

# An Assessment of Impacts of African Elephants (*Loxodonta africana*) on the Structure of Mopane (*Colophospermum mopane*) in the North Eastern Lake Kariba Shore, Zimbabwe

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## Abstract

A study on impacts of African elephants (*Loxodonta africana*) on the structure of *C. mopane* was done on the north eastern Lake Kariba shore, Zimbabwe. The objectives of the study were to determine the structure and abundance of *C. mopane*, determine the levels of elephant induced damage on *C. mopane* along a distance gradient from the lake and to determine the relationship between elephant induced damage on *C. mopane* trees and distance from the north eastern Lake Kariba shore. *C. mopane* trees were sampled in May 2013. Four belt transects were demarcated extending from the lake towards the ZESA pylons. Eight plots measuring 20 m x 30 m were systematically placed at 100 m, 500 m, 1000 m and 2000 m distances from the lake shore within each belt. *C. mopane* variables, that is, tree height, basal area, tree density, shrub density, number of stems per plant, density of damaged plants and number of dead trees were recorded within each plot. Damage was also assessed and rated depending on the intensity of damage. A total of 479 *C. mopane* trees were sampled in 32 plots. Data was analysed using STATISTICA Version 7

Results from Kruskal-Wallis ANOVA test (KWH test), indicated that Height ( $P=0.5423$ ), basal area ( $P=0.9463$ ), tree density ( $P=0.2465$ ), shrub density ( $P=0.3027$ ), number of stems per plant (0.7503, density of damaged plants ( $P=0.1802$ ) and density of dead trees ( $P=0.4603$ ) were not significantly different across all distances from the lake. The results also indicated no significant difference in the level of damage ( $P=0.8050$ ) across all distances from the lake. PCA indicated that trees were densely populated in areas close to the lakeshore (100 m and 500 m) and it is within this area where the highest number of damaged and dead trees was recorded. HCA showed that plots within 2000 m recorded the highest average sapling density, plots within 1000 m recorded the highest average tree height and shrub density and plots within 100 m recorded the highest of density of damaged trees and basal area. Findings from linear regression showed that distance from water create an herbivory gradient of *C. mopane* utilization though the herbivory gradient might not lead to overall degradation of *C. mopane*. Management should focus on maintaining herbivore populations within ranges that does not lead to *C. mopane* woodland degradation.

**Keywords:** Vegetation; Piosphere; Elephant; Damage; *Colophospermum mopane*

## Background

Mega herbivores such as elephants exert a top-down regulation on savannah ecosystems [1]. The impacts of elephants on woodland structure and composition have been reported from many parts of the African continent [2-4]. Large herbivores such as elephants (*Loxodonta africana*) apparently have a negative impact on woody vegetation at moderate to high population densities [3]. Pronounced reductions in trees and other woody plants due to elephant herbivory have been experienced across the African continent, including Cameroon, Tanzania, and South Africa [4-6]. In many game parks in east and southern Africa, the impacts of elephants, have been suggested as being important in converting the vegetation structure of the game parks [7-10]. Studies done in East Africa indicate that the effects of elephants have contributed to massive declines in woodlands and have led to conversion of woodlands to grasslands in some areas [9,11,12]. The middle Zambezi valley region on the Zimbabwean side supports a large population of elephants [13]. The impacts of these elephants on the woodland that they forage on has not been monitored in recently, mainly due to lack of resources, hence need for information for effective park management. Thus, this study investigates the impacts of elephants on *C. mopane* woodland in Kariba, middle Zambezi.

The African elephant is the largest extant land mammal, with females attain their maximum body mass of over 3 tons and males over 6 tons [14]. Elephants are both browsers and grazers, utilising a very

wide range of plants. Grasses are most often taken just after the rainy season, with trees and browse making up the majority of their diet hence its feeding habit is greatly controlled by seasonal changes in food quality [15], Palatable species such *Acacia tortilis*, *Acacia xanthophloea* [16], *Acacia dudgeon* [17], *Blakeanaboehmii* [18], *Colophospermum mopane* [19], *Commiphora* species and *Adansoniadigitata* [20], have declined as a result of elephant browse while less preferred species such as *Julbernadiaglobiflora* [18], or disturbance tolerant species such as *Lonchocarpus laxiflorus* [11], and *Combretum mossambicense* increase. Constant browsing and breaking of preferred plant species by elephants can lead to reduced regeneration and can trap trees into size classes exploitable by elephants preventing recruitment to the taller

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size classes [9].

Despite many years of research by many scientists, the dynamic impact of elephant on the environment is poorly understood [21]. Vegetation modification by elephants is commonly termed 'elephant impact', mostly takes place through elephants toppling, including pollarding whole trees, by breaking and removing branches from their canopies and by preventing or reducing regeneration and recruitment [22]. Elephant utilization can alter the vertical structure of the woody plant community, commonly manifested as reduced tree density and increased shrub density [6]. In particular, where elephant populations are high, tree-dominated savannas are converted to a grass-dominated state [11,22]. For example, an analysis of fixed-point photographs taken in the Kruger National Park, South Africa, has shown that there has been a decrease in the number of large trees due to high fire frequency and high levels of herbivory, particularly that of elephants [7,23], records a reduction in the proportion of mature *Acacia tortilis* (>6 m in height) in the Serengeti National Park, Tanzania, from 48% to 3% of the population between 1971 and 1978, by which time individuals below 3 m in height comprised 94% of the population.

Surface water availability has a strong influence on elephant movements at the habitat and land scape scale [24]. There is a general assumption that water provision leads to the degradation of woodland structure in the influence range of water points or piospheres as a result of trampling and increased herbivory by large herbivores [25]. Vegetation change often decreases as distance to water increases [26]. The concentration of elephant populations around permanent water sources in the dry season can lead to "damaged epicenters" [6,12], suggest that the aggregative response by elephants, and other smaller herbivores, around water points in the dry season results in increased browsing pressure and severe trampling around those areas, suppressing the regeneration of seedlings and shoot growth. A pattern of decreasing browsing pressure with distance from a waterhole is one factor that has been found around waterholes, as well as the creation of a "sacrifice area" of complete vegetation loss at the closest vicinity of water, partly derived from the heavy trampling by game [27].

The North Eastern Lake Kariba shore is dominated by *C. mopane* woodlands and it is a home for resident and migratory elephants (Lake Harvest, undated). This might mean that resident elephants depend on *C. mopane* as their main food source throughout the year and migratory elephants can also utilize *C. mopane* during their stay. Several authors mention *C. mopane* as a bulk food for elephants and claim that elephants have been found feeding exclusively on *C. mopane* and regarded it as a staple food item in elephant's diet [15,28,29]. Elephant densities tend to be higher within *C. mopane* areas than outside them [15]. This implies that *C. mopane* is an important food source for elephants particularly during the dry season since its one the few food plants still carrying leaves during this bottleneck period, and maintaining high feed value throughout the year [15,29] also suggest that *C. mopane* is an essential browse for elephants, as re-growth of leaves and the long leaf-carriage period continuing in the dry season are crucial to sustain elephants through this resource deficit time of the year.

Mapaure and Mhlanga [30], examined the extent, types and patterns of elephant (*Loxodonta africana*) damage on mopane (*Colophospermum mopane*), on six islands in Lake Kariba, Zimbabwe. They found that 77.6% were found to be damaged, the most common form of damage being broken stems. The heavily affected size class were plants less than 20 cm girth, of which 50% were coppicing but most of the coppice shoots were continuously browsed back. Their study focussed on Islands in Lake Kariba, therefore, this study focuses on the

mainland and it sought to determine the impacts of elephants on the structure of *C. mopane* in the north eastern Lake Kariba shore.

## Statement of the problem

Concern has been raised on the excessive browsing of *C. mopane* trees by elephants in the north eastern Lake Kariba shore. Field patrol reports and personal observations show that *C. mopane* woodland structure in this area has been changing. Elephant browsing might have resulted in the alteration of *C. mopane* woodland structure. Elephant browsing has long been suggested a prime factor in the suppression of woody vegetation and preventing tree recruitment and regeneration [31]. Continued heavy utilization of woody vegetation significantly reduced tree basal area, biomass and plant densities which lead to an unsustainable situation [32]. Continued browsing by elephants can also lead to woodland thinning and possible local extirpation of favoured species [19]. This study aims to determine the impact of elephants on *C. mopane* woodland structure in the north eastern Lake Kariba shore.

## Specific objectives of the study

1. To determine the structure and abundance of *C. mopane* in the north eastern Lake Kariba shore
2. To determine the levels of elephant induced damage on *C. mopane* along a distance gradient from the north eastern Lake Kariba shore.
3. To determine the relationship between elephant induced damage on *C. mopane* trees and distance from the north eastern Lake Kariba shore

## Research questions

1. What is the structure and abundance of *C. mopane* in the north eastern Lake Kariba shore?
2. What are the levels of elephant induced damage on *C. mopane* trees along a distance gradient from the north eastern Lake Kariba shore?
3. What is the relationship between elephant induced damage on *C. mopane* trees and distance from the north eastern Lake Kariba shore

## Research hypotheses

1.  $H_0$  There is no significance differences in the structure and abundance of *C. mopane* in the north eastern Lake Kariba shore
2.  $H_0$  There is no variation in the level of elephant induced damage on *C. mopane* along a distance gradient from the north eastern Lake Kariba shore
3.  $H_0$  There is no relationship between elephant induced damage on *C. mopane* and distance from the north eastern Lake Kariba shore

## Significance of study

This research will contribute to knowledge on vegetation structure around piospheres in relation to elephant herbivory. This would provide baseline information on the structure of *C. mopane* woodlands around the north eastern Lake Kariba shore which is one of the largest water impoundments in Zimbabwe. Results could also be used by wildlife managers and ecologists to make decisions on how to conserve and manage piospheres and to manipulate elephant populations. Results from this research can also be used as a baseline for future studies on woody vegetation damage by elephants along the north eastern Lake

Kariba shore.

## Literature review

Mega herbivores such as elephants exert a top-down regulation on savannah ecosystems [1]. Large herbivores being less affected by predation [33], they greatly influence the dynamics of savannah vegetation and ecosystems in general [1]. Numerous studies have been conducted on the impacts of elephants on the woody vegetation and the environment at large. Although literature covers a wide range of such studies, this review will focus on empirical and theoretical studies on the structure of *C. mopane* and factors which influence the structure of *C. mopane*. The impact of elephants on savannah woody tree species in relation to proximity to water sources will also be reviewed.

## Factors influencing abundance and structure of *C. mopane*

Vegetation structure is the vertical, horizontal and temporal arrangement of vegetation [34].

Coulloudon et al. [35], defined vegetation structure as the organization of plants in three dimensional spaces. *C. mopane* woodlands may contain stands of trees up to 20 m and they are termed cathedral mopane [36]. Mopane scrub exhibits regeneration from underground stems that readily coppices, probably as an adaptation to a combination of periodic drought, frost, fires and damage from vertebrates [37]. Usually *C. mopane* ranges from about 10 m [38], to low scrub attaining only 1-2 m and dwarf mopane [39]. *C. mopane* provide woodland cover where few other tree species occur [40]. Mopane woodland stands are often even aged in appearance indicative of episodic or cohort [41].

Mlambo and Mapaure [42], also mentioned that mopane occurs in several physiognomic forms ranging from short mopane (SM, 1-2 m in height); medium mopane (MM, 8-12 m) and tall mopane (TM, >15 m). The cause of the small stature in *C. mopane* has been a matter of debate. Several researchers have suggested that dwarf mopane is a result of excessive browsing pressure by large mammals such as elephants [28,31].

## Impacts of African elephants on structure and abundance of Savannah vegetation

Elephant browsing has long been considered a prime factor in the suppression of woody vegetation, preventing tree regeneration and eventually reducing species richness of Savannah woodlands [31]. When feeding on woody plants, elephants are capable of feeding very delicately causing gross destruction [43]. Vegetation modification by elephants is commonly termed 'elephant impact', mostly takes place through elephants toppling, including pollarding whole trees, by breaking and removing branches from their canopies and by preventing or reducing recruitment and regeneration [19].

Mapaure and Campbell [9], conducted a study on the Changes in miombo woodland cover in and around Sengwa Wildlife Research Area, Zimbabwe, in relation to elephants and fire. The aim of the study was to investigate and quantify changes in miombo woodland cover in and around Sengwa Wildlife Research Area in relation to trends in elephant populations and occurrences of fire in the area. Miombo woodland cover in SWRA and the communal lands around it has been decreasing since 1958, with slight recovery in the former area after 1983 [9]. Loss of woody cover in SWRA was largely attributed to the impacts of fire and large herbivores, particularly elephants. [44], reported a tree

loss of 30.1% caused by elephants and fire in Gonarezhou National Park over 13 years. This figure is comparable to the loss of 27% in SWRA in the study by Van Wilgen [9].

Effects of elephants have contributed to massive declines in savannah woodlands and have led to conversion of woodlands to grasslands in some areas [9,19]. Pronounced reductions in trees and other woody plants have been experienced across the continent, including Cameroon, Tanzania, and South Africa [5,6,45].

Gandiwa et al. [46], conducted a study on the variation in woody vegetation structure and composition in a semi-arid savanna in Gonarezhou National Park. The study showed that elephant browsing significantly affected the woody vegetation structure across Gonarezhou National Park. A higher number of elephant damaged trees was recorded in northern Gonarezhou National Park, particularly on *C. mopane* woodland [46]. This may be a result of *C. mopane* being the common species in the study area, hence, increasing the probability of it being targeted by elephants. Larger trees were less damaged by elephants and most damage was recorded on small trees.

Field observations showed that elephant damage was characterized by breaking of branches and stems, uprooting, pushing over and scarring of woody species [46], trees on hilltops and rocky outcrops were, however, slightly damaged by elephants compared to trees in the plains and this concurs with findings from Mpofo et al. [47]. Moreover, another study in northern Gonarezhou National Park reported marked woodland degradation on *Acacia tortilis* Hayne woodland patches as a result of elephant activity [19].

## Impact of African elephants on woody vegetation around watering points

A piosphere is the basic ecological unit in arid areas under grazing or browsing animals is envisaged as a zone round a watering point [48]. In an arid zone, the animals forage outwards from a watering-point, to which they are obliged to re- turn frequently for drink. This leads to the development of a distinct ecological system, in which the interactions are determined by the existence of the water-point and by the capacity of the animals to forage away from the water-point (Lange, undated).

Mukwashi et al. [22], conducted a study on the impact of African elephants on *Baikiaea plurijuga* wood land around natural and artificial watering points in northern Hwange National Park, Zimbabwe. The aim of the study was to assess the relationship between elephant induced damage to *Baikiaea plurijuga* dominated woody vegetation with distance from artificial and natural watering points, and to compare and establish structural and compositional changes to *B. plurijuga*-dominated vegetation in elephant occupancy zones at both artificial and natural watering points. *B. plurijuga* woodlands around artificial watering points and natural watering points showed major differences in canopy cover, suggesting that high damage to woody vegetation by elephants is associated with artificial watering points than natural watering points [22]. The linear increase in canopy cover with increase in distance from artificial and natural watering point could partly be explained through a reduction in damage to mature *B. plurijuga* as a result of a decrease in animal density with distance from the water points. Mature *B. plurijuga* occurred further away from watering points. Smaller and fewer plants were found closer to watering points and the increase in tree dominance with increasing distance from water supported increased canopy cover.

The distinct aggregation of elephants around permanent watering points may result in the opening-up of the canopy layer [22]. Elephants



over-utilize woody vegetation when they remove more biomass than what plants can produce at any given time [49]. In Kruger National Park, density and canopy cover of *Combretum apiculatum* and survival of all woody plants were affected by the construction of a dam [50]. Elephants drink water regularly hence this restricts foraging to within about 15 km from the water source [51].

Elephant concentration has an influence on woody vegetation changes in ecosystems and the habitat modification that results, particularly at high elephant densities, may alter the compositional, structural, and possibly functional diversity of ecosystems [22]. In northern Gonarezhou National Park, South Eastern Zimbabwe, a study by [19], recorded a slight decrease in plant density with increase in distance from natural water sources suggesting that there were slight degradation of woody vegetation around water points [19], conducted a study on the impact of African elephants on the structure and composition of *Acacia tortilis* woodland in northern Gonarezhou National Park, southeast Zimbabwe. The main objective was to establish the extent to which *A. tortilis* woodland structure and composition differed in areas with contrasting elephant utilisation in relation to distance from perennial and natural surface water in northern GNP. Mean tree densities, basal areas, tree heights and species diversity were lower in areas with medium and high elephant utilisation as compared to low elephant utilisation areas. Plants damaged by elephants increased with increasing elephant utilisation. The study findings suggest that *A. tortilis* woodland was gradually being transformed into open woodland.

It is likely that continued elephant browsing on the *A. tortilis* species would lead to thinning of the *A. tortilis* woodland and possible threat of local extirpation of this species particularly in areas near perennial and natural surface water sources [19]. Elephant browsing affect the woody species composition of the *A. tortilis* woodland. In areas where elephant populations are high, tree-dominated savannas can be converted to a grass-dominated state [52].

This modification, commonly termed “elephant impact”, mostly takes place through elephants toppling, including pollarding whole trees, by breaking and removing branches from their canopies and by preventing or reducing recruitment and regeneration [53]. Findings from [19], indicated a decreasing trend in mean tree heights, tree densities, basal areas and species diversities with increasing elephant utilisation in *A. tortilis* woodland patches and elephant damage was mostly in the form of breaking of branches and stripping of tree barks. These findings support the assertions of [3], that herbivores, in this case elephants, influence arid and semi-arid savannas. Observations throughout the African savannas show that elephants prefer Acacia species over other woody species as a source of browse during critical dry periods [54]. Elephants cause vegetation change in structure and composition through their varied seasonal choice of food items that include debarking in the dry season [55].

Boundja and Midgley [56], studied the patterns of elephant impact on woody plants in the Hluhluwe-Imfolozi Park, KwaZulu-Natal, South Africa. The major aim of this study was to determine whether there was any spatial pattern of tree damage across the park landscape in terms of preferred vegetation structure and access to water. Their results indicated that elephants targeted larger stems for all types of damage, with a strong preference for some of the less abundant species such as *A. versicolor* (breaking and toppling) and *C. caffra* and *S. brachypetala* (debarking).

Elephant impacts tended to be distributed evenly across the park landscape, irrespective of stem density or proximity to permanent

water [56]. However [22], suggested that browsing by large herbivores near watering points leads to the degradation of vegetation. Macgregor also stated that elephant impacts are correlated with distance to water as well as tree density

Kupika et al. [57], conducted a study on the impact of African elephant (*Loxodonta africana*) on population structure of baobab trees (*Adansonia digitata*) was assessed in northern Gonarezhou National Park (GNP), south east Zimbabwe. The main aim of the study was to assess the impact of elephants on baobab population structure in relation to distance from permanent water sources in northern GNP. A larger proportion of elephant damaged baobabs recorded were located closer to permanent water sources. This was attributed to the fact that sites close to permanent water source were characterized by rough terrain with a higher proportion of damaged baobab trees largely in areas that appeared easily accessible to elephants [58].

Edkins et al. [10], suggested that damage incurred on any tree depends on its position relative to water, elephant population density, and timing of the initial damage, i.e. early or late in the dry season. Elephants usually encounter baobabs close to permanent water sources, if they are easily accessible, more regularly before or after drinking water during the dry season [57]. This increases the chances of bark stripping and vegetation damage since forage is scarce during the dry season as recorded in several earlier studies [19,22,44,58].

Mhlanga and Mapaire [30], carried out a study on patterns of elephant damage to *Colophospermum mopane* on selected islands in Lake Kariba, Zimbabwe. Their study focussed on the extent, types and patterns of elephant damage to *C. mopane* on some islands of Lake Kariba. They highlighted the impacts of elephants on *C. mopane* regeneration and woodland structure. They noted that *C. mopane* woodland was heavily damaged by elephants, and *C. mopane* appeared to be a favoured food plant. Continuous breaking and browsing appeared to be maintaining *C. mopane* at heights of <1 m and recruitment to higher size classes was prevented. This study is located in the similar region as that of Mhlanga [30]. However, the previous study was focusing on islands but the current study focuses on the mainland. This study contends that the previous study is outdated since it was conducted in 2000, thus the current study will build onto the previous study and will use an area utilised by a larger number of elephants.

## Materials and Methods

### Study area

The research was done on the north eastern part of Lake Kariba (16° 31'S-28° 48'E and 16.517°S -28.8°E) along the lakeshore within Charara Safari Area located in Kariba, Mashonaland West, Zimbabwe. Charara Safari area occupies the north eastern shore of Lake Kariba. The climate of study area can be divided into four seasons based on temperature and rainfall - the cold dry season (June to August), hot dry season (September to November), hot wet season (November to March), and cool dry season (March to May) [59]. The mean temperature during the hot wet season is 28°C and during the cool dry season is 17°C. Kariba receives a variable mean annual rainfall of about 600 mm [60]. Rain starts sporadically in October, increasing slightly in November and reaches its peak in December and February [61].

The north eastern Lake Kariba shore is dominated by *C. mopane* woodland and woodland thicket, *Colophospermum* and *Combretum* species (Lake Harvest, undated). The area is a home for resident and migratory herds of elephants (*L. africana*) and other mammals such as buffalo (*C. caffer*), zebra (*Equus burchelli*), Impala (*A. melampus*), kudu

(*Tragelaphus strepsiceros*) and a range of other antelopes (Lake Harvest, undated).

The whole Kariba shoreline from the head of the lake to the Sengwa estuary consist of partially submerged hillsides formed of karoo sandstone grits of molten series [30]. Basalts and interbedded sandstones occur in Sibilobilo area, while gneisses occur on either side of Sanyati gorge, at Nyadzwa River and near Kariba town [62].

### Research design

A reconnaissance survey which included walking around the study area to have a general idea of the structure of *C. mopane*, identify areas favoured by elephants and evidence of damage by elephants was conducted prior to the study. Systematic sampling procedure was adopted in this study. The study area was demarcated by artificial features [25,46]. Generally the Zimbabwe Electricity Supply Authority (ZESA) power line (pylons) runs along the north eastern Lake Kariba shore and these formed the other boundary of the study area. Therefore the study area consisted of the area bounded by Nyanyana camp, ZESA pylons, National Anglers Union of Zimbabwe and the north eastern part of Lake Kariba.

Four transects (1 km apart) were established extending from the lake towards the ZESA pylons. A distance of 1 km was left from both National Anglers Union of Zimbabwe and Nyanyana Camp. A plot size of 20 × 30 m was used in this study. This plot size was determined following Walker's [63], method of having at least 15 to 20 trees of the dominant vegetation inside a plot. Two plots were systematically placed at 100 m, 500 m, 1000 m and 2000 m distances along each transect to give a total of 8 plots in each transect [25], AGPS (Garmin etrex H) was used to locate position of the sampled plots.

### Data collection

Data on structure of *C. mopane* was collected done in May 2013 since this time of the year species composition is most conspicuous and easy to identify [25], A plot size of 20 × 30 m was used in this study as determined by [63], method of having 15 to 20 trees inside the plot. In each study plot the following vegetation variables were measured and recorded: tree/shrub height, basal circumference, number of stems per plant, number of dead trees and plant damage.

Trees were defined as any woody plants greater than 3 m in height and greater than 6 cm basal diameter above the buttress swell, shrubs were those less than 3 m but greater than 1 m and saplings were those less than 1 m in height [64], *C. mopane* trees located at plot margins were considered as they are inside the plot if half of the root system is inside the plot [63]. For multi-stemmed plants, stems with more than half their base inside the plot were recorded as they were inside the plot [25].

**Measuring tree height:** Mopane tree height was measured using a graduated pole Brack [65]. This was done by placing a pole that will be calibrated in a way that one was able to read the height values when the pole was raised against a tree. For trees greater than the graduated pole height, the pole was manually lifted by a person of a known height and the tree height was visually estimated. For multi-stemmed trees the height of the tallest tree only was measured and recorded [25].

**Measuring basal circumference:** This was done by placing a tape measure right round the tree stem at a height of about 1.3 m from the ground [25]. For multi-stemmed trees, the circumference of all stems was measured and the average circumference was calculated and recorded.

**Assessment of elephant damage on *C. mopane* trees:** Damage was defined as any form of vegetation utilization by elephants [30]. Elephant damage was characterized by breaking of branches and stems, uprooting, pushing over and scarring (bark striping) of woody species. The damage scoring was determined by the form of damage and intensity [22]. Damage was estimated through eye observations Smith [66], and rated within five damage ratings shown on the Table 1.

### Data analysis

**Calculation of *C. mopane* trees' basal area:** The data on basal circumference was used to calculate the basal area for each woody plant in each plot. The basal area was calculated using the formula:

$$\text{Basal area} = (C^2/4\pi)$$

Where C is the basal circumference

**Calculation of *C. mopane* tree, shrub, damaged trees, dead trees and sapling density:** The density of the *C. mopane* was calculated using the data from the physical count. The density was calculated using the formula:

$$\text{Density (trees/ha)} = [x/(\text{plot area hac}^{-1})],$$

Where

x is the recorded number of trees, shrubs, damaged trees, dead trees or saplings.

**Size Structure analysis:** Statistical analyses were conducted using STATISTICA Version 7 [67].

All data were first tested for normality using the Shapiro-Wilk test [68]. All the measured variables were non-normal. Since all the data on *C. mopane* data were not normal, a non-parametric test, the Kruskal-Wallis ANOVA test (KWH test), was used to test for differences across the four study distances away from the lake [69].

Data on basal circumference was used to group *C. mopane* trees were grouped into 5 classes based on the girth size. The girth size classes were <10 cm, 10.1-20 cm, 20.1-30 cm, 30.1-40 cm and >40 cm [30]. A graph was plotted to show the percentage of individuals in each girth size in the north eastern Lake Kariba shore using Microsoft office Excel 2007. Another graph indicating the percentage of individuals in each girth size class across all the distance away from the lake was constructed using Microsoft Excel.

A hierarchical (HCA) was performed on all the 32 studied plots across all the distances to show similarities and dissimilarities among the measured variables (height, basal area, number of stems per plant, tree, shrub and sapling density, density of dead plants and density of dead plants). Principal Component Analysis (PCA) was done to show the structure of *C. mopane* data across all the distances away from the lake [69]. Descriptive statistics were used to summarize the data, comparing damage with distance from the lake and graphical representation using Microsoft Office Excel 2007.

Damage rating Description	Description
0	No damage visible
1	Slight damage, from wind, weather, etc.
2-3	Slight elephant damage
4-5	Moderate elephant damage
6-7	Severe elephant damage

Table 1: Scale used to record browsing damage to *C. mopane* trees [63].

**Analyses of elephant induced damage with distance from the lake:** Kruskal-Wallis ANOVA test (KWH test), was used to test for variation in damage along a distance gradient from the north eastern Lake Kariba shore.

**Relationship between damage and distance from the lakeshore:** A simple linear regression analysis was performed in order to establish the relationship between density of damaged trees and distance from north eastern Lake Kariba shore [22].

## Results

A total of 479 *C. mopane* trees were assessed in 32 sampling plots, 8 plots in each of the 4 belt transects. Eight plots were assessed within the 100 m, 500 m 1000 m and 2000 m distances away from the Lake (Table 2).

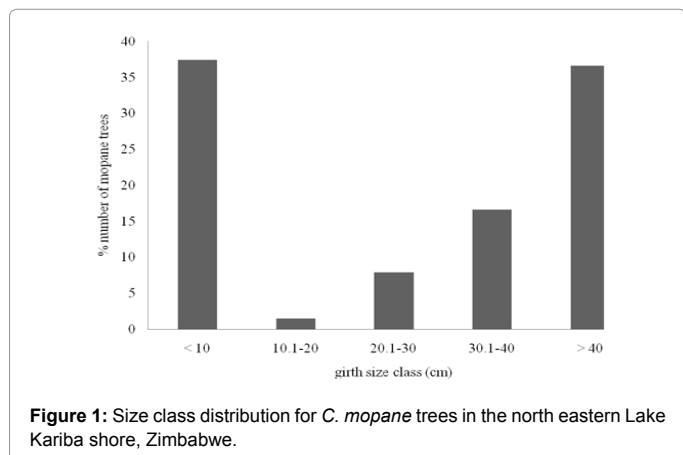
### The structure of *C. mopane* in the north eastern Lake Kariba shore

**Size class distribution of *C. mopane* trees in north eastern Lake Kariba shore:** Trees with a girth size of <10 cm (n=180; 37.4%) and >40 cm (n=176; 36.6%) core dominated the North Eastern Lake Kariba shore whilst trees with a girth size range of 10.1-20 cm were the least dominant (n=7; 1.5%). The graph on girth size class showed a reverse bell-shape curve (Figure 1). This shows that there were more saplings and trees with a girth size of <10 cm and >40 cm core dominated across all distances from the north eastern Lake Kariba shore. Trees with a girth size range of 10.1-20 cm were the least dominant across all distances. The graph on girth size class showed a reverse bell-shape curve across all distances (Figure 2). This shows that there were more saplings and big trees than shrubs.

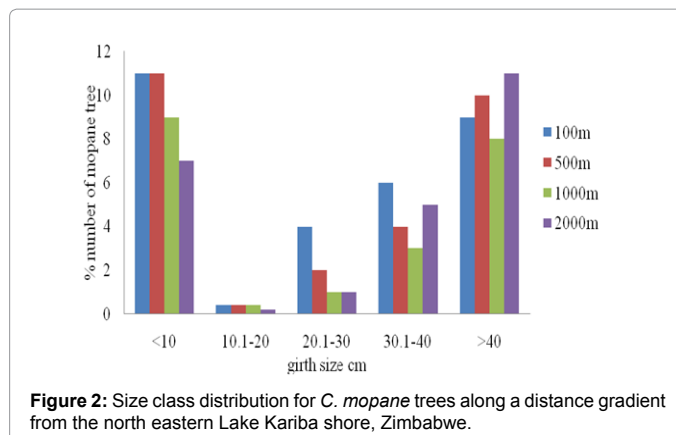
**Analysis of structural attributes and abundance of *C. mopane* in the north eastern Lake Kariba shore:** Analysis of Variance test (Kruskal Wallis H test) indicated that there were no significant differences in all the measured variables (height, basal area, tree density, shrub density, number of stems per plant, density of damaged plants and

Distance from the Lake (m)	Number of <i>C. mopane</i> trees
100	140
500	125
1000	97
2000	117

**Table 2:** Number of *C mopane* trees assessed in North Eastern Lake Kariba shore.



**Figure 1:** Size class distribution for *C. mopane* trees in the north eastern Lake Kariba shore, Zimbabwe.



**Figure 2:** Size class distribution for *C. mopane* trees along a distance gradient from the north eastern Lake Kariba shore, Zimbabwe.

Variables	Median (range)	P – value
Height (m)	5.57 (2.15)	0.5423
Basal Area (m <sup>2</sup> hac <sup>-1</sup> )	0.02 (0.37)	0.9463
Number of stems per plant	1.63 (1.21)	0.7503
Sapling density hac <sup>-1</sup>	366.67 (1.40)	0.7055
Shrub density hac <sup>-1</sup>	91.67(3.64)	0.3027
Tree density hac <sup>-1</sup>	150.00(4.14)	0.2465
Density of Damaged Plants hac <sup>-1</sup>	75.00(4.89)	0.1802
Density of Dead Plants hac <sup>-1</sup>	0.00(2.58)	0.4603

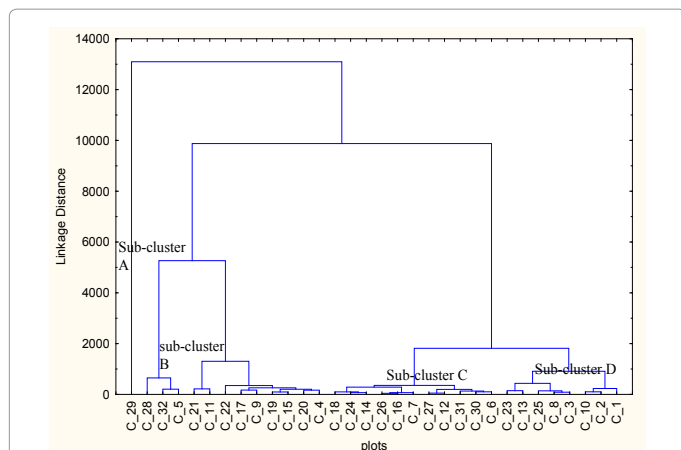
**Table 3:** Summary of statistical analyses from Kruskal-Wallis H test results of the study variables in the north eastern Lake Kariba Shore.

density of dead trees) across all distances away from the lake (P>0.05) (Table 3).

**Cluster analysis of all sample plots in the north eastern Lake Kariba shore:** Cluster analysis was performed to indicate similarities and dissimilarities in the measured variables across all the distances away from the lake. The 32 studied plots were grouped into four sub-clusters. Sub cluster A composed of 3.1% of the study plots and it was drawn from plots located at a distance of 2000 m away from the lake. Study plots in this sub-cluster had the highest average sapling density. Sub-cluster B comprised of 37.5% of the studied plots and it was dominated with plots drawn from a distance 1000 m away from the lake. It is within this cluster where the highest average tree height and shrub density was recorded. Sub-cluster C contains 34.4% of the studied plots and this category contains a mixture of plots across all distances. Plots in this category had low sapling density and high average number of stems per plant. Sub-cluster D contains 25% of the studied plots and it was dominated by plots drawn from a distance of 100 m from the lake. Plots in sub-cluster D recorded the high density of damaged trees and basal area (Figure 3).

**Principal component analysis of the assessed variables:** Principal component 1: defines a gradient from sites with taller trees, high basal area and higher sapling density to areas with shorter and multi-stemmed trees. Principal component 2 defines a gradient of plots with higher tree density, higher density of damaged and dead trees to areas with taller and multi-stemmed trees (Table 4).

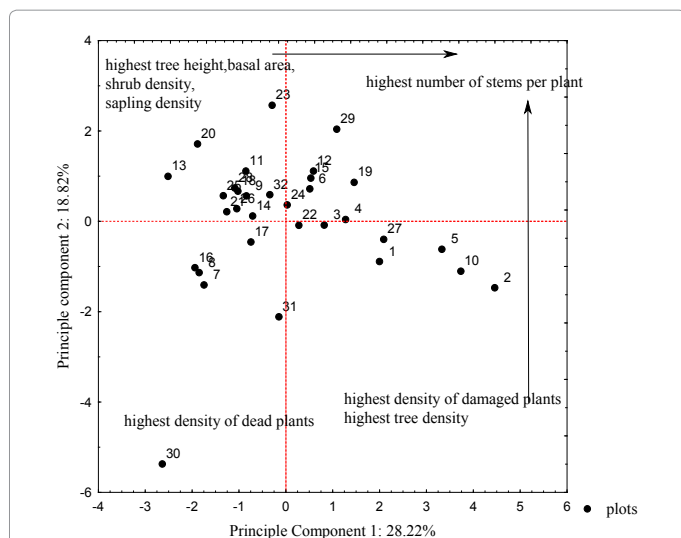
A PCA-biplot with 32 study plots from *C. mopane* woodland in north eastern Lake Kariba shore was performed (Figure 4).



**Figure 3:** Hierarchical cluster analysis dendrogram showing classification of sample plots into four clusters based on sampled variables (height, basal area, number of stems per plant, tree, shrub and sapling density and density of damaged and dead plants) from the 32 sample plots in the north eastern Lake Kariba shore, Zimbabwe. C denotes sample plots.

Variables	Principle	Principle
	component 1	component 2
Height	-0.27	0.47
Basal area	-0.06	0.38
Number of stems per plant	0.12	-0.0006
Tree density	0.82	-0.26
Shrub density	-0.02	0.24
Sapling density	0.14	0.35
Density of damaged plants	0.93	-0.2
Density of dead plants	-0.41	-0.80
Eigenvalue	3.10	2.07
Variance explained (%)	28.22	18.82
Cumulative variance explained by axis (%)	28.22	47.04

**Table 4:** Ordination statistics summary for principal component analysis.



**Figure 4:** Scatter plot of 32 sample plots of *C.mopane* and structural variables (height, basal area, number of stems per plant, tree, shrub and sapling density and density of damaged and dead plants) in the north eastern Lake Kariba shore, Zimbabwe. Numbered data points denotes sample plot.

### Elephant induced damage on *C. mopane* along a distance gradient from the lake

Results from the Kruskal Wallis H test showed that there was no significant differences on the density of damaged trees in the north eastern Lake Kariba shore,  $P=0.1802$ . There was no significant differences in the level of damage along a distance gradient from the north eastern Lake Kariba shore,  $P=0.8050$ . However the overall total sample had 55.2% ( $n=246$ ) damaged *C. mopane* trees and 41.7% ( $n=225$ ) undamaged *C. mopane* trees, while 1.4% of the damaged *C. mopane* trees were coppicing and 1.8% *C. mopane* were slightly damaged by other factors other than elephants. The highest percentage of damaged plants was recorded on plots located at a distance of 100 m away from the lake shore where 64.3% damage was recorded, followed by plots at 1000 m, 500 m and 2000 m with 57.7%, 53.6% and 45.5% damage respectively (Table 5).

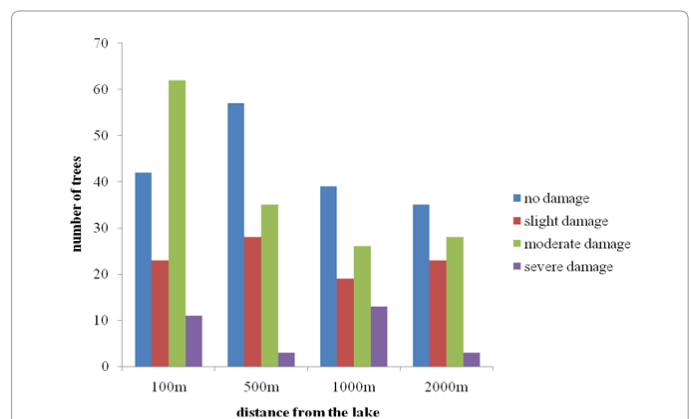
Most trees ( $n=147$ ) were moderately damaged across all distances. Trees within 100 m distance from the lake recorded the highest number ( $n= 63$ ) of moderately damaged trees followed by trees within 500 m, 2000 m and 1000 m respectively. The highest number of slightly damaged trees was recorded at 500 m distance away from the lake. 100 m and 2000 m distances recorded equal numbers of slightly damaged mopane trees and 1000 m distance recorded the lowest number of slightly damaged tree. The highest number of severely damaged trees was recorded at the distance of 1000 m away from the lake followed by trees within 100 m and trees within the distance of 500 m and 2000 m were equally severely damaged (Figure 5).

### Relationship between elephant induced damage on *C. mopane* and distance from the water

Regression analysis results showed that there was an insignificant negative relationship ( $R^2=0.386$ ;  $P<0.05$ ) between density of damaged

	Distance from the lake shore			
	100 m	500 m	1000 m	2000 m
% plants slightly damaged	1.4	0.8	0	5.1
% plant damaged	64.3	53.6	57.7	45.3
% plants not damaged	30.7	46.4	40.02	49.6
% plants coppicing	2.4	0	3.1	0

**Table 5:** Percentage of individuals damaged and coppicing mopane in North Eastern Lake Kariba shore, Zimbabwe.



**Figure 5:** Elephant damage level of *C. mopane* with distance from the north eastern Lake Kariba shore.



*C. mopane* trees and distance from the lake. Density of damaged *C. mopane* trees generally decreases with increasing distance from the lake (Figure 6).

## Summary

*C. mopane* saplings dominated the north eastern Lake Kariba shore and they dominated across all distances from the lake. There were no significant differences in abundance (sapling density, shrub density and tree density) and structure (height, basal area, number of stems per plant) of *C. mopane* across the north eastern Lake Kariba shore. There were no significant differences in the density of damaged and dead plants. The results also revealed there was an insignificant difference in damage along a distance gradient from the north eastern Lake Kariba shore. This study indicated that there is an insignificant negative relationship between density of damaged trees and distance from the north eastern Lake Kariba shore.

## Discussion

This section contains an interpretation of the research findings based authorities' work related to the findings of the current research. It highlights similarities in the results of the current study and differences and also tries to deduce the possible causes to these differences or similarities. This section will cover findings on the structure and abundance of *C. mopane* in the north eastern Lake Kariba shore, level of elephant induced damage on *C. mopane* along a distance gradient from the north eastern Lake Kariba shore and the relationship between elephant induced damage on *C. mopane* and distance from water.

### Structure of *C. mopane* in the north eastern Lake Kariba shore

Trees with a girth size class of <10 cm and >40 cm core dominated the north eastern Lake Kariba shore. More *C. mopane* trees in the low girth size class show that there is high regeneration of *C. mopane* in the study area. The reverse bell shaped graph of girth size classes indicates that there was high *C. mopane* regeneration and reduced recruitment in the study area. This supports the notion that elephants do not prevent regeneration of *C. mopane* as such but prevent recruitment into taller size classes [56,70], found that elephants had little impact on woody plants' saplings in Hluhluwe-Imfolozi.

Dominance of saplings can also be explained by low frequency of fires in this area since burning is prohibited within this area (Park's fire management plan). Annual fires destroy and weaken the vulnerable

small plants and coppice shoots thereby converting woodland to shrub land or grassland savanna [71]. On the other hand [25], found that fires have relatively less negative impact on woody vegetation near water sources in Gonarezhou. In the event that uncontrolled fires happened in this area the notion that fires can have little negative impacts on woody vegetation can support the idea of sapling dominance.

The smaller proportion of plants between the girth size ranges of 10.1-20 cm might be an indication of their vulnerability to elephant damage [30,56], put forward the idea that elephants target plants according to the stem size and favoured stem sizes become vulnerable to elephant damage. Mapaura and Mhlanga [30], found that plants of girth size <20 cm were the most damaged and they suggested that this is an indication how vulnerable plants of this girth size class are to damage by elephants.

This study showed no significant differences in *C. mopane* structure and abundance in the north eastern Lake Kariba shore. This might be an indication that *C. mopane* was uniformly affected by elephant utilization across the north eastern Lake Kariba shore [25], stated that the effect of large herbivores on watering points may be one of utilization rather than destruction, and woody vegetation may be utilized evenly with distance from water. In northern Botswana, Ben-Shahar [64], reported that woodlands dominated by *C. mopane* subjected to obtrusive elephant damage had largely unchanged densities of tall trees. Additionally, savanna woody plants have evolved with disturbances such as fire and herbivory and hence have traits to resist or tolerate both these disturbances Helm [72].

However insignificant differences on structural and abundance attributes (height, basal area, tree density, shrub density, number of stems per plant, density of damaged plants and number of dead trees) were against the general assumption that aggregative response by elephants, and other smaller herbivores, around water points result in increased browsing pressure and severe trampling around those areas, suppressing the regeneration of seedlings and shoot growth [25,73], recorded changes in tree density and basal area with distance from water points, despite the increasing elephant population in Gonarezhou National Park found that tree and shrub density was low close to water, and generally increased as with distance in Hwange National Park.

Results from cluster analyses indicated that samples plots from a distance of 100 m had a high density of damaged plants. Plots within a distance of 1000 m were dominated with tall trees. High density of damaged trees within the 100 m distance is in support of Conybeare [51], who categorized the distance <1 km away from a watering point as high elephant occupancy zone where severe woody vegetation damage take place. Similarities in the number of stems per plant indicate a uniform utilization of *C. mopane* across all distances. The presence of tall trees at a distance of 1000 m could be attributed to the entrance of another elephant occupancy zone which is the moderate elephant occupancy at 1-2 km away from a watering point and where there is relatively reduced woody vegetation damage [51].

All sample plots across all distances indicated an almost similar average number of stems per plant. This might be an indication of resprouting after herbivore utilization. Disturbance, such as herbivory are likely to promote vigorous resprouting [62]. This concurred with [46], on their study on the variation in woody vegetation structure and composition in a semi-arid savanna of Southern Zimbabwe. Their results shows that the majority of trees were multi-stemmed, a situation normally resulting from resprouting in response to disturbances.

Result from Principal Component analysis indicated that plots that

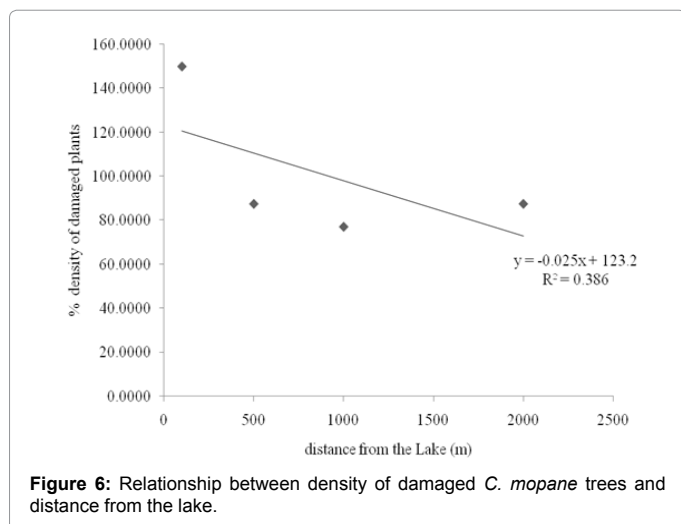


Figure 6: Relationship between density of damaged *C. mopane* trees and distance from the lake.



were at a distance of 1000 m and 2000 m recorded the highest trees height, sapling density shrub density and basal area and plots within the distance of 500 m and 100 m recorded the highest tree density, highest density of damaged and dead trees. This is meant to say more saplings, big and tall trees were located within the 1000 m and 2000 m distances away from the lake as compared to 100 and 500 m distances. It also means that more trees were located in areas close to water (100 m and 500 m) and they were the most damaged.

Elephants often change the structure particularly in areas close to water sources [22], Browsing herbivores can indirectly decrease seedling establishment by drastically reducing tree reproductive output [74]. It has been demonstrated that browsing by herbivores reduces woody seedling survival substantially in savanna ecosystems [75]. This can be used as an explanation to the less dominance of saplings within the distance of <500 m away from the lake. Continuous browsing from elephant results in many small and medium sized trees being knocked down [13]. Dominance of big trees and more shrubs at >1000 m than at <500 m distances can be a good indicator that shrubs are the most vulnerable group targeted by elephants in areas close to water sources. Shrubs in close proximity to the lake might have been knocked down by elephants and other herbivores.

### Elephant induced damage on *C. mopane* along a distance gradient from north eastern Lake Kariba shore

There was no significant difference in damage across all distances from the north eastern Lake Kariba shore and this can be equated to uniformity in utilization of *C. mopane* by elephants or even distribution of elephants across the area. In addition most of the trees were moderately damage across all distances. Makhabu et al. [76], also recorded no severe degradation of habitat around water points in Central Kalahari Game Reserve of Botswana stated that the effect of large herbivores on watering points may be one of utilization rather than destruction, and woody vegetation may be utilized evenly with distance from water. In northern Botswana reported that woodlands dominated by *C. mopane* subjected to obtrusive elephant damage had largely unchanged densities of tall trees. Additionally, savanna woody plants have evolved with disturbances such as fire and herbivory and hence have traits to resist or tolerate both these disturbances Helm [72].

However the insignificant differences in damage across a distance gradient from the north eastern Lake Kariba shore is against the general idea vegetation damage is severe on areas in close proximity to water sources and reduced as distance from water increase [51,77], in HNP recorded highest elephant occupancy and most severe woody vegetation damage within 1 km radius within an artificial watering point, moderate elephant occupancy at 1–2 km radius, and a fairly low and uniform zone between 2 and 16 km radius.

### Relationship between elephant damage and distance from water

An insignificant negative linear relationship between density of damaged *C. mopane* trees and distance from the lake was recorded. Density of damaged trees decreased as distance from the lake increased. This might be a result of a decrease in animal density with distance from the water points [22]. Water dependant animals gather around waterholes and impose heavy browsing pressure on adjacent vegetation [27,78], also recorded a reduced gradient of vegetation utilization away from water in the Tembe Elephant Park, Maputaland, South Africa.

Other social and ecological factors not investigated by this study could have influenced the *C. mopane* woodland structure in the

North Eastern Lake Kariba shore. These factors range from droughts, frost, fire, disease, herbivores other than elephants, edaphic factors, topography and human activities [3]. The study is surrounded by human settlements and human tourism activities such as game viewing and wire sweeping activities are some of the regular activities which are conducted within the study area. Human presence influence animal movements and distribution within an area. Animals in continuous human disturbed areas generally leave these areas if the costs involved in repeatedly leaving the feeding area are greater than the physiological consequences of chronic stress [79]. The uniformity in abundance and structural attributes (height, basal area, tree density, shrub density, number of stems per plant, density of damaged plants and number of dead trees) can be an indication that there is a relatively reduced density of elephants and other herbivores within the study area as a result of such human activities.

### Conclusion

This study shows no significance differences in structure and abundance of *C. mopane* structure and abundance in the north eastern Lake Kariba shore. There was no variation in the level of elephant induced damage on *C. mopane* along a distance gradient from the lake. *C. mopane* shrubs were the most damaged plants compared to saplings and big trees in the study area. The study also indicated that there is a negative relationship between elephant induced damage on *C. mopane* and distance from water. Distance from water creates an herbivory gradient of woody vegetation utilization as indicated by the reduction in density of damaged *C. mopane* with an increase in distance from the lake. Therefore there is need to constantly monitor elephant populations within this area since an increase in elephant population can have drastic impacts on mopane woodland in this area.

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