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Influence of Soil Drainage and Elephant (*Loxodonta africana*) Damage on Abundance and Structure of *Colophospermum mopane* in Central Mana Pools National Park Zimbabwe

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Abstract

A study on the influence of soil drainage and elephant damage on the abundance and structure of *Colophospermum mopane* was carried out in Central Mana Pools National Park (MPNP) Zimbabwe. Data were collected in April-May 2013. The stratified random sampling method was employed. The study area was stratified according to soil drainage. Three strata were established namely; well drained, moderately drained and poorly drained soils. Ten plots were sampled in each strata and a total of 30 plots were sampled to determine the abundance and structure of *C. mopane* in Central MPNP. Results from One way ANOVA showed significant differences in tree height, basal area, tree canopy volume, shrub canopy volume, sapling density, tree density, number of stems per tree and damaged trees density ($P<0.05$). There was no significant difference in the number of dead trees across the three strata ($P>0.05$). Moderately drained soil had the highest number of undamaged trees (n=91; 42%), saplings and stems per tree. Well drained soils had the highest number of damaged live trees (n=112; 51%) and poorly drained soils had the highest number of dead trees (n=60; 51%). There were significant differences in damage ($P<0.001$). Regression analysis showed a negative relationship between elephant density and damaged trees density ($R^2=0.03$; $P>0.05$), however, there was a positive relationship between elephant density and dead trees ($R^2=0.3865$; $P<0.05$). Results from this study suggest that soil properties as well as elephant damage have an influence on the abundance and structure of *C. mopane*, therefore the need for constant monitoring of this tree species.

Keywords: Abundance; Damage; Soil drainage; Structure

Introduction

Background of the study

Top down regulation of ecosystems by large mammals has created an active debate between scientist and managers and a prime example is the interaction between the African elephant (*Loxodonta africana)* and trees in African savannas [1]. Scientists have considered elephant browsing to be the prime factor in the suppression of woody vegetation preventing tree regeneration in savannah ecosystems [2]. However, the physiognomy of most plants is known to be influenced by both biological and physical factors [3]. Climate, topographic positioning, soils, large herbivores, fires and anthropogenic influences are important determinants of woodland composition and structure in savanna ecosystems [4]. Differences in soils have been linked to variations in woody vegetation structure over large areas [4].

Altitudinal variations have an effect on natural occurring processes like soil erosion. Erosion supports soil detachment, movement and deposition which cause movement of top soil and organic matter down the slope there by influencing cropland productivity on different levels of soil drainage [5]. Topsoil is rich in nutrients and soil life and builds over time through erosion. Soil fertility can regulate the physiognomy of plants [6]. There is a paucity of literature on variations in savannah vegetation structure and abundance in different soil groups. The effects of the tree species on soil properties is somehow known but despite several decades of research into *C. mopane* the influence of soil properties on *C. mopane* dominated vegetation is largely unknown [7].

Research has revealed that *C. mopane* itself has an influence on soil properties. Lynan et al. [8] investigated the influence of *C. mopane* on soil properties by collecting soil samples under and outside small, medium and large canopied *C. mopane* trees in open woodland on shallow sandy loam soils. The concentration of soil nutrients beneath trees increased with tree size and soils beneath trees had higher fertility than between tree interspaces. *C. mopane* is often found in landscapes that are characterised by denuded soil surfaces, a lack of perennial plant cover and severe soil erosion [9]. In another study in Mana Pools National Park (MPNP) [10], investigated litter fall, nutrient fall and production in *A. albida* woodlands. Results from this study showed that litter fall influenced nutrient composition in the *A. albida* woodland and a conclusion was made that *A. albida* woodland in Mana Pools National Park floodplain was not deficient in phosphorus.

Elephants are a major determinant of vegetation structure and abundance in the Mana Pools National Park (MPNP) and are believed to be responsible for opening up areas of both the floodplains and the inland woodlands [10]. Surveys indicate that the Mana Pools elephant population may be between 3 and 4 thousand individuals and that of the entire survey area in Zimbabwe is close to 20,000 [11]. Much of these populations range is within *C. mopane* woodland which often forms pure stands [12]. *C. mopane* is a principal food source for elephants in many conservation areas of southern Africa [13].

C. mopane shrubs and trees are heavily browsed by elephants throughout northern Zimbabwe with their water retaining capabilities

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[14]. Timberlake [3] investigated long term changes in Zambezi riparian woodlands. The study was aimed at determining the changes in the woodlands as well as identifying factors causing the changes. The study concluded that the flooding caused by the closure of the Kariba dam had an effect on the riparian vegetation. The results of the study also showed lack of recruitment attributed to elephant density. However, mortality did not vary in relation to temporal changes in elephant density.

Although being considered unspecialised feeders, there are some plant species that appear preferentially selected by elephant feeding in forests and woodlands. Elephants browse intensively on *mopane* trees and prefer *mopane* to many other trees [14]. The interactions between elephants and *C. mopane* shrubs and trees were examined with reference to elephant off take and growth rates of plants [13]. A logistic model predicted maximum levels of biomass removal from plants and differentiated between sustainable utilization and over-utilization of *C. mopane* by elephants. The predictions were based on recorded range of above ground biomass of *C. mopane* shrubs and trees and elephant densities in some parts of the Zambezi valley [3].

Soil characteristics influence the response of plants to elephant damage. The probability of tree death on elephant impact has been found to be related to aridity, soil type, and size of the tree, nutrient status and the response of woody species to elephant damage [15]. The high water infiltration rate on deep, light-textured soils favours the growth of woody species. As a result, density and biomass of woody plants are usually higher than on heavier soils and browse removed by elephants is more quickly replaced. Many of the tree species that grow in deep sandy soils are relatively unpalatable to elephants, for example *B. plurijuga* and *E. africanum* [16]. This can also reduce the visual impact of elephant browsing. The same species may even respond differently to elephant browsing on nutrient-poor and nutrient rich soils [1]. In sandy soils, trees are more likely to be pushed over than broken; although the species and it's rooting characteristics also have an influence. The occurrence of natural coppice mopane shrubland that appears to have no potential to develop into woodland has been linked to soil characteristics [17].

Previous studies on biological and physical impacts on vegetation in Mana Pools National Park (MPNP) have been confined to the flood plain which is dominated by *F. albida* species. Dunham, (1989b) studied vegetation environment relationship of a middle Zambezi floodplain. Other studies have focused on the impact of elephants on baobab trees in the park [18-19]. A few studies have been done on the impact of elephants and other environmental factors (particularly soils) on vegetation within the valley flow which is dominated by *C. mopane*. Therefore, this study aimed at determining the influence of soil drainage and elephant damage on *C. mopane* structure was conducted in Mana Pools National Park (MPNP) Zimbabwe an area which lies in the mid Zambezi valley floor.

Statement of the research problem

Elephants have modified patches of *mopane* woodlands on the valley floor especially on sodic soils adjacent to the Zambezi alluvium [10]. Briefings from patrols have reported the woodlands to be under threat as the pressure from elephants is so high and this may affect the important regeneration of these tree species. Concerns have been raised but no empirical data exists to substantiate this.

Significance of the study

This study seeks to set a benchmark for park managers to be able to monitor elephant damage and also seeks to be a baseline study of *C. mopane* so as to give reference to other studies on other tree species. Investigating the influence of elephant abundance and soil drainage on the structure of *C. mopane* woodland in a savanna environment such as MPNP may assist in better understanding of the complexity of some of the factors altering *C. mopane* woodland.

Research objectives

1. To determine and compare the structure and abundance of *C. mopane* across three soil categories along an altitudinal gradient in Central MPNP.

2. To compare elephant damage to *C. mopane* across three soil categories along an altitudinal gradient in Central MPNP.

3. To determine the relationship between elephant density and elephant damage to *C. mopane* in Central MPNP.

Research questions

1. What is the structure and abundance of *C. mopane* across three soil categories along an altitudinal gradient in Central MPNP?

2. What are the levels of elephant induced damages across three soil profiles in Central MPNP?

3. What is the relationship between elephant density and damage on *C. mopane* structure in Central MPNP?

Research hypothesis

1. H_0: there is no difference in structure and abundance of *C. mopane* along an altitudinal gradient in Central MPNP.

2. H_0: there is no difference between elephant damage to *C. mopane* across soil groups in Central MPNP.

3. H_0: there is a positive relationship between elephant density and damage on *C. mopane* in Central MPNP.

Literature Review

Influence of soil catena on soil properties and vegetation

Topographic positioning and soils are considered to be major determinants of woodland composition and structure [20]. Topographic gradient, however, influence vegetation on a large scale whereas minor altitudinal gradients can have an effect on soil variations as established by the concept of a soil catena suggested. The concept suggests that soil variations develop down a slope affected by the same climatic conditions namely, precipitation, runoff, infiltration and evaporation [21]. These processes affect soil depth, acidity (PH) and soil moisture continuously along the slope [22]. These variations in soil properties in turn affect vegetation development down the slope [6].

Ping et al. [9] investigated the soil catena sequences and fire ecology in the Boreal forests of Alaska. The study was aimed at characterising soils and landscape relationship in the study area. The study concluded that vegetation development had a relationship with slope, aspect and slope gradient hence they are considered major controlling factors for the contrasting soil types along the catena sequences in the watershed. Also in Canada, Claudio et al. [23] investigated the downward movement of phosphorus in paddy soils were they concluded that phosphorus concentration declines along an altitudinal gradient due to the difference in soil drainage.

Influence of soil properties on *C. mopane* structure: Soil properties are responsible in shaping the physiognomic structure of tree species. Wildlife management [10] investigated the natural vegetation of gypsum bearing soils in south central Africa. The findings of this study showed that there is no species entirely confined to the gypsum soils, however, there is an ecologically distinction in the flora in that there is significant dwarfing of woody species, particularly *C. mopane*. Findings showed that the effect on the vegetation of the gypsum soils is, at least in part, physical, partly due to compaction and partly due to the creation of very sticky black soils in the wet season. The percentage of clay in these soils is very high.

C. mopane is often found in landscapes that are characterised by denuded soil surfaces, a lack of perennial plant cover and severe soil erosion [9]. In dry, low altitude areas of southern Africa, the species forms large monotypic stands on landscapes with heavy, calcareous and sometimes sodic soils by Mlambo et al. [9], Wessel [24]. Van-Rensburg [25] mentioned that *C. mopane* is widespread on heavy clays and calerete soils which are overlain by sand or in dense clays with high sodium content along flood plains and it may also occur on heavy clay overlying shales, on shaly hillsides and on sands overlying calerete.

Mlambo and Mapaure [7] explored the influence of soil fertility on the physiognomy of the African savanna tree *C. mopane* in Gonarezhou National Park, Zimbabwe. *C. mopane* were classified according to their physiognomic forms which include short mopane (SM, 1–2 m in height), medium mopane (MM, 8–12 m) and tall mopane (TM, >15 m). In each *C. mopane* type, soil samples were collected up to a depth of 15 cm to investigate the level of soil nutrient concentrations. SM stands were associated with low phosphorus and high levels of calcium and sodium relative to MM and TM. The low levels of phosphorus in SM relative to other mopane types suggest that phosphorus may be an important nutrient limiting growth in dwarf mopane.

Lynan et al. [8] explored the influence of *C. mopane* on under storey vegetation in Southern African Savanna in Bulawayo, Zimbabwe. Soil samples were collected (depth 0-10 cm) under and outside small, medium and large canopied *C. mopane* trees in open woodland on shallow sandy loam soils. Soil nutrient concentration beneath trees increased with tree size. Soils beneath trees with bigger canopies were also more fertile than those with smaller canopies. Soils beneath trees had higher fertility than between tree interspaces. Trees seem to be the major suppliers of nutrients to the understory vegetation in the crown zone in the form of litter.

Effects of elephant damage on abundance and structure of woody vegetation

The modification of woodlands by elephants is commonly termed as 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 [26]. Noticeable impacts of elephants on plants are largely referred to as elephant damage [27]. Elephant browsing has been considered a key factor in the suppression of woodlands where it prevents regeneration and also affects richness of savanna woodlands [28].

In a study in Gonarezhou, Zisadza-Gandiwa et al. [29] investigated the variation in woody vegetation composition and structure. The study concluded that elephant browsing affected woody vegetation structure across Gonarezhou National Park with a high number of elephant damaged trees recorded in Northern Gonarezhou National Park particularly on *C. mopane* woodland. Field observations showed that elephant damage was characterized by breaking of branches and stems, uprooting, pushing over and scarring of woody species [30]. Mhlanga and Mapaure [31] suggested that elephants can convert a mopane to a shrubland. Timberlake [3], also stated that continuous browsing from elephants results in many small and medium sized trees being knocked down, effectively forming a shrubland 1.5-2 m high. Zisadza-Gandiwa et al. [29] also found that larger trees are less damaged by elephants and most damage is on small trees.

Most damage to woody plants occurs in the dry season where elephant distribution is restricted by availability of surface water [16]. Kupika et al. [20] investigated the impact of African elephant (*Loxodonta africana*) on population structure of baobab trees (*Adansonia digitata*) in northern Gonarezhou National Park (GNP), southeast Zimbabwe. The study was aimed at assessing the impact of elephants on baobab population structure in relation to distance from permanent water sources in northern GNP. Results concluded that large proportions of elephant damaged baobabs recoded were located closer to permanent water sources. Findings were attributed to the fact that sites close to permanent water source were characterized with rough terrain and a higher proportion of damaged baobab trees mostly in areas that appeared easily accessible to elephants.

In a study on the impact of African elephants on *Baikiaea plurijuga* woodland around natural and artificial watering points in Northern Hwange National Park, Zimbabwe Mukwashi et al. [32] aimed to assess the relationship between elephant induced damage to *Baikiaea plurijuga* dominated woody vegetation with distance from artificial and natural watering points. The study also aimed to compare and establish structural and compositional changes to *B. plurijuga*-dominated vegetation in elephant occupancy zones at both artificial and natural watering points. Results from this study conclude that artificial watering points were mainly associated with elephant damaged trees.

Studies have linked elephant browsing to have an effect on exposing trees to other activities which eventually cause tree death. These include fungal infections, ants and exposing those to herbivore from smaller herbivores [33]. *C. mopane* tree trunk also protects the tree species from fire as damage from fires is reduced by the presence of the trunk. Elephants expose the tree to fires by bark stripping. Owen-Smith [33] explored the relationship between elephant damage and fungal infections on *C. mopane* in North Luangwa Zambia. The results of this study suggested that the severity of physical damage from elephants had a relatively small influence on the activity of fungi colonizing and utilizing *C. mopane* heartwood. The majority of fungi isolated from infected trees were saprophytes, and the common existence of fungal agents in healthy trees suggests that heartwood degradation is not detrimental to the health of the tree. 'Internal roots' produced from the cambium inside the hollow trunk, which apparently utilize the detritus accumulated there, is probably an adaptation through which *C. mopane* can recycle minerals and nutrients.

Ben-Shahar [2] investigated changes in structure of savanna woodlands in Northern Botswana following interactive impacts of elephants and fire. Woodlands dominated by *C. mopane* plants were subjected to obtrusive elephant damage; however, the densities of tall trees remained mostly unchanged. This study also indicated that when feeding on woody plants, elephants are capable of feeding very delicately or causing gross destruction and these effects of elephant utilisation are often referred to as "damage".

Relationship between elephant density and vegetation damage

There is a concern that high densities of elephants in southern Africa could lead to the overall reduction of other forms of biodiversity.

In areas where elephant's populations are high the dominated savanna woodlands can be converted to grass dominated state [33]. The African elephant exerts a major impact on woody vegetation by selectively felling, debarking and snapping stems, breaking leader shoots or otherwise damaging trees and shrubs [33].

Gandiwa [4] studied the impact of African elephants on *Acacia tortilis* woodland in northern Gonarezhou National Park, Zimbabwe. The study aimed at assessing elephant impact on *Acacia tortilis* in relation to elephant utilisation. The study was stratified according to elephant utilisation levels based on dung counts which were used as an indirect indicator of elephant density. 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 density.

Mashapa et al. [30] assessed the status of African baobab *Adansonia digitata* across Gonarezhou National Park, Zimbabwe. The study was aimed to determine the abundance and structure of baobab *Adansonia digitata* across Gonarezhou National Park. Damage was also assessed in relation to elephant density. Results of the study showed that there were no significant differences in basal area, height and density of baobabs across Gonarezhou and also elephant dung counts and damaged baobabs were similar across Gonarezhou. This might be an indication that elephant densities were evenly distributed across Gonarezhou.

Ben-Shahar [2] investigated elephant densities and impact in the Kalahari woodlands. The study aimed at assessing elephant damage in three woodland types dominated by *Acacia erioloba, Buikiuea plurijuga* and *Colophospermum mopane* which were monitored in plots distributed throughout Northern Botswana. Damage was mainly associated with the structure of the woodland. It seemed that woodlands sustaining high elephant impact, such as *C. mopane* can carry more elephants because of a healthy age structure. O'Connor et al. [34,35] stated that plants respond differently to elephant use as some species decline rapidly, while others are able to persist in the presence of elephants.

Materials and Methods

Study area

Location and climate: Mana Pools National Park (MPNP) is found 15°40′-16°20′S and 29°08′-29°45′E in the semi-arid region of Northern Zimbabwe [11]. Covering an area 2 196 km², the park is flanked by safari areas namely Sapi, Chewore and Hurungwe as well as the Mukwichi Communal land on the south of the park. MPNP experiences a single rainy season from November to April and the long-term 45 years annual average rainfall is 708 mm from period 1967-2012. MPNP experiences its highest temperatures in November and lowest temperatures are recorded in July [11].

Geology and soils: Pebbly Arkoses and Forest Sandstone fluvial and Aeolian sequences of the Upper Karoo Group of Triassic to Jurassic age overlain by post-Karoo Red Beds are found covering most of the valley floor up to the Escarpment foot. The alluvial floodplain vary consisting of deep, poorly consolidating, stratified deposits [11].

Highly saline sodic soils occur above the southern edge of the floodplain. Moving from Zambezi, the Kalahari-type Jesse Sands exhibit deep, well-drained, poorly consolidated red sandy loams, formed in strongly pre-weathered material, which are very acidic and are in marked contrast to the immediately adjacent upper Karoo soils [36].

Flora: *Colophospermum mopane* woodland, *F. albida* woodland, *Brachystegia – Julbernardia* woodland and *Commiphora - Combretum* thicket are the four main types of vegetation types found in MPNP as established by Guy [36]. *F. albida* woodland dominates on rich alluvial soils; hence it is closely associated with the rivers. *Kigelia africana, Lonchocarpus capassa, Trichelia emetica, Tamarindus indica, Ficus zambesiaca, Garcinia livingstonei and Cordyla africana* are some of the species found in the alluvial deposits. The understorey in the floodplains isles developed and consists of species such as *Combretum mossambicense, Combretum obovatum*, *Diospyros senensis*, *Gardenia spatulifolia*, *Grewia flavescens* and *Cardiogyne africana*. Annual grasses found in the floodplain include *Panicum maximum, Rottboellia exaltata, Echinochloa colonum* and *Urochloa trichopus*, and various annual forbs. Perennial grass species usually found lining watercourses which drain the floodplain, with *Vetiveria nigritana* and *Setaria shacelata* are mostly occurring. Dunham [11] subdivides the vegetation in the alluvial floodplain as young *F. albida* woodland, established *F. albida* woodland, *F. albida* dominated mixed woodland, mixed riverine woodland and the *mopane* ecotone.

Fauna: High concentration of large mammals is found in the flood plain during the dry season and increases as the dry season progresses, the pools and Zambezi river will be main water sources and *F. albida* the main food source [11]. MPNP is home to a large number of wild ungulates, notably African buffalo (*Syncerus caffer*), African elephant (*Loxodonta africana*), eland (*Taurotragus oryx*), hippopotamus (*Hippopotamus amphibius*), impala (*Aepyceros melampus*), kudu (*Tragelaphus strepsiceros*), plains zebra (*Equus quagga*), sable antelope (*Hippotragus niger*), nyala (*Tragelaphus angasaii*) and waterbuck (*Kobus ellipsiprymnus*). The large carnivores include cheetah (*Acinonyx jubatus*), lion (*Panthera leo*), *(Lyacon pictus*) and spotted hyena (*Crocuta crocuta*).

Research design

A reconnaissance was conducted to determine the presence of elephants and prevalence mopane trees in Central MPNP. Data collection was carried in April and May of 2013 in the Central MPNP valley floor covering approximately 41 km from Nyakasikana to the Zebra vlei. A stratified random sampling design was used to collect the data. Data were collected along an altitudinal gradient from Nyakasikana to Zebra vlei. The study used the assumptions of the soil catena concept which suggests that soil drainage differs along a slope or an altitudinal gradient with soils on a steeper slope being well drained (Figure 1).

The sequence of soil profiles which develops along a slope or an altitudinal gradient tends to differ in soil nutrient content (Table 1). Three strata were defined according to soil drainage, Nyakasikana area was defined as well drained (WD), Lion's den as moderately drained (MD) and Zebra vlei as poorly draind (PD). An equal number of plots measuring 20 m × 30 m were randomly sampled within each stratum.

Data collection

Structure of *C. mopane*: Vegetation structural attributes of *C. mopane* were assessed in 30 plots. Plots were randomly placed in each stratum. Ten plots were assessed in each stratum. Plot sizes of 20 × 30 m were used following Walker [37] method of having at least 15 to 20 trees inside a plot. In each plot these variables were recorded: tree height, basal circumference, plant damage, woody vegetation species and number of stems per plant. Trees were defined as woody species above 3 m and having above 6 cm basal diameter, above buttress

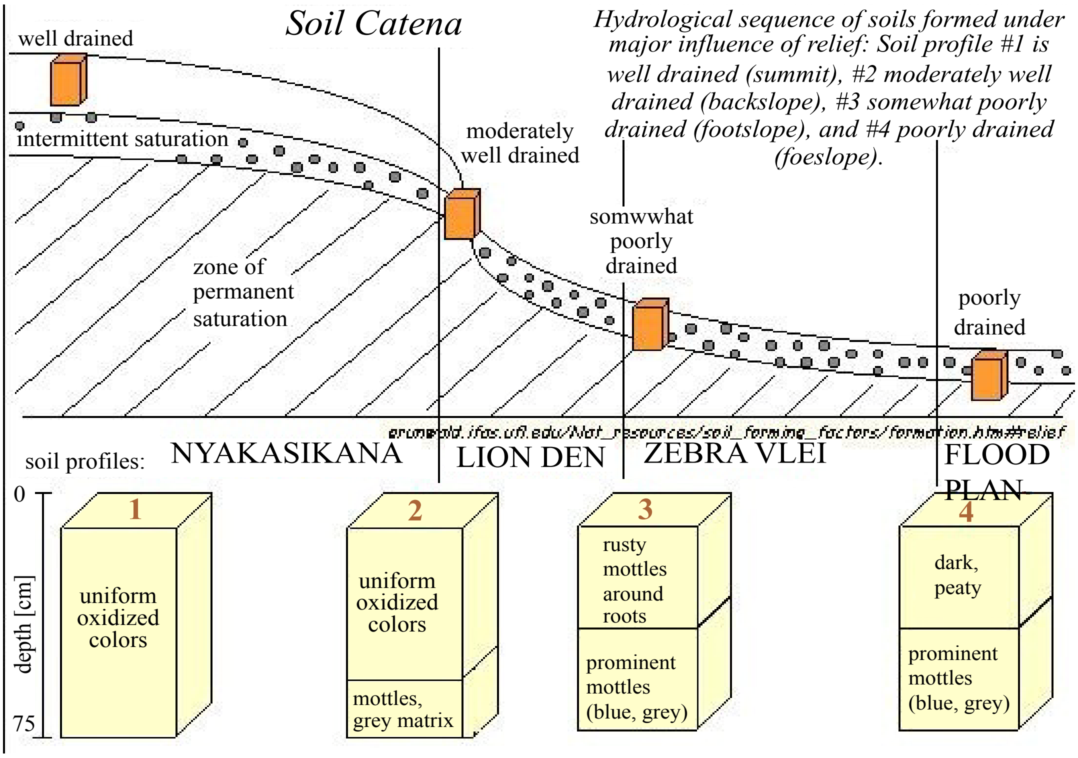

Figure 1: Soil catena showing sampled sections/ strata based on soil drainage along an altitudinal gradient in MPNP.

Mean/100 g soil								
STRATA	**N**	**P**	**K**	**Ca**	**Na**	**CEC**	**Mg**	**PH**
WD (Nyakasikana)								
Mean	13.8	10.1	0.48	77.26	8.98	6.74	1.45	6.5
SE	3.11	1.1	0.03	7.26	1.09	0.42	0.02	1.11
MD (Lion's Den)								
Mean	13.8	30.2	0.7	9.85	3.63	5.44	2.06	4.9
SE	2.11	3.98	0.1	2.41	0.33	0.21	0.07	0.21
PD (Zebra vlei)								
Mean	2.06	41.4	1.06	15.65	2.18	5.31	2.13	5.8
SE	3.28	3.17	0.12	1.65	0.24	0.27	0.36	1.47

Table 1: Soil nutrient concentration along the catena.

swelling [2]. For multi-stemmed plants, stems with more than half their base inside the plot were recorded as they are inside the plot [15].

Tree height: A graduated pole was used to measure woody vegetation height. A pole calibrated in a way that the data collector was able to see the values when placed against each tree and the height was then recorded [4]. Estimations were used for trees greater than the calibrated pole. The height of the tallest tree was recorded for multi stemmed trees.

Basal circumference: Basal circumference was measured using a tape measure. This was measured at 1,3 m because damage from elephants is mostly above this height.

Canopy dimensions: The short canopy diameter (SD) and the long canopy diameter (LD) were measured using a measuring tape. This is a measure of the trees brows able parts. This data were used to calculate canopy volume.

Elephant damage: Elephant damage was scored on every live tree according to the level of damage. Damage was defined as any form of vegetation utilization by elephants [31]. Elephant damage was characterized by breaking of branches and stems, uprooting, pushing over and scarring (bark striping) of woody species [28]. The damage scoring was determined by the form of damage and intensity [32]. The number of dead elephant induced trees was also recorded [30]. The scoring was done using the system proposed by Walker [37] (Table 2).

Estimation of elephant density: Elephant dung was counted in all plots [30]. Data collection was done in April – May 2013. This was just at the end of the rain season where elephant populations are spread all over the park since water will be available in rivers and water pans all over the park.

Data analysis

Calculations: Stem circumference data were used to calculate stem basal areas for each woody stem using the formula: Basal Area (m^2)=($C^2/4\pi$) Where C is stem circumference.

Data from the Physical counts of *C. mopane* trees sampled for each plot was used to calculate tree density using the formula: Density=[(x ×

Damage	Rating description
0	No damage visible
1	Slight damage, from wind, weather, etc.
2-3	Slight browser
4-5	Moderate browser
6-7	Severe browser

Table 2: Scale used to record browsing damage to *C. mopane* trees (after Walker, 1976).

10000 m^2)/(plot area, m^2)] where x is the recorded number of trees or/and shrubs or/and saplings.

Canopy dimensions data and tree height data were used to calculate canopy volume of all *C. mopane* woody species. This was calculated using the formula:

Shrub canopy volume (SCV): (SCV) m^3=¼ (π) (H) (SD) (LD)

Tree canopy volume (TCV): (TCV) m^3=¼ (CD) (SD) (LD)

Where

H: Shrub height

SD: Short canopy diameter

LD: Long canopy diameter

Size structure analysis: Statistical analyses were conducted using STATISTICA Version 7 [38]. Data were first tested for normality using the Shapiro-wilk test [39]. Some of the measured variables were non-normal. The non-normal data log transformed and a one way ANOVA test was used to test for differences across the four study distances away from the lake.

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 [31]. A graph showing the percentage of *C. mopane* species in each girth size class across all three soil drainage classes was constructed using Microsoft excel. A Principal Component Analysis (PCA) was done to show the level of damage structure of *C. mopane* data across all three soil categories [4]. Descriptive statistics were used to summarize the data and graphical representation was done using Microsoft Office Excel 2007.

Damage: One way ANOVA test was used to test for variation in damage across three soil drainage strata in Central MPNP.

Relationship between damaged trees and elephant densities: A simple linear regression analysis was performed in order to establish the relationship between density of damaged trees and elephant densities [40].

Results

Sample effort

A total of 860 *C. mopane* species were sampled. These included saplings and shrubs. 525 *C. mopane* trees were sampled in thirty 20 m × 30 m plots. (n=167; 31.7%) of the total sample was undamaged, (n=284; 54%) was damaged and (n=74; 14%) of the overall sample was elephant induced dead trees [41-43].

Comparison of *C. mopane* structure across the strata in central MPNP

There were significant differences in tree heights and basal areas in *C. mopane* woodland across the three strata (P<0.01). Plots in poorly drained soil had the highest tree heights and basal areas compared to the other two strata (Table 3).

There were significant differences in sapling density and number of stem per plant across the three strata (P<0.001). Plots in moderately drained soil had the highest sapling density and stems per plant compared to other strata; however, stems per tree in well-drained soil and moderately drained soils did not have much difference. There were no significant differences in Tree canopy volume and Shrub canopy volume across the three strata (P<0.001). Plots in poorly drained soils had the highest tree canopy volumes as compared to the other strata while plots in well drained soils had the highest shrub canopy volumes when compared to the other strata. There were significant differences in tree density and damaged trees density (P<0.05). There was no much difference between plots in well drained soils and moderately drained soil in these two variables [44]. There was no difference in the number of dead trees across the three strata (P> 0.05). Poorly drained soils had a slightly higher mean of dead trees when compared to the other strata.

Size class distribution of *C. mopane* trees in central MPNP: *C. mopane* species with a girth <10 cm dominated the study area. *C. mopane* with a girth size range 10.1-20 cm were the least dominant (Figure 2). *C. mopane* with a girth size of <10 cm (n=330; 41%), 10.1-20 cm (n=25; 3.2%), 20.1-30 cm (n=81; 10.3%), 30.1-40 cm (n=122; 16%) and >40 cm (n=249; 32%) were recorded in Central MPNP. The graph on girth size class showed a reverse bell-shape curve (Figure 3). This shows that there were more saplings than big trees within the study area (Figure 4).

Principal Component Analysis (PCA) output of 9 vegetation variables shows Factor 1 accounting for 49.59% and Factor 2 accounting for 18.07%. Tree height, Basal area, Tree canopy volume, sapling density and stems per plant were negatively correlated to Factor 1 whilst, dead trees, damaged trees, tree density and shrub canopy volume were positively correlated to Factor 1. Factor 1 therefore defines a gradient from taller trees with large basal areas and high tree canopy volumes

STRATA			
	WD	MD	PD
Number of trees sampled	220	217	118
% Undamaged trees	32	42	7
% Damaged trees	51	48	42
% Dead	17	10	51

Table 3: Showing sampling effort in the study area.

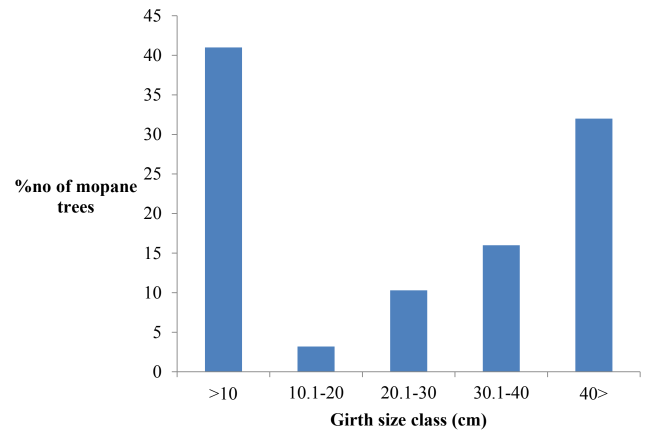

Figure 2: Size class distributions for all sampled *C. mopane* trees in the Central MPNP, Zimbabwe.

Citation: Moses M, Simbarashe M, Farai M (2017) Influence of Soil Drainage and Elephant (*Loxodonta africana*) Damage on Abundance and Structure of *Colophospermum mopane* in Central Mana Pools National Park Zimbabwe. Poult Fish Wildl Sci 5: 175. doi:10.4172/2375-446X.1000175

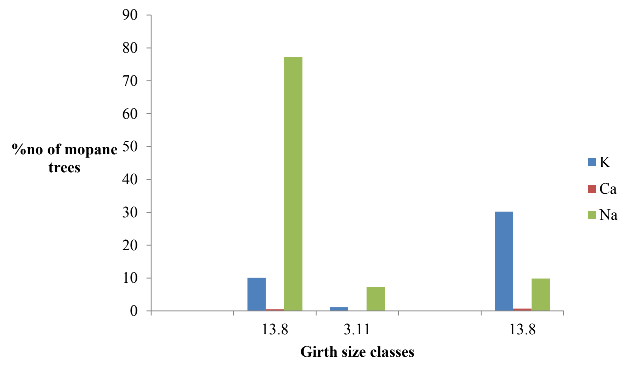

Figure 3: Size class distributions for *C. mopane* trees across three strata in Central MPNP.

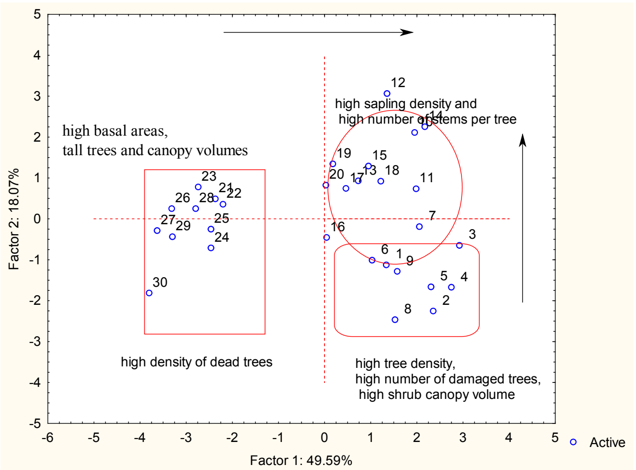

Figure 4: Principal Component Analysis (PCA) scatter plot of 30 sample plots in *C. mopane* woodland in Central Mana Pools National Park (MPNP).

to higher tree densities, high density of damaged trees and high shrub canopy volumes, whilst Factor 2 defines a gradient from high density of dead trees to high sapling density and high numbers of stems per tree. Consequently, plots with taller trees, high basal area and high tree canopy volume scored lower on Factor 1, mostly these sampled plots were derived from poorly drained soils, whereas those with high tree densities, damaged trees, and high shrub canopy volume scored high on Factor 1 and mostly were from sampled plots derived from well drained soils. Plots with a high number of dead trees scored low on Factor 2, mostly these sampled plots were derived from poorly drained soil, whereas high sapling density and high number of stems per tree scored high on Factor 2, mostly these sampled plots were derived from moderately drained soil.

Comparison of elephant damage across three strata

There were significant differences in *C. mopane* damage across the three strata (P<0.05; Table 4). There was a significant difference in the level of damage across the three strata (P<0.001; Table 4). Most of the trees in SM and MM fell in the no damage category as they did not show any form of elephant damage (n=70; 32% and n=91; 42% respectively). TM had the highest number of dead and severely damaged trees (n=60; 51%). Overall the highest percentage of plants sampled did not show damage (32.3%). Moderately damaged plants constituted 25.3% of the total sample.

Relationship between elephant density and elephant damage in central MPNP

Relationship between elephant density and damage was tested using linear regression. Results show that there is no relationship between elephant density and mean elephant damage (R^2=0.003; P>0.05; Figure 5).

Also a regression analysis was done to test if there was any relationship between density of dead trees and elephant density. The results show that there is a relationship between dead trees density and elephant density. As elephant density increase also does the number of dead trees (R^2=0.3865; P<0.05; Figures 6 and 7).

Discussion

Mopane structure and abundance in central MPNP

The study recorded significant differences in height, basal area, tree density, shrub canopy volume, tree canopy volume, sapling density and number of stems per tree. Results only showed no significance in the number of dead trees per plot/hectare. Differences in structure between differently drained soils can be attributed to be probably resulting from the differences in soil nutrition. In support of this view they found out that the availability of shrub form of *C. mopane* may be due to unsuitable soils because was noticeably absent from the deep sands and the fertile alluvial river banks. Well drained soils were characterised with dwarf mopane and poorly drained soils characterised with cathedral mopane. This can be attributed to soil nutrient concentrations. A study to determine the influence of soil properties on the physiognomy of *C.*

STARTA				
Variables	**WD**	**MD**	**PD**	**P-value**
Height	2.00 ± 0.10^a	2.00 ± 0.10^a	2.02 ± 0.04^b	0.00**
Basal area	0.20 ± 0.14^a	1.10 ± 044^b	2.23 ± 0.10^c	0.00**
Stems/plant	1.01 ± 0.14^a	1.20 ± 0.10^b	1.00 ± 0.12^a	0.00***
Tree canopy Volume	2.00 ± 0.31^a	2.20 ± 0.22^b	2.30 ± 0.10^c	0.00***
Shrub canopy volume 2.00 ± 0.20^c	2.00 ± 0.20^c	1.10 ± 0.60^b	0.40 ± 1.00^a	0.00***
Tree density	4.00 ± 0.12^a	4.00 ± 0.10^a	3.00 ± 0.10^b	0.02*
Dead trees/ha	3.00 ± 1.00^b	2.11 ± 1.20^a	3.00 ± 0.20^a	0.1
Damage score	1.20 ± 0.61^b	0.30 ± 0.30^a	4.00 ± 0.26^c	0.00***
Damaged trees/ha	3.20 ± 0.40^a	3.23 ± 0.10^b	3.10 ± 0.10^a	0.03*
Sapling density	3.00 ± 0.40^b	4.00 ± 0.22^c	2.33 ± 1.00^a	0.00***
Dung density	3.21 ± 0.22^b	3.10 ± 0.14^a	3.41 ± 0.10^c	0.00***

ns, P> 0.05; *P< 0.05; **P< 0.01; ***P< 0.001.
Different superscript letters in the same column indicate significant differences between mean values.

Table 4: Vegetation attributes for sample plots across different soil profiles (mean ± standard error) and significant levels from one-way ANOVA.

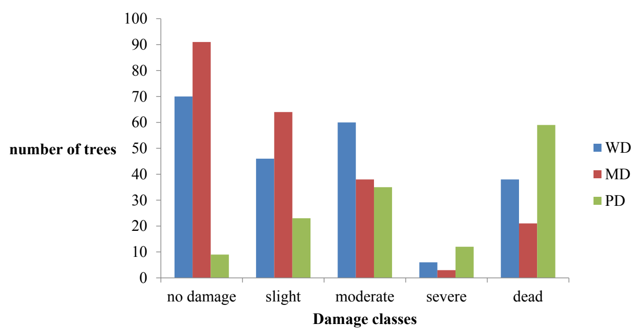

Figure 5: Showing Levels of damage for each strata.

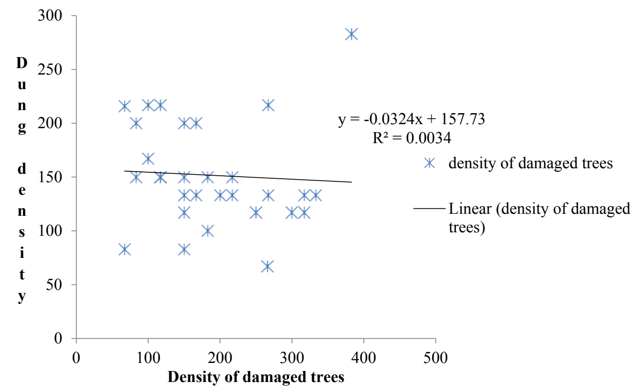

Figure 6: Scatter plot showing the relationship between elephant dung density and mean elephant damage.

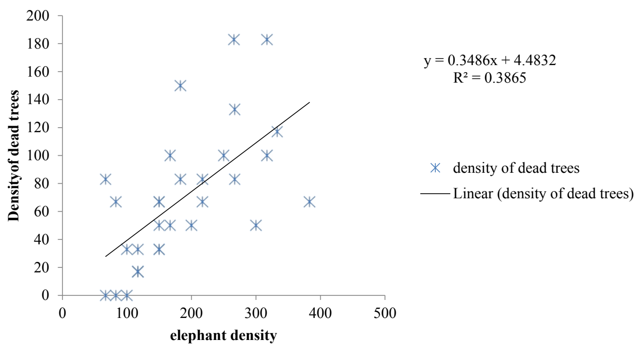

Figure 7: Scatter plot showing the relationship between elephant dung density and dead tree density.

mopane in Gonarezhou national park showed that Phosphorus might be the limiting nutrient in dwarf *mopane* [7]. Unpublished reports from MPNP showed that well drained soils have the lowest phosphorus concentration, moderately drained soils have better concentrations of phosphorus and poorly drained soils have the highest levels of phosphorus. Koch [6], and Lovelock et al. [5] also revealed that low phosphorus concentrations have been found to limit growth in dwarf *Rhizopora* mangle tree therefore this can also hold for this study.

Relationship between elephant density and elephant induced damage: Results show by linear regression that there is a negative relationship between mean elephant damage and dung density. Gandiwa [4] concluded that elephant damaged plants increased with increasing numbers of elephants which is contrary to the findings of this study. Results of this study also show a positive relationship between dead trees and elephant density. Other studies have found a clear link between elephant density and damage to vegetation. In Luangwa Valley Zambia, Caughley [40] established through regression analysis that the number of trees felled were 14 times dependent on elephant density than tree density. This support the findings of this study that dead trees increased with the density of elephant dung.

Results from this look at propose that soil properties in addition to elephant damage have an influence at the abundance and shape of *C. mopane*, therefore the need for constant tracking of this tree species.

Conclusion and Recommendation

This study provides evidence that *C. mopane* structure changes with different altitudinal gradient. It also provides evidence that damage of *C. mopane* species also differs according to topographic positioning of the woodland. This study provides a reference baseline for monitoring changes in *C. mopane* structure which is of vital importance to the ecology of Mana Pools National Park. Trees in moderately drained soils showed a healthy state with the highest number of saplings and tree with slight and no damage.

The recommendation is there is need for constant monitoring of *C. mopane* especially in poorly drained soils. Severely damaged trees and dead trees were mostly concentrated in poorly drained soils so there is need for constant monitoring vegetation and herbivore populations within ecologically sustainable ranges in the area. The studies can also be undertaken in the dry season to try and incorporate the effect of surface water availability on the structure and abundance of *C. mopane*.

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