Adansonia digitata distribution, structure, abundance and elephant damage across Gonarezhou National Park, southeast Zimbabwe.

By

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ABSTRACT

An assessment was made to determine density, structure and distribution of baobabs across Gonarezhou National Park (GNP) management strata, southeast Zimbabwe. The three GNP management strata coincide with a soil group type gradient derived from (i) rhyolite, (ii) malvernia and (iii) granophyre substrates/bedrocks. A total of 225 baobabs were sampled on 15 belt transects of constant width of 0.3km and cumulative total length of 17.2km. The fifteenth baobab point in each belt transect determined the length of a particular belt transect. Abundance was determined from baobab density and frequency. The present study observed that baobab density in GNP ranged from 34.3/km^2 in the Central GNP stratum to 69.8/km^2 in the Northern GNP stratum. Analysis of variance (P>0.05) showed overall insignificant differences in baobab distribution of basal area, number of stems per plant, plant height and stem density across GNP management strata. The hypothesis that baobabs do not significantly differ in density, structure and distribution across three management strata of GNP was, therefore, accepted. Elephant dung counts and elephant damage levels on baobabs showed no significant differences across study sites (ANOVA: P>0.05), highlighting uniform elephant damage on baobabs across the entire GNP as elephants roam across the park. Some 84.4% baobabs were damaged and some 15.6 % were undamaged, of which 2% were dead. In contrast, the results suggested that baobab density, structure and distribution were significantly different across the GNP soil substrate gradient. Analysis of variance (P>0.05) showed overall significant differences in baobab distribution of plant height and number of stems per plant across the soil substrate gradient. The results highlighted a concern over the unbalanced size class structure distribution of baobabs on malvernia beds plains in GNP, which suggested a recruitment bottleneck. Study sites on granophyre and rhyolite soil substrates/bedrocks were predicted by redundancy analysis (RDA), to be positively correlated and they were of a similar grouping with inversely J-shape size class distribution of baobabs, which indicated viable recruitment and regeneration of baobab population. Overall, GNP did not seem to indicate that baobabs are in danger of extirpation. Baobab extirpation might be the case only on malvernia bed plains in future. The hypothesis that baobabs do not significantly differ in density, structure and distribution across soil substrates in GNP was, therefore, rejected. The present study recommended that protected area management in arid and semi-arid areas should consider (i) formulating clear thresholds of potential concern to allow for the conservation of sensitive woodlands such as *Adansonia digitata* woodlands and (ii) establishing long-term baobab monitoring programmes for conservation and (iii) management of elephant to attain GNP carrying capacity levels.

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DEDICATION

The study is dedicated to all villagers on earth, as well as elephants and baobabs.

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CHAPTER 1

1. Introduction

Plant species distribution, abundance and structure are determined by climatic, edaphic and biotic factors operative on the environment (Guisan and Zimmermann, 2000; Wills and Whittacker, 2002). Disturbance regimes, such as herbivory, fire and edaphic factors, would likely modify and influence state-and-transition dynamics in woodland ecosystems, thus affecting population structure, abundance, distribution and regeneration potential (Campbell *et al.*, 1995). Thus, although mean annual precipitation may be the primary determinant of woody biomass (Sankaran *et al*., 2005), in dry savannas, large-scale vegetation patterns may be determined primarily by rainfall. On the other hand, landscape-scale variation in vegetation may primarily relate to soil resources (Aarrestad *et al*., 2011). This, in turn, has profound effects on plant species communities, directly via soil resource availability and indirectly by influencing woody growth patterns and intensity of herbivory and fire disturbance regimes (Scholes and Walker, 1993).

In Gonarezhou National Park (GNP), soil resource gradient (soil substrate/bedrock) and elephant disturbance regime gradient in relation to proximity to natural perennial water sources, are perceived to play a major role in *Adansonia digitata* abundance, structure and spatial distribution, because soil type/stratum may compensate or aggravate the climatic aridity (Aarrestad *et al*., 2011). The present study aimed at providing a baseline information on landscape-level dynamics in baobab demography, subject to soil substrate/bedrock strata and elephant impact across the three strata of GNP, namely; Northern GNP, Central GNP and Southern GNP.

1.1 Background

1.1.1 Background of vegetation destruction in GNP

In GNP, there is an obvious, but not simple, relationship between tree mortality rate and changes in elephant density and fire disturbance regimes. Previous studies in GNP suggest that fire-elephant disturbance regimes are important factors determining woodland stand dynamics (GNP, 2010). Photo panoramas were used to study tree loss in GNP between 1970 and 1983. The tree population was found to decline due to low recruitment and loss of trees at 30.1% in 13 years, with nearly 2.3% per annum at panorama points not close to water. Tree losses were mainly attributed to elephant damage, fire damage and droughts (Tafangenyasha, 1997).The association between elephant density and tree mortality rate was more evident during the 1975-1983 period as elephant population in GNP reached 7315 (Sharp, 1982). Mean percentage tree loss during period 1970-1971 was 4.7%, and this was reduced to 2.9 % in 1971-1975, while in 1975-1983, the loss increased from 5.3 to 11.2 %, thus, suggesting a coincidence in elephant density and excessive woodland destruction which reached a peak during the same period (Tafangenyasha, 1997). In addition, fire-elephant disturbance regimes in GNP, are important factors on *Colophospermum mopane* and *Combretum apiculatum* woodlands (Gandiwa and Kativu, 2009), *Androstachys johnsonii* woodlands (Gandiwa *et al*., 2011a), *Acacia tortilis* woodlands (Gandiwa *et al*., 2011b) and *Adansonia digitata* stands in southern GNP (Mpofu *et al*., 2012).

1.1.2 Background of elephant (*Loxodonta africana*) population in GNP

In recent years, the elephant population has been subjected to regular culling programmes, and has been affected by the severe droughts of 1981-1982, 1991-1992, and 2000-2001 (GNP, 2010). Elephant population had a noticeable increase since 1980. Between 1980 and 1982, the elephant population increased from approximately 4700 to 7315 (GNP, 2010). This increase has been attributed to natural recruitment, in-migration from Kruger National Park or immigration due to heavy poaching in Mozambique at the height of the civil war in that country (GNP, 2010). The impact of this population on the riverine habitats of the Runde, Save and Mwenezi Rivers has been severe, prompting park authorities to cull elephants in 1983, 1986, and 1987 (GNP, 2010). This resulted in the reduction of the population to about 3802 ± 40% (Dunham, 2012).

Elephant population also increased in 1992, up to 6406 ± 37% (Dunham, 2012), prompting the park authorities to further reduce the population (GNP, 2010). In 1993, an aerial survey of the park estimated the population at 5421 ± 59% (Dunham, 2012). Two 1995 surveys estimated the population at around 4625 ± 37% (Dunham, 2012). A 2002 survey estimated the elephant population at around 4992 ± 27.5% (Dunham, 2012), and a 2007 survey estimated the elephant population at around 6516 ± 27% (Dunham, 2012).

Dunham (2012) estimated at 9125 (+-CI1898) elephants during the 2010 survey. Taken with the results of other aerial elephant surveys conducted post 1992 drought and since the completion of the 1993 elephant capture operation of about 600 elephants, the year 2010 estimate of 9125 elephants, implies that the number of elephants in GNP has increased at a mean annual rate of 6.2% (lower and upper confidence limits 3.9% and 8.5%) during the past sixteen years. Thus, such a high elephant population annual rate is a cause for concern to a park the size of GNP (Dunham, 2012). The park’s elephant numbers are at an all-time high, with a mean elephant density of 1.8 per km^2 (Dunham, 2012). Thus, the elephant is currently regarded as an international conservation problem despite its local overabundance within Zimbabwe's conservation areas. These high elephant numbers are perceived as accompanied by large-scale destruction of baobabs (GNP, 2010).

1.2 Baobab (*Adansonia digitata*)

1.2.1 Evolutionary background

Origin of the vernacular name "baobab" is uncertain. Most scientists however believe it to be derived from the Arabic name "buhibab" meaning fruit with many seeds (Diop *et al*., 2005). The genus name *Adansonia* is used in honour of the botanist Michel Adanson (1727–1806), (Esterhuyse *et al*., 2001). The species name *digitata* (hand-like) was selected in reference to the shape of the leaves. Eight baobab species have been identified globally, and six species are endemic to Madagascar, the postulated centre of evolutionary origin of the genus *Adansonia* (Wickens and Lowe, 2008; Drake, 2006). The African species, *Adansonia digitata* is widely distributed throughout the savanna woodlands of sub-Saharan Africa (Wickens and Lowe, 2008). The only species not endemic to the African continent is *Adansonia gibbosa* (A.Cunn.) Guymer ex D.A.Baum which is native to Australia (Drake, 2006; Wickens and Lowe, 2008). In southern Africa, *Adansonia digitata* commonly occurs in Malawi, Zimbabwe, Mozambique and South Africa, especially in the warm savanna areas (Adesanya *et al*., 1988; UNCTAD, 2005; Lamien-Meda *et al*., 2008).

1.2.2 Description of *Adansonia digitata*

The baobab tree (*Adansonia digitata* L., Family; Malvaceae, subfamily; Bambacaceae) is a fruit bearing tree species, characterized by a massive size of up to 25 m height and 10 m trunk diameter (Coates-Palgrave, 1997), and its bottle-shaped trunk which accumulates water (Sidibe´ and Williams 2002; Wickens and Lowe 2008). It is regarded as the largest succulent (Coates-Palgrave, 1997). During the leafless period, physiological processes such as photosynthesis take place in the green inner layer of the trunk and branches, utilizing water stored in the trunk (Gebauer *et al*., 2002).The tree produces an extensive lateral root system which can extend up to 50 m from the trunk and down to a depth of 10 m (Diop *et al*., 2006).

The deciduous leaves which are 5–7 palmately compound can reach a diameter of 20 cm. The large and pure white bat-pollinated bisexual flowers have five curled-black waxy petals and numerous stamens fused to form a central column (Sidibe´ and Williams 2002). The fruits, which are filled with reniform seeds embedded in the whitish acidic mealy pulp, are variable in size (up to 15 cm), and contains many seeds (Wickens 1982; Sidibe´ and Williams 2002). It is estimated that it takes between eight and twenty-three years before the baobab produces seeds, and the mature plant (over 60 years) can produce more than 160–250 fruits per year (UNCTAD, 2005).

1.2.3 Baobab age estimation

Work from carbon dating and examination of core samples from the stem have been used to estimate the age of baobabs. Although some baobab trees are reputed to be many thousands of years old, this is impossible to verify as the wood does not produce annual growth rings (Wickens and Lowe, 2008). Few botanists believe these claims of extreme age. Research on radiocarbon dating of baobabs (Patrut *et al*. 2010c), as well as dating results presented by other researchers (Woodborne *et al*. 2010) show that very large specimens are not necessarily among the oldest trees, and that medium sized individuals can also be very old.

A number of authors have pointed out that baobab recruitment is often underestimated because of the false predictions made about baobab growth rates. Dhillion and Gustad (2004) argued that the direct conversion of girth to age underestimates baobab recruitment, as young baobabs grow faster relative to older trees. This was supported by Patrut *et al*. (2007), who did radiocarbon dating of the ‘Grootboom’ (meaning big tree) baobab in Namibia. Girth measurements have often been used as a rough guide to baobab population demography (Wilson, 1988; Swanepoel, 1993a; Barnes *et al.*, 1994). The baobab tree shrinks in times of drought (Wyk, 1974), and this affects age estimation by means of girth. Thus, caution should be taken when one uses girth measurements in estimating the age of baobabs (Guy, 1970, 1982; Swart, 1963). The baobab tree is a very long-lived species. It has been reported that it can survive for more than 400 years (Gruben and Denton, 2004).

1.2.4 Ecological significance of *Adansonia digitata.*

Baobabs are a keystone species with ecological significance as they provide important ecosystem services (Whyte, 2001). The baobab trees add organic matter and nutrients through leaf-fall. The species reduces soil temperature and water loss (Amundson *et al*., 1995) and attracts birds and large mammals that add nutrients to the soil with their droppings (Wickens and Lowe 2008). The trees have convolutions in the trunks which form cracks and holes. These provide shelter to many small animals and birds, and offer ideal sites for breeding (Whyte, 2001). For instance, in the Kruger National Park, the only known nesting sites of both the Batlike Spine tail (*Neafrapus boehmi*) and the Mottled Spine tail (*Telecanthura ussheri*) are in hollow baobabs (Whyte, 2001). Baobabs provide breeding sites for Mosque Swallows (*Hirundo senegalensis*) and Cape Parrots (*Poicephalus robustus suahelicus*) (Whyte, 2001). Baobabs are also nesting sites for the Greyheaded Parrot (Smyes and Perrin, 2004), the Barn Owl (*Tyto alba*) and the White-headed Vultures (*Trigonoceps occipitahs*). In GNP, Red billed Buffalo Weavers' nests were seen on baobab trees (personal observation). Any decline in the number of baobabs would also have an effect on the populations of these birds (Whyte, 2001).

Jeltsch *et al*., (1996) noted that baobabs provide forage opportunities and refuges for a myriad of species, and also play a key role in nutrients cycling, and soil conservation. In Senegal, the removal of many baobab trees as a result of lettuce production in 1979 lead to noticeable soil erosion (Chasm, 1982). Baobabs act as a pollen food resource for bats and provide fruit for baboons, humans and elephants (Van Wyk, 1984). Baobabs are also browsed upon by kudu, nyala, and impala (Venter and Venter, 1996). It is a protected species in South Africa (Edkins *et al.*, 2007).

1.3 The research problem

Elephant impacts on woody species in GNP have been a concern for park officials from the Parks and Wildlife Management Authority (Sherry, 1975; Tafangenyasha, 1991; GNP, 2007; GNP, 2010). Elephant impacts on baobabs are a research priority for GNP (GNP, 2010). Swanepoel and Swanepoel (1986) suggested that severe damage to baobabs may indicate that elephant population, irrespective of its absolute density, has reached a level at which it has already initiated major vegetation changes in the area. Thus, there is need to establish whether there is any relationship between baobab population demography and elephant damage.

Park management is being re-evaluated in GNP (GNP, 2010). The new policy proposes that the park is divided into management regions inclusive of wilderness zones, namely; the Pombadzi in Northern GNP and Chefu-Guluwene in Central GNP, with intensive specific conservation reserves, established to protect rare, endangered, or otherwise botanically important species (GNP, 2010). Elephant occupancy control could take place in these specific conservation zones. One of the tree species aimed at being conserved in the park is *Adansonia digitata* because of its important role in the ecosystem and its distinctive and emblematic aesthetic value (GNP, 2010).

There have been suggestions that baobab populations are unaffected by elephants in certain areas in GNP because of difficult access (Mpofu *et al.*, 2012). In GNP, there has been a suggestion that ‘baobab refugia’, or relatively elephant-free rocky hillsides of higher elevation, might serve as sources for baobabs on lower plains (Gandiwa, personal communication). The present study also aimed at assessing baobab plant density, recruitment, and size class distribution in relation to elephant damage and habitat elevation and rockiness. Size class distributions may indicate population stability or decline (Tanner, 1977) in different GNP sites.

Primarily, the present study sought to establish whether elephant browsing significantly interferes with baobab structure, abundance and distribution across the three strata of the entire GNP. This study aimed at describing baobab population trends and comparing populations in three strata of the entire GNP. This study further assessed the aerial extent of baobabs on three major soil substrates/bedrocks in the entire GNP. The study emanated from the recommendation of Mpofu *et al.*, (2012) and GNP (2010), to investigate soil substrate/bedrock, fire and elephant interactions as determinants of baobab population dynamics in the entire GNP, to allow for deeper understanding of the ecology of baobabs.

1.4 Justification of study

In recent years, the GNP baobab population seems to show unusually low recruitment (Gandiwa, personal communication). If these factors are left unchecked, they are likely to eventually shift the plant species composition of GNP, particularly in relation to *Adansonia digitata*. This phenomenon is associated with future local extirpation of a species. Such a shift would pose significant challenges to the management of the park. If there is a lack of recruitment and if this is due to elephants, this would give support to the new management strategy in discussion by the park's authority, that is, delineation and management of baobab refugia zones. This study assessed the recruitment levels of baobab population in relation to elephant occupancy and utilization across GNP.

The study attempted to quantify exactly what may constitute baobab refugia, i.e where elephant access may be restricted. The study hypothesizes that the demographic structure of baobabs in perceived baobab refugia ought to differ (stability and/or regeneration progression) to the demographics of those more accessible to elephants. Finding a balance between elephant population size and its effect on the ecosystem probably lie in the creation of some 'sacrificed' areas of high elephant densities while promoting other areas inaccessibility to elephants during the dry season (Lewis, 1987b). This study also aimed at investigating fire damage on baobab, a pre-requisite to the use of fire as a management tool to control elephant populations in baobab refugia. Perceived baobabs refugia can be fenced with thin fire zone belts. Fire manipulation is often thought a necessary accessory to habitat elephant occupancy and utilization control (Lewis (1987b). The creation of relatively elephant-free reserves within parks was suggested to protect species of concern (Whyte *et al.,* 1999; Johnson *et al.,* 1999).

Within the southeastern Zimbabwe lowveld plains, variations in rainfall, altitude and temperature are negligible, consequently vegetation communities can be considered according to the soil types which generally change with variations in geological types (Magadza *et al*., 1993). The vegetation of the GNP is related to soils (Sherry 1977, Tafangenyasha, 1992; Clegg, 2003), with the *Adansonia digitata* preferring well drained loams (Wickens and Lowe, 1988). The soil groups of GNP are not uniform (Nyamapfene, 1991; Clegg, 2003) across the three management regimes which make the GNP strata. Northern GNP, which is north of Runde River, is dominated by granophyre soil substrate; Central GNP, which is south of Runde River and north of the railway line, is dominated by malvernia soil substrate, while there are patches of rhyolite soil substrate in Southern GNP, which is south of the railway line. The differences in soil groups may contribute to variations in abundance, distribution and structure of baobabs in GNP. It is against this background that an attempt was made to further explore baobab population dynamics in relation to soil substrate/bedrock and fire-elephant damage.

Studies of plant species response to disturbance regimes in various parts of the world continue to provide more information. In Zimbabwe, GNP presents an excellent opportunity for related study. GNP was chosen as a study area mainly because it contains sizable patches of *Adansonia digitata* stands on pronounced gradients of soil substrate and elephant utilization. A fundamentally important component of the nation's effort to maintain a high quality environment is the management of protected areas to sustain ecological processes and biological conservation (Arcese and Sinclair, 1997; Shafer, 1999; Dale *et al*., 2000). The study could provide baseline data on *Adansonia digitata* structure, abundance and distribution across the entire GNP, in relation to soil groups and elephant damage. With GNP being the second largest protected area in Zimbabwe, the scientific findings of the study will significantly contribute to elephant herbivory and baobab conservation in the park and other parks.

1.5 Objectives of the study

The primary objective of the present study was to assess the impact of elephant damage on *Adansonia digitata* growing on different strata soil types across the GNP.

1.5.1 Specific objectives of the study were:

a) To determine density, structure and distribution of baobabs across the three strata of entire GNP.
b) To determine density, structure and distribution of baobabs across the three soil substrates/bedrock in GNP.
c) To determine elephant damage levels on baobabs across GNP and relate this to structure, distribution and abundance of baobabs across the three strata of GNP.

d) To identify potential viable baobab population refugia zones of GNP as informed by assessment of elephant occupancy and elephant damage on baobabs, in relation to habitat elevation and rockiness.

1.6 Research Questions

a) How do baobab density and structure vary across three strata of entire GNP?

b) How do baobab density and structure vary across the three main soil substrates/bedrocks in GNP?

c) Is there any variation in elephant damage on baobabs located in different sites?

d) Is there any relationship between elephant damage on baobabs and baobab size class distribution?

1.7 Hypotheses of the study

H01: Baobabs do not significantly differ in density, structure and distribution across three strata of entire GNP.

H02: Baobabs do not significantly differ in density, structure and distribution across three soil substrates/bedrocks in GNP.

H03: Elephant damage levels on baobabs do not significantly differ across GNP strata.

1.8 Study Area

1.8.1 Location

GNP has been part of the Great Limpopo Transfrontier Park since 2000 (GNP, 2010). It is located in the southeast lowveld of Zimbabwe, between latitudes 21^0 00′ to 22^0 15′ S and longitudes 30^0 15′ to 32^0 30′ E. GNP is made of two management stations: Chipinda Pools, in the north, occupies three fifths of GNP, and Mabalauta, in the south, occupies the remaining two fifths. Together, the two sections cover an area of 5,053 km^2 (GNP, 2010).

1.8.2 Climate

Mean annual precipitation for GNP (1972–2012) is 446.56 mm, and has varied between 92.3 mm in 1992 and 1114.6 mm in 2000 (GNP, 2010). Droughts (annual rainfall less than 200 mm) are a characteristic of GNP (GNP, 2010). The climate of GNP therefore, may be regarded as semi-arid (Walker, 1979). Mean monthly maximum temperature ranges from 25.9^{0}C in July to 36^{0}C in January, whilst mean monthly minimum temperature ranges from 9^{0}C in June to 24^{0}C in January (1975–2012 GNP temperature records). The high summer temperatures (with peaks in the January-February period) and clear skies induce high evapo-transpiration rates. Effective rainfall is thus generally lower than the recorded values (GNP, 2010). On average, the lowveld's precipitation exceeds evapo-transpiration for only two to two and a half months per year (GNP, 2010).

1.8.3 The Physical environment of GNP

1.8.3.1 Relief

GNP has a relatively low relief (Figure 1.1). In terms of elevation, the park altitude varies between 165 m above sea level (Save-Runde River confluence; Zimbabwe's lowest point) to 578 m above sea level (Makamandima Hill in the Chivonja Mountain range) (GNP, 2010). There are Ntambambovu Red Hills ranges in Southern GNP which fall away to the Mwenezi River. There is Nyamutongwe Plateau (Table Mountain) which is a significant isolated hill feature in the central GNP.

1.8.3.2 Drainage

There are three major rivers draining through GNP, (Figure 1.1), Save, Runde and Mwenezi, but the flow pattern in all the three rivers have been disturbed by upstream activities, vegetation degradation, dams, and irrigation (GNP, 2010). The central parts of GNP are the headwater of the seasonal Guluene/Chefu River which becomes a significant feeder of the Limpopo River in Mozambique (GNP, 2010). The pan system in the GNP is quite extensive. Apart from the two huge pans near the Save/Runde confluence (Tambahata and Machiniwa) there are a number of larger pans which hold water well into the dry season (GNP, 2010). Two artificial weirs (Benji and Massassanya) hold water through most years (GNP, 2010).

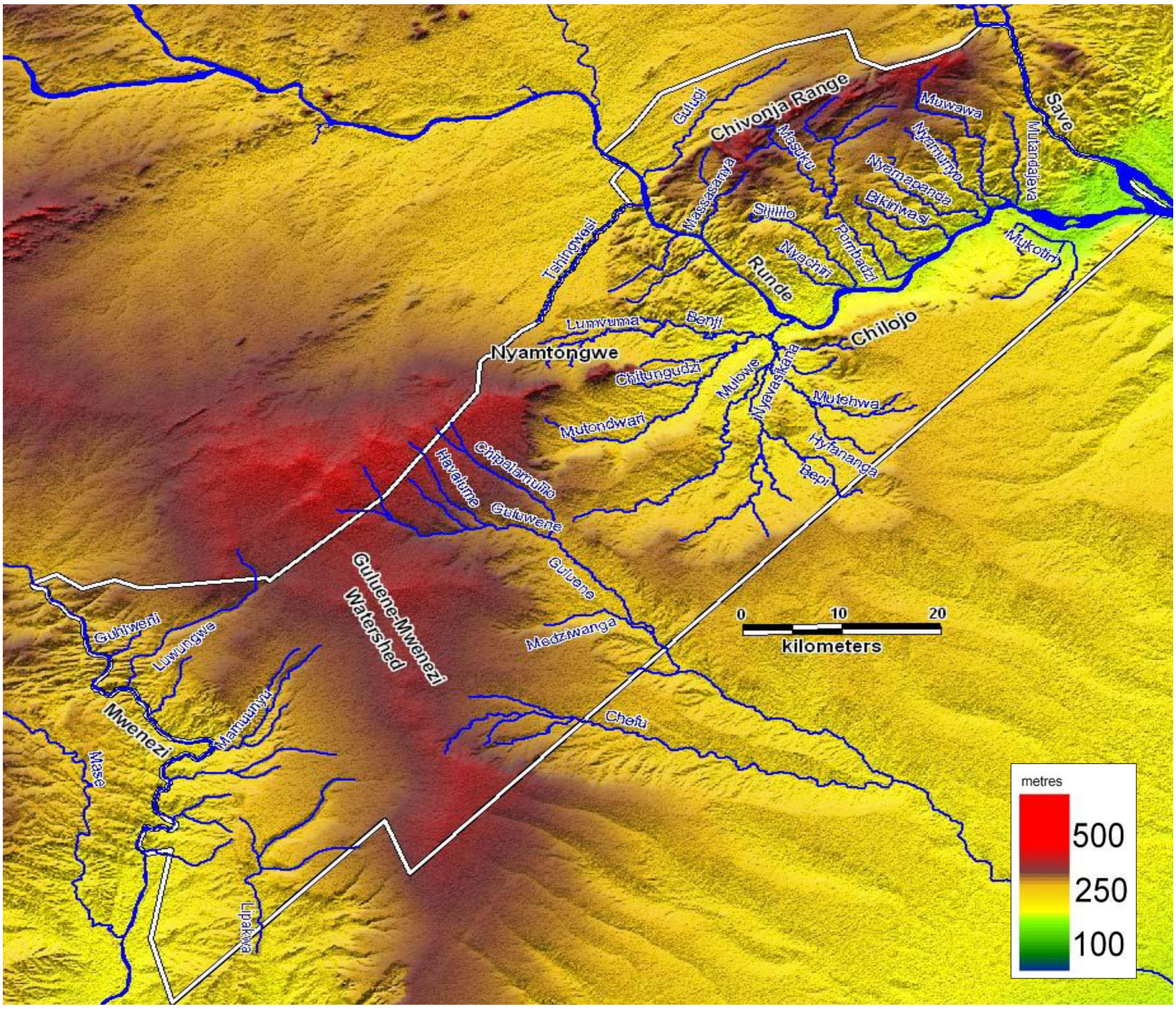


Figure 1.1: Relief and drainage of Gonarezhou National Park., Source GNP, (2010).

1.8.3.3 Geology and soils

There are three main geological formations in GNP (Figure 1.2), which cover nearly 95% of the park (GNP, 2010). The geology of the park consists of the granophyre complex to the north of GNP, the basaltic intrusions located to the extreme north-west, with a smaller intrusion in the south-west, and Cretaceous sedimentary series of the cave sandstone type (Purves and Fullstone, 1975). The sandstone gives rise to deep, highly permeable soils. According to Nyamapfene, (1991); Tafangenyasha, (1991); and Clegg, (2003); the largest soil substrate is the malvernia cretaceous sandstones which cover most of the park between the Runde and Mwenezi Rivers. This is an unusual formation for Zimbabwe (Nyamapfene, 1991). Jurassic basalt is found predominantly along the north western boundary with a small exposure in the Mwenezi valley. Small areas of alluvial and rhyolite constitute the remainder of the park and mainly in Mabalauta station in Southern GNP.

The geology in GNP relates to the main surface soil categories (Tafangenyasha, 1992; Clegg, 2003). About five categories of soil type based mainly on colour, depth, and amount of calcareous material incorporated in the soil can be recognized namely, lithosol, regosol, vertisol, siallitic, and sodic groups (Purves and Fullstone, 1975). These soils occupy a large part of GNP on undulating ground. The granophyres, basalt and rhyolite geological types all give rise to shallow soils particularly on upland terrain (Nyamapfene, 1991). They are variable in coloration, from dark soils to reddish brown. The granophyres give rise to shallow finely textured sandy loams. In depressions, the soils tend to be sodic because of relatively high amounts of exchangeable sodium (Purves and Fullstone, 1975).

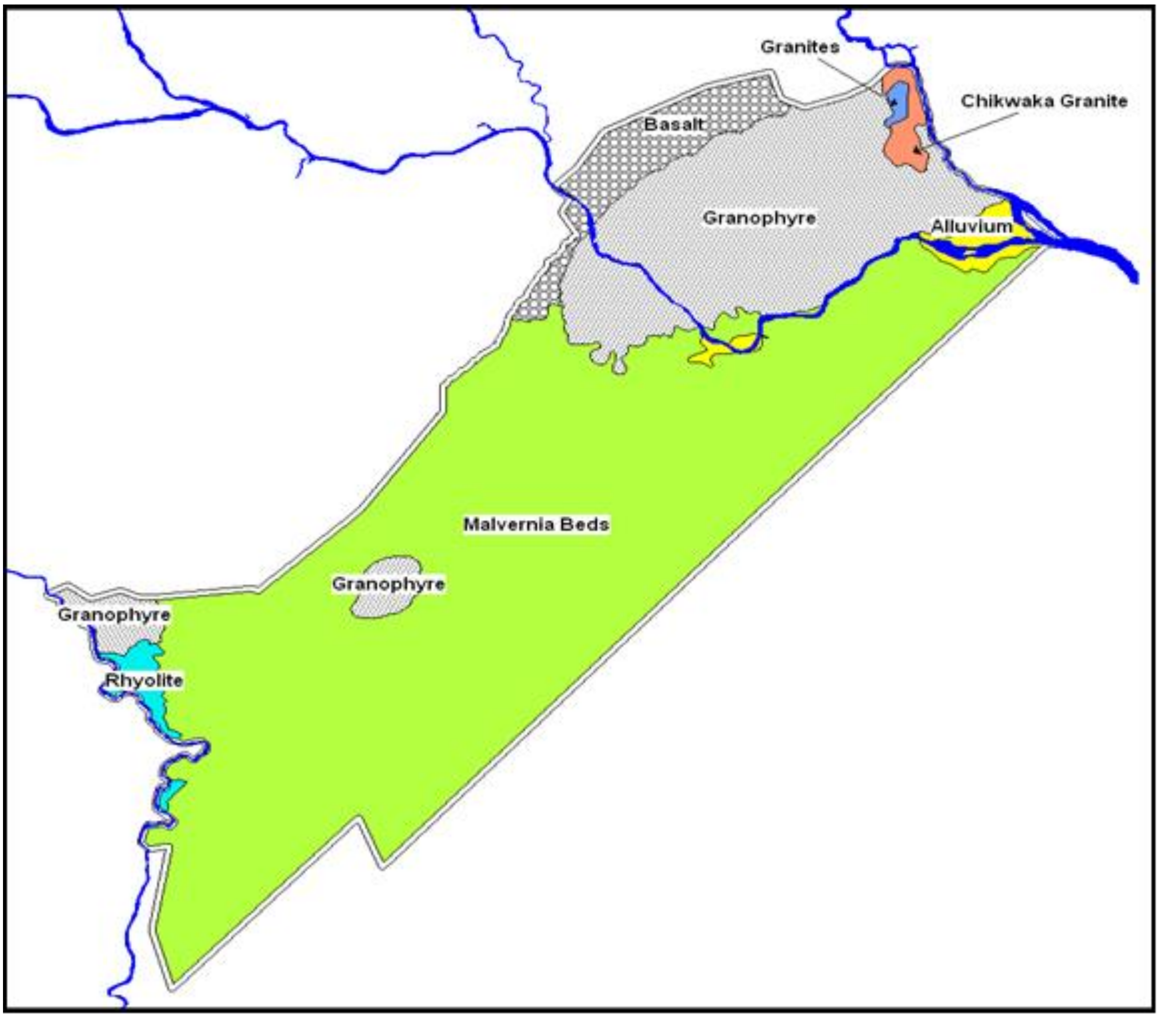


Figure 1.2 Geological map of Gonarezhou National Park, showing soil substrates/bedrock., Source GNP, (2010).

1.8.4 The biotic environment of GNP

1.8.4.1 Vegetation

Sherry (1977) provided a description of the vegetation of GNP. The plant checklist for GNP includes 924 species from 118 families and 364 genera, with 265 trees, 310 shrubs, 55 woody climbers and 137 grasses (Sherry, 1977; GNP, 2010). Broadly speaking the two main vegetation types in GNP are mopane and sandveld woodlands/thickets which cover about 80% of the park (GNP, 2010).

a) *Colophospermum mopane* woodland

This veld type is dominated by *Colophospermum mopane*, and covers approximately 40% (200,000 ha) of the GNP. Mopane is mostly distributed along the larger river valleys, and is found in low altitude, low rainfall areas, that coincide with high temperature (Mapaure, 1994). *Colophospermum mopane* woodland occurs on almost all soil types.

b) Dry deciduous sandveld woodland and scrub

This vegetation community occurs predominantly on sandstone uplands with deep sandy loamy soils. Important species associated with this woodland community include *Pteleopsis myrtifolia, Strychnos madagascariensis, Ochna pulchra, Diplorhynchus condylocarpon, Cassia abbreviata*, *Xeroderris stuhlmanii*, *Terminalia sericea*, *Acacia burkeii* and *Afzelia quanzenzis*.

1.8.4.2 Wildlife

GNP has a diverse vertebrate fauna that consists of 89 species of mammals, 400 species of birds, 76 species of reptiles, 28 species of amphibians and 50 species of fish (GNP, 2010). The mammal fauna includes both large herbivores and carnivore species with the large herbivore dominated by elephant (*Loxodonta, Africana*) which make up approximately 80% of the total biomass, followed by buffalo (*Syncerus caffra*), giraffe (*Giraffa camelopardalis*) and impala (*Aepyceros melampus*) which contribute another 10% (GNP, 2010). Unusual and interesting species include Nyala (*Tragelaphus angasi*) and Suni (*Neotragus moschatus*).

CHAPTER 2

2. Literature review

2.1 Introduction

The stability and complexity of large expanses of woodlands in semi-arid areas in the face of disturbance regimes and post disturbance continues to stimulate debate on the plant succession concept (Laycock, 1991; Grundy, 1993). The tolerance and resilience of plant species communities to disturbance and the direction of progression/retrogression would likely vary with the disturbance regime severity and prevailing environmental conditions (edaphic factors) during the intervening period (Westoby, 1980). Descriptors of disturbance magnitude such as severity (White and Pickett, 1985) are related to disturbance frequency (White and Jentsch, 2001). Disturbance regimes are often characterized as high severity and low severity, or mixed in severity (Turner *et al*., 2001). Characteristics of mixed-severity disturbances are intricately linked to "gap size," but are typically intermediate to high and low-severity disturbances. Plant species response to intermediate severity disturbance is extremely variable, and is often called ''gap phase'' (Veblen, 1992). Low-severity disturbances are commonly associated with limited growing space, low light levels, limited exposed mineral soil, and a high level of competition with existing high tree density and large plant basal area. In contrast, high-severity disturbances typically create increased growing space, high light levels, expose mineral soil, and reduced competition with low plant density and small plant basal area (Oliver, 1981).

Perceived progressions/retrogressions of woody vegetation were recently explained by contradicting theories, in support of or against the conventional Clementsian monoclimax theory. The state and-transition (Westoby *et al*., 1989), steady states (Laycock, 1991) and thresholds (Friedel, 1991) concepts and lately, the invasibility theory (Davies *et al*., 2000) all have tradeoffs but remain unreconciled (Chinuwo *et al*., 2010). Mpofu *et al*., (2012) suggested the need to investigate impacts of disturbance regimes such as; fire, elephants and edaphic factors as potential key determinants of baobab distribution, structure and abundance across entire GNP.

2.2 Elephant impact on savanna ecosystems

Declines in mature trees and other canopy trees related to elephant browsing have been documented in southern Africa for over 30 years (Buechner and Dawkins, 1961). In areas where elephant populations are high, tree-dominated savannas can be converted to a grass-dominated state (Owen-Smith *et al.,* 2006). 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 (Balfour *et al*., 2007). Noticeable impacts of elephants on plants are largely referred to as ‘elephant damage’ (Campbell *et al*., 1996).

The spatial variation of elephant impacts, however, still needs more understanding, given that the relationship between elephant density and the ecological impact of elephants is complex and variable (Balfour *et al*., 2007). It is difficult to separate elephant influence from that of other causes of tree mortality, including wind storms (Spinage and Guinness, 1971), drought (Lewis, 1991; van de Vijver *et al*., 1999), fire (Higgins *et al*., 2000), especially when interactions among them may occur (De Beer *et al*., 2006). At high local density, elephants may reduce plant primary production apart from other factors such as climate and natural mortality (Scholes and Walker, 1993). Heavy utilization of all or most species by elephants may depress plant biomass and hence primary production (Owen-Smith, 2006). Elephants may create gaps giving room to the establishment of new plants and growth of suppressed ones

(Owen-Smith, 2006). Furthermore, the consequences for woodland dynamics depend on the size classes of the trees affected, as well as on the disturbance regime severity.

2.2.1 Elephant impacts on individual plant species

At species level, elephants can be selective, and are able to eliminate preferred woody species in woodland communities (Osborn, 2002). Evidence from previous studies suggests that this selective elimination of trees has occurred in protected areas in Zimbabwe. Gandiwa *et al.*, (2011b) recorded a decreasing trend in mean tree heights, tree densities, and basal areas and species diversities with increasing elephant utilization in *Acacia tortilis* woodland patches in northern GNP. Gandiwa *et al.*, (2011b) noted that, it is likely that continued elephant browsing on the *Acacia tortilis* species would lead to thinning of the *Acacia tortilis* woodland and possible threat of local extirpation of this species particularly in areas near perennial and natural surface water sources, e.g. Save-Runde River catchments, in northern GNP.

Osborn (2002) studied elephant induced change in woody vegetation and its impact on Sengwa Wildlife Reserve Area in Zimbabwe. The studies revealed that elephants browsed heavily and more frequently on *Combretum fragrans*, *Colophosperum mopane* (Osborn, 2002), and typical miombo trees like *Brachystegia boehimii* and *Afzelia quanzensis* (Guy, 1989) than other trees. Chafota (1998) observed that 40-70% of seasonal browse intake of elephants feeding in the Chobe River front of northern Botswana comprised of three shrubs, namely: *Bahia massaiensis*, *Bauhinia petersiana* and *Diplorhynchus condylocarpon*. Generally, the African elephant commonly prefer species in the following genera: *Acacia, Azima*, *Colophospermum, Combretum, Commiphora, Cordia, Cynodon*, *Dichrostachys, Grewia, Faudherbia, Gardenia, Portulacaria, Premma, Sclerocarya, Tamarix*, *Terminalia and Ziziphus* (Kruger *et al.*, 2007). Affected plant species can persist depending on whether they can cope with herbivory of this nature or if they have the capacity to restrict or compensate for the damage inflicted by resprouting and regrowth. Some plant species are, however, poor re-sprouters after cutting or following elephant damage, e.g. *Commiphora* species (Kruger *et al*., 2007).

2.2.2 Elephant impacts on *Adansonia digitata*

Several studies described the African baobab (*Adansonia digitata*) as being targeted by elephants (Caughely, 1976; Wilson, 1988; Swanepoel, 1993a; Barnes *et al.*, 1994). Studies have also documented that distribution and structure of the baobab is determined by elephant population. Much of the baobab mortality was attributed to elephant utilization (Barnes, 1980; Swanepoel, 1993a; Barnes *et al.*, 1994). Swanepoel (1993a) also indicated that small baobabs are likely to die from elephant utilization than big ones. This was also contended by Swanepole (1993); Barnes *et al.*, (1994) who believed that elephants cause baobab mortality. A study by Wilson (1988) discounted the importance of elephants in structuring baobab populations and suggested that land use and drought could be the determinant of absence of young trees. The Southampton Centre for Underutilized Crops, ICUC (2006) stressed that baobabs needed to be protected against animals, especially during juvenile state.

Conybeare (2004) noted that elephant impact on large trees like baobabs is of concern since they are conspicuous, and are aesthetically appealing. Plant species, which are most preferred by elephants, e.g. baobabs, have declined in numbers within protected areas, while some mature individual trees that elephants prefer, have remained intact in some areas now inhabited by people (Guy, 1989; Mpofu *et al*., 2012). Barnes *et al.,* (1994) made surveys on the long-term impact of elephant browsing on baobab tree population at Msembe, Ruaha National Park (RNP) in Tanzania. The surveys revealed that tree densities dropped between

1976 and 1982, but no significant changes occurred between 1982 and 1994, most probably due to a decline in bull elephants because of poaching (Barnes *et al.*, 1994). Baobab trees were also slightly affected at Lake Manyara in 1969 and 1981. During this period, only 13% of the trees remained undamaged, but annual tree mortality was about 1 % per annum (Owen-Smith, 1988). At Mana Pools, 24% baobabs were killed by elephants along the Zambezi River Frontage, while away from the river 6% of trees were severely damaged and a few died (Owen-Smith, 1988).

2.3 Elephant habitat and home range

Guy (1981) reported an elephant home range of 94-263km^2, and probably this reflects a lower availability of food and water. Elephants were reported to move up to 80 km in response to localized rainfall (Leuthold and Sale, 1973) and, as mentioned above, available water can concentrate elephant impacts (Swanepoel and Swanepoel, 1986; Pamo and Tchamba, 2001), as can localized nutrient rich soil in rugged terrain (Nellemann *et al*., 2002). For most African ungulates, only female home ranges can be related directly to nutritional requirements, because male home ranges are restricted by social pressure. The African elephant forms clans of 100 or more individuals, sharing a common area of about 200-700 km^2, with little overlap between different areas (Skinner-John, 2002). Skinner-John (2002) suggested that habitat destruction may be part of a stable limit cycles where elephant numbers increase while thinning the woodland, and then decline until reaching a low density that allows regrowth of trees. This then allow elephant numbers to increase again, and the cycle repeats itself.

2.4 Fire impacts on *Adansonia digitata*

Savanna patterns shape the cross-scale processes (Gillson, 2004): fire regimes depend on available grass biomass, which is in turn can be determined by edaphic factors (soil moisture and nutrient availability) and the intensity of herbivory on the landscape. Herbivory at high intensities can upset the tree–grass ratio by causing bush encroachment, which leads to positive feedback as fire intensities are reduced (Archer, 1989; Archibald *et al*., 2005). Fire can facilitate rapid growth by serving as a thinning agent, thereby reducing competition and providing a competitive advantage to the few surviving fire tolerant saplings (Bond and van Wilgen, 1996). This influence depends not only on differences in sensitivity of species to fire, but also on type, frequency and intensity of the fire, and on developmental stage of each plant at time of burning.

Succulent, live, standing baobabs trees are fire tolerant (Wickens and Lowe, 2008). Fire is likely to play a secondary role in baobab destruction (Laws *et al.*, 1975). Fires that do occur in dry periods can cause more damage to the grass layer than to baobab trees (Trollope *et al*., 1999). Perceived effect of fire on broken, ring barked, bark-stripped or uprooted baobabs in GNP are probably speculative and needs investigation (Mpofu, *et al*., 2012). Intense and severe fires may account for immediate deaths of baobab seedlings and baobab trees which have been pushed over by elephants (Whyte, 2001).

2.5 Soil substrate/bedrock and elephant damage influence on vegetation change in savanna ecosystem

Plant species habitat modeling studies based on niche theory; seek correlations between environmental factors and plant species presence (Grubb, 1977). Plant species distribution is usually modeled as a function of climatic, geologic or edaphic variables, which are postulated to exert a prominent effect on species' natural distribution (Guisan and Zimmermann, 2000; Willis and Whittaker, 2002). Edaphic factors are important drivers of plant community composition (Aerts and Chapin, 2000; Willis and Whittaker, 2002). Soil texture and structure strongly influence the soil water balance and therefore plant species community development (Aerts and Chapin, 2000; Willis and Whittaker, 2002). In GNP, plant species presence can be analyzed in relation to locally defined variables, such as stand structure, density or elephant damage and edaphic factors (Mpofu *et al*., 2012). These studies often distinguished the different population demography and plant size developmental stages (Bugmann, 2001; Busing and Mailly, 2004).

Collins and Carson (2004) clearly stressed the concept of regeneration niche (Grubb, 1977) that species-environment relationships vary with plant life stage (size class distribution), consequently, seedlings, saplings have different requirements from adults and may therefore have different distribution patterns from adults (Stohlgren *et al*., 1998; Collins and Carson, 2004). The plant species community composition and diversity of vascular plant species was described as being an outcome of soil resource availability, e.g. soil structure, nutrients, and soil water and/or outcome of the pattern of loss of plant resources or biomass, e.g., due to herbivory and fire, causing modification of plant species community composition in ecological time (Grime *et al*., 1997; Huntly, 1991; Pickett and White, 1985). Depending on spatial scale, habitat and taxonomic affiliation, plant species abundance and distribution may be positively, negatively or unimodally related to soil resource availability (Turner *et al.*, 1987; Waide *et al*., 1999). The soil substrate/bedrock of the entire GNP is not uniform, ranging from granophyre, malvernia and rhyolite substrate/bedrock derived soil groups (Nyamapfene, 1991; Clegg, 2003). Soil groups are perceived to be key determinants of baobab abundance, structure and distribution in GNP.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Introduction

A total of 225 baobabs were randomly sampled within a cumulative total belt transect length of 17.2km with a constant width of 0.3km in GNP. The study area was stratified according to Gandiwa *et al*. (2012). GNP was subjectively divided into three strata based on management regimes, coinciding with soil substrate/bedrock gradient and elephant occupancy in relation to proximity to natural water sources. These were referred to as Northern GNP, Central GNP and Southern GNP. GNP soil substrate/bedrock delimitation followed Nyamapfene (1991), as cited by Tafangenyasha (1992) and Clegg (2003). The present study focused on impact of elephant damage and population dynamics of *Adansonia digitata* stands in three GNP strata with a gradient of soil substrate/bedrock and elephant occupancy, in relation to natural water sources, in this case, perennial water sources. There has been no water supply from artificial pumping in GNP since 2007 (GNP, 2010). Such characteristics of study sites as soil substrate/bedrock, study site elevation, percentage estimate of study site rockiness, elephant dung counts and grass height were recorded. Based on Gandiwa *et al.* (2011b), dung count provided a fair idea of the measure of elephant occupancy and utilization of a stratum. Figures 1.1 and Figure 1.2 show the relief, drainage and geology (soil substrates/bedrock) of GNP, respectively.

3.2 Study design

The Northern GNP stratum comprised of the area north of Runde River. The Northern GNP stratum is on granophyre substrate/bedrock. A variety of granophyres and granites of the late Jurassic are concentrated in the defined northern stratum (Tafangenyasha, 1992; Clegg, 2003). In the Northern GNP stratum, there are two huge pans near the Save/Runde River junction

(Tambohata and Machiniwa) and an artificial weir (Massassanya) that holds water through most years (GNP, 2010). The defined Northern GNP covered Chilojo Plain, Chiwonja Mountain range, Nyagwama Mountain range and Sililijo Range, Sililijo Road and Sililijo Plain.

The Central GNP stratum comprised the area south of Runde River to the railway line. . Chinzunzwani Ridge and Nyamtongwe Plateau are the two conspicuous topographical features on the malvernia plain beds of Central GNP. The Central GNP stratum is mainly on malvernia beds, with a small patch of granophyre bedrock which is well defined on the immediate south of Runde River. Malvernia cretaceous sandstones derived soils, cover much of the defined Central GNP stratum (Tafangenyasha, 1992; Clegg, 2003). The central parts of the GNP is relatively dry, it is the headwaters of the Guluene/Chefu seasonal river system. The artificial weir (Benji) is the main natural water source of Central GNP. The defined Central GNP stratum covered Muchingwizi Stream, Muchingwizi Mountain range, Sibonja Hills, Chigono Mountain range and Lower Benji Weir area.

The Southern GNP stratum comprised of the area south of the railway line to the Mwenezi River. The immediate south of the railway line has Ntambambovhu Red Hills on malvernia beds. There is a small granophyre patch where Mwenezi River enters GNP (see Figure 3.2). The Southern GNP stratum has a stretch of rhyolite substrate/bedrock along Mwenezi River. Patches of rhyolite derived soils mainly constitute the margins of Mwenezi River in the Southern GNP stratum (Tafangenyasha, 1992; Clegg, 2003). Most of internal drainage of the GNP feeds the Runde river system and, to a lesser extent the Mwenezi river system, thus leaving the defined Southern GNP zone as a stratum of moderate natural perennial water source (GNP, 2010). The defined Southern GNP stratum covered Lipakwa Pool, Mabalauta Station, Swimuwini and Ross Pool.

3.2.1 Sampling design

The study was based on stratified random design (Mueller-Dombois and Ellenberg, 1974) on the basis of two gradients of soil substrate/bedrock and elephant occupancy in relation to proximity to natural perennial water sources. The first gradient was the soil substrate/bedrock gradient varying from granophyre, malvernia to rhyolite substrate/bedrock derived soil groups. The second gradient was the elephant occupancy and utilization in relation to availability of natural perennial water sources of GNP, in relation to Save-Runde catchment, Benjie Weir and Mwenezi River.

Table 3.1: GNP strata study sites and natural water source proximity.

Stand	**GNP strata**	**Natural water source proximity**	**Replicate belt transects**
Adansonia digitata	Northern GNP	High	6
	Central GNP	Low	5
	Southern GNP	Moderate	4

Table 3.2: **GNP study sites of soil substrates/bedrocks**

Stand	**GNP soil substrate/bedrock**	**Elevation and Rockiness**	**Replicate belt transects**
Adansonia digitata	Granophyre	High	10
	Malvernia	Low	2
	Rhyolite	Moderate	3

3.3 Selection of sampling belt transects

Belt transects were categorized according to the defined three GNP strata. Belt transects were also recorded on soil substrate/bedrock on which baobabs were growing as granophyre, malvernia and rhyolite substrate/bedrock, based on the geological map of GNP. All *Adansonia digitata* stands in GNP which falls in the three defined GNP strata were selected from the GNP topographical map (Nyamapfene, 1991 cited in Tafangenyasha, 1992; Clegg 2003) and vegetation map (Sherry, 1977; Tafangenyasha, 1991; GNP, 2010). Sampling study sites, as belt transects, were randomly selected using random number tables based on GNP topographical map grid square intercept system, in relation to the stratified study sites. Sampling belt transects within the study site gradients were located by generating random points (GPS coordinates) in the selected *Adansonia digitata* stands/patches on a vegetation map in Arc View 3.2 software package (GNP, 2010).

Dunham, K.M. 2012. Trends in populations of elephant and other large herbivores in Gonarezhou national Park, Zimbabwe, as revealed by sample aerial surveys. *African Journal of Ecology* **50**: 476-488.

Guided by GNP topographical map, GPS handsets were used to track the position of belt transects in the *Adansonia digitata* stands/patches. Inaccessible areas were, however, rejected and the next sampling belt transect was considered. A 2003 remotely sensed vegetation map of GNP (GNP, 2010) was used in the stratification and ground truthing. For each of the three GNP strata, at least four replicate belt transects, depending on spatial extent of *Adansonia digitata* stands/patches, were identified as a way of maximizing representation of the *Adansonia digitata* stands in a stratum. A total of 15 belt transects were demarcated across the entire GNP following the study strata.

3.4 Sampling procedure

Sampled baobabs were randomly selected according to Campbell *et al.* (1996). A standard sample belt transect width of 0.3km wide was used at each study site, in accordance with methods by Mapaure (2001) and Anderson and Walker (1974). A belt transect width of 0.3km to 0.5km is considered adequate for surveys in savanna vegetation (Coetzee, 1975). Density was calculated from distance within which some fifteen baobabs were encountered. Walker (1976) considered that a belt transect should have at least 15-20 plants. Measurements were recorded from the first fifteen baobab individuals encountered in each belt transect following the nearest neighbor concept (Samet, 2006). Nearest neighbour concept examines the distances between each baobab individual and the closest baobab point to it (Beyer *et al.*, 1999). Fifteen baobabs within a belt transect were recorded and measured. According to (Mapaure, 2001), baobabs occurring along belt transect margins were included if at least half of the canopy was inside the belt transect.

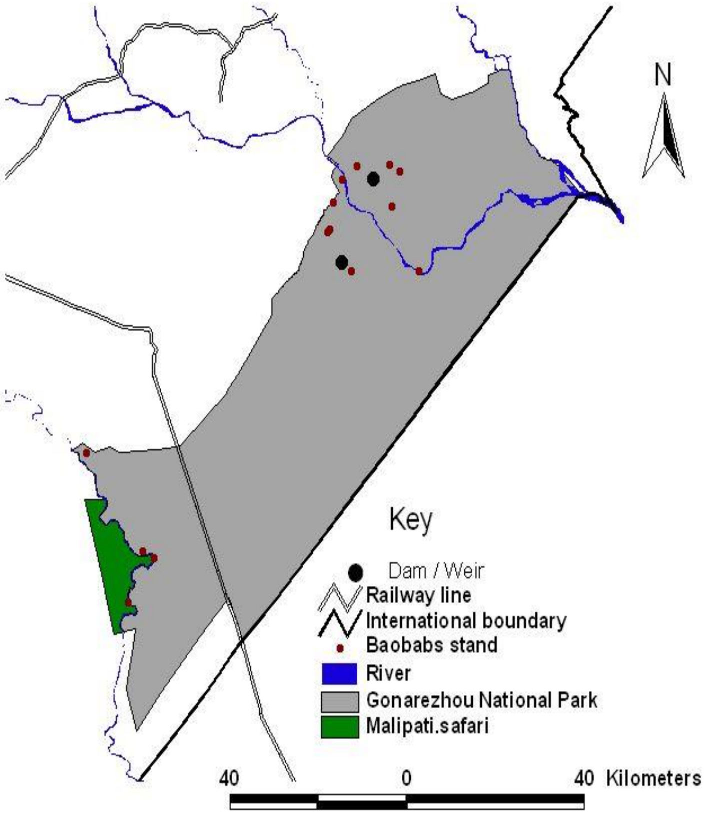


Figure 3.1: GNP map showing the distribution and density of baobab study sites.

To establish an elephant inaccessibility criterion, the elevation of a belt transect was recorded with a GPS, and percentage estimate of rockiness within a belt transect was noted. Sampling belt transects was based on presence of *Adansonia digitata* as the species was not the dominant species in GNP. Six belt transect were sampled in northern GNP, five in central

GNP and four in southern GNP. Some trees still had leaves and fruit during the study period of May-June 2012. This assisted with species identification. When small, and without leaves, baobabs are identifiable through terminal buds which have characteristic red leaflets. An additional character for identifying baobabs is the twig which can twist without breaking (Edkins *et al*., 2007). *Adansonia digitata* was identified at seedling stage from the field guide of Coates-Pelgrave (1997). Baobabs were sampled by walking from one tree to its nearest neighbour, and a record of GPS co-ordinates of all the baobab samples was made. GPS co-ordinates of all sampled baobab individuals were recorded following methods of (Edkins *et al*., 2007). This enabled compilation of GNP baobab database for future assessments of the baobabs.

Baobab size class categorization was adopted from Swanepoel and Swanepoel (1986), size class distribution was based on 2.5m girth intervals, i.e. 0-2.5m; 2.51-5.00m; 5.01-7.5m; 7.5-10.00m; 10.01-12.5m; 12.51-15.00m; 15.01-17.50m. Demographics of sampled baobabs were represented as number of individuals per size-class, based on the 2.5 m gbh size classes. Juvenile baobabs were of gbh size class ≤5m, and sub-adult baobabs were of gbh size class 5.01≥ gbh ≤ 10.00m. Adult baobabs were of gbh size class > 10.00m (Swanepoel and Swanepoele, 1986; Mpofu *et al*., 2012). The number of baobabs within each girth interval was also grouped according to elephant damage classification. Elephant damage was assessed to scale from 0 to 4: (0)-no damage, (1)-slight elephant damage-few scars, (2)-moderate damage-scars more numerous, (3)-severe damage-scarred deeply, and (4)-tree completely damaged-dead according to (Swanepoel and Swanepoel, 1986; Edkins *et al*., 2007; Gandiwa *et al*., 2011a).

Data sheets were pressed on a clipboard, and data for each belt transect were recorded on a separate sheet (see Appendix A). Table 3.1 shows belt transect attributes on the three GNP strata, and Table 3.2 shows belt transect attributes on the main three soil substrates/bedrocks of GNP.

3.5 Recorded variables and measurement techniques

Belt transects were assessed only once during the study period, May-June 2012. To describe the cumulative and interactive determinacy of soil substrate/bedrock and elephant impact on baobab structure, abundance and distribution in GNP. The following were measured or recorded: plant height, basal stem circumference at 1.3m height, number of stems per plant, fire damage, elephant damage, plant status (alive or dead) and stem density. The measured variables followed the methods of Mpofu *et al*. (2012) and Gandiwa *et al*. (2012).

3.5.1 Plant height

The height of *Adansonia digitata* specimens was measured to the nearest metre by placing a calibrated 12 m pole against the plant. For trees >12 m, the pole was manually uplifted or height visually estimated by observing it at a distance away from the tree. For multi-stemmed plants, only the height of the tallest stem was considered.

3.5.2 Basal stem circumference

The basal circumference of each stem was measured at breast height (1.3m) to the nearest centimeter, using a flexible 50 m tape measure. Where plant height was less than 1.3m, basal stem circumference was measured just above the buttress swelling, according to Mpofu *et al*. (2012). From the basal stem circumference, basal area was calculated using the formula:

Basal area = ($C^2/4\pi$), Where C is basal stem circumference.

From the basal stem circumference, diameter at breast height was calculated using the formula: **Girth at breast height (gbh) = C/π**

3.5.3 Number of stems per plant

Baobab stems were physically counted for each belt transect. Total number of baobab stems was divided by number of baobabs in a particular belt transect, to give an average number of stems per plant.

3.5.4 Stem density

Density (e.g. baobab stems per km^2) for each belt transect, was calculated using the formula:

$$\text{Density (stems/km}^2) = \frac{\text{Number of baobab stems}}{\text{Belt transect area (km}^2)}$$

3.5.5 Plant status

For dead plants, the cause of death was attributed to one of four factors i.e. (4) elephant herbivory, (3) fire, (2) elephant-fire damage (1) drought, and (5) unknown. Any signs of elephant damage, such as broken branches, leaves and trampling, bark stripping and scaring, and uprooted trees or shrub were considered as elephant-induced death. Fire scars or burn marks and characteristic regrowth from the base of dead stems or charred plant remains were considered as fire-induced death. Combined signs of elephant damage and fire damage were considered as elephant-fire induced damage. On the other hand, where dieback was limited to upper portions of intact branches, death was attributed to drought. If dead, the plant's cause of death was recorded, and no other variable measurement was taken**.**

3.5.6 Fire damage on baobabs

The baobabs were assessed for fire damage. Fire damage was measured in terms of presence of charred remains on the trunk or branch surface or characteristic re-growth (Ben-Shahar, 1998). Indicators of fire damage were scorch marks on branches, fire scars and characteristic new growth from the plants (Stronach, 1989). Evidence of fire that is fire scars, burn marks, dead stems and charred plant remains was noted. Fire damage was assessed as presence (yes/no).

3.5.7 Elephant damage on baobabs

The baobabs were examined for signs of elephant damage (e.g. broken branches, leaves and trampling, bark stripping and scaring, and uprooted trees or shrub) to give insight of elephant herbivory damage. Elephant damage was assessed to scale from 0 to 4: (0)-no damage; (1)-slight damage-few scars; (2)-moderate damage-scars more numerous; (3)-severe damage-scarred deeply; (4)-tree completely damaged and dead.

3.5.8 Elephant dung counts and elephant occupancy/utilization of belt transect

Elephant dung count according to Gandiwa *et al.* (2011b) was used to indicate a measure of elephant occupancy and utilization of a stratum. Total counts of old elephant dung and fresh elephant dung were recorded in each belt transect. The sum of old and fresh dung represented an accumulation of elephant occupancy and utilization of a belt transect, while fresh elephant dung counts only represent dry season elephant utilization and occupancy of a belt transect. Dung counts have the advantage that they give data, not only on numbers, but also on distribution and differential habitat use (Gandiwa *et al*., 2011b).

3.5.9 Grass height

Grass height was noted in each belt transect. Five random points were recorded for grass height, where mean grass height was calculated from the sum heights of five grass swards. Grass height was thought to have some implication on exposure of elephant dung and baobab seedlings where sampling (Gandiwa *et al*., 2011b).

3.6 Data Analysis

Data were summarized by descriptive statistics (means and standard errors) per each belt transect before further analyses in Microsoft Excel 2007. Box and whisker plots were presented for data from the *A. digitata* stands in the three strata across GNP, and soil types for each respective grouping variable, using non–parametric tests.

3.6.1 GNP baobab stands density and spatial distribution

GPS coordinates (Appendix T) of the sampled baobabs were transformed in ILWIS GIS Version 3.3 from LATLONG to UTM 36 coordinates. The distribution of baobab stands was mapped using UTM 36 coordinates. GNP topographical map (1:50 0000) was scanned and geo-referenced in GIS using Arc view 3.2. GNP map was digitized in order to enter the actual geographical location of the sampled baobab stands after overlaying GPS coordinates. UTM 36 coordinates for the sampled baobab stands were entered in Microsoft Excel 2007, and then exported into a GIS version 3.3. Data were analyzed in Arc View 3.2 to produce a GNP polygon map that includes all fifteen study sites of the GNP. For the spatial distribution of baobab stands, data points recorded from GPS were entered into a GIS environment using ArcView 3.2 to produce baobab stands location map overlaid on top of the three GNP strata. A GNP map showing the spatial distribution and density of baobab stands of study sites within the three GNP strata was then produced (Figure 3.1).

3.6.2 Baobab density, structure and distribution on soil substrates across the three strata of entire GNP

One-way ANOVA tests with GNP strata and soil substrates, each as separate grouping variables and measured variables from the belt transects as dependent variables in SPSS version 19 were done in each case, to find if there were significant differences in structure and density of baobabs across GNP strata and soil substrates/bedrocks, respectively. Data were first tested for normality sing the Shapiro-Wilk Test, and if not normal, data were transformed to meet the normality assumption of ANOVA procedures.

Baobab stem density and distribution across GNP strata and the soil substrates were determined. Baobab stem density was calculated from the following formula: Baobab stem density= numbers of baobab stems in the study site area (per km^2). The demographics of baobabs were presented as baobab frequency per study site in the three GNP strata and the three soil substrates/bedrocks, respectively. Baobab size class categorization was carried out according to Swanepoel and Swanepoel (1986) and Edkins *et al*. (2007). Baobab size class distribution across study sites was presented as histogram graphs (indication of reverse J-distribution) derived from descriptive analysis Microscoft Excel, (2007).

Multivariate analyses procedures further explored the relationship between environmental variables, grouping variables (GNP strata and soil substrates) and baobab density, structure and distribution. A Principal Component Analysis (PCA) was carried out in CANOCO for Windows version 4.5 to check the length of the gradients of the environmental determinants. The gradient (standard deviation) was less than 4, hence, a Redundancy Analysis (RDA), a constrained form of the linear ordination method of **(**PCA) was then used to indirectly explore the relationship between the baobab stem density, structure, distribution and environmental variables (both quantitative and qualitative). Monte-Carlo permutations were used to calculate the significance of environmental variables. CanoDraw for Windows version 4.14 was used to produce the ordination diagrams, the scatter plot.

3.6.3 Assessment of elephant damage levels on baobabs across GNP.

One-way analysis of variance was used to test whether there was significant difference in the elephant damage level of baobabs located across the three GNP strata. These data were used to test whether there was any variation in elephant- induced bark damage among the study sites. Elephant damage on baobabs was categorized according to Gandiwa *et al*., (2011a), that is to scale from 0 to 4: (0)-no damage; (1)-slight damage-few scars; (2)-moderate damage-scars more numerous; (3)-severe damage-scarred deeply; (4)-tree completely damaged (dead).The frequency of baobabs within each damage class per study site was noted (Swanepoel and Swanepoel, 1986). The frequency of baobabs within each elephant damage category per baobab size class was presented in tables (Swanepoel and Swanepoel, 1986). Graphs were drawn from descriptive analysis (Microsoft, 2007; Edkins *et al*., 2007) to show elephant damage levels related to baobab size class and study sites of different baobab density.

Multivariate analyses procedures explored the relationship between environmental variables (elephant damage, study site habitat rockiness and study site elevation) and baobab structure, density and distribution. A PCA was carried out in CANOCO for Windows version 4.5 to check the length of the gradients of the environmental determinants. The gradient (standard deviation) was less than 4; again, (RDA) was used to explore the relationship between environmental variables and the measured plant variables. Monte-Carlo permutations were used to calculate the significance of environmental variables. Cano-Draw for Windows version 4.14 was used to produce the ordination diagrams.

3.6.4 Assessment of baobab recruitment and regeneration

The distribution of baobabs in the gbh size class categories can be used to trace the growth patterns of the baobab population as it gives an indication of the recruitment at any particular stage in the population history (Wilson, 1998; Edkins *et al*., 2007). Thus, the gbh baobab size class categories data were used to assess recruitment of the baobab populations within the different sites. This was done through comparison of the gbh baobab size class measurements of the baobab populations. The demographics of baobabs sampled was represented as percentage frequency of baobab size class distributions according to Swanepoel and Swanepoel (1986), based on 2.5 m gbh size classes per study site for populations in the different GNP strata and soil substrates/bedrocks. Graphs were also drawn using descriptive analysis, Microsoft Excell (2007) to show baobab population stability or decline in different study sites as indicated by baobab size class distribution (Edkins, *et al*., 2007).

To identify potential baobab refugia in GNP, the argument was that a healthy baobab population should have a reverse-J size-class distribution, with a smooth decline (mono-modal distribution) in numbers from a maximum in the juvenile size class (gbh ≤5m) (Wilson, 1988; Edkins *et al*., 2007). A correlation of elephant damage on baobabs, habitat rockiness, habitat elevation, baobab density and structure was assessed by multivariate procedures to inform identification of preferred potential baobab refugia in GNP.

3.6.5 Fire damage on baobabs

In this study, fire was not a major factor as no evidence of fire damage was recorded on all the 225 sampled baobabs. This was related to Mpofu *et al.* (2012), where no evidence of fire damage was found on all sampled 117 baobabs in southern GNP.

CHAPTER 4

4 RESULTS

4.1 GNP baobab stands density and spatial distribution

The study sought to determine spatial distribution of baobabs across the three GNP strata. Figure 3.1 shows the spatial distribution and density of baobab stands within the three GNP strata, as was found by the baobab stands survey. A total of fifteen baobab stands were surveyed. Out of the fifteen belt transects, ten, two and three baobab stands were found on granophyre, malvernia and rhyolite substrate/bedrock, respectively (Table 3.2). A total of 225 baobabs were assessed. About 98% of the baobabs were living plants, 2% were dead stems, and 84.4% showed evidence of elephant damage, and the entire sampled baobab showed no evidence of fire damage. *A. digitata* was not the dominant species, and for most of the time it was rarely found**.** There was rare evidence of baobab stands on malvernia beds.

4.2 Baobab density and distribution across the three strata of entire GNP

There were no significant differences on mean baobab stem density, plant basal area, plant height and number of stems per plant across the three GNP strata (one-way ANOVA, both *p>0, 05*; see table 4, 1). The variables measured during the study are summarized in Table 4.1. Table 4.1 provides relationships and differences of variables on the three GNP strata and their associated impacts on baobab structure and density (see also Table 4.2). Baobab density was highest in the Northern GNP stratum (69.8 stems per km^2) and lowest in Central GNP stratum (34.25 stems per km^2), (Table 4.2). The distribution of baobabs in Northern GNP is generally clustered. The distribution of baobabs in Central GNP is clustered as well, although all baobab stands are in the northern part of Central GNP (see Figure 3.1).

Table 4.1: Summary of statistical analysis; One-way ANOVA results of the measured variables and GNP strata as grouping variables

		Sum of Squares	df	Mean Square	F	P value
Plant basal area	Between GNP strata	20995.41	2	10497.71	2.22	0.152
	Within GNP strata	56829.79	12	4735.82		
	Total	77825.20	14			
Plant height (m)	Between GNP strata	34.74	2	17.37	3.30	0.072
	Within GNP strata	63.28	12	5.27		
	Total	98.02	14			
Stem density	Between GNP strata	1754.58	2	877.29	0.86	0.447
	Within GNP strata	12213.55	12	1017.80		
	Total	13968.13	14			
Elephant damage	Between GNP strata	3841.06	2	1920.53	3.37	0.069
	Within GNP strata	6831.75	12	569.31		
	Total	10672.81	14			

Notes: Not significant if P value > 0.05

The baobab stands in Southern GNP are relatively dispersed along Mwenezi River (Figure 3.1). Highest number of baobab stands, 40% was found in the Northern GNP stratum, and the lowest was found in the Southern GNP stratum with 26.7% (Table 4.2).

Table 4.2: Baobab density and distribution for the study sites (figures represent values for all belt transects within each GNP strata

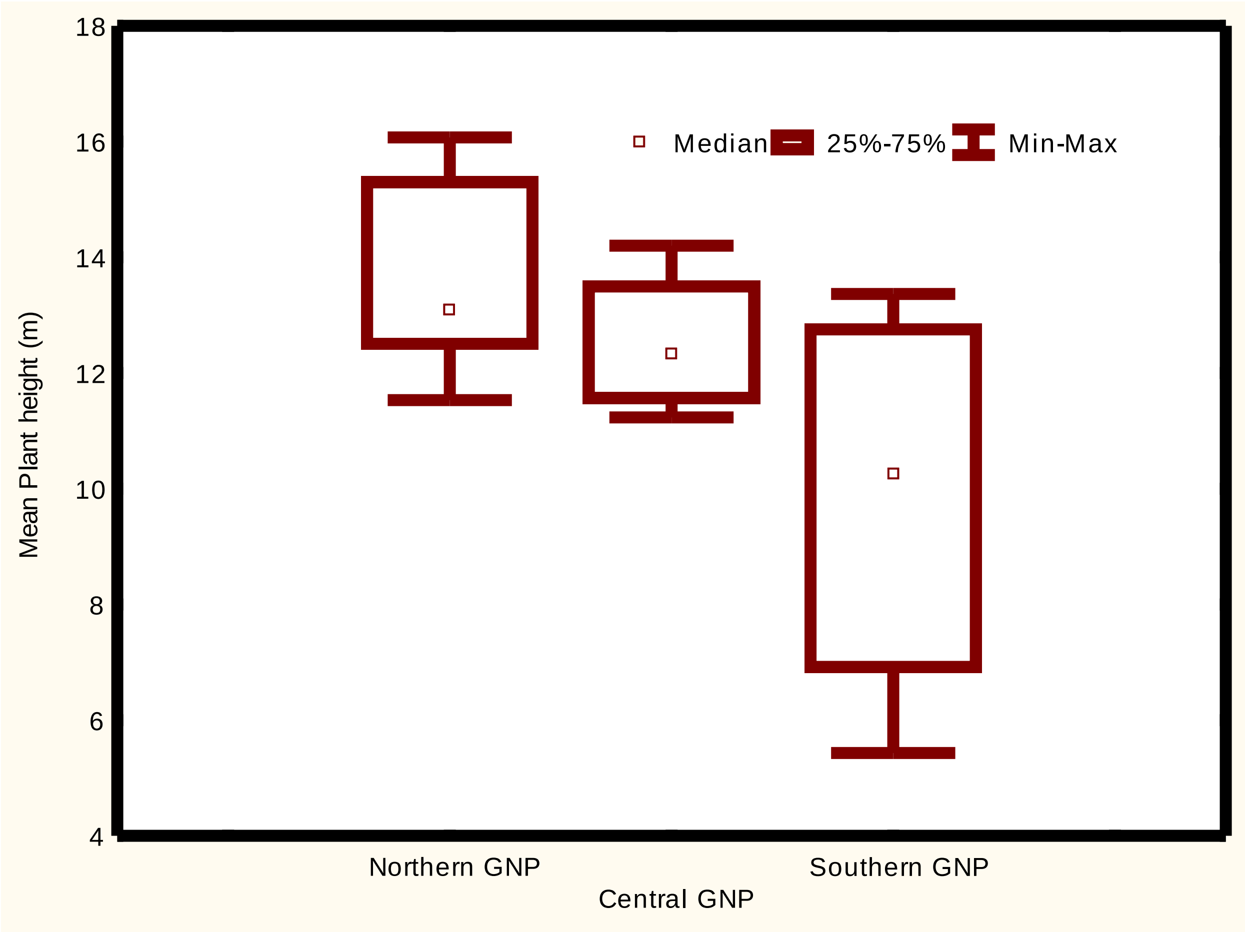
GNP stratum	**Sample number**	**Sample area (km^2)**	**Mean Stem density-/km^2**	**Baobab stand (%)**
Northern GNP	90	1.29	69.77	40
Central GNP	75	2.19	34.25	33.3
Southern GNP	60	1.68	35.71	26.7
GNP	225	5.16	43.6	100

4.2.1 Box and whisker plots of measured study variables in the *A. digitata* stands in the three strata across GNP (Northern GNP, Central GNP and Southern GNP) (Figures 4.1 to 4.4; Using Non–parametric test.

Kruskal-Wallis ANOVA by Ranks**; Mean Plant height (m)** (Adstudy)

Independent (grouping) variable: GNP stratum

Kruskal-Wallis test: H (2, N= 15) =2.960833 p =.227



GNP strata

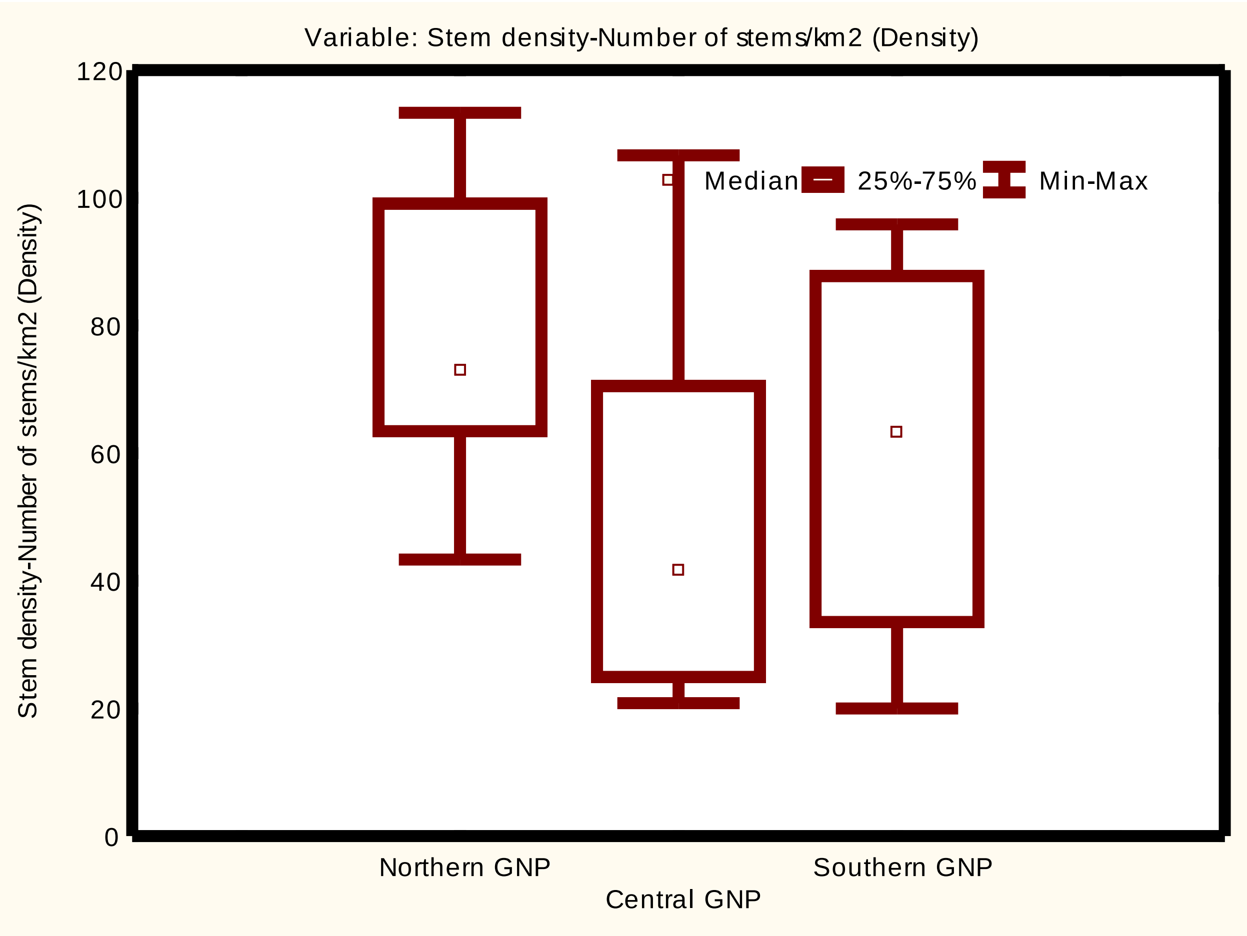
Figure 4.1: Mean Plant height (m)

High plant height was observed frequently in Northern GNP, while low plant height was frequently observed in Southern GNP (Figure 4.1).

Kruskal-Wallis ANOVA by Ranks; **Stem density-/km2** (Density) (Adstudy)

Independent (grouping) variable: GNP stratum

Kruskal-Wallis test: H (2, N= 15) =1.760833 p =.4146



GNP strata

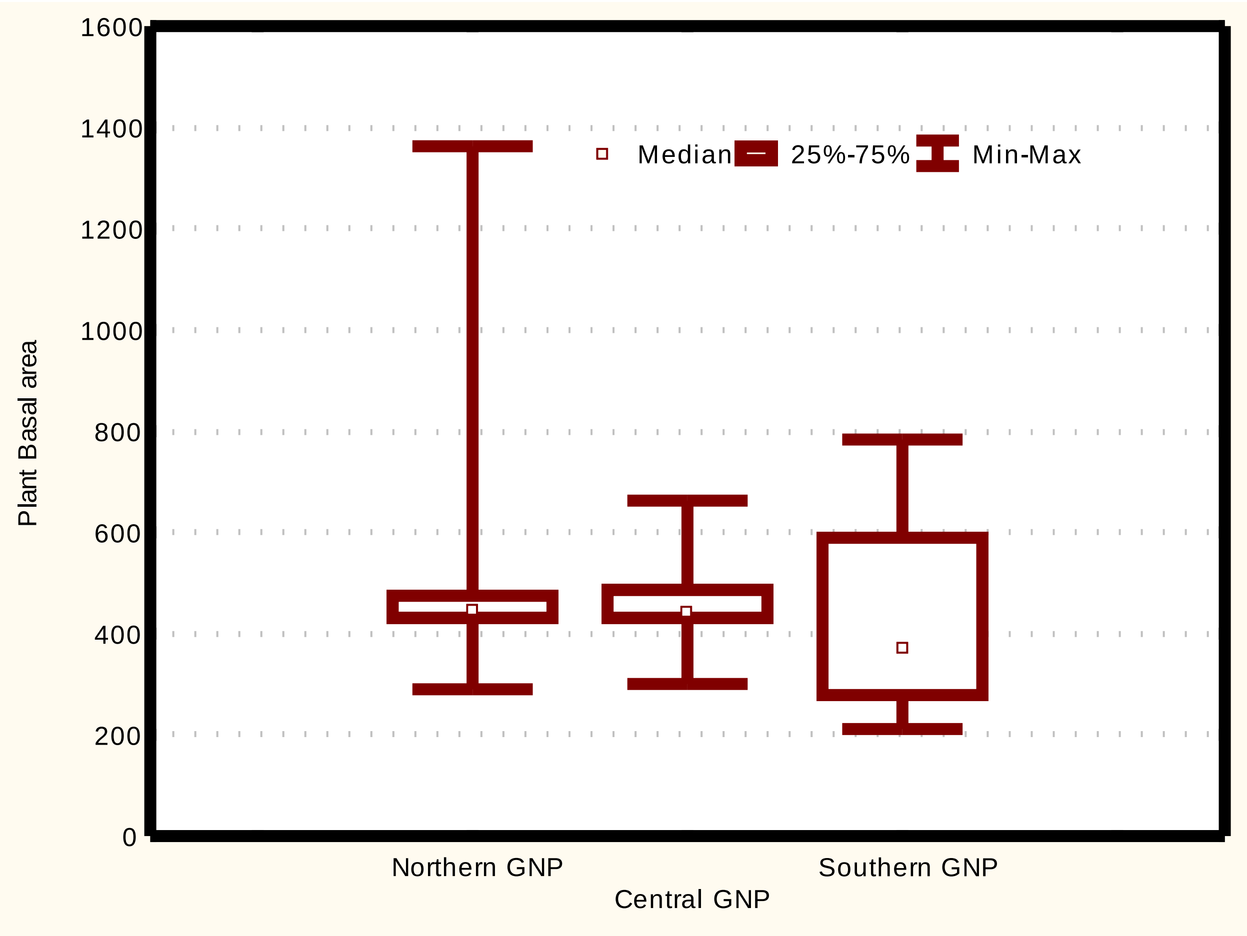
Figure 4.2: Stem density-/km^2

Baobab stem density was high in Northern GNP and lowest in Central GNP (Figure 4.2).

Kruskal-Wallis ANOVA by Ranks; **Mean Plant basal area** (Adstudy)

Independent (grouping) variable: GNP stratum

Kruskal-Wallis test: H (2, N= 15) =1.098333 p =.5774



GNP strata

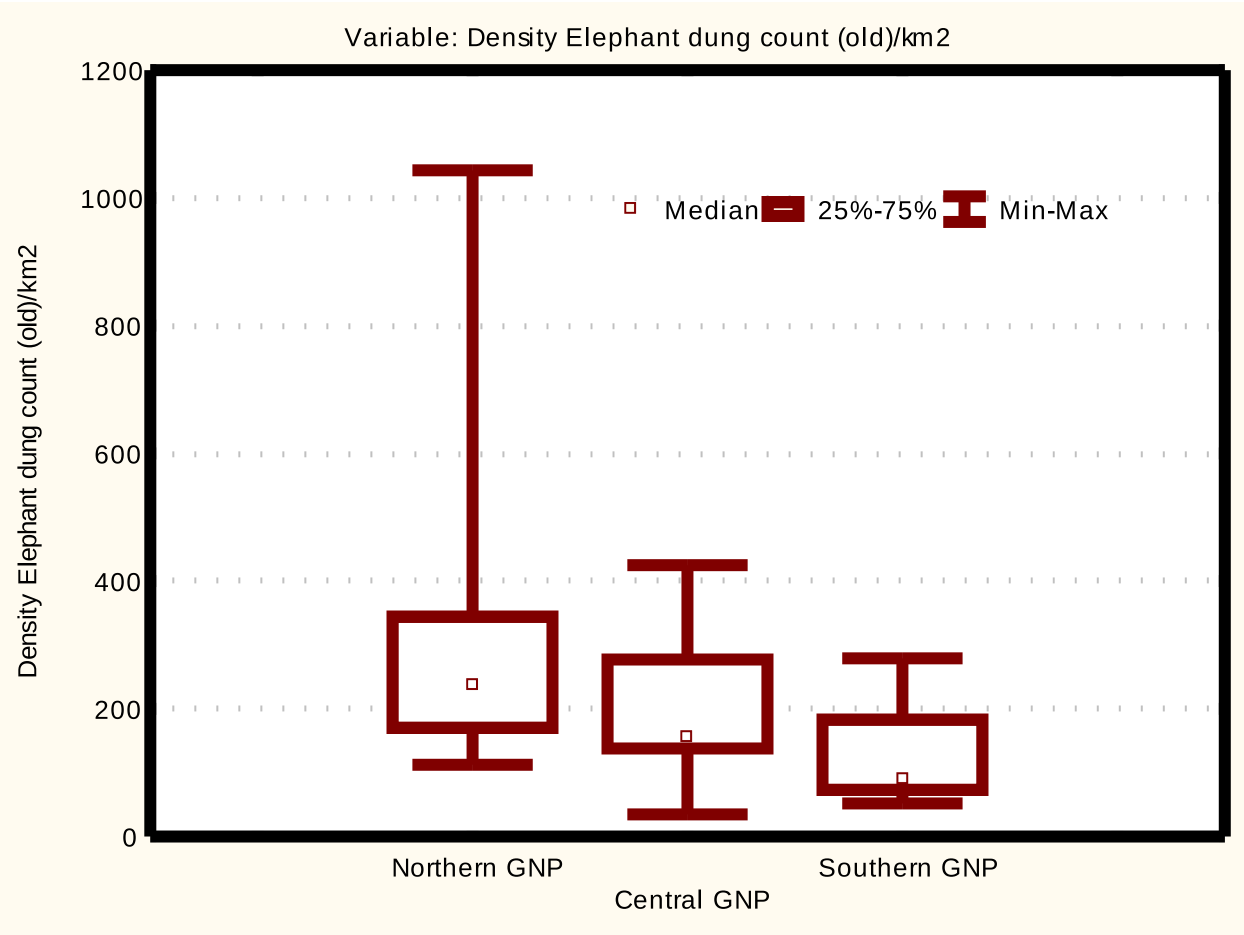
Figure 4.3: Mean Plant basal area (m^2)

Large baobabs of large basal area were found in Northern and Central GNP as compared to Southern GNP (Figure 4.3).

Kruskal-Wallis ANOVA by Ranks; **Density: Elephant dung count /km^2** (Adstudy)

Independent (grouping) variable: GNP stratum

Kruskal-Wallis test: H (2, N= 15) =3.000000 p =.2231



GNP strata

Figure 4.4: Density: Elephant dung count /km^2

Elephant dung were more frequent in Northern GNP and least frequent in Southern GNP (Figure 4.4)

4.2.2 Baobab structure and distribution across the three strata of GNP

There were no significant differences on mean plant basal area, mean plant girth at breast height (gbh) and mean plant height across the three GNP strata (one-way ANOVA, both *p>0, 05*; see table 4.1). The variables measured during the study were summarized in Table 4.1. Table 4.1 provides relationships, differences, of study variables on GNP strata as grouping variables and their associated impacts on baobab structure and density of sampled baobabs (see also Figure 4.5). Size class frequency distribution of the sampled baobabs in the study sites, namely; Northern GNP, Central GNP and Southern GNP are shown in Tables and Figures in Appendix B, C and D, respectively. Summary baobab size class frequency distribution of the entire sample of GNP is shown in Figure 4.5 as derived from a table in Appendix E.

Basing on baobab size class categorization according to Swanepoel and Swanepoel (1986), the highest frequency of juvenile baobabs of the size class gbh $\leq$ 5m was found in Southern GNP, with 63.3% (Figure 4.5), dominated by Mabalauta Station and Swimuwini (Appendix D), followed by Northern GNP with 48.9% (Figure 4.5), dominated by Chivonja Mountain range, Nyagwama Range and Sililijo Range (Appendix B). The least frequency of juvenile baobabs was found in Central GNP having 45.4% (Figure 4.5), dominated by Muchingwizi Mountain range and Sibonja Hills (Appendix C).Sub-adult baobabs (5.01m $\geq$ gbh $\leq$ 10.00m) were mostly found in central GNP with 50.7% (Figure 4.5), dominated by Muchingwizi Stream and Chigono Range (Appendix C), followed by Northern GNP with 44.5% (Figure 4.5), dominated by Sililijo Plain and Sililijo Range (Appendix B), while the least frequency of sub-adult baobabs was found in Southern GNP with 26.7% (Figure 4.5), dominated by Ross Pool and Lipakwa Pool (Appendix D). Adult baobabs (gbh > 10.00m) were of highest frequency in Southern GNP with 10% (Figure 4.5), dominated by Swimuwini (Appendix D), followed by

Northern GNP with 6.6% (Figure 4.5), and dominated by Chilojo Plain (Appendix B). The least frequency of adult baobabs was found in Central GNP with 2.6% (Figure 4.5), dominated by Muchingwizi Stream (Appendix C).The largest baobab of the sample was recorded at Swimuwini in Southern GNP with a gbh size of 17.5m.

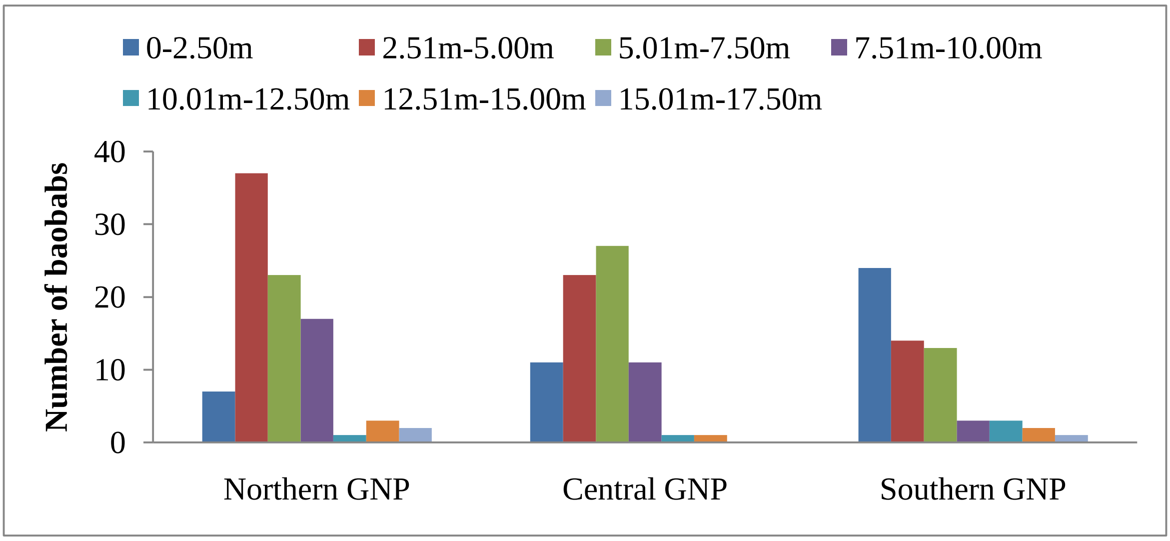


Figure 4.5: Size class distribution of baobabs within GNP strata study sites.

4.2.3 Baobab structure and distribution across GNP

Size class frequency distribution of the sampled baobabs for the entire GNP is shown in Figure 4.5 (see also table in Appendix E). The size structure of the baobabs in much of GNP had a high frequency of juvenile baobabs with 51.6%. Sub-adult baobab population accounted for 41.8%, while adult baobabs accounted for 6.3% of the sampled baobabs. Baobab gbh size class 0-2.50m was of highest frequency in Southern GNP and lowest in Northern GNP, whilst the highest frequency of baobab gbh size class 2.51m-5.00m was in Northern GNP and the lowest in Southern GNP. Baobabs of size class gbh 5.01m-7.50m had its highest frequency in Central GNP and its lowest in Southern GNP, whilst the highest frequency of baobab size class gbh 7.51m-10.00m was in Northern GNP and the lowest was in Southern GNP. Northern

GNP and Southern GNP each recorded six, the same number of baobabs of gbh size greater than 10m, whilst Central GNP recorded only two baobabs.

4.3 Results of a Redundancy Analysis (RDA)

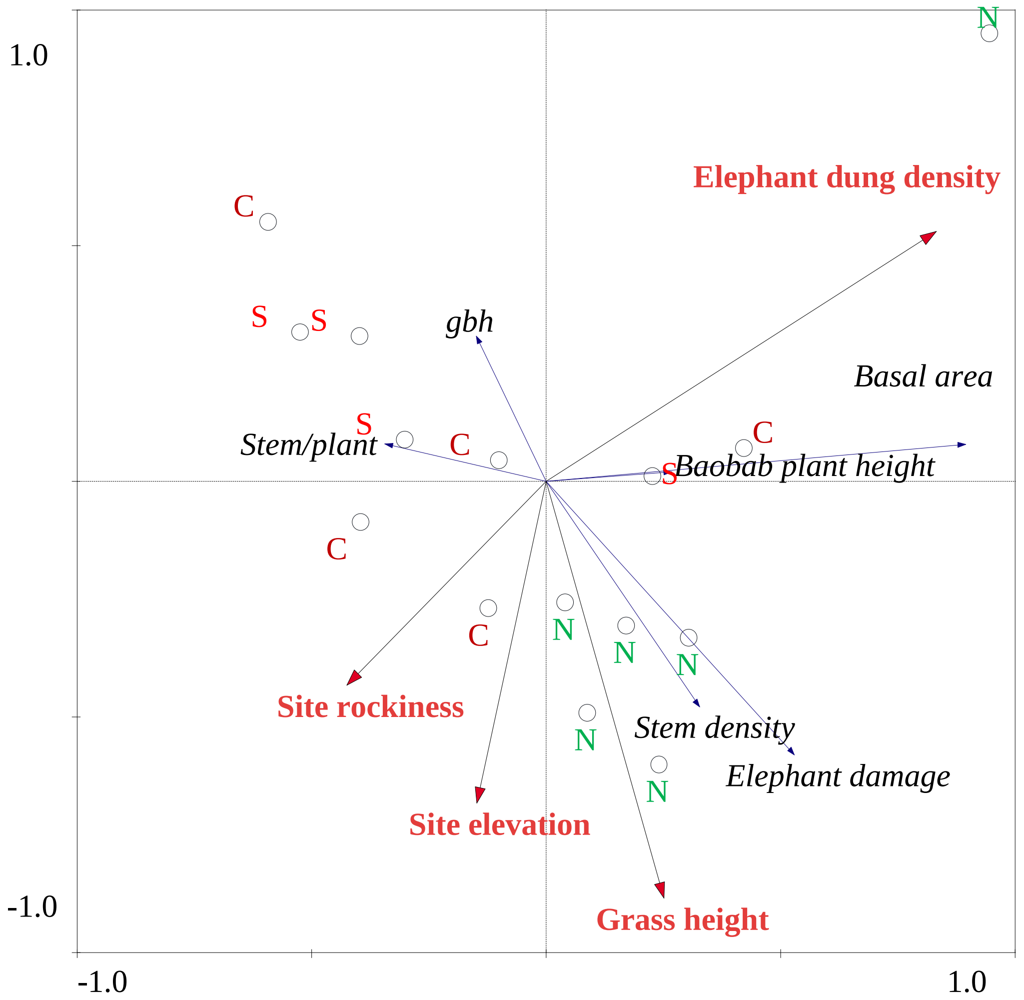


Figure 4.6: Scatter plot of 15 sample belts transect in the Baobab stands, measured plant variables and environmental variables in the Gonarezhou National Park, southern Zimbabwe. Lettered data points denotes sample belt transect; with letter N representing belts transect from northern GNP stratum, C representing sample belts transect from central GNP stratum and S representing sample belts transect from southern GNP stratum: RDA CanoDraw Output.

Table 4.3: Eigenvalues and variance explained by Redundancy Analysis (RDA), with GNP strata as qualitative environmental variable

Cannoco-RDA

Axes	1	2	3	4	Total variance
Eigenvalues :	0.618	0.071	0.001	0.243	1.000
Species-environment correlations:	0.862	0.744	0.164	0.000	
Cumulative percentage variance					
of species data :	61.8	68.9	69.0	93.3	
of species-environment relation:	89.6	99.8	100.0	0.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.690

Constrained Principal Components Analysis, which is the Redundancy Analysis (RDA) results of 10 study variables showed Factor 1 accounting for 89.6% and Factor 2 accounting for 10.4% of the variance (Fig. 4.6), see also the Monte-Carlo permutations results for RDA in Appendix F. Plant height and basal area were positively correlated to Factor 1 whilst number of stems per plant was negatively correlated to Factor 1. Factor 1 therefore defines a gradient from taller baobabs with large basal area (large size) to smaller, shorter baobabs of more stems per plant. Factor 2 defines a gradient from areas with higher basal areas to areas of high baobab density with greater elephant damage levels on baobabs. Consequently, belt transects with greater basal areas and taller baobabs scored high on Factor 1, mostly, belt transects from the southern and central section of the GNP. Similarly belt transects with small plant gbh and greater baobab density with greater elephant damage levels scored high on Factor 2, mostly, belt transects from Northern GNP.

From the ordination diagram, (the scatter plot on Figure 4.6), baobab stem density is predicted to have a large negative correlation with both baobab size as measured by girth at breast height (gbh) and number of stems per plant. Baobab structure as measured by plant basal area and plant height is also negatively correlated to number of stems per plant. Baobab plant height is strongly positively correlated to plant basal area. The GNP strata (qualitative environmental variables) as study sample points, if projected perpendicularly to the arrows of the measured plant variables, gives the approximate ordering of the stratum in order of increasing value of that particular measured plant variable (if one proceed towards the arrow tip and beyond it). Thus, most of Northern GNP study sites were predicted as of high baobab stem density, whereas, the Southern and Central GNP study sites were mostly predicted to have baobabs of large girth size. There is one outlier on the Northern GNP study site which is predicted to have baobabs of large basal area and taller plant height, the same outlier study site is predicted to be characterized by high elephant dung and less habitat rockiness and within a low habitat elevation.

4.4 Baobab density and distribution across the three soil substrates/bedrocks in GNP

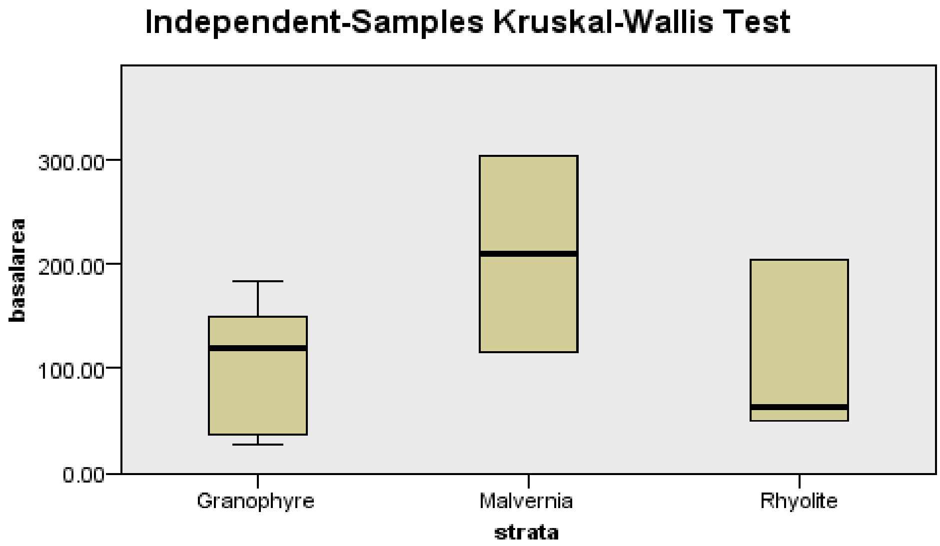
There were significant difference in number of stems per plant and plant height across the three soil substrates strata (one-way ANOVA, both $p<0, 05$; see Appendix G). In contrast, there were no significant differences on mean baobab stem density and plant basal area across the three soil substrates/bedrocks strata in GNP (one-way ANOVA, both $p>0, 05$; see Appendix G). The variables measured during the study are summarized in Appendix G. Appendix G provides relationships and differences of variables on three different soil substrates/bedrocks strata and their associated impacts on baobab structure and density of sampled baobabs (see also Table 4.4). Rhyolite soil substrate had the highest mean number of stems per plant, which was 1.4; mean number of stems per plant was 1.1 on granophyre soil substrate, whilst on malvernia soil substrate, the mean number of stems per plant was 1.

Baobab density was highest on the rhyolite substrate with 74.2 stems per km^2, followed by 66.5 stems per km^2 on granophyre substrate and the lowest density being on malvernia substrates with 42.5 stems per km^2, (Table 4.4). Highest number of baobab stands in GNP was found on granophyre derived soils (66.7% of sampled baobabs), while the least number of baobab stands found on malvernia substrate (13.5% of sampled baobabs) (Table 4.4). Evidence of baobab stands was rare on malvernia beds. The distribution of baobab stands is highly clustered on granophyre and rhyolite soil substrates/bedrocks, while relatively highly dispersed on malvernia substrate/bedrock.There was rare evidence of baobab stands on malvernia substrate soil beds (see Figure 1.2 and Figure 3.1).Baobab stands are associated with habitat of high elevation and rockiness (see Figure 1.1 and Figure 3.1).

Table 4.4: Baobab frequency and distribution for the study sites (figures represent values for all belt transects within each GNP soil substrate/bedrock)

Soil substrate/bedrock	**Sample number**	**Sample area (km^2)**	**Mean Stem density-/km^2**	**Baobab stand (%)**
Granophyre	150	3.69	66.5	66.7
Malvernia	30	0.54	42.5	13.3
Rhyolite	45	0.93	74.2	20

4.4.1 Box plots of measured study variables in the *A. digitata* stands in the three soil substrates/bedrocks strata in GNP (granophyre, malvernia and rhyolite) (Figures 4.7 to 4.9); Using non–parametric test.

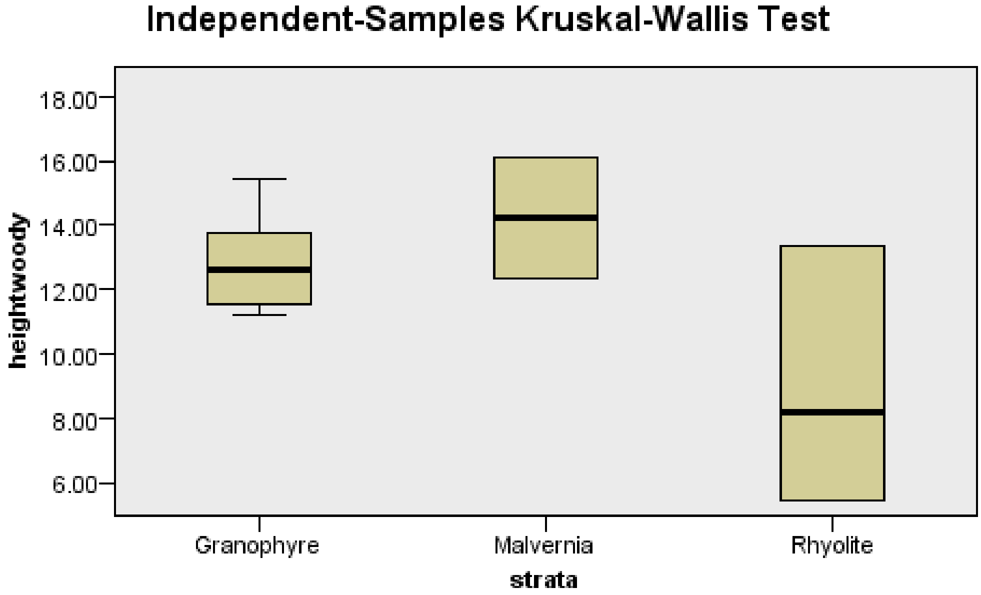


Total N	15
Test Statistic	1.422
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.491

1. The test statistic is adjusted for ties.
2. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Figure 4.7: Mean Plant basal area across soil substrate

Large baobabs of large basal area were more frequent on malvernia substrate/bedrock and least on rhyolite substrate/bedrock (Figure 4.7).

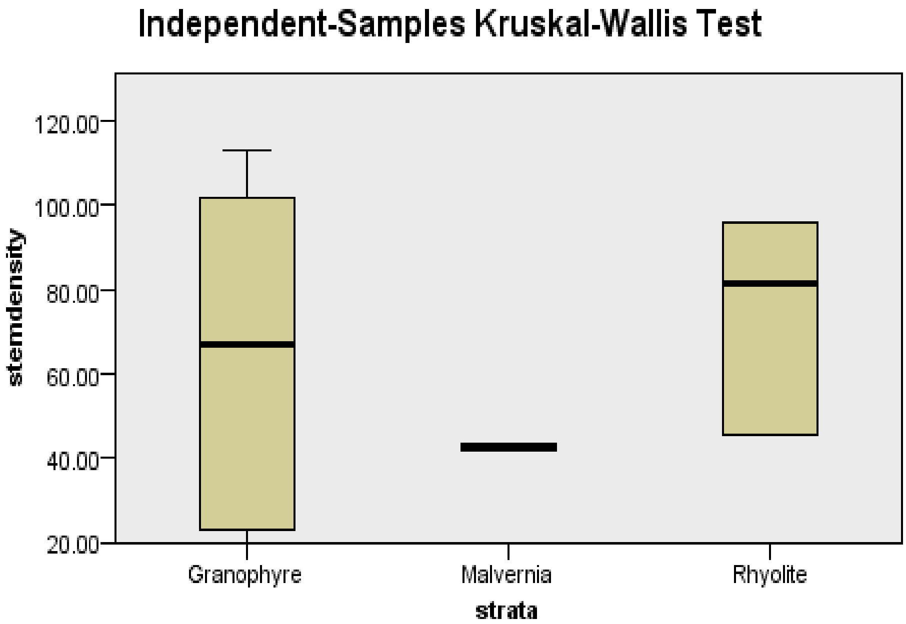


Total N	15
Test Statistic	2.417
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.299

1. The test statistic is adjusted for ties.
2. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Figure 4.8: Mean plant height across soil substrate

High plant height was dominant on malvernia substrate and low on rhyolite substrate (Figure 4.8).



Total N	15
Test Statistic	1.537
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.464

1. The test statistic is adjusted for ties.
2. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Figure 4.9: Mean baobab stem density across soil substrate

Baobab stem density was lowest on malvernia substrate/bedrock as compared to rhyolite and granophyres soil substrate/bedrock (Figure 4.9).

4.4.2 Baobab structure and distribution on three soil substrates/bedrocks in GNP

There were no significant differences on mean plant basal area and mean plant gbh across the three soil substrates/bedrocks strata in GNP (one-way ANOVA, both *p>0, 05*; see Appendix G).In contrast, there were significant difference in baobab plant height across the three soil substrates strata (one-way ANOVA, both *p<0, 05*; see Appendix G). The variables measured during the study are summarized in Appendix G. Appendix G provides relationships and differences of variables on three different soil substrates/bedrocks strata and their associated impacts on baobab structure of sampled baobabs (see also Appendix J).

Size class frequency distribution of the sampled baobabs in the study sites categorized by soil substrate/bedrock type, namely; granophyre, rhyolite and malvernia are shown in Appendix I. The study sites on rhyolite substrate had a frequency of 64.4% of baobabs within the juvenile size class, 22.3% of sub-adult baobabs and 13.3% of adult baobabs. (Appendix I), The study sites on granophyre substrate had a frequency of 54% of baobabs within the juvenile size class, 45.3% of sub-adult baobabs and 0.7% of adult baobabs (Appendix I), whilst the study sites on malvernia substrate had a frequency of 20% juvenile baobabs, 53.3% of sub-adult baobabs and 26.7% of adult baobabs (Appendix I).There were significant differences in plant height among the soil substrates (Appendix G), with the malvernia, granophyre and rhyolite soil substrate having the mean plant height of 14,20m, 12.83m and 9m, respectively.

4.4.3 Baobab structure and distribution across GNP soil substrates/bedrocks

Out of the sampled 225 baobabs, the highest number of baobabs was found on granophyre substrate 66.7%, followed by rhyolite substrate with 20% and malvernia substrate with 13.3% (Appendix J). The frequency of juvenile baobabs was 51.6%, sub adult baobab frequency being 41.8%, the two size classes dominating on granophyre soil substrate/bedrock. Adult baobabs had a frequency of 6.6%, dominating on malvernia and rhyolite soil subatrates/bedrocks (see table in Appendix J and Figure 4.10). Unlike the other two soil substrates, there was no record of baobab size class gbh greater than 12.5m on granophyre soil substrate (Appendix J).

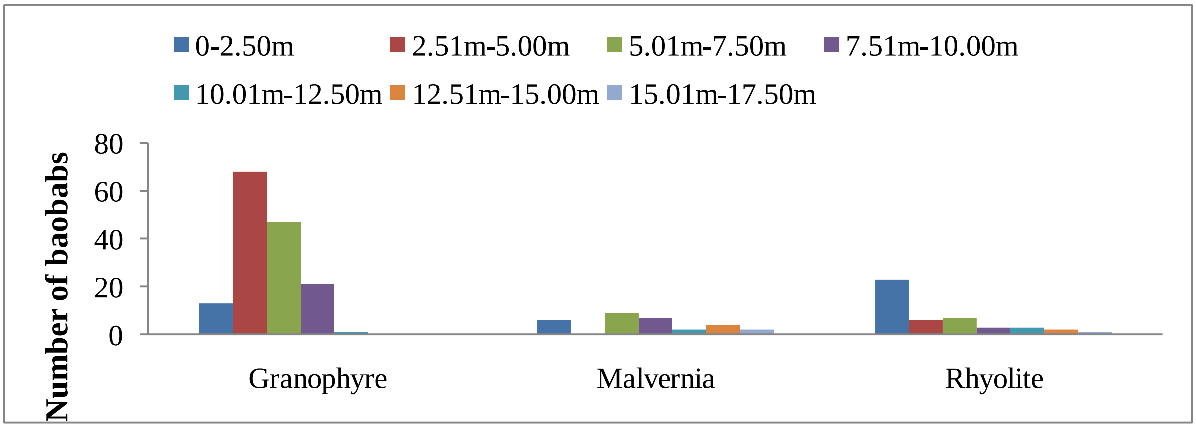


Figure 4.10: Size class distribution of baobabs within GNP soil substrates study sites

4.5 Summary results of a Redundancy analysis (RDA)

Table 4.5: Eigenvalues and variance explained by RDA, with soil substrate as a qualitative environmental variable

Cannoco-RDA

Axes	1	2	3	4	Total variance
Eigenvalues :	0.650	0.071	0.008	0.000	1.000
Species-environment correlations:	0.883	0.744	0.452	0.267	
Cumulative percentage variance					
of species data :	65.0	72.1	72.9	72.9	
of species-environment relation:	89.2	98.9	100.0	100.0	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.729

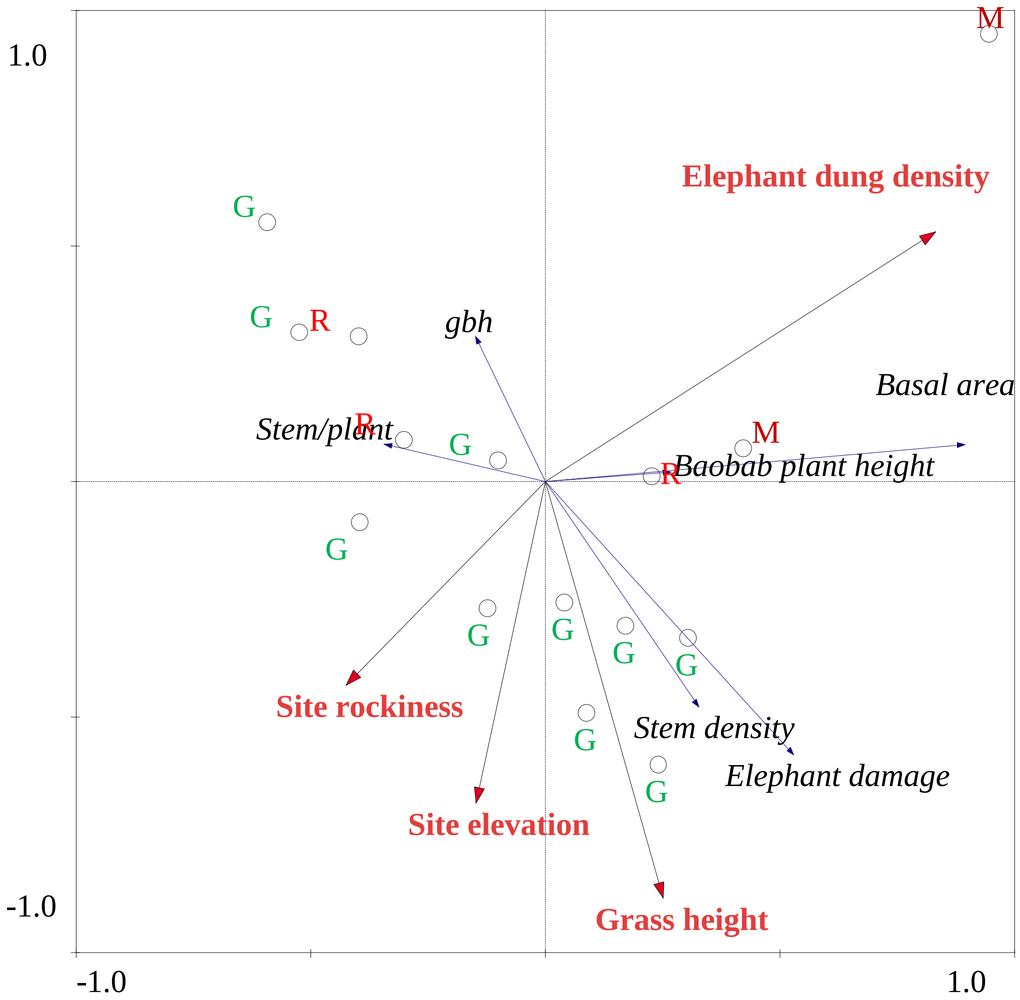


Figure 4.11: Scatter plot of 15 belts transect in the baobab stands, measured plant variables and environmental variables in the Gonarezhou National Park, southern Zimbabwe. Lettered data points denotes sample belt transect; with letter G representing belts transect on granophyre substrate, M representing sample belts transect on malvernia substrate and R representing sample belts transect on rhyolite substrate.

Constrained PCA and RDA results of 10 study variables show Factor 1 accounting for 89.2% and Factor 2 accounting for 10.8% of the variance (Figure. 4.11). Plant height and basal area were positively correlated to Factor 1 whilst number of stems per plant was negatively correlated to Factor 1. Factor 1 therefore defines a gradient from taller baobabs with large basal area (large size) to smaller shorter baobabs of more stems per plant. Factor 2 defines a gradient from areas with higher basal areas to areas of high baobab density with high elephant damage levels on baobabs. Consequently, belt transects with greater basal areas and taller baobabs scored high on Factor 1, mostly belt transects on malvernia beds derived soils. Similarly, belt transects with small plant gbh and greater baobab density with greater elephant damage levels scored high on Factor 2, mostly belt transects on the granophyre substrate/bedrock.

From the ordination diagram, (Figure 4.11), related to Figure 4.6, baobab stem density was predicted to have a large negative correlation with both baobab size as measured by girth at breast height (gbh) and number of stems per plant. Baobab structure as measured by plant basal area and plant height was also negatively correlated to number of stems per plant. Majority of study sites on granophyre soil substrate/bedrock were predicted to be of high baobab stem density, whereas, the study sites on rhyolite and malvernia soil substrates/bedrocks were mostly predicted to be of baobabs of large girth size and taller plant height. Distances between sample points (study sites) in an ordination diagram as measuring the dissimilarity or similarity between sample points using Euclidean distance, generally, the study sites on granophyre and rhyolite soil substrates/bedrocks are predicted to show greater similarity.

4.6 Assessment of elephant damage levels on baobabs across the three GNP strata

One way analysis of variance showed no significant differences in mean elephant damage values of baobabs among the three GNP strata and soil substrates, each as a grouping variable ($P>0.05$, see table 4.1 and Appendix G, respectively). Elephant damage was only close to significant difference across GNP strata ($P=0.069$, see table 4.1). The highest mean elephant damage value of 63.6 was recorded in Northern GNP, whilst the lowest value of 25 was recorded in Southern GNP. Central GNP recorded a mean elephant damage value of 28.7.

4.6.1 Northern GNP stratum

The highest mean number of damaged baobabs was recorded in the slight to moderate damage category in Northern GNP (Figure 4.12), which had a total baobab damage of 36.9% (Appendix O). In Northern GNP, Chivonja Mountain range had a relative higher baobab density of 100/km^2 with a no elephant damage to slight elephant damage level on baobabs, while Nyagwama Range had a relative higher baobab density of 83.3/km^2 with a slight elephant damage on baobabs (Appendix L). Sililijo Plain and Sililijo Range in Northern GNP had high baobab density of 113.3/km^2 and 62.9/km^2 respectively, with relatively moderate to severe elephant damage on baobabs (Appendix L). Chilojo Plain in Northern GNP had a relative low baobab density of 43.3/km^2 with severe elephant damage, Chilojo Plain recorded two dead baobabs (Appendix L).

4.6.2 Central GNP stratum

Central GNP recorded a moderate mean number of damaged baobabs with a slight elephant damage level (Figure 4.12), which had a total baobab damage of 28.9% (Appendix O). Sibonja Hills had relatively no elephant damage to slight elephant damage category with a relative low baobab density of 20.8/km^2, while Chigono Range and Muchingwizi Mountain range had relative high baobab density of 71.4/km^2 and 106.7/km^2 respectively, with a slight elephant damage category (Appendix M).

4.6.3 Southern GNP stratum

The lowest mean number of damaged baobabs was in the slight damage category in Southern GNP (Figure 4.12), which had a total baobab damage of 18.7% (Appendix O). In Southern GNP, Mabalauta Station dominated the no damage category on baobabs with a relative high baobab density of 81.5/km^2, while Swimuwini had a relative high baobab density of 95.8/km^2 with a moderate to severe elephant damage level on baobabs (Appendix N). Swimuwini recorded dead baobabs (Appendix N).

4.6.4 Elephant damage levels on baobabs across GNP

From a sample of 225 baobabs, 84.4% of baobabs were damaged and 15.6 % were undamaged (Appendix O). Overall, 49.8% of the sampled baobabs had a slight elephant damage level, 19.1% baobabs had a moderate elephant damage level, and 13.3 % baobabs had severe elephant damage level, while 2.2% baobabs were dead (Appendix O and Figure 4.12). GNP sample had a mean baobab density of 43.6 per square kilometer with a slight to moderate elephant damage on baobabs (Appendix O and Figure 4.12).

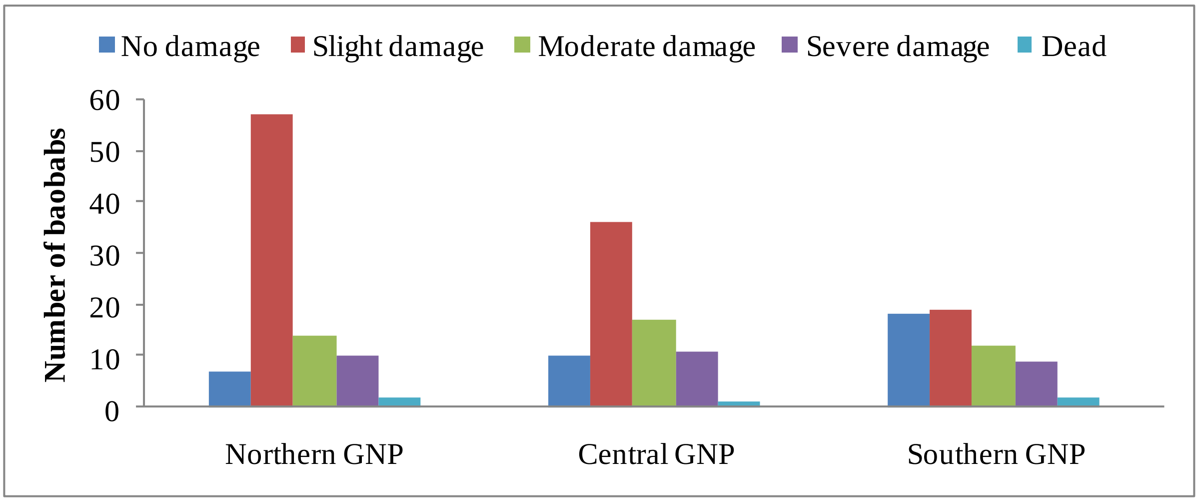


Figure 4.12: Number of baobabs at each GNP stratum sample, grouped according to damage classification

4.7 Assessment of elephant damage levels across soil substrates/bedrocks

One way ANOVA results ($P>0.05$, see Appendix G) showed that there were no significant differences in the mean elephant damage levels on baobabs across the soil substrates/bedrocks. In contrast, there were significant differences in elephant occupancy as elephant dung density was significantly different across the three soil substrates ($P>0.005$, see Appendix G). Malvernia beds had the highest mean elephant dung density of 439.7/km^2, followed by granophyre substrate with 102.7/km^2 and rhyolite soil substrate with a mean elephant dung density of 88.8/km^2.

Malvernia beds with a relatively very low baobab density of 42.5/km^2, recorded severe elephant damage on baobabs, where 100% of the sample was damaged and dominated by moderate to severe elephant damage (Appendix P and Figure 4.13). Dead baobabs were only recorded on malvernia and rhyolite soil substrates (Figure 4.13). Granophyre and rhyolite substrates with relatively high baobab density of 66.5/km^2 and 74.2/km^2 respectively, recorded no elephant damage to slight elephant damage on baobabs (Appendix P and Figure 4.13). No dead baobabs were recorded on granophyre soil substrate (Figure 4.13). Malvernia beds were dominated by severely elephant damaged baobabs (Figure 4.13).

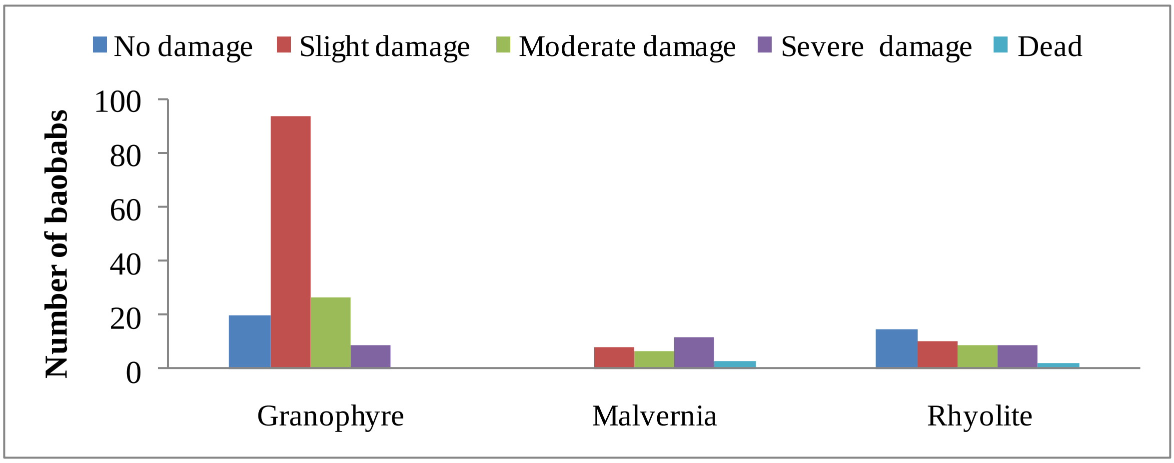


Figure 4.13: Number of baobabs at each GNP soil substrate/bedrock sample, grouped according to damage classification

4.8 Assessment of elephant damage related to baobab size class

The GNP sample distribution of elephant damage on baobab per baobab size class is shown in Appendix Q and Figure 4.14. The equal frequency of damaged baobabs (38.2%) was recorded in both the juvenile baobabs size category (gbh ≤5m) and sub-adult baobabs (5.01m ≥ gbh ≤ 10.00m) whilst adult baobabs (gbh>10m) recorded (8%) of damaged baobabs. Dead baobabs were encountered during the study and the majority was within the juvenile baobab size class (Figure 4.14). The size class of gbh 0-2.5m was dominated by a category of no elephant damage on baobab, whilst the baobab size class of gbh 2.51m ≥ gbh ≤ 5.00m; 5.01m ≥ gbh ≤ 7.50m; 7.51m ≥ gbh ≤ 10.00m; and 10.01m ≥ gbh ≤ 12.50m were all dominated by a slight elephant damage level category. Baobab size class of 12.51m ≥ gbh ≤ 15.00m were dominated by severe elephant damage level on baobabs. Dead baobabs dominated on the baobab size class of gbh ≤ 2.50m.

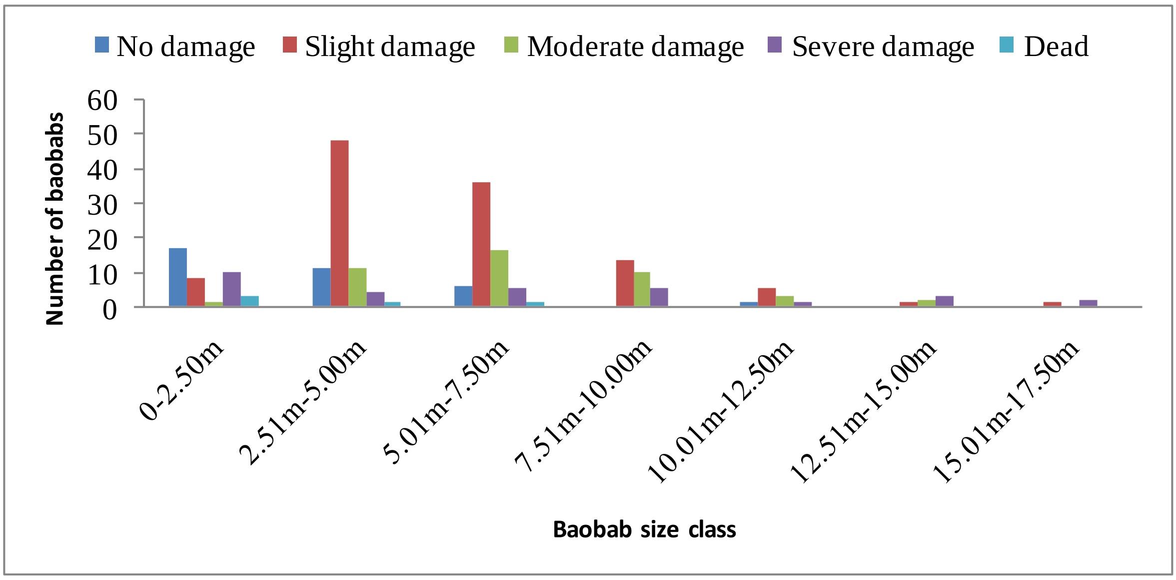


Figure 4.14: Number of baobabs in each girth size interval grouped according to damage classification

4.9 Assessment of elephant damage related to baobab density, structure and distribution across GNP

Figure 4.6 and Figure 4.11, RDA scatter plots, showed the arrow for elephant damage and that for baobab stem density as pointing in the same direction and this corresponds to variables that are predicted to have a large positive correlation, whereas baobab girth size (gbh) and number of stems per plant was predicted to be negatively correlated to elephant damage levels on baobab. Elephant damage on baobabs was predicted to be more pronounced on most of the Northern GNP study sites of high baobab density which are on granophyre soil substrate/bedrock, whilst there are a few study sites on granophyre and rhyolite soil substrate/bedrock which were predicted to be less prone to elephant damage. By drawing the Van Dobben circles on the elephant damage arrow on the scatter plot (see Ter Braak and Sˇmilauer, 2002) this deduce a significant positive relationship between elephant damage and baobab stem density with a positive regression coefficient for elephant damage with the corresponding t-value larger than 2.0, while baobab girth size and number of stems per plant had a corresponding significant negative regression coefficient.

4.10 Relationships between and among the study variables across GNP

Inference from the ordination diagrams, scatter plots Figure 4.6 and Figure 4.11, habitat site elevation was predicted to be largely positively correlated to habitat rockiness and these two quantitative environmental variables were predicted to be highly negatively correlated to elephant habitat occupancy as depicted by elephant dung counts. Granophyre and rhyolite soil substrates/bedrock habitat were predicted to be on high elevation with greater habitat rockiness. Elephant dung was predicted to be mostly found on malvernia beds, which are largely negatively correlated to high habitat elevation and rockiness. Habitat rockiness was predicted as slightly negatively correlated to elephant damage on baobabs.

4.11 Baobab recruitment and regeneration in GNP

The argument is that a healthy baobab population should have a reverse-J size-class distribution, with a smooth decline (mono-modal size class distribution) in numbers from a maximum in the juvenile size class (Wilson, 1988; Edkins *et al*., 2007). The frequency distribution of baobabs in the gbh size class categories was used to trace growth patterns of the baobab population, as it give an indication of the recruitment at any one particular stage in the population history (Wilson, 1988; Edkins *et al*., 2007).

The size structure of the baobabs in Southern GNP stratum (Figure 4.5), with a relatively high baobab density, Mabalauta Station and Swimuwini indicated a high recruitment of juvenile baobabs (Appendix N and see figure in Appendix D). Swimuwini, however, was prone to a moderate to severe elephant damage level on baobabs, whilst Mabalauta Station was dominated by no elephant damage to slight elephant damage level on baobabs (see figure in Appendix N). Second in indicating a high recruitment of juvenile baobabs was the Northern GNP stratum (Figure 4.5), with relatively high baobab density, as Chivonja Mountain range, Nyagwama Range and Sililijo Range dominated as study sites of juvenile baobab recruitment (Appendix L and see figure in Appendix B). Sililijo Range, however,was prone to a moderate to severe elephant damage level on baobabs, whilst Chivonja Mountain range and Nyagwama Range were prone to a slight elephant damage level on baobabs (Appendix L). Central GNP stratum had a size structure which indicated the least recruitment of juvenile baobabs (Figure 4.5), save for Muchingwizi Mountain range and Chigono Range with relative high baobab density which was prone to a slight elephant damage level on baobabs (Appendix M; and Appendix C).

Out of the eight study sites that indicated potential high recruitment and viable regeneration, six were found on granophyre soil substrate/bedrock, namely; Chivonja Mountain range, Nyagwama Range, Muchingwizi Mountain Range, Chigono Range, Sibonja Hills and Sililijo Range, while two study sites were found on rhyolite soil substrate, namely; Mabalauta Station and Swimuwini. Malvernia substrate/bedrock had a very low baobab density with a size structure which indicated very little recruitment of juvenile baobabs, and baobabs were prone to severe elephant damage levels (Appendix P; Figure 4.10 and Figure 4.13).

CHAPTER 5

5 DISCUSSIONS

5.1 GNP baobabs stand density and spatial distribution

The study revealed that baobabs stand density and distribution varied among sites. Majority of baobabs stands were found in Northern GNP, and a few were found in Central GNP. It was rare to find baobabs in Central GNP in relation to its area, while scattered baobabs were found along Mwenezi River in Southern GNP. Several factors could explain this spatial distribution. Wilson, (1988) and Barnes *et al.*, (1994) suggested that baobab densities are very variable in the landscape as they are affected by a number of establishment factors, such as herbivory, past human activities, droughts or soil character requirements (Edkins *et al*, 2007). Within GNP, variations in rainfall, altitude and temperature are negligible, consequently plant species communities can be considered in reflection to soil type which generally changes with variation in geological types (Magadza *et al.*, 1993).

A central goal of plant ecology is to understand which factors that influence local distribution pattern of plant species (Guy, 1981). A key to this focus was the observation that baobab plant community in GNP tends to occur at the same relative position along similar environmental gradients of geology and habitat elevation and rockiness. Most of the baobab stands sampled in this study were clustered on the granophyre steep rocky hill tops with the malvernia bed plains landscape being the least dense. The baobabs on malvernia beds landscape were probably most prone to elephant damage. Natural distribution of plant species is essential in understanding the natural history and ecology of baobabs.

5.2 Baobab density and distribution across GNP strata

Results suggested that baobab density and distribution across GNP strata were insignificantly different. This implies that disturbance regimes on GNP baobabs are uniform across GNP strata. Savanna plant species abundance and distribution is dependent on a combination of factors: drought, herbivory, humans, fire, insect outbreaks and soil factors, all interacting in complex and unpredictable ways (Scholes and Walker, 1993). Factors that could have influenced baobab abundance and distribution in the GNP which were not investigated in the present study include past droughts and human activities inside the GNP (O'Connor and Campbell, 1986; Tafangenyasha, 1998). Baobab densities in GNP ranged from 34.3/km^2 in the central strata to 69.8/km^2 in the northern strata. The recorded GNP mean baobab density was 49/km^2 and appeared to be within the range previously recorded in other protected areas in sub-Sahara Africa. For instance, Barnes (1980) recorded a mean density of 69 per square kilometer, varying between 3 and 723 per square kilometers in Ruaha National Park, in Tanzania. This implies that current baobab abundance in GNP is low as compared to the related baobab densities of protected areas of African savannas and this could be attributed to damage by the overabundant elephants in GNP (Dunham, 2012).

Excessive elephant browsing, particularly during the drought periods of 1981-1982, 1991-92 and 2000-2001 could have affected baobab population demography in GNP. Most conspicuously, the droughts phenomenon of GNP should not be dismissed with a shrug. The resilience and progression of plant species community to repeated occurrences of droughts of such magnitude in GNP is not known, and is a cause for concern. Contingency measures informed by scientific research ought to be put in place to cope with such drought episodes in the management of biodiversity in GNP (Magadza *et al*., 1993). Extended dry seasons or prolonged droughts can compromise tree viability (Scholes and Walker, 1993) and amplify negative elephant effects (van Wyk and Fairall, 1969).

5.3 Baobab structure and distribution across GNP strata

The results showed no significant difference in baobab structure and distribution across GNP strata. This suggests that the rate of baobabs growth was the same across GNP strata. Insignificant differences in baobab structure across GNP strata suggests that recruitment of baobabs from a lower size class to another size class has been taking place at the same rates across the three GNP strata. This follows the insignificant differences in elephant occupancy across the three GNP strata as indicated by elephant dung counts. Baobab structure and distribution could be suggested as being determined by the uniform climate of GNP as well. The mean annual precipitation may determine the uniformity of baobab biomass in GNP, in dry savannas, plant species community patterns may be determined primarily by rainfall and temperature (Sankaran *et al*., 2005). There is no climatic variation in GNP (GNP, 2010). Size class frequency distribution of the sampled baobabs for the entire GNP is shown in Appendix E and Figure 4.5. Overall, the size structure of the baobabs in GNP had a high frequency of juvenile baobabs with 51.6%. Sub-adult baobab population accounted for 41.8%, while adult baobabs accounted for 6.3% of the sampled baobabs. GNP lacks adult baobabs. It is possible that the structural and distributional changes in *A. digitata* stands in GNP may lead to stands degradation with loss of adult baobabs, making such areas less visually appealing and unattractive to tourists. Additionally, changes in *A. digitata* stands may affect the biodiversity and ecosystem functioning in GNP.

Saayman and Saayman (2009) stated that ensuring quality service and biodiversity products guarantees repeat visits to national parks. A product such as woodland structural and distributional integrity can be an attraction to a national park, for example, adult *A. digitata* populations produce an attractive, emblematic and aesthetically appealing large tree canopy (Wilson, 1988). The high summer temperatures in GNP approach the physiological limit of enzyme activity. Thus, thermal refugia become important at such temperatures. Canopy shade is important thermal refugia for large mammals in GNP (Magadza *et al.*, 1993). Thus, the gigantic *A. digitata* canopy provides an important forage and shade for wildlife and as a result, adult baobabs are prone to elephant damage (see Figure 4.14). Large baobab trees provide opportunities for more than one elephant to forage at a time (Owen-Smith, 1988), hence the severe damage which leads to their declining numbers. *A. digitata* showed evidence of resprouting from the base after being pushed over by elephants. Disturbance such as herbivory likely promoted vigorous resprouting of *A. digitata*. This is an important observation, as it is likely to modify and influence state-and-transition dynamics in *A. digitata* stands, thus affecting the resultant population structure. Resprouting is a response to disturbance and the study suggests that all the strata were being affected by disturbance factors.

5.4 Baobab abundance and distribution across the three soil substrates/bedrocks in GNP

The present study showed significant differences in baobab abundance and distribution across soil substrates/bedrocks in GNP. Baobab density ranged from the least being 42.5/km^2 on malvernia soil substrate and the maximum being 74.2/km^2 on rhyolite soil substrate. Moderate baobab density was on granophyre soil substrate which was 66.5/km^2. Highest number of baobab stands in GNP was found on granophyre derived soils (66.7% of sampled baobabs), while the least number of baobabs stands found on malvernia substrate (13.5% of sampled baobabs) (Table 4.10). As expected for savanna vegetation (Scholes and Walker, 1993), the most important explanatory variables for baobab stands abundance and distribution was predicted to relate to resource availability, primarily soil resources, with herbivory and fire related variables being the least important (Figure 4.11 and Appendix G). Similar results were obtained for other arid and semi-arid regions (Milchunas and Lauenroth, 1993; Aarrestad, *et al.,* 2011). The present study results confirmed the strong dichotomy in savanna vegetation on whether plant growth is limited primarily by soil group availability (dystrophic savannas), or by moisture (eutrophic savannas) and that is, this pattern in a landscape scale as in GNP is related mainly to soil productivity (Scholes and Walker, 1993).

In GNP, distinct soil substrates/bedrock resources appear to be key determinants of baobab abundance and distribution. As shown in Figure 4.11, study sites on granophyre and rhyolite soil substrates/bedrocks were predicted as positively correlated and they were of a grouping of similarity. It was rare to find baobabs on malvernia soil substrate/bedrock in GNP. Baobabs are known to grow on a wide range of well-drained soils, from clays to sands, but not on deep unconsolidated soils, where the species is unable to obtain sufficient moisture or anchorage (Wickens and Lowe, 2008). In general, granophyre and rhyolite derived soils are relatively well drained as compared to the malvernia derived soil groups (Nyamapfene, 1991, Clegg, 2003) and this could explain the abundance and distribution of baobabs across soil substrates/bedrocks in GNP.

5.5 Baobab structure and distribution across the three soil substrates/bedrocks in GNP

The result showed significant differences in baobab structure and distribution across soil substrates/bedrocks in GNP. Plant height significantly differed across soil substrates/bedrocks. Baobabs on granophyre and rhyolite substrates were relatively shorter, probably this could be due to habitat rockiness or other edaphic factors not measured in this present study which negatively affects plant growth. Plant height is influenced by edaphic factors such as soil nutrients and soil depth. Nitrogen influences primary productivity and where it is limiting, plants tends to be stunted with thin weak stems. Where it is abundant, plants tend to be robust and healthy (Kraaij and Ward, 2006). However, the present study highlighted and indicated a concern over the unbalanced size structure of baobabs on malvernia soil substrate/bedrock in GNP, which suggested a recruitment bottleneck (Appendix J and Figure 4.10). Baobab size class distribution on malvernia beds was irregular; this indicated the existence of irregular growth patterns (Botha Wirkowski and Shackleton, 2000). Seedling and sapling recruitment was critically low on malvernia soil substrate/bedrock. This is likely to lead to baobab extirpation on malvernia derived soil groups, in the near future.

5.6 Elephant damage on baobabs across GNP strata

The results showed insignificant difference in elephant damage levels on baobabs across GNP strata and this was in relation to the insignificant difference in elephant occupancy as was indicated by elephant dung counts. Evidence of elephant damage on baobabs did not differ significantly across GNP strata, suggesting that baobabs were uniformly affected by elephants. This suggested that elephants range more or less uniformly across the studied baobab stands in the GNP strata; this could be so, since baobab stands were found close to perennial natural water sources in GNP (Figure 3.1). This may probably be a result of closely related elephant densities upon the study sites as confirmed by Dunham (2012). The present study confirmed findings by Skinner-John (2002), who reported that elephant ranges almost anywhere except where man has exterminated them or subjected them to too much pressure. Elephants were reported to move up to 80 km in response to localized rainfall (Leuthold and Sale, 1973) and available water can concentrate elephant impacts (Swanepoel and Swanepoel, 1986). While elephants show no territorial behaviour, they do have home range, which vary greatly in size between habitats (De Beer *et al.*, 2006). In Kaokoland, Skinner-John (2002) found the mean home range for 52 desert dwelling elephants to be 2172.3 ± 426.5 km^2, with that of bulls being slightly large than that of family groups. The present study noted that *A. digitata* plants occurring in all the three GNP strata were to some extent damaged by elephants. *A. digitata* fail, to grow to its maximum attainable height of about 25m (Coates-Pelgrave, 1997). There was noticeable severe damage to *A. digitata* in areas of high elephant density (see figure 4.12). According to Dunhum (2012), elephant densities for both the northern and Central GNP study sites in terms of elephant utilization categories were 2.01 to 3.00 elephants per km^2 whereas it was 1.01 to 2.00 elephants per km^2 for Southern GNP elephant utilization category. The overall elephant density in all the study sites was 2.01 to 3.00 elephants per km^2 (Dunham *et al.*, 2012).

One of the major reasons why elephants target *A. digitata* trees can be attributed simply to their conspicuous nature and aesthetically appealing (Pamo and Tchamba, 2001; Conybeare, 2004) or due to their rich nutrient content such as calcium and nitrogen (Napier-Bax and Sheldrick, 1963). This is compounded by the social behaviour of elephants, which involve indiscriminate destruction of trees, especially by the male groups (Hofmeyr *et al*., 2006). In areas with high elephant densities, baobabs were destroyed not only by browsing but also by trampling. It was noted that some of the baobabs felling could have been a social display unrelated to feeding (Midgley *et al*., 2005). Pruning by elephants could strongly influence baobab sapling morphology and recruitment to adult size (Fornara and Du Toit, 2008).

The present study noted that 2% of sampled baobabs were dead. This is related to earlier observations elsewhere. Barnes (1980) studied the decline of the baobab tree in Ruaha National Park, Tanzania. The study confirmed that elephants killed 3% of baobab trees resulting in decline in baobab population in the Msembe area of Ruaha National Park. An increase in elephant densities, most probably caused a drop in recruitment as was indicated by baobab age distribution (Barnes, 1980). 84.4 % of sampled GNP baobabs showed evidence of elephant damage; this confirmed that GNP baobabs are highly targeted by elephants, thus, GNP baobab stands need monitoring as they could be threatened by elephants as happened in other protected areas with elephants. Elephants caused a decrease in baobab tree density at Ruaha in Tanzania from 72 per km^2 to 40 per km^2 over an 11-year period (Owen-Smith, 1988). Declines in baobab populations occurred widely where elephants reached densities that resulted in a shortage of food during the dry season (Owen-Smith, 1988). GNP elephants tend to concentrate in areas of permanent natural water sources during the dry season due to food shortages (Magadza *et al*., 1993; Dunham *et al*., 2012; Gandiwa *et al*., 2012) Studies revealed that baobab populations were virtually eliminated in the Tsavo East Park in Kenya in 1974, less than 20 years after first reports of damage by elephants. In Tsavo National Park (Kenya), dense woodland was changed into open savanna and baobabs are now very rare where they were once common (Whyte, 2001).

Wilson (1988), on the other hand, discounted the importance of elephants in structuring two of the baobab populations he studied. He suggested changes in land-use and drought as determining the absence of young trees in the Mali and Sudan baobab populations, and proposed that only in specific areas do elephants play a crucial role in structuring baobab populations (Wilson, 1988).

5.7 Elephant damage related to baobab size class

Results from the present study suggested that elephants target sub-adult to adult baobabs (girth> 5m) in GNP. The prevalence of moderate to severe elephant damage on larger baobab size classes (gbh >5m) supported the view that elephants prefer larger baobabs than smaller ones. These results suggested that elephants prefer larger baobabs than smaller ones in GNP.

These results contradicted with previous studies by Barnes (1980) and Caughley (1976) who suggested that elephants prefer juvenile baobabs than adult ones. Although opinions differ on whether adult or juvenile baobabs are preferred (Edkins *et al.*, 2007), herbivores generally forage on sub-adult to adult trees (Weyerhaeuser, 1985; Swanepoel, 1993b). Most damage to sub-adult to adult baobabs involved excavation of large cavities in baobab stems by tusks and trunk. The scarred parts of a baobab allow entry to borer beetles and fungi, however, the softwood of the baobab rots quickly and the tree's life span is shortened (Coetzee *et al.*, 1979; Osborne, 2002). Thus, elephants are more important as both direct and indirect agents of baobab mortality. Elephant damage on baobabs in the GNP indicated that juvenile baobabs, just like adult baobabs are in danger of excessive mortality, even though it appears that elephants target sub-adult to adult baobabs (Appendix Q and Figure 4.14). This confirmed the findings by Swanepoel, (1993b) who also observed that baobab samplings appeared more likely to die from the same amount or less elephant disturbance severity than the sub-adult to adult baobabs. GNP baobab mortality pattern confirmed to a number of authors (Caughley, 1976; Barnes, 1980, 1985, 1994; Weyerhaeuser, 1985) who considered that the elephant is a major influence in the ecology of baobab, responsible for lack of recruitment by the destruction of samplings and an accelerated decline in natural populations by causing damage to adult baobabs.

5.8 Baobab recruitment and regeneration in GNP

The size class distribution of baobabs in GNP strata showed an inverse J-shape size class distribution for each stratum. Such a pattern shows that there have been a balance between recruitment and mortality of baobabs (Wilson and Witkowski, 2003). The current GNP environment allows regeneration to develop into progressively larger size classes and does not depend on periodic disturbances for regeneration of baobabs. The study of plant population dynamics assesses changes in population size and age distribution. Abundant juveniles relative to adults resulting in an inverse J-shaped size-class distribution curve may be interpreted as a healthy and potentially growing population; the presence of juveniles indicates a steady state and transition population (Condit *et al*., 1998; Miller, 1998). The classic inverse J-shaped size class distribution is generally used by biologists as an indication of a healthy, regenerating population, deviation from this would normally be a cause of concern (Wilson and Witkowski, 2003). The inverse J-shape shows that a species population is in a steady state. This information is vital in revealing the state of baobabs in GNP.

Size class distribution of baobabs in Chivonja Mountain range, Nyagwama Range (Northern GNP), Muchingwizi Mountain range, Chigono Range (Central GNP) and Mabalauta Station (Southern GNP), these study sites of relatively high baobab density, showed a reverse J-shaped curve of baobab size class distribution. This suggested that baobab recruitment within these study sites was high (Lykke, 1998), and represents a steady state and transitional increasing baobab population. This type of baobab size class distribution suggests a continuous viable regeneration (Wilson and Witkowski, 2003). Browsing pressure on seedlings and saplings within these study sites is low probably due to their inaccessibility to elephants and other herbivores, thus implying high juvenile baobab abundance. These study sites constituted potential baobab rufugia in GNP.

The observed potential GNP baobab refugia sites were on habitat of rugged rocky terrain and high elevation on granophyre soil substrate/bedrock save for Mabalauta Station study site which is on human settlement on rhyolite soil substrate/bedrock. Habitat rockiness and elevation plays an important role in influencing elephant damage on baobabs in GNP. There were notable negative correlation between elephant damage on baobabs in relation to habitat rockiness and site elevation (Figure 4.6 and Figure 4.11). Study sites with high estimate of percentage rockiness have the least elephant damage levels on baobabs as well as low elephant dung counts which were indicators of habitat occupancy by elephant. This confirmed findings by Nelleman *et al.*, (2002) who suggested that plant species distribution within a particular vegetation type may be affected by terrain ruggedness which may in turn also affect the pattern of elephant utilization. It was suggested elsewhere that baobab populations were unaffected by elephants in certain areas because of difficult access. In Lake Manyara National Park, the baobab population of the southern parts was less heavily damaged than the north (Weyerhaeuser, 1985). The southern escarpment is steeper, which restricts elephant access. In Kruger National Park, it was suggested that 'baobab refugia', or elephant-free rocky hillsides, might serve as sources for baobabs in plains (Edkins *et al*., 2007).

Rocky outcrops also provide good areas for baobab recruitment probably because of seed dispersal by baboons which roost in rocky areas, as well as the protection inaccessible rocky areas afford baobabs from elephants (Duvall, 2007; Edkins *et al*., 2007; Hofmeyer, 2001; Watson, 2007; Wickens and Lowe, 2008). Mpofu *et al*. (2012) found that baobabs in Southern GNP were affected by human settlements as they were more juvenile baobabs recorded in the developed areas suggesting that areas close to humans have restricted access of wild animals because of physical barriers and man also facilitate seed dispersal and scare aware the animals.

On the other hand, Sililijo Range, Sililijo Plain, and Swimuwini, these study sites had high baobab density on relatively undulating terrain with easy elephant access, thus, had a higher frequency of damaged baobabs. A distinct irregular size class distribution of baobabs was recorded at Chilojo Plain and Muchingwizi Plain which are on malvernia soil substrate/bedrock; this suggested the presence of irregular baobab growth patterns (Botha

Witkowski and Shackleton, 2000). Recruitment relative to adult density was most successful on the malvernia soil substrate/bedrock, which exhibited the most positively skewed size class distribution curves, steepest and the smallest percentage of juvenile baobabs, thus, indicating a recruitment bottleneck. This trend is mainly predicted as the adverse impact of malvernia derived soil groups on baobab growth and development. Malvernia soil substrate/bedrock gives rise to deep highly permeable soils generically called rigosols soil group with a poor water holding capacity, rigosols soil group are prone to capping (Purves and Fullstone, 1975). Baobab growth and development is predicted as negatively impacted on deep unconsolidated soils, where baobabs are unable to obtain sufficient moisture or anchorage (Wickens, 1982; Wilson, 1988; Wickens and Lowe, 2008). In GNP, it was rare to find baobabs even on habitats of rocky rugged terrain and high elevation on malvernia soil substrate/bedrock, notably the Nyamtongwe plateau (Table Mountain range) in Central GNP and the Ntambambovhu Red Hills range in Southern GNP, as was confirmed by GNP vegetation maps (Sharry, 1977; GNP, 2010), Mpofu *et al*., 2012 and the ground truthing and reconnaissance activity of the present study.

5.9 Fire damage on baobabs in GNP

There was no evidence of fire damage on the sampled 225 baobabs. This is related to the findings by Mpofu *et al*. (2012), where they also observed no fire evidence on the sampled 117 baobabs in Southern GNP. This suggested that GNP fire regime attributes interact in such ways, which leave no fire damage marks on live standing baobabs. This suggested that, in the case of the GNP, droughts present periods of high moisture deficit that results in decreased fuel loads which lead to low fire frequencies and low fire intensity in the park. In woody vegetation, fire frequencies and fire intensity are determined by the rate of fuel accumulation (grass biomass). The present study results confirmed that succulent live standing baobabs trees are fire tolerant in relation to GNP fire regimes (Laws *et al.*, 1975). Fires that do occur in dry periods can cause more damage to the grass layer than to baobab trees (Trollope *et al*., 1999).

Perceived effect of fire on broken, ring barked, bark-stripped or uprooted baobabs in GNP are probably speculative as noted by Mpofu, *et al*. (2012) and this present study. Intense and severe fires, however, may account for immediate deaths of baobab seedlings which might not leave any sign of existence upon death (Whyte, 2001). Although there was no evidence of fire scars on baobabs in the study area, such evidence was observed in the Kruger National Park (Edkins *et al*, 2007). Secande *et al.* (2006) also suggested that intense veld fires during the dry season limit the number of baobab trees. This indicates that fire can play a role in determining where in the environment baobabs can establish, especially by suppressing baobab seedlings.

5.10 Analysis of methods used in this study

The present study focused on the changes influenced by elephants on *A. digitata* in GNP. The results could have been affected by the fact that sampling was done once. The impact of elephants on the *A. digitata* stands was thus assessed at a small temporal scale, and the degree of damage recorded may not be typical of elephant damage over a period of years. Another possible limitation in the present study was that the sampling belt transects were relatively close to each other since the *A. digitata* studied were rare to find and not a dominant species in GNP, thus, could not allow a wider distribution of the sampling belt transects to capture for greater variability. The small distances between belt transects, therefore, may have had some influence on the results due to possible pseudo-replication. Tobler's first law of geography states that 'everything is related to everything else, but near things are more related than distant things' (Tobler, 2004).

Patterns of baobab abundance, structure and distribution in GNP may also be influenced by other confounding factors which were not considered in this present study, such as; past land use practices in GNP (O'Connor and Campbell, 1986), past bush clearing in anti-tsetse fly (*Glossina* sp.) operations (Tafangenyasha, 1997), droughts (Magadza *et al*., 1993) and climate change impact (Secande *et al.*, 2006).

CHAPTER 6

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Overall, the results suggested that there were no significant structural, abundance and distributional differences of *A. digitata* stands across the three GNP strata. The hypothesis that baobabs do not significantly differ in density, structure and distribution across three strata of GNP was, therefore, accepted. Elephant dung counts and evidence of elephant damage on baobabs did not differ significantly across GNP strata, suggesting that baobabs are uniformly affected by elephants which are more or less uniformly transverse the entire GNP. The hypothesis that elephant damage levels on baobabs do not significantly differ across GNP strata was, therefore, accepted.

In contrast, there were significant differences on baobab structure, abundance and distribution on three soil substrates/bedrocks in GNP. Results of the present study suggested that underlying geology which dictates soil groups type; is a key determinant on the pattern of baobab abundance, structure and distribution in GNP; whereas granophyre and rhyolite derived soil groups tends to promote recruitment and regeneration of baobabs, unlike the malvernia derived soil groups. The hypothesis that baobabs do not significantly differ in density, structure and distribution across granophyres, rhyolite and malvernia soil substrates/bedrocks in GNP was, therefore, rejected.

Results of the study indicated that baobab density in GNP was within the same range as in other protected areas, despite being highly targeted by elephants. Elephants tend to browse more frequently on sub-adult to adult baobabs. It was concluded that in GNP, current levels of recruitment were enough to maintain the steady state and transitional increasing baobab population, given a constant elephant density. In GNP, baobabs have somewhere to hide from elephants, as ideal baobab refugia are perceived to be available on granophyre or rhyolite soil substrate/bedrock, in the form of rocky rugged terrain on high elevation, where elephant access is limited. In GNP, mountain ranges can serve as sources of baobabs for the plains. Developed areas with human settlement also serve as baobab refugia with limited elephant access.

The study results pointed to the importance of continued *A. digitata* monitoring in GNP and the study results could add value to further detailed studies that explores the interactions of environmental determinants in shaping savanna ecosystems. The present study provided strong evidence that GNP fire regimes are of less quantifiable impact on baobab structure, abundance and distribution**.** These findings, therefore, could have implications for fire as a management tool for elephant occupancy control in perceived ideal baobab refugia zones in GNP. This study could serve as a benchmark baseline database for GNP baobabs and other protected areas, in the light of baobab demographic changes that may arise from increasing elephant density, changing soil group gradients and a predicted reduction in rainfall due to climate change recruitment.

6.2 Recommendations

6.2.1 Implications for management

While it remains unknown how elephants-fire damage and plants coexisted historically, theories have concentrated on the “compression” hypothesis (Lamprey *et al.,* 1967; Lewis, 1986), the existence of multiple stable states (Dublin *et al.,* 1990; Dublin, 1995), or long-term cycles reminiscent of predator-prey dynamics (Caughley, 1976). Lewis (1991) emphasized the interaction of soil type with fire-elephant-vegetation dynamics. According to Barnes (1983a);

Pellew (1983) and Lewis (1987b), the present study emphasized the need for consideration of ecosystem complexity and varying species responses to any management policies implemented. Management could embark on both short term and long term strategies that ensure sustainable elephant browsing and stabilization of the baobab population structure. Long term continuous monitoring of the baobab populations is necessary in order to identify the sustainable browsing level within GNP. Long term continuous monitoring of baobab populations is necessary in perceived baobab refugia zones in order to identify the sustainable baobab recruitment within GNP.

a) Elephant management

Considering the longevity of life expectancy of baobabs, management should focus on reduction of elephant density. This protects the targeted adult baobabs as juvenile trees take longer time to recruit into the adult size class. A reduction in elephant density is likely to minimize chances of elephant browsing on juvenile baobabs as well. Authority can reduce elephants in a series of steps until monitoring shows a reversal of the trend of overall canopy reduction attributable to elephants. Management objective could be to maintain the elephant population at densities such that this species does not initiate overall canopy loss and such that gains in canopy cover are initially possible.

Management action options

Limit elephants to a prescribed number as in the nearby Kruger National Park (KNP) of South Africa, probably based on a low crude density figure; if the figure of 0.5 elephants per km^2 is used as it appears to be the case for KNP (Whyte *et al.*, 2003) a figure of 2500 elephants is desirable; if a slight higher density of 0.6 elephants per km^2 is used, this implies a total population of about 3 000 elephants could be desirable for GNP.

Various elephant population reduction options could include the following: encourage annual migration of elephants into buffer zone area for trophy hunting with corresponding quota setting; translocate elephants to receiving protected areas or undertake large culling operations say every 5 to 10 years, even though, there have been no recent culls, partly because the ivory trade ban prevents tusks from culled elephants, from being sold to offset the costs of management and protection (Dunham, 2012).

b) Baobab conservation

Management could put in place baobab monitoring programmes, i.e. monitoring plots in strategic baobab stands. Baobab refugia reserves could be delineated and monitored in sites like Chivonja Mountain range, Nyagwama Range, Chilojo steep Cliff (Northern GNP), Muchingwizi Mountain range, Chigono Mountain range (Central GNP) and Mabalauta Station staff residence (Southern GNP). The creation of zones and relatively elephant-free reserves within parks was suggested to protect species and habitats of concern (Whyte *et al.*, 1999; Johnson *et al.*, 1999; Edkins *et al.*, 2007). Combated early dry season burning could be done in delineated baobab refugia reserves. Lewis (1987b) found that elephants move out of burned areas in the early dry season due to the reduction in grass forage and suggested early dry-season burning as a means of repelling elephants from heavily impacted sites.

Barnes (1983a) discussed the relative benefits of management options to control the effects of elephant impacts, viz. fire as an elephant occupancy management control tool, elephant culling, supply of water and laissez- faire as means of elephant population control.

The establishment of experimental baobab plots in GNP could enable the scientific monitoring of baobab stands and assessment of results to determine baobab responses to different disturbance regimes. Experimental baobab plots would also play an important role in comparative elephant behaviour studies and the role of edaphic factors on baobab recruitment. These experimental baobab plots and baobab refugia reserves could be planned in line with the biodiversity and natural resource management programme objectives as outlined in the current GNP Management Plan of 2011 to 2021 (GNP, 2010).

6.2.2 Further studies

A comparative study of baobab population structure and abundance between elephant inhabited protected areas of different elephant density and protected areas with no elephants should be made. The study should also further investigate the influence of edaphic factors on baobab abundance and recruitment. Long-term comparative studies could provide an indication of trends in elephant impacts on baobab abundance and structure within protected areas. The study could also provide an indication of trends in baobab abundance and recruitment as detected by the underlying geology and respective soil groups. These studies are likely to assist protected area managers with informed decisions on sustainability of baobabs within protected areas in view of elephant impacts. These studies could also assist to further explain the influence of soil resource availability, on baobab abundance, structure and distribution in savanna ecosystems. Future studies could incorporate advanced technology such as arial survey, remote sensing and GIS in such baobab studies.

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APPENDICES

APPENDIX A

Sample Field Data Sheet

Date………Time start………Time end………GNP strata (northern/central/southern) ***(Tick)***

Study site name……………Belt transect length…………...   Belt transect number……………..

Soil strata/type……………Rhyolite/Malverina/Granophyres   ***(Tick).***

Study site elevation………………….Study site percentage of rockiness………………………

Sample No.	**Plant status** *Alive/Dead*	**Plant height (m)**	**Basal circumferance @ 1.3m height (m)**	**Number of stems/plant**	**Plant GPS code**		**Elephant dung count (Fresh/old)**		**Elephant damage** *(0-4)*	**Fire damage** *(yes/no)*	**Fruit presence (yes/no)**	**Leaf presence (yes/no)**
1												
2												
3												
4												
5												
6												
7												
8												
9												
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11												
12												
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14												
15												

Remarks/comments

APPENDIX B

Table of frequency distribution of baobabs per size class for northern GNP stratum (% proportion per size class shown in brackets)

Size class (m)	Chivonja Maountain range	Sililijo Range	Sililijo Plain	Nyagwama Range	Chilojo Plain	Sililijo Road	Total
0-2.50	3	1	0	1	2	0	7 (7.8 %)
2.51-5.00	6	7	7	8	0	9	37 (41.1%)
5.01-7.50	5	4	6	3	2	3	23 (25.6%)
7.51-10.00	1	3	2	3	5	3	17 (18.9%)
10.01-12.50	0	0	0	0	1	0	1 (1.1%)
12.51-15.00	0	0	0	0	3	0	3 (3.3%)
15.01-17.50	0	0	0	0	2	0	2 (2.2%)
Total	15	15	15	15	15	15	90 (100%)

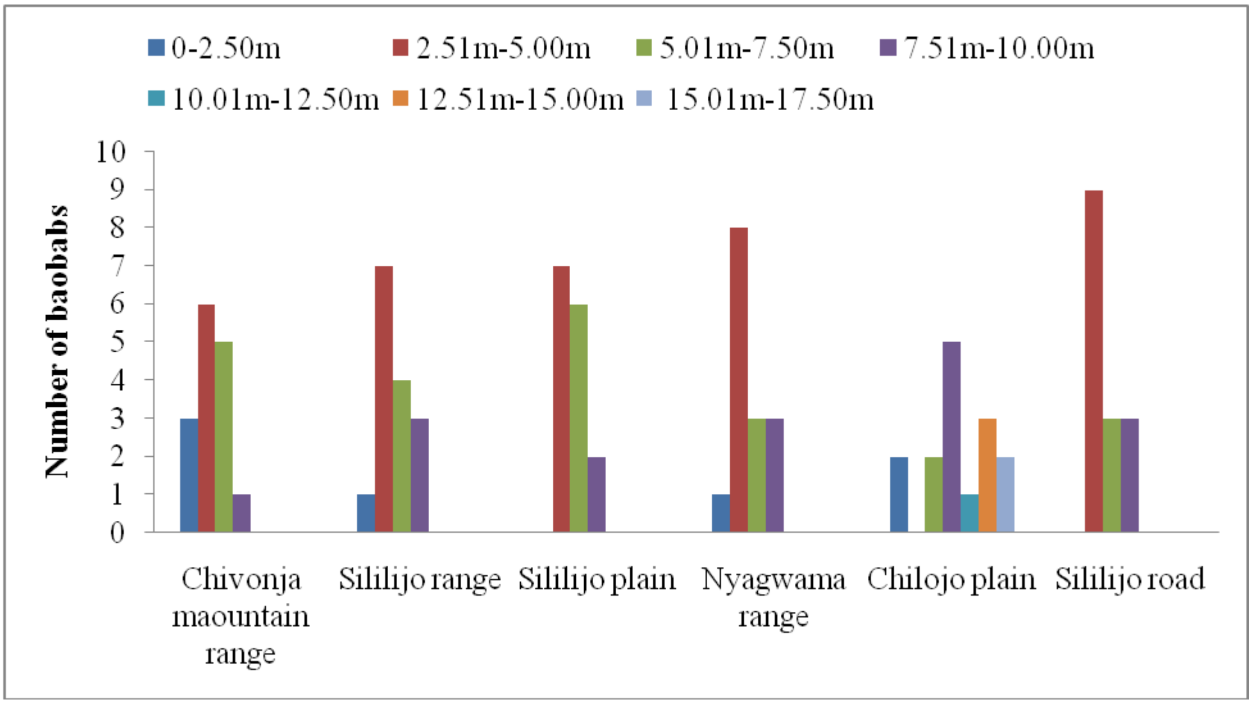


Figure of Size class distribution of baobabs within northern GNP study sites

APPENDIX C

Table of frequency distribution of baobabs per size class for central GNP (% proportion per size class shown in brackets)

Size class (m)	Muchingwizi stream	Sibonja hills	Lower Benjie weir	Chigono range	Muchingwizi mountain range	Total
0-2.50	4	2	1	0	4	11 (14.7%)
2.51-5.00	0	5	7	5	6	23 (30.7%)
5.01-7.50	7	6	4	7	3	27 (36.0%)
7.51-10.00	2	2	3	2	2	11 (14.7%)
10.01-12.50	1	0	0	1	0	1 (1.3%)
12.51-15.00	1	0	0	0	0	1 (1.3%)
15.01-17.50	0	0	0	0	0	0 (0%)
Total	15	15	15	15	15	75 (100%)

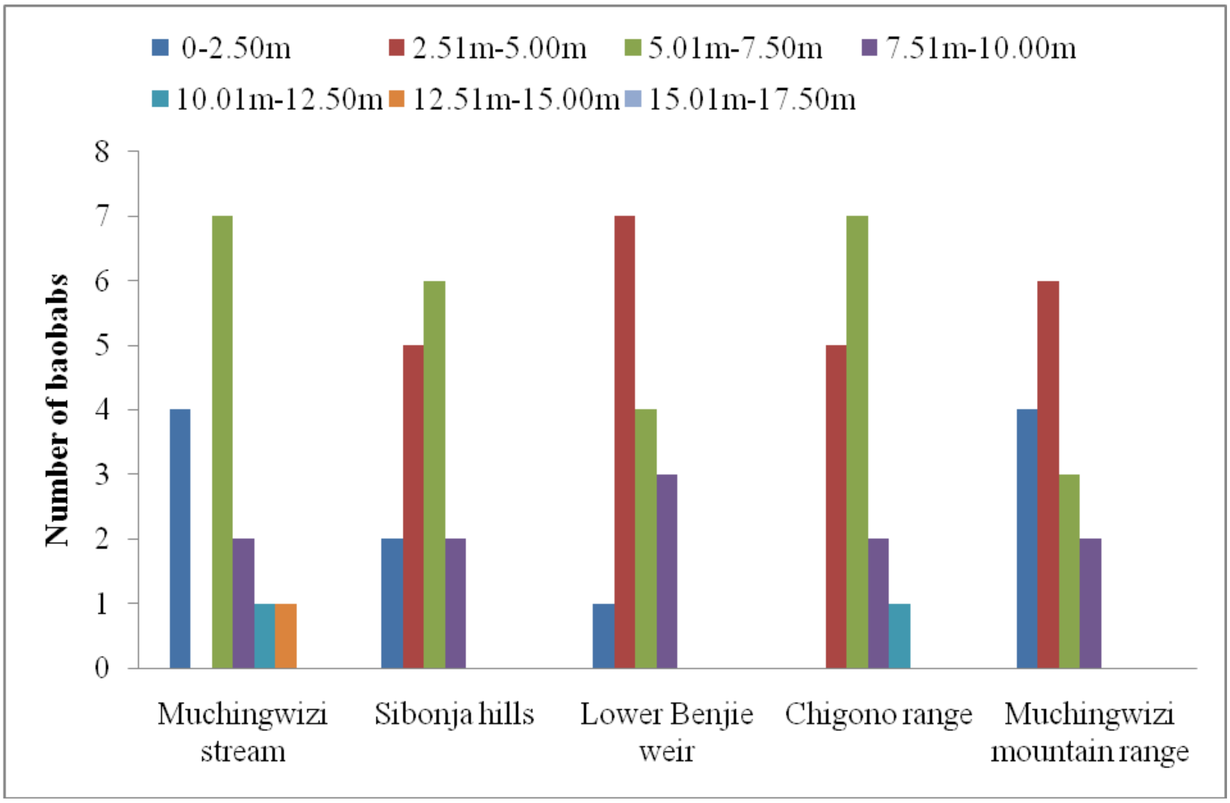


Figure of size class distribution of baobabs within central GNP study site.

APPENDIX D

Table of frequency distribution of baobabs per size class for southern GNP (% proportion per size class shown in brackets)

Size class (m)	Swimuwini	Ross pool	Lipakwa pool	Mabalauta station	Total
0-2.50	9	3	1	11	24 (40.0%)
2.51-5.00	0	4	8	2	14 (23.3%)
5.01-7.50	1	6	6	0	13 (21.7%)
7.51-10.00	0	2	0	1	3 (5.0%)
10.01-12.50	2	0	0	1	3 (5.0%)
12.51-15.00	2	0	0	0	2 (3.3%)
15.01-17.50	1	0	0	0	1 (1.7%)
Total	15	15	15	15	60 (100%)

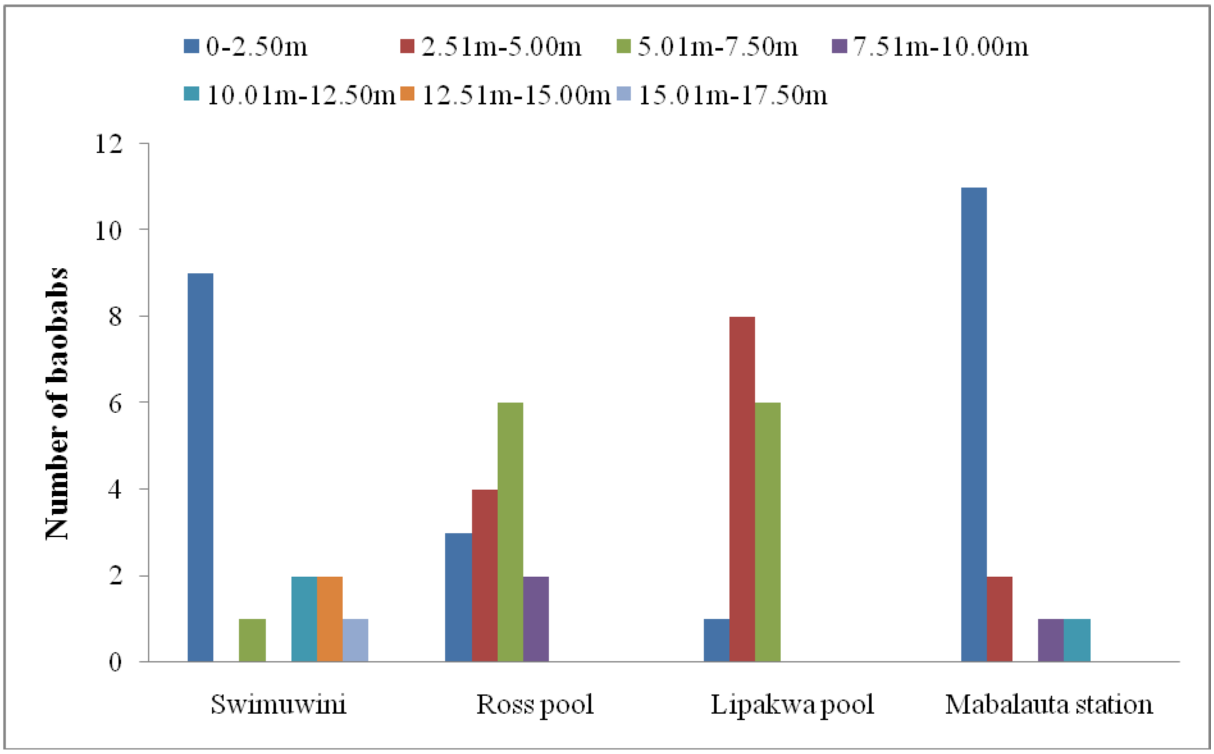


Figure of size class distribution of baobabs within southern GNP study sites

APPENDIX E

Table of frequency distribution of baobabs per size class across the three GNP strata (% proportion per size class shown in brackets)

Size class (m)	Northern GNP	Central GNP	Southern GNP	Total
0-2.50	7	11	24	42 (18.7%)
2.51-5.00	37	23	14	74 (32.9%)
5.01-7.50	23	27	13	63 (28%)
7.51-10.00	17	11	3	31 (13.8%)
10.01-12.50	1	1	3	5 (2.2%)
12.51-15.00	3	1	2	6 (2.7%)
15.01-17.50	2	0	1	3 (1.4%)
Total	90	75	60	225 (100%)

APPENDIX F

Table of Monte-Carlo permutations results for RDA output figure 4.14

Elephant dung density-P-value 0.0020 (variable 3; F-ratio=11.50; number of permutations= 499)
Grass height - P-value 0.0100 (variable 4; F-ratio= 7.23; number of permutations = 499)
Site rockiness- P-value 0.2340 (variable 1; F-ratio= 1.34; number of permutations = 499)
Site elevation P-value 0.3920 (variable 2; F-ratio= 0.89; number of permutations = 499)

APPENDIX G

Table of summary of statistical analyses results of the measured variables and soil substrate/bedrock as grouping variables Notes: Not significant if P value is >0.05

One-way ANOVA		Sum of Squares	df	Mean Square	F	P value
Basal area	Between soil groups	18344.34	2	9172.17	1.850	0.199
	Within soil groups	59480.87	12	4956.72		
	Total	77825.20	14			
gbh	Between soil groups	17.53	2	8.76	2.159	0.158
	Within soil groups	48.71	12	4.06		
	Total	66.24	14			
Baobab plant height	Between soil groups	42.72	2	21.36	4.635	0.032
	Within soil groups	55.30	12	4.61		
	Total	98.02	14			
Stems/plant	Between soil groups	0.387	2	0.19	23.461	0.000
	Within soil groups	0.10	12	0.008		
	Total	0.49	14			
Stem density	Between soil groups	1287.85	2	643.92	0.609	0.560
	Within soil groups	12680.28	12	1056.69		
	Total	13968.13	14			
Elephant damage	Between soil groups	1149.92	2	574.96	0.725	0.505
	Within soil groups	9522.89	12	793.57		
	Total	10672.81	14			
Site rockiness	Between soil groups	10141.67	2	5070.83	10.580	0.002
	Within soil groups	5751.67	12	479.31		
	Total	15893.33	14			
Elevation (Belt transect)	Between soil groups	30854.17	2	15427.08	4.400	0.037
	Within soil groups	42077.17	12	3506.43		
	Total	72931.33	14			
Elephant dung density	Between soil groups	201096.89	2	100548.45	12.179	0.001
	Within soil groups	99067.99	12	8255.67		
	Total	300164.88	14			
Grass height	Between soil groups	0.09	2	0.05	0.766	0.486
	Within soil groups	0.71	12	0.06		
	Total	0.80	14			

APPENDIX H

Table of Tests of Normality (study variables)

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Basal area	0.118	15	0.200*	0.924	15	0.222
gbh	0.445	15	0.000	0.411	15	0.000
Baobab plant height	0.217	15	0.056	0.894	15	0.077
Stems/plant	0.258	15	0.008	0.828	15	0.009
Stem density	0.133	15	0.200*	0.940	15	0.379
elephant damage	0.131	15	0.200*	0.967	15	0.819
Site rockiness	0.198	15	0.116	0.853	15	0.019
Elevation (Belt transect)	0.187	15	0.165	0.923	15	0.212
elephant dung density	0.237	15	0.023	0.701	15	0.000
grass height	0.172	15	0.200*	0.941	15	0.396

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

APPENDIX I

Table of frequency distribution of baobabs per size class for study sites on granophyre substrate/bedrock in GNP (% proportion per size class shown in brackets)

Size class (m)	Chivonja Mnt range	Sililijo Range	Sililijo Plain	Nyagwama Range	Sililijo road	Sibonja Hills	Lower benjie Weir	Chigono Range	MuchingwiziMnt range	Lipakwa Pool	Total
0-2.50	3	1	0	1	0	2	1	0	4	1	13 **(8.7%)**
2.51-5.00	6	7	7	8	9	5	7	5	6	8	68 **(45.3)**
5.01-7.50	5	4	6	3	3	6	4	7	3	6	47 **(31.3%)**
7.51-10.00	1	3	2	3	3	2	3	2	2	0	21 **(14.0%)**
10.01-12.50	0	0	0	0	0	0	0	1	0	0	1 **(0.7%)**
12.51-15.00	0	0	0	0	0	0	0	0	0	0	0 **(0%)**
15.01-17.50	0	0	0	0	0	0	0	0	0	0	0 **(0.0%)**
Total	15	15	15	15	15	15	15	15	15	15	150 **(100%)**

Table of frequency distribution of baobabs per size class for study sites on rhyolite substrate/bedrock in GNP (% proportion per size class shown in brackets)

Size class (m)	**Swimuwini**	**Ross Pool**	**Mabalauta Station**	**Total**
0-2.50	9	3	11	23 (51.1%)
2.51-5.00	0	4	2	6 (13.3%)
5.01-7.50	1	6	0	7 (15.6%)
7.51-10.00	0	2	1	3 (6.7%)
10.01-12.50	2	0	1	3 (6.7%)
12.51-15.00	2	0	0	2 (4.4%)
15.01-17.50	1	0	0	1 (2.2%)
Total	15	15	15	45 (100%)

Table of frequency distribution of baobabs per size class for study sites on malvernia substrate/bedrock in GNP (% proportion per size class shown in brackets)

Size class (m)	**Chilojo Plain**	**Muchingwizi Stream**	**Total**
0-2.50	2	4	6 **(20%)**
2.51-5.00	0	0	0 **(0%)**
5.01-7.50	2	7	9 **(30%)**
7.51-10.00	5	2	7 **(23.3%)**
10.01-12.50	1	1	2 **(6.7%)**
12.51-15.00	3	1	4 **(13.3%)**
15.01-17.50	2	0	2 **(6.7%)**
Total	15	15	30 **(100%)**

APPENDIX J

Table of frequency distribution of baobabs per size class for study sites across the three substrates/bedrocks in GNP (% proportion per size class shown in brackets)

Size class (m)	Granophyre	Malvernia	Rhyolite	Total
0-2.50	13	6	23	42 (18.7%)
2.51-5.00	68	0	6	74 (32.9%)
5.01-7.50	47	9	7	63 (28%)
7.51-10.00	21	7	3	31 (13.8%)
10.01-12.50	1	2	3	6 (2.7%)
12.51-15.00	0	4	2	6 (2.7%)
15.01-17.50	0	2	1	3 (1.3%)
Total	150	30	45	225 (100%)

APPENDIX K

Table of Monte-Carlo permutations results for RDA output figure 4.28

Elephant dung density-P-value 0.0020 (variable 3; F-ratio=11.50; number of permutations= 499)
Grass height - P-value 0.0100 (variable 4; F-ratio= 7.23; number of permutations= 499)
Site rockiness- P-value 0.2340 (variable 1; F-ratio= 1.34; number of permutations= 499)
Site elevation - P-value 0.3920 (variable 2; F-ratio= 0.89; number of permutations= 499)

APPENDIX L

Table of Number of baobabs within each damage class per study site of northern GNP (% proportion of damaged baobabs per study site sample baobab density)

Northern GNP	Stem density (km^2)	No damage	Slight damage	Moderate damage	Severe damage	Dead	Elephant damage (%)
Chivonja mountain range	100	6	7	2	0	0	4
Sililijo range	62.9	0	10	4	1	0	6.7
Sililijo plain	113.3	0	12	3	0	0	6.7
Nyagwama range	83.3	1	11	3	0	0	6.2
Chilojo plain	43.3	0	2	2	9	2	6.7
Sililijo road	62.5	0	15	0	0	0	6.7
Northern GNP	69.8	7	57	14	10	2	36.9

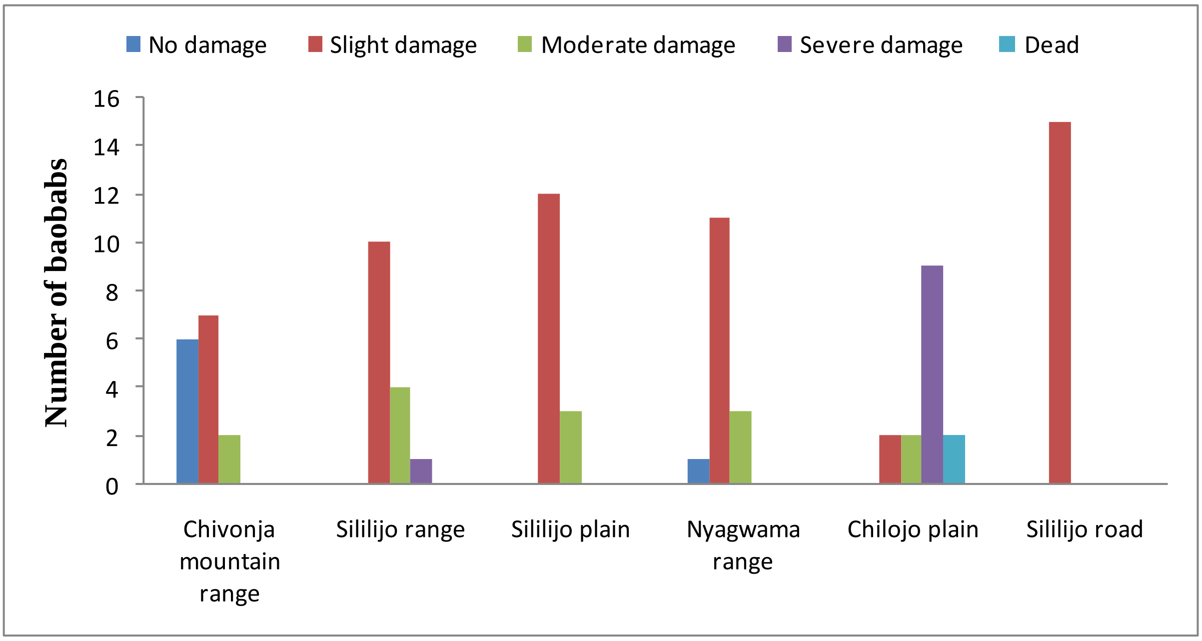


Figure of Number of baobabs at each study site of northern GNP grouped according to damage classification

APPENDIX M

Table of Number of baobabs within each damage class per study site of central GNP (% proportion of damaged baobabs per study site sample baobab density)

Central GNP	Stem density (km^2)	No damage	Slight damage	Moderate damage	Severe damage	Dead	Elephant damage (%)
Muchingwizi stream	41.7	0	6	5	3	1	6.6
Sibonja hills	20.8	8	5	1	1	0	3.1
Lower Benjie weir	24	0	2	8	5	0	6.7
Chigono range	71.4	1	10	3	1	0	6.2
Muchingwizi mountain range	106.7	1	13	0	1	0	6.2
Central GNP	34.25	10	36	17	11	1	28.9

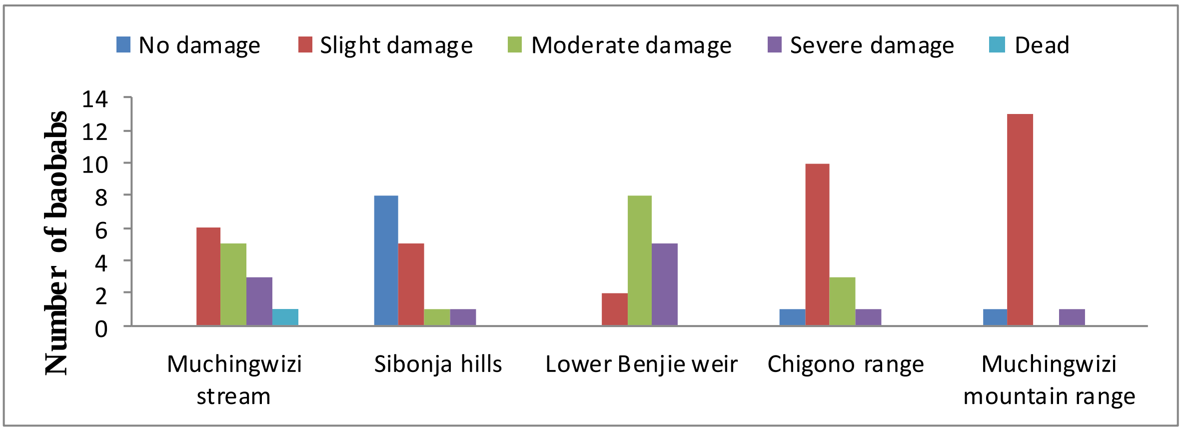


Figure of Number of baobabs at each study site of central GNP, grouped according to damage classification

APPENDIX N

Table of Number of baobabs within each damage class per study site of southern GNP (% proportion of damaged baobabs per study site baobab density sample)

Southern GNP	Stem density (km^2)	No damage	Slight damage	Moderate damage	Severe damage	Dead	Elephant damage (%)
Swimuwini	95.8	1	6	2	4	2	6.2
Ross Pool	45.2	0	3	7	5	0	6.7
Lipakwa Pool	20	3	9	3	0	0	5.3
Mabalauta station	81.5	14	1	0	0	0	0.4
Southern GNP	35.7	18	19	12	9	2	18.7

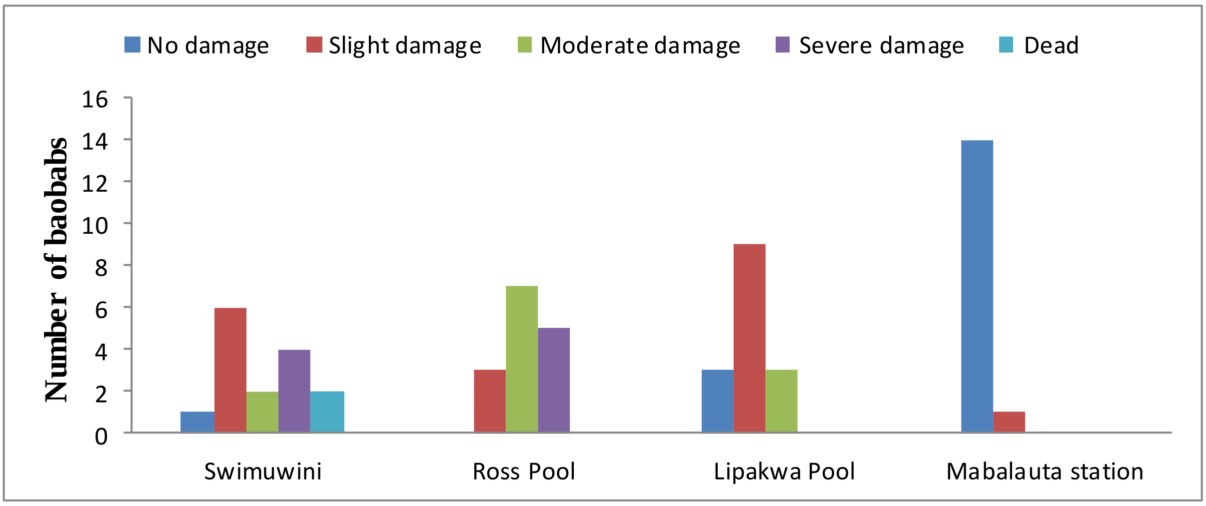


Figure of Number of baobabs at each study site of southern GNP, grouped according to damage classification

APPENDIX O

Table of Number of baobabs within each damage class per GNP strata (% proportion of damaged baobabs per GNP stratum baobab density sample)

GNP strata	Stem density (km^2)	No damage	Slight damage	Moderate damage	Severe damage	Dead	Elephant damage (%)
Northern GNP	69.77	7	57	14	10	2	36.9
Central GNP	34.25	10	36	17	11	1	27.1
Southern GNP	35.71	18	19	12	9	2	18.7
GNP	43.6	35	112	43	30	5	84.4

APPENDIX P

Table of Number of baobabs within each damage class per soil substrate strata (% proportion of damaged baobabs per soil substrate baobab density sample)

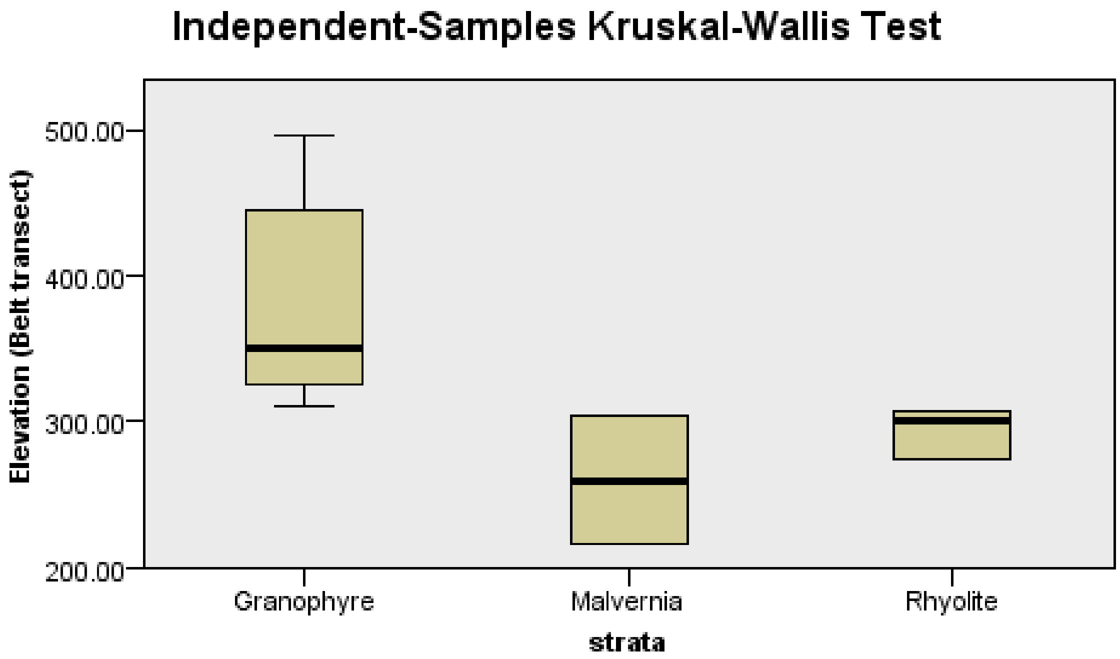
Soil substrate/bedrock	Stem density (km2)	No damage	Slight damage	Moderate damage	Severe damage	Dead	Elephant damage (%)
Granophyre	66.5	20	94	27	9	0	86.7
Malvernia	42.5	0	8	7	12	3	100
Rhyolite	74.2	15	10	9	9	2	66.7

APPENDIX Q

Table of Summary frequency of damaged and undamaged baobabs per size class across GNP

Size class (m)	No damage	Slight damage	Moderate damage	Severe damage	Dead	Total damaged
0-2.50	17	8	1	10	3	22 (9.8%)
2.51-5.00	11	48	11	4	1	64 (28.4%)
5.01-7.50	6	36	16	5	1	58 (25.8%)
7.51-10.00	0	13	10	5	0	28 (12.4%)
10.01-12.50	1	5	3	1	0	9 (4%)
12.51-15.00	0	1	2	3	0	6 (2.7%)
15.01-17.50	0	1	0	2	0	3 (1.3%)
Total	35	112	43	30	5	190

APPENDIX R

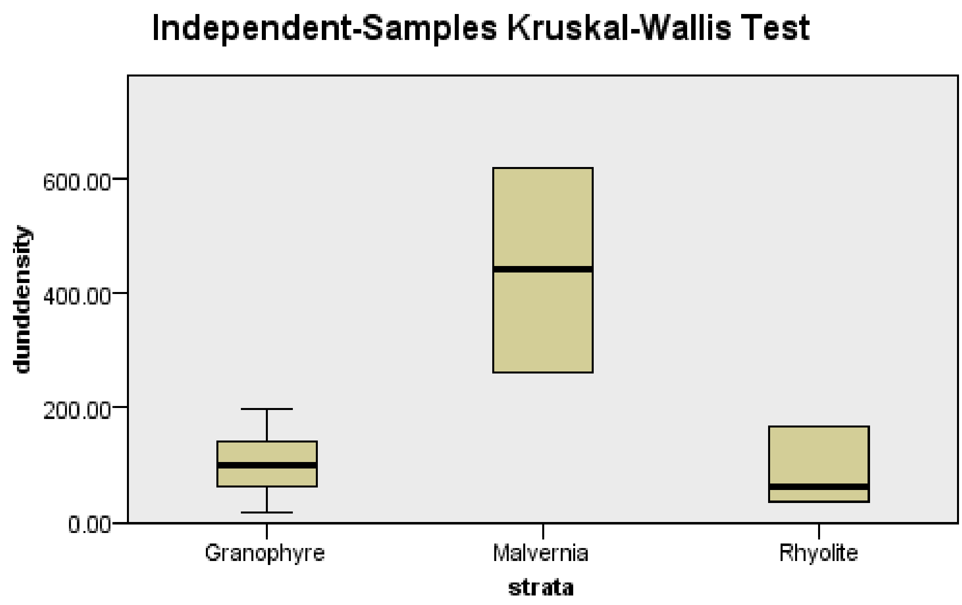


Total N	15
Test Statistic	9.417
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.009

1. The test statistic is adjusted for ties.

Figure of mean value of habitat elevation across soil substrate
Granophyre and rhyolite soil substrate/bedrock are relatively of higher elevation, while the malvernia soil substrate/bedrock forms plains of lower elevation.

APPENDIX S



Total N	15
Test Statistic	5.070
Degrees of Freedom	2
Asymptotic Sig. (2-sided test)	.079

1. The test statistic is adjusted for ties.
2. Multiple comparisons are not performed because the overall test does not show significant differences across samples.

Figure of Mean value of Elephant dung density
Frequency of encountering elephant dung was highest on malvernia beds as compared to granophyres and rhyolite soil substarate/bedrock.

APPENDIX T
GNP Baobabs data for the measured variables

Place	Soil substrate	Plant basal area/km2	Plant gbh (m)	Plant height (m)	Number of stems/plant	Stem density-Number of stems/km2	grass height (m)	strata
Chivonja mountain range	Granophyres	128.9135	1.449371	11.53333	1	100	0.81	1
Sililijo range	Granophyres	112.6629	1.795268	12.4	1.133333	62.96296	0.45	1
Sililijo Plain	Granophyres	183.0013	1.761315	13.33333	1.133333	113.3333	0.55	1
Nyagwama range	Granophyres	156.3524	1.740094	12.86667	1	83.33333	1	1
Sililijo road	Granophyres	109.2685	1.682798	15.4	1	62.5	0.69	1
Muchingwizi stream	Granophyres	115.0564	1.905191	12.32	1	41.66667	0.55	1
Sibonja Hills	Granophyres	38.32598	1.752826	14.2	1	20.83333	0.5	1
Lower Benjie Wier	Granophyres	34.9764	1.718873	13.6	1.2	24	0.15	1
Chigono range	Granophyres	148.1859	1.903493	11.46667	1	71.42857	0.7	1
Muchingwizi mountain range	Granophyres	125.2134	1.385709	11.23333	1.066667	106.6667	0.55	1
Swimuwini	Rhyolite	204.0355	1.583061	8.2	1.533333	95.83333	0.55	2
Ross Pool	Rhyolite	62.29735	1.618075	13.36667	1.266667	45.2381	0.54	2
Mabalauta station	Rhyolite	49.00012	10.05859	5.433333	1.466667	81.48148	0.25	2
Lipakwa	Malvernia	26.84107	1.517277	12.34667	1	20	0.25	3
Chilojo Plain	Malvernia	302.8383	3.146721	16.07143	0.866667	24	0.16	3