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Is Elephant Damage to Woody Vegetation Selective of Species, Plant Parts and What could be Plausible Factors Influencing such Selectivity? A Case Study of South Luangwa National Park, Zambia'

[1]Chansa Chomba & [2]Costance Banda

[1]School of Agriculture and Natural Resources, Disaster Management Training Centre, Mulungushi University,
P. O. Box 80415, Kabwe, Zambia.
[2]C/O Mr. Banda, Lusaka, Zambia; Corresponding Author: Chansa Chomba (chansachomba@rocketmail.com)

Abstract

This survey was carried out in the Luangwa Valley eastern Zambia. The main aim and objectives were to; determine the pattern of elephant damage to wood vegetation by examining damage categories, species and plant parts affected and plausible factors influencing such selectivity in South Luangwa National Park, Zambia. Objectives were to; observe and classify elephant damage categories, identify tree species and plant parts affected by each damage category, determine tree height and girth size selected. The Point Centre Quarter Method, a plot less method which does not require a correction factor was used**.** Results obtained showed that elephant damage to woody vegetation was selective. Five damage categories were recorded, and these were; broken branch/stem, debarking (including stripping and ring barking), scarring, push over, and uprooting. Of the five damage categories, broken branch/stem had the highest frequency 80 %, and the least was up rooting 2 %. Major factors influencing such damage categories were; tree species specific characteristics, tree height, and trunk girth size. Further research is required to determine the influence of season (dry and wet seasons), water availability, soil factors, distance from water source and other factors on elephant foraging behaviour in South Luangwa National Park.

Keywords: Damage categories, baobab, tree, height, girth, frequency

1. Introduction

Elephants (*Loxodonta africana*) are known ecosystem engineers, capable of altering landscapes by reducing plant biomass, changing species composition and increasing landscape patchiness. The ability of elephants to transform landscapes is of major concern in elephant dominated areas as the impact of elephants on woody vegetation could have negative consequences for other species that require a particular vegetation structure (Valeix *et al.*, 2008). As a mega-herbivore they consume a large quantity and wide variety of plant material. This foraging behaviour can in certain instances have a significant impact on the physiognomy of vegetation communities. Although, Zyambo's (2016) paper presented dichotomous opinions on whether elephant transformation of forest or woodland habitats leads to loss of biodiversity or whether the opening up of forests and woodlands creates favourable habitats for other species, this area of ecology still remains a contested and debatable area of study and will for some time remain fairly controversial.

The main argument in support of the view that elephants transform forest and woodland habitats to grasslands is based on the understanding that when feeding on woody plants, elephants are capable of feeding very delicately or causing gross destruction. Because of this, the effects of elephant utilization are often referred to as "damage"; which generally refers to any removal of woody biomass, and not only to suggest excessive destruction (AWF 2004). When feeding on shrubs, where the foliage is within easy reach, elephants generally pull off leaves and twigs, sometimes tearing off branches. With smaller plants, the stems may be broken off just above the ground or, with seedlings, the entire plant with the roots may also be pulled out (Figure 1 a, b).

(a)

(b)

Figure 1 a) Elephant feeding on *Acacia* shrub where the foliage is within easy reach, pulling off leaves and twigs, b) small plant being dug out to access roots
(Source: Photograph courtesy of, www.dewetwild.com)

Subterranean plant parts are therefore also not safe from elephants as they are excavated to expose roots and other parts, for example tubers of favoured plants in sandy soils (Williamson, 1975) (Figure 1 b). With larger trees, where the foliage is beyond reach, trees may be uprooted or pushed over or the trunk or large branches may be broken off.

Shallow-rooted trees are likely to be pushed over without breaking and frequently continue to grow in a horizontal position. With deeper rooted trees the stem is likely to be snapped and coppice growth may be produced from the stump. Both results may even be seen in the same tree species, perhaps depending partly on soil type and moisture regime. Elephants eat the bark of many trees, which they tear off in long strips or break off in pieces depending on the tree species. If bark is removed around the complete circumference of the trunk, the tree may die above the ring barked point. Even if not completely ring barked the exposed wood may with a combination of other factors such as fire and boring insects lead to direct mortality. Baobab (*Adansonia digitata*) though may in many instances be an exception to this rule. The vascular structure of baobab enables them to survive ring barking and deep scarring (Figure 2, a, b, c). Since elephants forage in a selective manner the first to disappear are those species they select over others. In case of large trunk girth and tall trees the damage is usually evident due to their visual dominance in the landscape and the aesthetic appeal to humans.

(a)

(b)

(c)

Figure 2 a, b a and c Light and deep scarring on baobab trees.
(Notes: Although baobabs are generally resistant to elephant damage and can continue to grow with deep scarring, regular and consistent feeding can lead to extensive damage and direct mortality particularly when combined with other factors such as fire and boring insects.
(Source: Photograph courtesy of, phenomena.nationalgeographic.com; ali2africa.blogspot.com; www.flicks.com).

Despite the differing views, there is no doubt that the foraging habits of elephants which involve browsing, breaking of branches, debarking and at times uprooting woody vegetation (Figure 3a, b, c and d) makes the damaged trees susceptible to other environmental factors. For instance, debarking makes trees more susceptible to other damages such as fires and diseases which may cause direct mortality. It also makes the tree more susceptible to termites, woodborers and other insect activity, shortening the trees' lifespan (Hatcher, 1995).

(a)

(b)

(c)

Figure 3 Common elephant feeding habits a) accessing browse on tree crown, b) breaking of branches, c) and debarking
(Pictures courtesy of: Chris and Tilde Stuart; Sciencephoto.com)

Based on this line of thought, it would be an acceptable norm to suggest that increased elephant densities are related to severe declines in large tree abundance as also acknowledged by Nasseri *et al*., (2011) as the damage to selected species such as baobab which take several hundreds of years to grow can be severe and lead to direct mortality (Figure 2 a, b, c, d). For this reason, protected area managers in sub-Saharan Africa often get concerned when large elephant populations are restricted to one locality or when populations seem to exceed the carrying capacity.

In East and Southern Africa which are the strongholds of the African elephant populations, records show that numbers declined significantly from the late 1970s to late 1980s mainly driven by the high prices of ivory in Asia, particularly the oil rich countries of Asia minor. In Zambia for instance, Prior to the 1960s and early 1970s elephant numbers were estimated to exceed 250, 000, but by 1989 numbers had fallen to about 18 000 individuals (Chomba *et al*., 2012). The elephant was subsequently placed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1989. Such listing prevented commercial trade in elephant specimens which significantly reduced the levels of poaching in many parts of the elephant range. As a consequence of this measure and public sympathy it attracted worldwide, elephant populations started to recover.

After about 10 years of Appendix I listing and improved law enforcement operations and the involvement of local communities through Community Based Natural Resources Management (CBNRM) system, populations stabilized and even started to increase such that by 2008, national population estimate had reached 27, 529 with the Luangwa valley accounting for 20, 200 individuals (73 %) of the national population.

As populations continued to increase, certain localities started to experience increased damage to woody vegetation. Such damage, coupled with persistent drought and high frequency of fires if not mitigated, may accentuate the negative effects on woody vegetation arising from elephant foraging behaviour and in many areas have been known to cause significant loss in woody vegetation cover by over-browsing, debarking and uprooting of trees (Ben - Shahar, 1996). Much as the increase in elephant population may symbolise overall effective management, it may on the other hand transform habitats and lead to loss of biodiversity and appropriate intervention measures to secure the habitats for the elephants own survival and that of other species may be necessary. This study therefore, examined species most damaged by elephants, woody plant part(s) targeted by elephants, and the height and girth of affected trees species.

This survey, was conducted not to debate the causal factors and the consequences of habitat transformation arising from elephant foraging patterns and behaviour as tackled by Zyambo (2016), but rather to assess the pattern of damage and whether elephants select certain species, plant parts or size of tree when feeding, which would help management in selecting appropriate intervention measures when the level of damage falls below the lower thresholds of change.

2. Materials and Methods

2.1Location and Description of Study Area

The study was undertaken in the Mfuwe area of South Luangwa National Park in eastern Zambia (Figure 4), which currently holds 73 % of the national elephant population and hence was found to be suitable for this study. The National Park lies between Latitude 12º 17’ - 13º 45’ South and Longitude 31º 00’ - 32º 08’ East, in the Luangwa Valley.

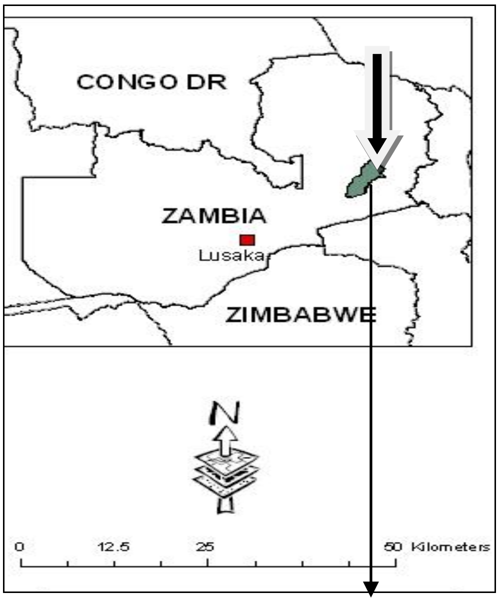
2.2Biophysical Characteristics

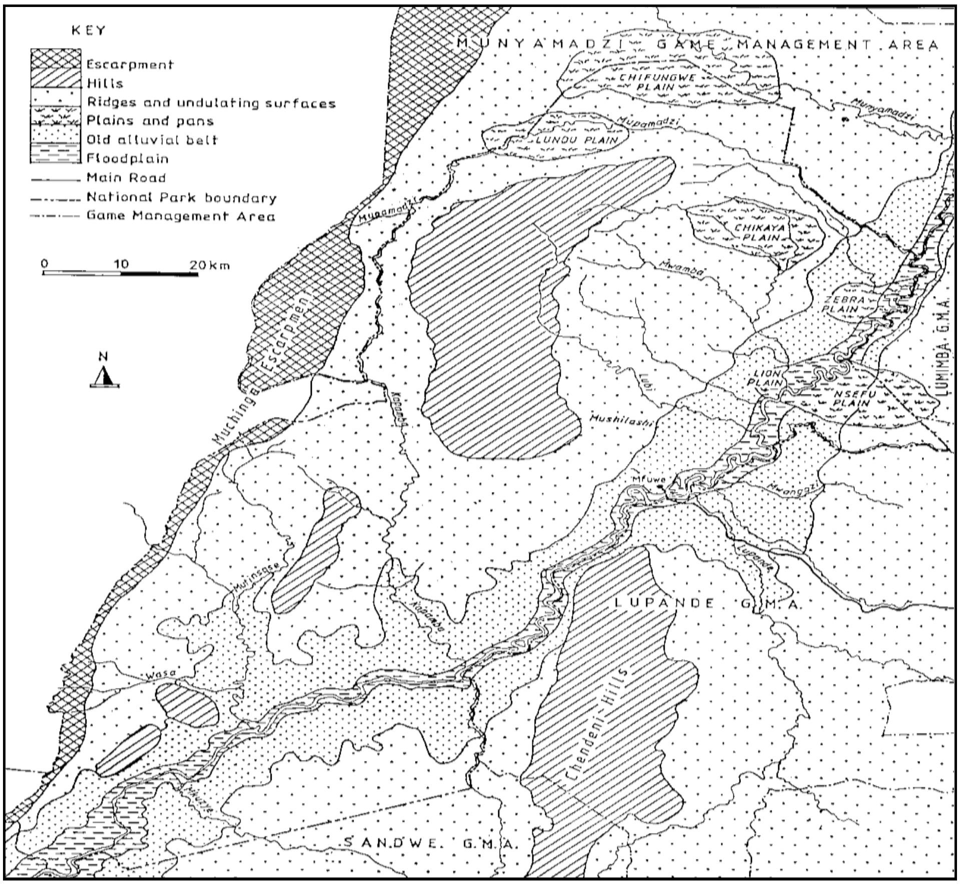
2.2.1Climate

South Luangwa National Park and surrounding Game Management Areas lie on the Central African plateau whose rainfall pattern is controlled by the movements of the Inter-Tropical Convergence Zone (ITCZ) and increases form south to north. Climate has three distinct seasons namely; hot rainy season from late November to April; a cool-dry season from mid May to August; and a hot dry season from September to early November. The Luangwa valley generally experiences a hot climate with the mean daily maximum temperatures in the range of 32-36^{0}C. The minimum and maximum temperatures are 15^{0}C (June-July) and 36^{0}C (October) respectively. The mean annual rainfall is in the range of 400-800 mm although records above 1,000 mm have been documented (Chomba, 2010).

2.2.2 Geology and Geomorphology

Geology and geomorphology of the Luangwa River basin is varied and complex. It is underlain by rock types of various ages ranging from Pre-Cambrian (up to 4,600 million years ago) to Quaternary times. Chomba (2010) described the basement complex as comprising mainly granites, granite-gneisses, gneisses, schists and quartzite, which have been extensively deformed by the processes of metamorphism and granitization, especially where severely affected by tectonic dislocation. Granites are usually characterized by high relief while the Katanga system occupies the western parts of the Luangwa basin. The Karoo sedimentary rocks, which include sandstones, mudstones and grit, are found in lower valleys of the Luangwa River and some of its major tributaries. The alluvium, mostly fine-grained materials overlie vast tracts of Luangwa river banks and most of its tributaries. These are the soils on which vast grassland plains such as the Nsefu plain is situated.





(b)

Figure 4 a) Location of South Luangwa National Park, b) details of the physiographic map of the Luangwa Valley, showing vegetation zones as potential foraging areas for elephants, Zambia (ZAWA, 2010).

2.2.3 Physiographic Regions

There are four major physiographic units found in the Luangwa valley as follows: (i) escarpment zone and hills, (ii) plains, pans and dambos, (iii) ridge and high undulating surfaces and, (iv) alluvial belt.

(i) The Escarpment Zone and Hills

The escarpment zone encloses the valley. On the eastern side, the area is characterized by a series of dissected and rolling hills including the Muchindeni hills located to the southeast. In contrast, the Muchinga escarpment on the western side has a linear feature, which is deeply dissected by a series of V- shaped valleys down through which flow some of the major streams from the plateau. It has a relief of about 750 m. The line of the escarpment follows a regional fault zone lying between the Karoo strata and the Precambrian crystalline igneous and metamorphic rocks. Numerous precipitous rock outcrops occur along the face of the escarpment. Slopes are straight and range from 20 - $30^{0.}$ Rivers which flow off the plateau are narrow averaging about six metres in width and are characterized by a series of cataracts and falls. Along the base of the escarpment, channels widen to about eight metres in width and numerous dambos are found (Astel, 1969).

(ii) Plains, Pans and Dambos

Large plains in the valley are mostly located in the northern part of the south Luangwa National Park of which the dominant ones are the Chifungwe, Chikaya, zebra, lion and Mutanda/Chifungwe plains. There also exist pans and dambos characterized by generally broad low lying depressions with undulating surfaces of broad interfluves and relative relief of about 10 m. Pans are flat lying to slightly concave features, which contain water. Dambos are also concave in cross-profile averaging 100-300 m in width and several kilometres in length. Stream courses are long and narrow and are generally found flowing down the center of dambos (Astel Webster & Lawrence, 1969; Phiri, 1998).

(iii) Ridge and High Undulating Surfaces

This area is distinguished by its upstanding plateaux and closely spaced long parallel ridges. Slopes range from 6^0-12^0. Many rivers in the area widen and are characterized by meandering and braiding platforms. Sand bars are common with deep banks. On the plateaux, slopes are low ranging from 0.5^0 - 2^0 (Astel Webster & Lawrence 1969; Phiri, 1998).

(iv) Alluvial Belt

The alluvial belt is characterised by variable, nearly flat landscape of recent alluvium displaying features such as levees, point bar deposits, flood channels, abandoned channels, oxbow lakes and lagoons. Relative relief here is about 1.2 m with channel depths averaging about six metres. The width of the meander belt ranges from 50-200 m being bordered along most parts of rivers by steep, nearly vertical banks up to five metres in height. Chomba (2010) distinguished three areas of alluvial zones. The active sedimentation area, characterized by unvegetated new deposits; sedimentation area, marked by grassland and occasional occurrence of trees and with anastomosing character of the drainage system; and the old sedimentation area which has no evidence of anastomosing drainage, but where there exists oxbow lakes, and a denser vegetation cover which includes numerous trees (Sichingabula, 1998).

(v) Soils

Various types of soils are found within the Luangwa River basin. Vertisols which are deep and mostly derived from Karoo sediments by colluvial and alluvial processes are the most dominant soil types. Chomba (2010) described the variation in colour as ranging from yellowish-brown, dark reddish brown to coarse alluvial soils topped by dark loamy alluvium. Clay soil types tend to produce cohesive riverbank materials but these are also easily eroded by high flow currents of the Luangwa River (White 1983; Sichingabula, 1998).

2.3 Biological Characteristics of the Study Area

2.3.1 Vegetation

The distribution of the vegetation types strongly correlates with a combination of topographic patterns, soil types and elevation. Astel *et al.* (1997) showed that where as each topographic unit carries distinct soil types, there is an equally strong corresponding correlation between topography and soil type on one hand and vegetation types on the other hand. The occurrence of various topographic units, lithologies and soil types has given rise to correspondingly different vegetation types each characterized by unique floristic composition, dominant species, structure and physiognomy. The common vegetation communities are: (i) riparian woodlands, *Combretum-Faidherbia* woodland, *Acacia-Combretum* woodland, mopane woodland, miombo woodland, thickets, *Hyphaene* woodland, Grasslands and wetlands.

(i) Riparian Woodlands

The riparian woodland is a narrow strip of arboreal (tree) species found along the banks of the Luangwa River, the lagoons and the tributaries. In the Luangwa Valley this riverine woodland is discontinuous and consists of a mixture of deciduous and evergreen trees and shrubs.

(ii) Combretum-Faidherbia Woodland

This type of woodland occurs within the meander belt. Since the taxi in this zone lie within reach of the annual floods, they are prone to occasional seasonal flooding when the Luangwa catchment area receives exceptionally high rainfalls. The plants are adapted to alluvial soils and high water table. In some places, such as the area around the recently formed Luangwa Wafwa Lagoon, the woodland transforms into a savannah-like formation.

(iii) Acacia-Combretum Woodlands

This woodland occurs in some sectors of the meander belt where the tributaries adjoin the Luangwa River. At higher elevations of about 520 to 600 m, *Acacia-Combretum* (Munga) woodland forms a broad belt outside the floodplains of the main rivers, such as the Kasenengwa, Lupande, Lusanganzi, Lutembwe, Matizye, Musandile, and Mwangazi which run through the GMAs.

(iv)Mopane Woodlands

The mopane woodland is a unique vegetation type in southern Africa. The woodlands are well developed along the central core of the valley, usually fringing the meander belt of the Luangwa and its main tributaries. The mopane also occurs on gentle gradients of the broad interfluves. This vegetation type usually occurs in areas that are underlain by Karroo lithological formations. Thus mopane (*Colophospermum mopane*), which is the dominant species, is a useful in geo - botanical explorations. In the central Luangwa Valley the mopane woodlands exhibit three physiognomic forms: the tall mopane (heights of up to 21 m or more), the low mopane (heights up to about 10 m high) and the scrub mopane (heights up to 2.5 m high).

(v) Miombo Woodlands

The Miombo occur on hill remnants found within the valley floor, along the escarpment slopes, descending to an elevation of about 650 m towards the center of the valley where the vegetation transforms into scrub formation. The Miombo woodland is dominated by species of *Brachystegia, Isoberlinia* and *Julbernardia*. Other vegetation types include; Thickets, Savannah, Hyphaene woodland (an extensive formation of palms found in low lying terrain bordering on the main tributaries of the Luangwa), Grasslands and Wetlands.

2.3.2 Fauna

The Luangwa valley is best known for its abundance and variety of large mammals; it has the largest number of hippopotamus and elephants in the country (Anon, 2008), which attract thousands of tourists every year. It is in fact christened the elephant kingdom. The diverse topography and mosaic of vegetation communities provide a suitable environment for the sustenance of high species diversity.

(i) Large Mammals

Large mammals recorded include; vervet monkey (*Cercopithecus pygerythrus*), moloneys' monkey (*Cercopithecus albogularis*), yellow baboon (*Papio cynocephalus*), side stripped jackal (*Canis adustus*), wild dog (*Lycaon pictus*), spotted hyaena (*Crocuta crocuta*), leopard (*Panthera pardus*), lion (*Panthera leo*), cheetah (*Acinonyx jubatus*), elephant (*Loxodonta africana*), black rhinoceros (*Diceros bicornis*) (not sighted in recent times), zebra (*Equus* spp), bush pig (*Potamochoerus porcus*), warthog (*Phacochoerus aethiopicus*), common hippopotamus (*Hippopotamus amphibius*), thornicroft giraffe (*Giraffa cameleopardalis thornicrofti*) (endemic to the Luangwa valley), common duiker (*Sylvicapra grimmia*), sharpes' grysbok (*Raphicerus sharpei*), oribi (*Ourebia ourebi*), klipspringer (*Oreotragus oreotragus*), reedbuck (*Redunca arundinum*), common waterbuck (*Kobus ellipsiprymnus crawshayi*), puku *(Kobus vardoni*), impala (*Aepyceros melampus*), roan antelope *(Hippotragus equines*), sable antelope (*Hippotragus niger*), lichtensteini hartebeest (*Alcelaphus lichtensteini*), coockson's wildebeest *(Connochaetes taurinus cooksoni*) (endemic to the Luangwa valley), bush buck *(Tragelaphus scriptus*), greater kudu (*Tragelaphus strepsiceros*), eland (*Tragelaphus oryx*) and buffalo (*Syncerus caffer*). The South Luangwa National Park and surrounding areas hold the country's largest hippopotamus and elephant populations in the country (Smithers, 1973; Ansell, 1978; Kingdon, 2008).

(ii) Birds

The meandering of the Luangwa River creates numerous ox-bow lakes/lagoons, which provide a rich habitat mosaic for many species of birds. Over 400 species of birds have been recorded (Leonard, 2005).

2.4 Field Methods

Data were collected using Point Centered Quarter Method (PCQ). Fifty transects 1 km long each were placed parallel to each other to avoid crisscrossing of transects and placed at an interval of 200 m apart. Twenty sample points were placed every 50m along each transect. Global Positioning System (GPS) was used for distance, location and transect bearing. Four quarters were established at each sample point as follows; compass line was established and the second line passed perpendicular to the compass line dividing the area into four equal quarters. The four distances of a number of sampling points were averaged and when squared were found to be equal to the mean area occupied by each tree.

This method does not require a correction factor. Mean Area was calculated by (MA) = D^2 . Where, D is the mean distance of four tree distances taken in each of the four quarters. The distance to the midpoint of the nearest tree from the sampling point was measured in each quarter. The tree species were identified, height and girth size were measured; plant part affected (branches, bark, roots) were recorded. Tree height was measured using a tree height measuring rod. The girth was measured using a linear calliper and measuring tape. The diameter at breast height was measured at 1.3 m from ground level.

Tree damage classes were categorized as follows; debarking (ring barking or stripping), push over, uprooting, scarring (when the bark is removed but inner tissue of the tree is also damaged) and broken branch and/or stem (Figure 5a, b, c, d, and e).

(a)

(b)

(c)

(d)

(e)

Figure 5 Tree damage categories, a) debarking, b) pushover, c) uprooting, d) scarring, and e) broken branch and or stem
(Pictures courtesy of: ali2africa.blogspot.com; www.traveladdicts.net; gettyimages.com; treknature.com)

3. Results

A total number of 1,000 sample points were examined along 50 transects of 1 km long each. A total of 72 tree species were recorded out of which only 16 (22 %) had signs of elephant damage. Results obtained are presented in sections 3.1 to 3.3 below.

3.1 Damage Categories

There were five (5) elephant damage categories recorded, broken branch/stem, debarked (including ring barking nd stripping), uprooting, scarring and push over. Of the five categories, the most frequent was broken branch/stem 136 (79 % of total) followed by debarking 22 (13 % of total). The other three combined had 14 (8 % of total) (Figure 6). Broken branch/stem had a significantly higher frequency than other categories (χ^2 = 9.488, DF = 4, $\alpha = 0.05$, $P < 0.05$).

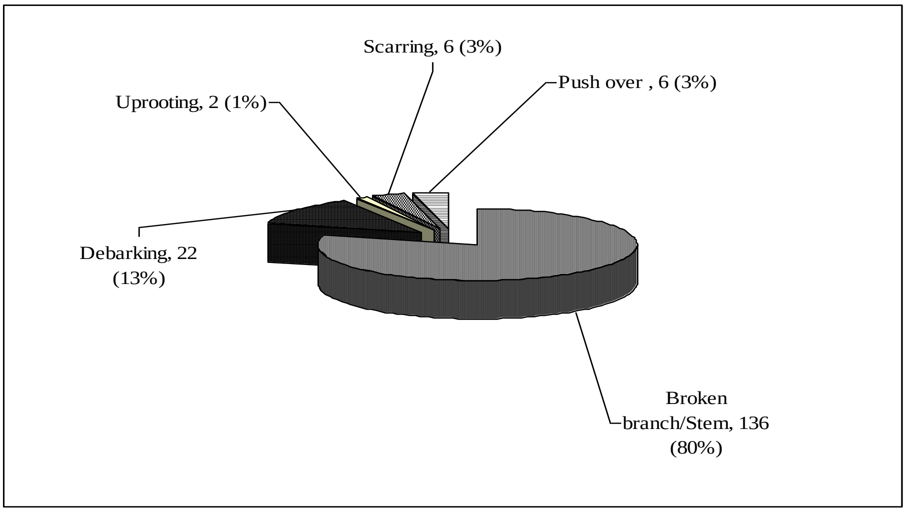


Figure 6 Elephant damage categories, South Luangwa National Park, 2015.

3.2 Selective Damage on Species

The cumulative damage of all the five elephant damage categories showed that some species were affected more affected by elephants than others. *Philenoptera violacea* had 54 (32 % of total), the second most important was *Xeroderris stuhlmannii* 17 (11 % of total), *Diospyros mespiliformis* 12 (7 % of total), *Feretia aeruginescens* 10 (6.5 % of total) and the rest had less than 10 (Figure 7). The difference on the cumulative impact of damage on tree species was significantly different ($\chi^2 = 28.869$, DF = 18, $\alpha = 0.05$, $P < 0.05$).

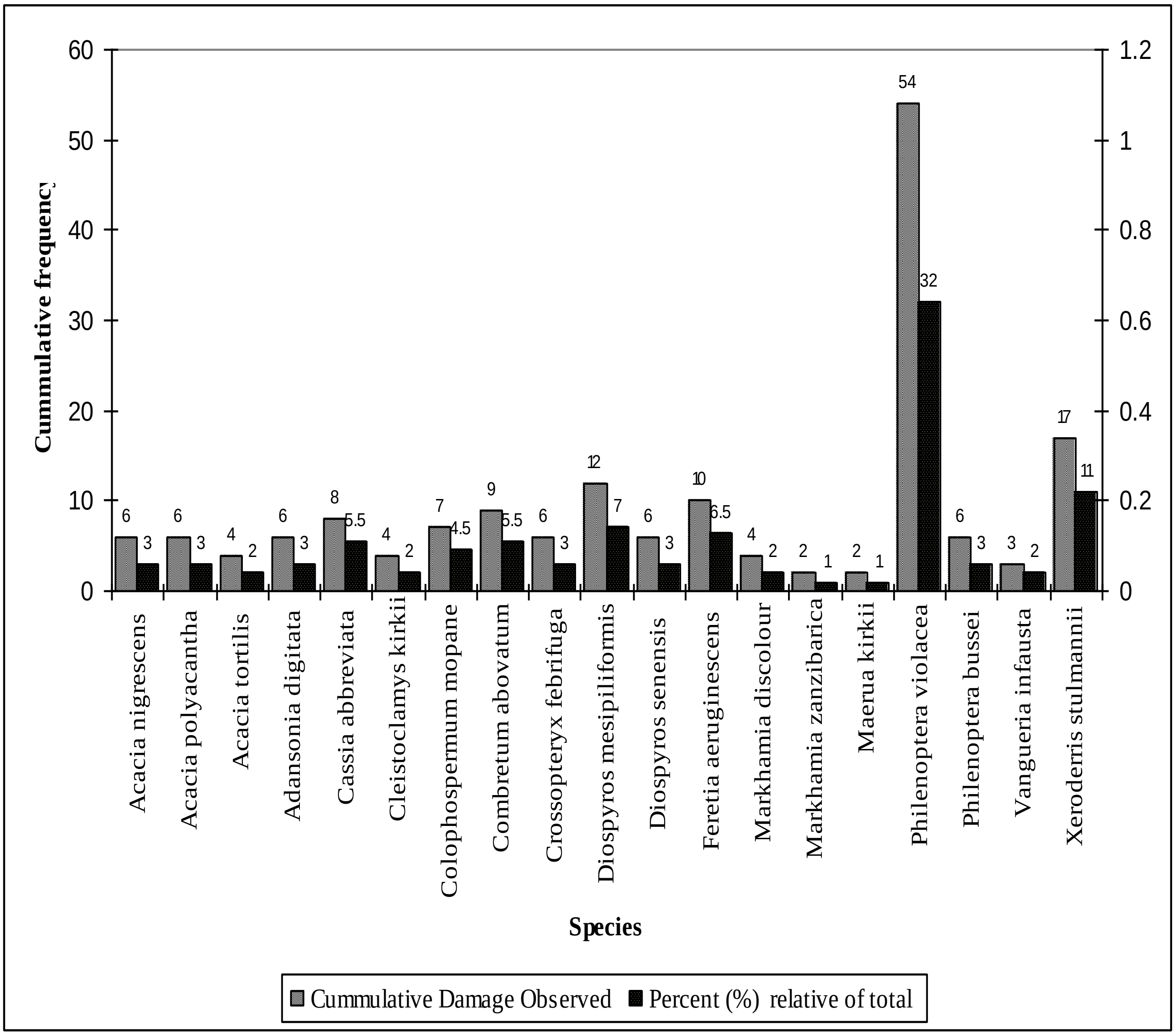


Figure 7 Elephant selective damage on tree species, South Luangwa National Park, Zambia, 2015.

3.3 Influence of Tree Height and Trunk Girth Size on Damage Category

Broken branch and debarking were the most significant elephant damage categories accounting for 92 % of total sighting frequencies of all the five damage categories. The two damage categories were selected to represent the rest as shown in sections 3.3.1 and 3.3.2 below.

3.3.1 Influence of Tree Height on the Sighting Frequency of Broken Branch/Stem and Debarking Categories

Tree height influenced debarking damage category. Only trees of mean height ≥ 9 metres had (100 %) debarking damage category. All trees with < 9 metres height did not have debarking damage category (Table 1). The tree species which had height ≥ 9 and carried 100 % debarking damage category were; *Diospyros mespiliformis* (12 m), *Crossopteryx febrifuga* (9 m), *Colophospermum mopane* (16 m), and *Acacia tortilis* (13 m).

3.3.2 Influence of Stem Size on the Sighting Frequency of Broken Branch/Stem and Debarking Categories

Small trunk girth size (< 60 cm) and short height (≤ 9 m) had 94.5% of all broken branch/stem damage category. Among these, only five (5) carried 73 % of all broken branch/stem damage category and these were; *Philenoptera violacea* (23cm), *Feretia aeruginescens* (25cm), *Combretum abovatum* (52cm) *Cassia abbreviata* (35 cm), and *Xeroderris sthulmannii* (20 cm).

Table 1 The influence of tree height, tree trunk girth size on the frequency of each elephant damage category, South Luangwa National Park, Zambia, 2015.

No.	Species	Mean Tree Height (m)	Mean Stem girth size (cm)	Frequency Damage Category		Percent (%) Relative Frequency of Total	
				Debarked	Broken Branch/Stem	Debarked	Broken Branch/Stem
1	*Diospyros mespiliformis*	12	100	7	5	32	4
2	*Crossopteryx febrifuga*	9	80	6	0	27	0
3	*Colophospermum mopane*	16	115	7	0	32	0
4	*Acacia tortilis*	13	125	2	2	9	1.5
	Sub total					**100**	**5.5**
1	*Philenoptera violacea*	4.5	23	0	54	0	40
2	*Feretia aeruginescens*	4	25	0	10	0	7
3	*Combretum abovatum*	5	52	0	9	0	7
4	*Cassia abbreviata*	4	35	0	8	0	6
5	*Xeroderris stuhlmannii*	3	20	0	17	0	13
Sub total							**73**
6	All other species with broken branch/stem frequency < 6						27

Notes: Baobab (*Adansonia digitata*) not included

4. Discussion, Conclusion and Recommendations

This chapter discusses major findings from this study and provides conclusive statements arising from the major findings. A set of recommendations has been provided to guide management in setting maximum thresholds of elephant damage to woody vegetation, above which appropriate intervention measures should be taken.

4.1 Discussion

4.1.1 Selection of Certain Species of Trees by Elephants over Others and Damage Categories

In this study, it was evident that certain tree species were selected more than others. For instance, baobab was the only species in which the scarring damage category was recorded (Figure 2; Figure 5d). The wood of baobab is soft, spongy and of low durability. It is much easy for the elephant tusks to pierce through which is the exact opposite of species such as mopane.

Dietary preferences could have played a role in selecting certain species over others. Studies by Jacobs and Biggs (2002a, b) also showed that dietary preferences ultimately influenced species selection. They further explained that while elephants were bulk feeders, they still demonstrate distinct preference or avoidance for different plant species, which in turn affects (along with the individual species responses to utilization) the extent and pattern of any vegetation change that may occur with elephant utilization of a habitat.

Preferentially utilized trees included those that provided shade or fruit (e.g. *Faidherbia albida* (Barnes, 1983a)) and marula, *Sclerocarya birrea* (Coetzee *et al.*, 1979; Duffy *et al.*, 2002), nutrients such as; calcium and nitrogen (*Sterculia* spp and baobab (*Adansonia digitata*)) and others (Williamson, 1975; Hiscocks, 1999) or simply those individuals that are more exposed or accessible (Pamo & Tchamba, 2001). It was found that elephants had a four- fold preference for trees from later successional stages (*Acacia caffra* and broadleaves) to earlier successional trees such as *A. nilotica*. Latex-bearing species such as *Euphorbia candelabrum* are generally avoided. As a result, elephant damage tended not to be distributed among species in proportion to their relative abundance. For example, elephant damage around Lake Kariba, Zimbabwe, revealed that in *Colophospermum mopane* (mopane)-dominated woodland, elephants used mopane, *Combretum* spp and *Croton gratissimus* roughly in proportion to their occurrence, but that in *Combretum* woodland elephants selected mopane in preference to the other two species; *Meiostemon tetrandrus* was avoided, even in *Meiostemon*-dominated woodland. Similarly, Ben-Shahar (1998) found that although *Brachystegia* woodlands in northern Botswana had higher elephant densities, mopane woodlands experienced more elephant damage. Mopane is generally considered a preferred species (Williamson

1975, Ben-Shahar, 1998), with coppiced trees often being continually pruned (Lewis, 1991; Ben-Shahar, 1993; Smallie & O'Connor, 2000; Landman *et al*., 2014).

Other workers, however, have argued that elephant dependence on mopane is over-emphasized (Lewis, 1986) yet *Acacia tortilis*, the iconic savanna "umbrella thorn" tree which is also generally considered a preferred species (Guy, 1976; Ben-Shahar, 1993; Smallie & O'Connor, 2000) is not emphasized. The baobab *Adansonia digitata* is frequently utilized for its soft pulpy wood in the dry season (Weyerhaeuser, 1995), but is usually treated differently mainly due to the unique type of damage which is different from other species (see Figure 2 a, b, c; Figure 8).

With regard to tree damage categories, it would appear that elephants may be reluctant to push over large trees or to reach branches and break them down, so the commonest and practically possible way of foraging on such species tree is debarking and/or where the stem is soft deep scarring into the stem (see Figure 2 a, b, c; Figure 8). Tree species such as mopane which have a very hard inner stem, but with a fibrous bark are usually stripped or ring barked. This happens when the elephants attempt to forage using tusks to scrap off the bark which is also common is some *Acacia* species).

Figure 8 Deep scarring into the stem is common in large baobabs which cannot be pushed over
(Source: Photograph courtesy of, magazine.africageographic.com)

4.1.2 *Influence of Tree Height and Trunk Girth Size on Damage Category*

Tree height presents a major challenge for elephants, because they cannot easily access the crown when the tree was > 9 m or in some instances can totally fail to reach foliage and twigs which are preferred browsing material. Smaller girth trunks and shorter ones were easily accessed (Figure 1a) and could easily have their trunks or branches broken.

However this pattern of foraging changed in areas with tall trees as was observed in many areas dominated by tall trees of large girth and which do not have young trees of the height < 9m whose crown is easily reached (see Figure 1a) and small trunk girth which can easily be pushed over or uprooted. In such instances the commonest damage category is likely to be debarking (Figure 9). This behaviour is also attributed to the species specific attributes as preferred by elephants.

Figure 9 Debarking by stripping or ring barking is common to certain species such as mopane (*Colophospermum mopane*) or when the tree is tall that the elephant cannot reach the crown or when the trunk girth size is too large to be pushed over.
(Source: Photograph courtesy of, thenewsfatigue.wordpress.com)

4.2 Elephant Feeding Selectivity and Patterns of Damage in General

In Kenya, Ihwagi *et al.* (2009) investigated the impact of elephants, on woody vegetation through selective debarking in Samburu and Buffalo Springs National Reserves. Results established selective tree species specific behavioural patterns. *Acacia elatior*, which was the most abundant tree species in the riverine zone, accounted for the largest proportion of 68% (n = 1375). *Acacia tortilis* dominated plots away from the river but was also affected. Debarking incidences were recorded to be significantly higher for *A. elatior* than for other species indicating selective utilization, which is similar to the results obtained during this study. The study suggested that, *A. elatior* and *A. tortilis* tree species respectively, were bound to die within the next 4–5 years because of severe debarking, 75% of bark circumference. Debarking was positively correlated with stem circumference; the medium sized trees being the worst affected by the elephants' selective debarking behaviour. Intense debarking incidences were recorded during the dry season. Through the elephants' selective debarking, the riverine habitat was bound to open up gradually, leading to considerable habitat change in the near future. Elephant impact on vegetation was less away from the river and increased with their densities.

From a general perspective, it is evident that the metabolic rate - body size relationship of an elephant would suggest that it would be least selective. However, the results of the present study as well as other current literature suggest that selection is practiced among plant species but this needs to be distinguished from selection for plant parts. For example, Chafota (2000) investigated seasonal variation in the selective utilisation and dietary contribution of woody plant species, parts, and height classes to vegetation consumed by elephants in Kalahari sandveld region of Chobe National Park, Botswana, while de Beer *et al.* (2014) investigated the alteration of woody vegetation in law rainfall areas, in Etosha National Park, Namibia. They noted that only 30 % of 27 common woody species were moderately or highly acceptable to elephants in the wet season, increasing to more than 50% in the hot dry season. Six woody species remained mostly or entirely rejected by elephants through out the year. Most of the browse consumed during each season came from 1 or 2 common shrub species. Leaves and leaf bearing shoots constituted 80 % of the material consumed from woody plants during the wet season. Stem, bark, and root tissues contributed 50 % of the woody plant component of the diet in the cool dry season increasing to 94 % in the hot dry season. This explains the high value 80% obtained in this study for broken branches and stems the parts which contain leaves and leaf bearing shoots as well as bark.

It is for this reason that despite the selection of species in their foraging, the selection of different plant parts coupled with hind gut digestion enables elephants to exploit a wide range of plant parts such as fibrous stems, bark and roots as also acknowledged by Chafota (2000). From this standpoint and since elephants seem to eat almost all parts of woody plants from roots, stem, branches and leaves as well as twigs, one would immediately assume therefore that, the relationship between elephants and woody vegetation is linear such that as numbers increase impact and mortality on woody plants also increases. Based on that assumption many management plans in sub-Saharan Africa desire to establish stocking densities which is based on the application of a linear relationship so that as elephant numbers increase or decrease the impact or mortality of woody plants increase or decrease linearly, for example if there were 100 elephants and a 10 % mortality rate of trees caused by elephants, reducing the population to 50 will reduce the impact to 5 %. However, this may not always be the case. As observed in this study where there was selectivity for species and plant parts, it is evident that the relationship may not be linear, because; i) factors influencing plant palatability and preference vary based on the attributes of the plant that can attract or repel them, animals usually select plants with comparative higher nutritional value. In support of this argument, Holdo (2003), Chafota & Owen – Smith (2012) reported on the relationship between elephant damage and leaf nutrient concentration across tree species in a semi-arid savannah in western Zimbabwe with the purpose of investigating possible nutritional factors influencing elephant feeding preferences in Kalahari sand woodlands. They recorded the presence of elephant damage in all trees above 1 m in height, and leaf samples were collected from all tree species encountered in 12 vegetation plots during the late dry season. It was found that elephant damage was positively correlated with leaf calcium, magnesium, potassium and protein concentration, but not with sodium, phosphorus or fibre. They also found that tree species associated with sandy soils appeared to be less preferred by elephants and to have lower nutrient concentrations than species occurring on more fertile soils, such as species associated with termite mounds. In preferred feeding sites therefore, elephant damage may suppress recruitment in such woodlands (Figure 10).

Figure 10 Example of elephant feeding on coppice after previous utilization which prevents the tree form growing further and therefore making forage material within reach. (Source: Photograph courtesy of - gettyimages.com)

This notion was supported by (1) the fact that 44% of all trees surveyed had had their main stems broken by elephants, a situation that leads to a multi-stemmed growth form with limited vertical growth; and (2) the negative correlation between the height of damaged trees and elephant damage across species. Plant parts were not eaten in equal proportion which accounted for the variation in the proportion of damage categories, growth stage of the plant such that shorter smaller stem girth plants even of the same species were easily accessed and may have experienced heavier browsing, structural component of the plant such that softer stems may experience debarking and scarring than harder stems as is the case with baobab, stimuli in the animal which brings desire to begin to eat and to stop which may have temporal variations, learned behaviour linked to previous experiences, internal physiology and use of senses of sight, smell, touch, and taste. Environmental factors such as weather and climate as determined by temperature, humidity and rainfall such that in drier parts of the year animals would rather take materials with higher moisture or succulent parts, Soil moisture, soil mineral content influence the type of plants which also enhances selectivity.

It is also evident that elephants are not the same. For instance, the foraging patterns of bulls may be such that they take more biomass than females and may be responsible for pushovers and uprooting and hence responsible for more tree mortality. Additionally, the impact of elephant feeding will usually impact differently depending on the vegetation community. Some vegetation communities may receive significantly higher impacts than others depending on species composition growth form and other factors.

Studies carried out by Sackey & Hale (2008) in Mole National Park in Ghana to determine the impact of elephants on woody vegetation showed that elephant damage to trees ≥ 2m tall involved uprooting, main trunk breakage, as well as debarking. They also found that elephant damage on trees in the two vegetation communities examined varied among different species and different height classes (see also Table 1). They concluded that these differential levels of impact were likely to favour the less utilized species such as *Terminally* spp., at the expense of the commonly used species such as, *Burkea africana, Mytenus senegalensis*, and *Vitellaria paradoxa*. However, the study found no compelling evidence to suggest that irreversible changes in vegetation were taking place.

In some instances and when combined with soil factors, fires and other factors, vegetation becomes stunted which is advantegeous to the elephants as they would easily access browing material (Figure 11) .

Figure 11 Example of stunted mopane caused by soil factors and elephant repeated browsing

Such observations have been recorded in the Luangwa valley, Zambia and many other elephant range states particularly when elephant densities were high. In the South Luangwa National Park, as earlier reported by Caughley (1976), large elephant populations, probably in excess of 100,000 animals at a density of more than 2 per km^2 were recorded in the early 1970s. In a study done in and around South Luangwa National Park, Caughley (1976) found that in *Colophospermum mopane* (mopane) woodland elephants felled 138 trees per km^2 per year which was 4% of the standing crop, and estimated that as many or more were killed by ring-barking. The effect of elephants was to change the structure of stands from a spread of sizes to a double-tiered form, the lower tier of coppice around 2 m high and an upper tier of trees over 8 m. When trees in the upper tier were felled by elephants they were not replaced, so elephants prevented recruitment rather than regeneration. As seeds were only produced by large trees their removal also reduced the seed bank (see also Figure 11).

In a *Kigelia-Combretum* woodland on alluvial soils in the same area, elephants felled 4% of the trees of over 20 cm girth in one year. They damaged 6% by pushing them more than 30 degrees from vertical, which caused root damage, and browsed 24% in excess of annual production, by removal of branches. In summary, elephants were killing mopane much faster than recruitment could take place into mature size classes, and converted woodland to grassland in some sites. In *Kigelia-Combretum* woodland there was also a trend to more grassland.

Decades later, Lewis (1991) also worked in the South Luangwa but concentrated on factors that affected elephant damage and the reasons for differences in woodland physiognomy, giving little direct impact data. He found that differences in mopane woodland composed primarily of adult trees and mostly coppice could be attributed to different soil types, but his results also supported Caughley's (1976) findings that browsing by elephants promoted coppice formation in *C. mopane*. Coppiced trees were able to sustain heavy browsing with a low mortality rate of 0.5% per year at an elephant density of about 1.1 per km^2. He hypothesized that soils with a high nutrient status in the A-horizon allowed coppice to persist in spite of heavy browsing, but that periodic die-offs of trees could occur, perhaps associated with depletion of soil nutrient levels or drought. At one site outside the main study area, where elephant density was particularly high owing to proximity to a lodge and some protection from poaching, coppice died after a season with 14% lower than average rainfall.

In Zimbabwe, mopane woodland on islands in Lake Kariba was also converted to bush land and maintained as coppice < 1 m high by elephants that were able to move between the islands and the mainland (Mapaure & Mhlanga, 2000). Elephant density could not be determined because of this movement, but there had been no fire for some time and the vegetation structure appeared to be stable. The authors hypothesized that frequent fires would weaken smaller plants and cause a slow regression to fire-climax grassland, while a reduction in elephant density would allow gradual redevelopment of woodland.

Studies on elephant impacts were also carried out in Kruger National Park, South Africa by van Wyk & Fairall (1969). At the time overall elephant density was low at 0.13 elephants per km^2 and utilization of the vegetation was found to be generally low to moderate, although *Aloe marlothii* had been almost completely eradicated locally 10 years earlier. Only in a few small areas were impacts severe and these were in dry season concentration areas near permanent water sources. Utilization of small trees and shrubs was reported to be negligible and elephants fed mostly from large shrubs. Utilization of trees was higher where shrub density was low or shrubs had been removed temporarily, such as by fire. Some species were selectively heavily used as was the case in this study and in later years the loss of marula (*Sclerocarya birrea*) and knob thorn (*Acacia nigrescens)* became a cause of concern to management.

In 1978, when elephant density had increased to 0.4 per km^2, up to 6.5% of the *Sclerocarya* in a sample near roads were ring barked or felled in one season (Coetzee *et al*., 1979). At that time, damage was thought to be localized and not a threat to the general population of *Sclerocarya*, but later work by (Jacobs & Biggs 2002a, 2002b) showed that they had been completely lost from one habitat and were severely damaged in others which also confirmed selective feeding on certain species.

In another survey Trollope *et al.* (1998) studied the change in woody plant cover in the four major vegetation types in the Kruger National Park using aerial photographs, two on sandy soils and two on clay soils. They concluded that between 1940 and 1960 there was negligible change to the density of large trees on the sandy soil types and a moderate decline on clay soils. Between 1960 and 1986/89 there was a moderate decline on the sandy soils and a moderate to marked decline on clay soils. It was thought that elephants reduced the density of large trees, and a combination of elephants and fire prevented regeneration. Changes in woody vegetation did not reduce species diversity but altered structure leading to short woodland (bush land) with a low density of large trees. Using herbivore enclosure plots in three vegetation types, it was found that although the density of shrubs was lower outside than inside, the differences were not significant. Phytomass was however, significantly lower outside than inside the plots at the two drier sites and there were a higher proportion of large shrubs inside than outside, indicating that elephants were having some impact on shrub density and biomass.

In Sabi Sand Game Reserve, bordering Kruger National Park, elephants were to a large extent excluded by a fence from 1961 to 1993. When the fence was removed elephants started to enter the Reserve, primarily during the dry season (Hiscocks, 1999). By 1998 (5 years) up to 29% of some species were dead as a result of elephant damage.

Similarly, in Ruaha National Park in south-central Tanzania which is 10,300 km2 in extent, with adjacent game reserves forming a 25,000 km^2 area that was first given protection early in the 1900s (Barnes, 1983a), serious tree damage in parts of the park was reported soon after it was proclaimed in 1964 (Savidge, 1968). An aerial survey in 1977 showed that tree loss was evident all over the park at a time when elephant density was 2.4 per km^2 (Barnes & Douglas-Hamilton, 1972). Part of the area falls into a section of rift valley where the average annual rainfall is 580 mm. Dry season elephant density was estimated to be 4.6 per km^2 when Barnes (1980, 1983b) investigated the effects of elephants on three tree species between 1976 and 1982. *Commiphora ugogensis* was an important component of the woodland in the area, *Faidherbia albida* occurred on alluvial soils along the Great Ruaha river and baobabs *were* particularly plentiful. In 1976/77 there was serious damage to all three species. The density of *C.*

ugogensis outside the Park was about 250 trees per ha, but inside the park had been reduced to 4% of this. Elephants were killing 17% of the trees annually and by 1982, *C. ugogensis* had been completely eliminated in places. Between 1977 and 1982 the density of live *F. albida* had declined by 72% in one stratum and 84% in the second. The density of baobabs had decreased by 45% and there were no small trees. The final outcome of this level of impact was not seen because poachers killed around 60% of the elephants in the Park between 1977 and 1984.

Regarding baobab as a species, Whyte (2001) studied it in Kruger National Park in two localities with different histories of elephant occupancy. Where elephants had been present for longest, a significantly higher proportion of the trees showed severe damage; smaller size classes were poorly represented in comparison to an area which elephants had occupied more recently. At a control site with no elephant, small size classes formed a higher proportion of the population than at either of the sites with elephants. Actual mortality was highest during a period of low rainfall between 1981 and 1994, suggesting that damaged trees were more liable to die from other stress factors such as low moisture levels. These impacts occurred even at relatively low elephant densities. At a higher elephant density of about 2 per km^2 in the Zambezi Valley in Zimbabwe, in a sample of 124 trees, 99% sustained damage over a 4 year period and 29% were killed (Swanepoel, 1993). Annual mortality was 7.5%, considerably higher than the 3% recorded at Ruaha with higher elephant density (Barnes, 1983b).

4.2 Conclusion

The results of this study show that elephants select species and plant parts when foraging. Five major damage categories are the commonest, broken branch/stem, debarking (including ring barking and stripping), light and deep scarring, push over and uprooting. Of these damage categories, broken branch/stem had the highest sighting frequency of all, mainly owing to easy access to foliage and twigs. Major factors influencing such selectivity were tree species specific characterists (including nutritional content, moisture levels, softness or hardness of the trunk etc.), height and trunk girth size and others such as season and proximity to water source.

4.3 Recommendations

This study only provided results from a localized site in South Luangwa National Park. It would be advisable to extend to areas where elephant populations are increasing. It is important to expand this work to be representative so as to establish bench marks for long-term monitoring of the interactions between elephants and woody vegetation. It would additionally be important to maintain information on the physiognomy of vegetation communities in preferred feeding areas and also to collect information on age structure and levels of recruitment of affected tree species.

Management should also consider implementing a comprehensive fire management programme because many broken branches may serve as course fuels for late fires while debarked trees may equally be negatively affected and perhaps experience direct mortality.

As already mentioned earlier, the debate as to whether elephant habitat transformation causes loss of biodiversity or not, remains an area of controversy. Having areas where such studies would be established and maintained in the long-term would add to the wealth of knowledge and help understand the role of elephants in forests and woodlands. We would also as a consequence of such long-term studies understand the impacts of elephant damage on woody vegetation and their tailing effects on soil processes and ecosystem functioning. This area of study still requires further vigorous research.

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