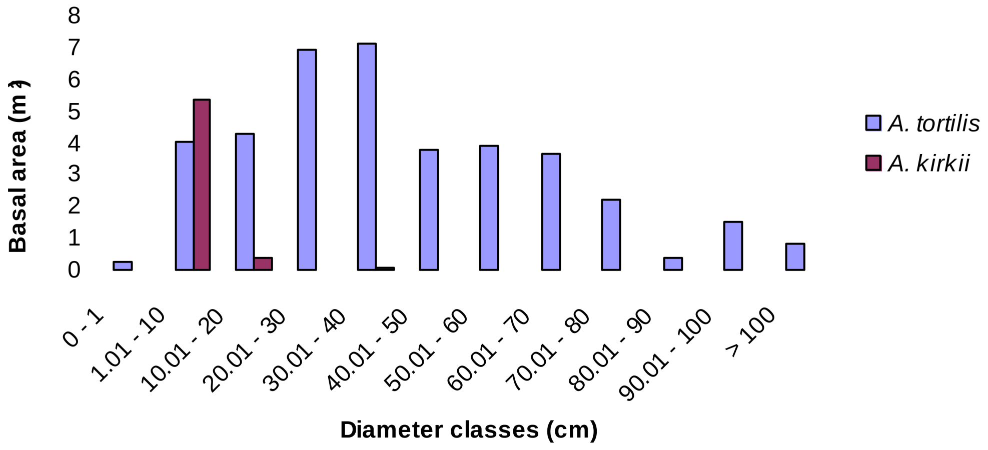

Figure 9: Distribution of basal area (m^2) by diameter classes of *Acacia tortilis* and *Acacia kirkii* in the study area in Ruaha National Park.

The mean tree height for *A. tortilis* was 7.4 ± 0.2 m and 4.5 ± 0.2 m for *A. kirkii*. The tree height class distribution for *A. tortilis* exhibit approximately a negative exponential curve (inverted J-curve), with a very high number of individual trees (84.6%) in regeneration potential (trees <1 m) followed by mature tree class (trees >3 m) (11.7%) and the recruitment potential (trees 1-3 m) with least number of individual trees (3.7%) (Fig. 10). On the other hand, *A. kirkii* trees had lower regeneration potential (16.6%), 43.9% in recruitment potential and 39.5% in mature class (Fig. 10).

Diameter class distribution for *A. tortilis* suggests interrupted regeneration and recruitment continuity at different stages of tree growth resulting more or less in bell-shaped curve instead of negative exponential curve (Fig. 9). The low proportion of trees in the recruitment potential (1-3 m) supports this argument (Fig. 10). The bell shaped curve could also be explained by the fact that some of *A. tortilis* trees were multi-stemmed, thus average diameters were used in grouping trees into diameter classes.

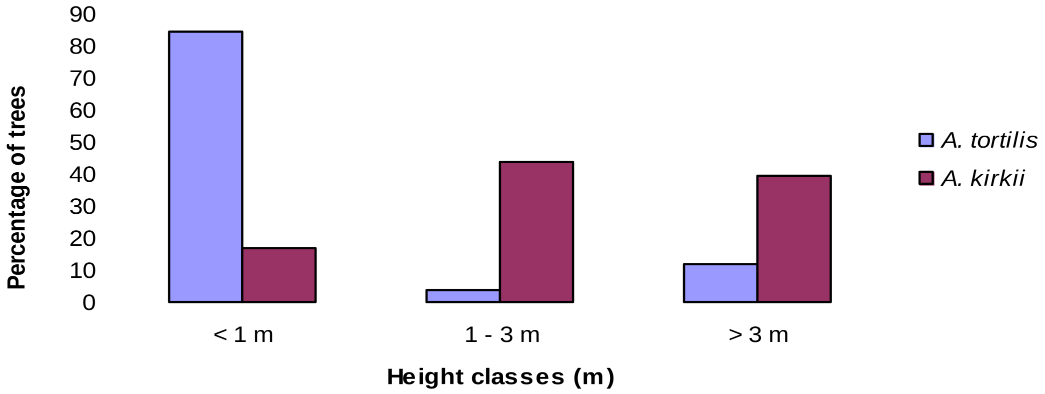

Figure 10: Tree height class distribution of *Acacia tortilis* and *Acacia kirkii* in the study area in Ruaha National Park.

Since the average diameters were smaller than actual diameters of largest stems of trees, they were grouped into lower classes than the largest stems would have been grouped if they were single-stemmed trees. The recruitment gaps could be a result of disturbances through browsing by elephants and other browsers, fires and prolonged drought which might have killed young seedlings or retarded their growth into recruitment potential. For *A. kirkii,* the basal area diameter distribution chart reflects the multi-stemmed growth form of the species, with many stems smaller in diameter, that did not vary much in diameters and very few single stemmed trees above 30 cm in diameter. This suggests that, the use of basal area and diameter alone in determining population structure of multi-stemmed trees species could lead to the wrong conclusion.

The low basal area in the 0-1 cm diameter class could also be an indication of low recruitment from the regeneration potential in addition to smaller diameters of trees in this class. This is supported by the large proportion (94.1%) of *A. tortilis* and *A. kirkii* seedlings with height below 0.3 m and low number of trees with height between 1 and 3 m, suggesting a suppressed growth of seedlings into recruitment potential class. Fire and browsing could have affected the recruitment potential as well, since the class falls in 1-3 m height class, which is within a preferred elephant browsing height (2-4 m) (Smallie and O'Connor, 2000; Mtui and Owen-Smith, 2006). Thus, the past elephant browsing could have suppressed recruitment of trees into mature class or killed trees in this height class. Moreover, *A. kirkii* height distribution indicates low number of individual trees in regeneration potential, highest in recruitment potential followed by mature trees class. This distribution suggests poor potential for future recruitment of trees from regeneration potential class and consequently into mature trees in the study area. The recruitment class was within the elephant's preferred browsing height (2-4 m); hence mortality due to elephant browsing could be high. However, the number of *A. kirkii* enumerated could be too small to show the actual population structure of the species, thus a further study needs to be extended to cover larger area. The small number of *A. kirkii* encountered in the study area could be one of the reasons for the significant difference observed in trees < 1 m between the two *Acacia* species.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A significant difference was observed only in regeneration potential but not in debarking and browsing. Trees with coppices could not be subjected to statistical tests due to low number of *A. tortilis* trees that had resprouts and none of *A. kirkii* trees had coppices. This therefore led to failure to reject the null hypotheses that, the two dominant *Acacia* species are equally damaged and resprout equally to elephant damage. Results, however, reject the assumption that the two species respond equally in regeneration. The observed variation along the transects in *A. kirkii* densities but not in *A. tortilis,* and the difference in population structures between the two species partially rejects the null hypothesis that, the two dominant *Acacia* species tree densities do not vary with distance from the river and population structures are the same.

The low level of damage reflects that elephant browsing was not a threat to most *Acacia* species except for *A. kirkii,* which could be locally affected due to its patchy and clumped distribution and low regeneration potential. This leaves fire as a key factor to be studied, manipulated or controlled, apart from small browsers. The variation in *Acacia* trees densities with increase in distance along transects was probably influenced by soil, vegetation cover and fire, and not by elephant browsing. Difference in population structure composition between the two species could be the function of soil and small number of *A. kirkii* enumerated. *Acacia tortilis* showed a high potential for future recruitment compared to *A. kirkii*. This is reflected by high *A. tortilis* regeneration potential.

Fire and small browsers could be causing suppression of regeneration potential while soil factors and climate variations determine both coppicing and regeneration of *Acacia* trees. Thus, fire could be used as a tool to suppress or enhance recruitment of *Acacia* species, particularly *A. tortilis* depending on management objectives. The area between Msembe and Lunda could develop into *A. tortilis* bush if factors that suppress recruitment of regeneration potential into recruitment potential are identified and controlled, where possible. Allowing the area to develop into *Acacia* bush could have adverse affect on some mammals such as Grant's gazelle *Nanger granti* and cheetah *Acynonyx jubatus* that prefer open grassland.

5.2 Recommendations

i) Elephant utilisation of *Acacia* trees is likely to vary along the Great Ruaha River (within RNP) depending on the availability of surface water in the dry season, hence it is important to conduct a study to see if such variations exist and assess its effects on vegetation around permanent water points.

ii) A study on damage by elephant and browsing by other species as well as assessment of *Acacia* species regeneration potential in the Msembe area is suggested to establish the actual causes for suppressed trees regeneration in the area. The study could also look at the influence of human activities around Msembe on elephants and other browsers.

iii) It is suggested for a similar study to be extended into *Acacia* vegetation zone to the north in addition to current study area in order get a better understanding of *A. kirkii* regeneration and coppicing as response after damage. The study may need a longer time in order to come up with better results on re-growth after damage by elephant.

iv) A study on effects of fire on regeneration of *Acacia* trees is suggested to facilitate the use of fire as a management tool.

v) Close monitoring of changes taking place in vegetation in the area should be done continuously to be able to predict the likely future vegetation cover and how the changes would affect the associated animal species.

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APPENDICES

Appendix 1: Field data collection form

Transect No.	*Acacia* Species	Tree height (m)	DBH/ (cm)	Browsing	Debarking	GPS reading/ Remarks

Browsing: a-not browsed, **b**-1/4 browsed, **c**-1/2 browsed, **d**-3/4 browsed **e**- the entire crown browsed, **f**-tree uprooted

Debarking: **g_1**- < ½ debarked; **g_2-**1/2 to 3/4 debarked; **g_3**-completely debarked.

Appendix 2: Transect start and end point GPS coordinates in the study area in Ruaha National Park

Transect no.	Start	End	Transect No.	Start	End
1	714749	714008	21	732664	731689
	9152320	9152988		9170454	9170288
2	715993	715552	22	733812	733707
	9152594	9153490		9171320	9172316
3	717428	716933	23	735368	735255
	9152950	9153812		9171002	9171978
4	718666	718914	24	736584	736139
	9153098	9154062		9172026	9172918
5	719650	718724	25	738120	738044
	9153890	9155268		9172000	9172992
6	720162	719881	26	739444	739370
	9155216	9156170		9172560	9173550
7	720102	719154	27	740570	741294
	9156590	9156906		9171458	9172140
8	720973	720571	28	742080	742025
	9157432	9158342		9172004	9172996
9	721287	720322	29	743372	743252
	9158858	9158594		9172756	9173744
10	721316	720461	30	744384	743877
	9160148	9160664		9173936	9174794
11	722077	721475			
	9161294	9162090			
12	723124	723123			
	9162226	9163220			
13	724008	723674			
	9163310	9164248			
14	725275	724957			
	9163998	9164940			
15	726109	725314			
	9165114	9165724			
16	726959	726040			
	9166342	9166748			
17	728068	727804			
	9167244	9168228			
18	729553	729628			
	9167108	9168112			
19	730982	730344			
	9167810	9168578			
20	731943	731140			
	9169040	9169636			

Appendix 3: Number of *Acacia* trees assessed in each transect in the study area in Ruaha National Park.

Transect No.	Regeneration potential (No. of trees)			Trees > 1 m (No. of trees)		
	A. tortilis	*A. kirkii*	All *Acacia* spp.	*A. tortilis*	*A. kirkii*	All *Acacia* spp.
1	0	0	0	0	0	0
2	62	0	62	0	0	0
3	135	0	135	1	0	1
4	35	1	35	33	12	44
5	90	10	100	9	90	100
6	74	0	75	29	0	29
7	85	10	95	4	35	39
8	31	9	40	3	113	116
9	109	3	113	2	69	71
10	395	4	401	11	1	11
11	154	27	181	2	9	11
12	67	1	68	2	0	2
13	143	0	144	10	1	12
14	145	0	146	34	0	34
15	274	0	274	36	0	37
16	85	0	87	24	0	25
17	116	0	117	19	0	28
18	64	0	69	24	0	29
19	30	0	46	3	0	5
20	116	0	122	26	0	28
21	359	0	359	17	0	23
22	180	0	179	71	0	72
23	204	0	208	13	0	15
24	213	0	214	31	0	35
25	10	0	10	40	0	41
26	24	0	24	33	0	33
27	150	0	152	25	0	28
28	131	0	131	60	0	69
29	22	0	22	20	0	22
30	4	0	4	42	0	47