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Impact of African elephant on baobab along a surface water availability gradient in Mana Pools National Park, Zimbabwe

ONIAS NDORO[1], CLAYTON MASHAPA[1*], SHAKKIE KATIVU[1] & EDSON GANDIWA[2]

[1]*Tropical Resource Ecology Programme, University of Zimbabwe, P.O. Box MP 167, Mount Pleasant, Harare, Zimbabwe*

[2]*School of Wildlife, Ecology and Conservation, Chinhoyi University of Technology, Private Bag 7724, Chinhoyi, Zimbabwe*

Abstract: An assessment of African elephant (*Loxodonta africana*) impact on baobabs (*Adansonia digitata*) was conducted along a surface water availability gradient in Mana Pools National Park, Zimbabwe. Data on baobab height, basal area, density and elephant damage were recorded from three strata with varying distance of 4 km, 26 km and 50 km from the Zambezi River. Rukomechi stratum which is furthest (50 km) from Zambezi River recorded tallest mean baobab height, largest mean basal area, highest mean baobab density and the least level of elephant induced damage on baobabs as compared to study sites on Sapi River and Fourways strata which are all less than 26 km from Zambezi River. It was concluded that there was high disturbance pressure on baobabs close to water sources and this seemed to influence baobab abundance and structure in Mana Pools National Park, Zimbabwe.

Key words: Herbivory, proximity, tree density, Zambezi River.

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Introduction

The African elephant (*Loxodonta africana*) has significant impact on vegetation due to its large body size and foraging behaviour (Guldemond & van Aarde 2008). The generation of scientific information on local elephant impact vegetation preferences across relevant spatial and temporal scales is important for decision making in the management of protected areas for the sustainability of both elephants and woodlands (Loarie *et al*. 2009; Tafangenyasha 1997). Elephant impacts on vegetation near water sources has been recorded in many protected areas in African savannas (De Beer *et al*. 2006; Gaugris & Van Rooyen 2010; Gandiwa *et al*. 2011), and the factors causing differences in impacts are well understood (Gandiwa *et al*. 2016; Staub *et al*. 2013). In Kruger National Park, South Africa, Brits *et al*. (2002) recorded low shrub density closer to water sources and highest shrub density further away from water sources, whereas, tree density did not show much change with distance from water sources. Gandiwa *et al*. (2012) recorded a decrease in woody density with closeness to natural water sources, suggesting woodland degradation around water points in Gonarezhou National Park, Zimbabwe. Elsewhere, in northern Botswana, Ben-Shahar (1998) reported that *Colophospermum mopane* woodlands subjected to excessive elephant damage had unchanged densities of trees. However, the concentration of elephants around watering points exposes vegetation in the vicinity to herbivory or trampling threats (Thrash & Derry 1999).

Kupika *et al*. (2014) found that elephant damage to baobabs (*Adansonia digitata*) was most

Corresponding Author; e-mail: ondoro2001@gmail.com

severe in areas located closer to water sources in Gonarezhou National Park, southern Zimbabwe. Elephants usually encounter baobabs close to permanent water sources. This increases the chances of bark stripping and baobab damage as recorded in several earlier studies (Brits *et al.* 2002; Gandiwa *et al.* 2011; Gandiwa *et al.* 2012; Kupika *et al.* 2014; Mukwashi *et al.* 2012). However, there have been suggestions that baobab populations are unaffected by elephants in certain habitats because of difficult access (Edkins *et al.* 2007; Mpofu *et al.* 2012; Weyerhaeuser 1985). A better understanding of local factors influencing elephant impact on woody species is thought to be important in the management of plant biodiversity as well as other large herbivore species, which often congregate around perennial water sources during the dry season (Chamaillé-Jammes *et al.* 2009; Gandiwa *et al.* 2012). African elephant distribution is suggested to be regulated by surface water availability (Redfern *et al.* 2003), with herds staying less than 10 km radius from permanent water sources on average during the dry season (Loarie *et al.* 2009; Stokke & du Toit 2002).

The African baobab is a deciduous woody-succulent plant native to dry regions of sub-Saharan Africa (Wickens & Lowe 2008). Lack of recruitment seems to threaten the baobabs, as little natural regeneration has been reported in different parts of Africa (e.g., Edkins *et al.* 2008; Schumann *et al.* 2010). Low natural regeneration of baobabs has been partially related to high frequents of drought events in dry lands of Africa (Sanchez *et al.* 2011; Wickens & Lowe 2008). Baobabs are mainly dispersed by elephants and baboons (*Papio* spp.), and are under considerable pressure due to use by humans for different purposes (Dovie 2003; Schumann *et al.* 2010; Wickens & Lowe 2008). Bark harvesting for small-scale commercial sale of mats was reported being done un-sustainably in Zimbabwe (Dovie 2003). The baobab plant is of conservation importance in Africa mainly because it is keystone species of ecological significance of the important ecosystem function it plays (Buchmann *et al.* 2010; Schumann *et al.* 2010; Symes & Perrin 2004; Wickens & Lowe 2008).

In Zimbabwe, elephant foraging behavior, and impacts on baobabs have been studied in Mana Pools National Park, northern Zimbabwe (Swanepoel 1993; Swanepoel & Swanepoel 1986) and Gonarezhou National Park, southern Zimbabwe (e.g., Kupika *et al.* 2014; Mashapa *et al.* 2014; Mpofu *et al.* 2012). Swanepoel (1993) noted with concern that elephant induced annual baobab mortality rate of 7.3 % in Mana Pools National Park and observed that elephant foraging behavior was a distinctly seasonal phenomena related to the position of woodlands relative to perennial water sources. Several factors could explain the spatial distribution of baobabs in African savanna as they are affected by a number of establishment factors, such as herbivory (Mashapa *et al.* 2014), past human activities (O'Connor & Campbell 1986), droughts (De Smedt *et al.* 2012), climate change (Sanchez *et al.* 2011) or soil type (Mashapa *et al.* 2013).

The increasing elephant population in northern Mana Pools National Park, Zimbabwe has been a cause for concern (Dunham & du Toit 2012). As elephants become increasingly confined to smaller fragmented landscapes coupled with their increasing densities there is concern over the modification of the vegetation and biodiversity (Gandiwa *et al.* 2011; Loarie *et al.* 2009). The present study sought to understand the effect of elephant browsing pressure on baobabs along a surface water availability gradient in Mana Pools National Park, Zimbabwe, given that the influence of elephant impact on woody species can be site specific and vary across space and time according to elephant density and/or among other factors (De Smedt *et al.* 2012; Mashapa *et al.* 2013, 2014; O'Connor & Campbell 1986; Sanchez *et al.* 2011). The specific objectives of the study were: (i) to investigate baobab density, height and basal area in relation to distance from a major perennial water source, and (ii) to determine elephant induced baobab damage in relation to distance from a major perennial water source.

Materials and methods

Study area

Designated as a United Nations Educational, Scientific and Cultural Organization World Heritage Site in 1984, Mana Pools National Park (2,196 km^2) is located in northern Zimbabwe, between latitudes 15° 40′ to 16° 20′ S and longitudes 29° 08′ to 29° 45′ E (Heath 1986; ZPWMA 2011). To the north, the park is bordered by the Zambezi River which forms the international boundary with Zambia and to the south it is bordered by Mukwichi Communal Land. The soils of Mana National Park are described by Guy (1977). The area located between the Chitake River and the Zambezi escarpment is characterized by colluvial deposits. Alluvial deposits are restricted to the larger rivers (Rukomechi and Sapi) and are especially pronounced and older along the Zambezi Valley, forming the Mana Pools "floodplain", covered by what is referred to as Zambezi riverine vegetation. The gneissic derived soils on and above the escarpment are generally shallow, medium-grained lithosolic sands (Thompson & Purves 1978).

ZPWMA (2011) recognised twelve vegetation communities in Mana Pools National Park, including riparian vegetation dominated by *Faidherbia albida* woodlands, dry deciduous *Commiphora-Combretum* thickets, and *Colophospermum mopane* woodland, which is the most extensive vegetation type which is common with baobab stands. In Mana Pools National Park, perennial water readily available to mega-herbivores is from the Zambezi River, apart from the water from springs and seeps associated with streams in the inaccessible escarpment. Surface water occurs only in pans, filled by rainfall runoff and these pans normally dry by mid-dry season (Guy 1982). Average rainfall across the period 2000 - 2010 is about 800 mm per year with a temperature range from 19 °C in July to 29 °C in October (ZPWMA 2011). The climate of Mana Pools National Park is, therefore, regarded as semi-arid (Moyo *et al.* 1993).

Sampling procedure and data collection

We stratified the study area by delineating three study strata namely, Sapi River road, Fourways road and Rukomechi road which are at a varying distance from the Zambezi River, the perennial water source in Mana Pools National Park (Table 1). The three study strata in Mana Pools were defined by perpendicular distance from the Zambezi River eastern bank as follows: Sapi River road study stratum is approximately 4 km, about 26 km away is the Fourways road study stratum which is in the middle of Mana Pools National Park and Rukomechi road study stratum which is furthest and is approximately 50 km and is at the base of the Zambezi escarpment. The three defined study strata are all almost parallel to Zambezi River with a general west-east compass alignment. We systematically sampled baobabs within a belt 300 m wide on either side of defined roads in April 2005. Edkins *et al.* (2007) noted that a random sampling scheme is not appropriate for baobabs, as juveniles tend to be under represented. Belt transects interspaced by one kilometer were used to sample baobab population in all the three defined study strata. The following variables were measured and/or recorded: baobab height, basal circumference and elephant induced damage on baobabs following the methods as outlined by Kupika *et al.* (2014) and Mashapa *et al.* (2014). Baobab height was measured by placing a calibrated 6 m pole against a baobab plant. For baobab trees > 6 m, the pole was manually uplifted and height visually estimated by observing it at a distance away from the tree. For multi-stemmed baobabs, only the height of the tallest stem was considered. The basal circumference at breast height (1.3 m above the ground level) of each baobab tree was measured using a 50 m tape measure. For baobab saplings, the basal circumference of each stem was measured just above the buttress swelling. The basal circumference was converted to diameter at breast height. Baobab damage by elephants was assessed on a 5-point category scale, from 0 = no damage, 1= slight damage with few scars: 2 = moderate damage with numerous scars; 3 = severe damage with the tree scarred deeply and 4 = tree dead.

Table 1. Study sites in northern Mana Pools National Park, Zimbabwe.

Study site	Distance from the Zambezi River (km)	Area covered in km^2	Number of belt transects
Sapi River road	4	16.8	28
Fourways road	26	15.0	25
Rukomechi road	50	6.6	12

Data analysis

Variables included in the analyses were woody plant height, basal area and density. Data were tested for normality using the Kolmogorov Smirnov test in STATISTICA version 6 (StatSoft 2001) and all data were not normal, therefore, we chose a non-parametric approach. Baobab density was calculated from the belt transect area within which the baobab trees were encountered along transect and converted to per km^2. Kruskal-Wallis ANOVA by Ranks tests were used to determine differences in baobab height, baobab density and basal circumference, and a Chi-square test was used to compare elephant induced baobab damage among the defined study sites. The frequency of baobabs within each elephant induced damage class per stratum was calculated and presented graphically. Baobab size class (dbh) distributions were used to trace growth patterns of baobabs across the three study strata. A Chi-square independence test was used to compare baobab size (dbh and height) across strata. Finally, we applied a Principal Component Analysis (PCA) ordination to explore the associations of baobabs in relation to elephant herbivory and proximity to surface water. Data were converted to per km^2 to ensure that there was a standard unit prior to running the PCA.

Results

Baobab abundance and structure in relation to distance from Zambezi River

A total of 284 baobabs were recorded across the three study strata. About 0.70 % (n = 2) of the baobabs were found dead or decomposing, 2.82 % (n = 8) were not damaged and 96.48 % (n = 274) were damaged. The highest frequency of baobabs (51.76 %; n = 147) were slightly damaged, while 22.89 % (n = 65) were moderately damaged, and 21.83 % (n = 62) were severely damaged. In general, more baobabs were recorded further away from the Zambezi River, the Rukomechi area at the base of the escarpment (Table 2). There was a significant difference in baobab density across the three study strata (Kruskal-Wallis ANOVA by ranks, H = 7.61, df = 2, p = 0.022), with a Rukomechi road stratum recording the highest baobab density of 22.40 per km^2, whereas, the Sapi River road and the Fourways road strata recorded baobab density less than 4.70 per km^2.

Table 2. Baobab density across the three study strata in Mana Pools National Park, Zimbabwe.

Study site	No. of baobabs	Area (km^2)	Density (baobabs / km^2)
Sapi River road	76	16.80	4.70
Fourways road	60	15.00	4.00
Rukomechi road	148	6.60	22.43

There was a significant difference in basal area across the three study stratum (Kruskal-Wallis test, H = 10.11, df = 2, P = 0.006). Rukomechi road stratum recorded the largest basal area while the Fourways road stratum recorded the smallest basal area of the three study strata (Fig. 1). Baobab height was similar across the three study strata (Kruskal-Wallis ANOVA by ranks, H = 3.69, df = 2, P = 0.158) with Rukomechi road stratum recording baobabs of mean height of 14 m, followed by Sapi River road stratum with a mean baobab height of 13 m, and Fourways road stratum with a mean baobab height of 11 m.

The highest frequency of baobabs sampled were in the baobab size class category of dbh (5.01-7.5 m) and the least baobab frequency were in the smallest baobab size class category of dbh (0.00 - 2.5 m) showing a bell-shaped pattern (Fig. 1). Fourways road study stratum had no baobabs recorded in the baobab size class category of dbh greater than 10 m.

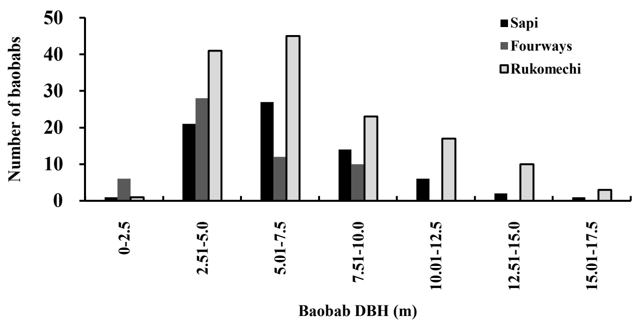

Fig. 1. Frequency distribution of baobabs in different DBH size class categories across Sapi River road, Fourways roads and Rukomechi road study strata in Mana Pools National Park, Zimbabwe.

Elephant induced baobab damage in relation to distance from water source

The highest frequency of elephant induced baobab damage was recorded in Sapi River road stratum where all baobabs recorded had some level of damage induced by elephants (χ^2 = 60.73, df = 4, P < 0.0001; Fig. 2). Of the three study strata, Rukomechi road stratum recorded the least number of baobabs damaged by elephants.

Principal Component Analysis results showed that two principal components explained the variance, namely, elephant herbivory and proximity of baobabs to a water source. The first two principal components explained 93.89 % of the variation. Principal Component 1 accounted for 67.78 % (eigenvalue = 2.03) of variance, while Principal Component 2 accounted for 26.11 % (eigenvalue = 0.78) of the variance. Baobab density and basal area were strongly positively correlated

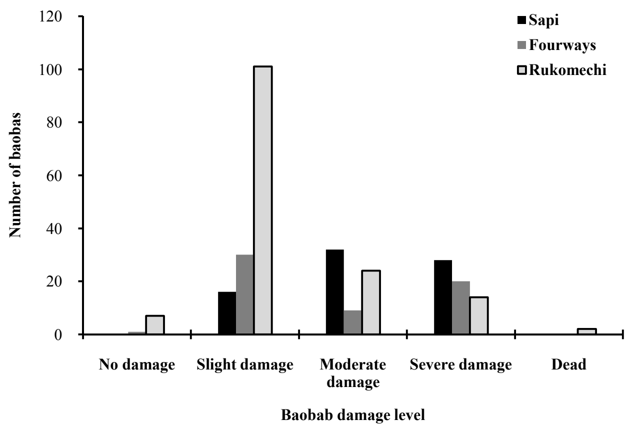

Fig. 2. Number of baobab found in different damage categories across Sapi River road, Fourways roads and Rukomechi road study sites in Mana Pools National Park, Zimbabwe.

with Principal Component 1 which could be defined as a gradient of increasing distance from a water source. However, baobab height was highly positively correlated to Principal Component 2 which can be described as a decreasing gradient of elephant browsing pressure. Baobab density was positively correlated with basal area.

Sample belt transects across the three study strata showed two distinct clusters with the majority of belt transects from the Rukomechi road stratum making one cluster and the other cluster group made from a grouping of belt transects from the Sapi River road and the Fourways road strata (Fig. 3). There is a distinct close relationship of study sites in Sapi River road and Fourways road strata which are all less than 26 km from Zambezi River.

Discussion

The study recorded a total of 284 baobabs with 96 % of baobabs damaged by elephants in Mana Pools National Park, northern Zimbabwe. Conybeare (2004) noted that elephant impact on large trees like baobabs is of concern since they are conspicuous, and are aesthetically appealing. The fact that baobab density was higher and elephant induced baobab damage was least at the Rukomechi road stratum which is furthest from Zambezi River compared to other strata suggests that elephant herbivory tend to be of less negative impact on baobab abundance with increasing distance from the water source in Mana Pools National Park (Table 2, Fig. 2). These findings are consistent with the findings of several studies in protected areas of Zimbabwe, which noted that elephants tend to concentrate close to water sources and cause serious damage to baobabs (Conybeare 2004; Kupika *et al.* 2014; Mpofu *et al.* 2012; Swanepoel 1993). Elsewhere, it is known that elephant distribution is influenced by surface water availability (Dunham 2012; Redfern *et al.* 2003) thus, findings of the present study confirms that close proximity to a water source is a determining factor on elephant impact on baobab abundance and survival in Mana Pools National Park, Zimbabwe. Dunham (1986) observed that elephants tend to utilize the Zambezi riverine woodland during the dry season and are confined within 20 km from the Zambezi River during the dry season; explaining the similarities of the recorded baobab variables in the Sapi River road and Fourways road strata occurring less than 26 km from Zambezi River. In Mana Pools National Park, elephant densities continue to increase as reported by Dunham & du Toit (2012) who recorded an elephant density of 8.11 km^{-2} within the Zambezi riparian zone during the dry season.

There was a distinct close relationship of baobab status in study sites on Sapi River road and Fourways road strata which are all less than 26 km from Zambezi River (Fig. 3). The highest frequency of elephant induced baobab damage was closer and the lowest further away to a water source. Interestingly, the present study also highlighted a trend in decreasing basal area and baobab density with decreasing distance to a water source (Tables 1 & 2, Fig. 1). Hence, these findings are consistent with several other studies that attribute elephant herbivory to influence baobab abundance and structure in relation to proximity to water source (Brits *et al.* 2002; Gandiwa *et al.* 2011, 2012; Kupika *et al.* 2014; Mukwashi *et al.* 2012).

A comparison of the three study strata over baobab size class distribution showed a decrease in smaller baobab size classes of dbh category of less than 2.5 m, indicating a baobab recruitment bottleneck across Mana Pools National Park. The baobab population across the three study strata had bell shaped baobab size class distribution pattern with fewer baobabs in the smallest and largest dbh baobab size class categories. Elsewhere, bell shaped baobab size class distributions were recorded (Chirwa *et al.* 2006; Edkins *et al.* 2007; Venter & Witkowski 2010). In these studies, the lower number of baobab individuals in the smaller baobab size classes, a proxy to baobab recruitment

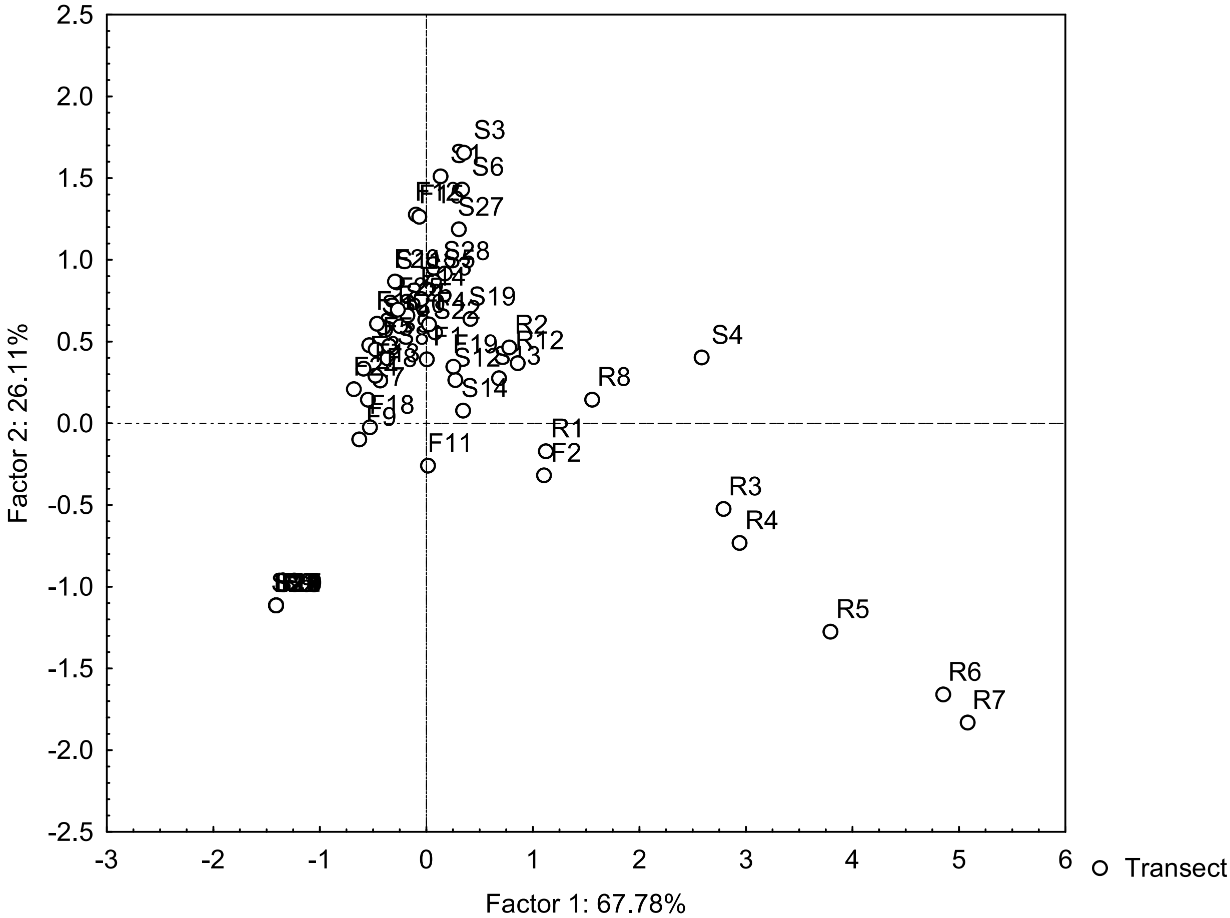

Fig. 3. PCA scatter plot of sample belt transects from the three study strata of Sapi River road (S), Fourways roads (F) and Rukomechi road (R) in Mana Pools National Park, Zimbabwe.

bottle neck was attributed to elephant herbivory which tend to target baobab saplings (Barnes *et al.* 1994; Mashapa *et al.* 2013) for their succulent nature during the dry season when water is limiting. Swanepoel (1993) also suggested that juvenile baobabs are likely to die from elephant utilization than adult ones. A number of studies have highlighted that the elephant is a major influence in the ecology of baobab, responsible for a lack of recruitment by the destruction of seedlings and an accelerated decline in natural populations by causing damage to mature trees (Barnes *et al.* 1994; Edkins *et al.* 2007; Kupika *et al.* 2014; Mashapa *et al.* 2014; Mpofu *et al.* 2012).

We noted with concern the recorded low mean baobab density of 10.2 baobabs km^{-2} in Mana Pools National Park which was far from related findings in protected areas in savanna ecosystem (Kupika *et al.* 2014; Mashapa *et al.* 2013, 2014). The recorded low baobab density coupled with a short mean baobab height of 12.7 m indicating that baobabs in Mana Pools National Park could be failing to grow to a maximum height of close to 25 m (Coates-Pelgrave 1997), this could be slightly attributed to the recorded high elephant induced damage on baobabs or other baobab disturbance regimes not covered by the present study. The impact of elephants on baobabs is confounded by interactions with drought (Wilson 1988; Whyte 2001), other herbivores (Edkins *et al.* 2007), soil type (Mashapa *et al.* 2013), land-use and human impact (Wickens & Lowe 2008; Wilson 1988).

Conclusions

The present study aimed at investigating the baobab abundance and structure in relation to distance from a major perennial water source and to determine elephant induced baobab damage as influenced by distance from a water source in

Mana Pools National Park. The study recorded a decreasing trend in mean baobab densities, basal areas and an increasing elephant induced damage on baobabs with decreasing distance from Zambezi River. The present study concluded that there was a baobab disturbance gradient directly proportional to the close proximity of Zambezi River water source in Mana Pools National Park. Future studies should investigate the driving factors of the observed baobab disturbance gradient particularly focusing on the implications of elephant herbivory given the recorded high elephant induced baobab damage. It is further recommended that park management come up with elephant management strategies that will reduce elephant induced damage on baobabs (see Owen-Smith *et al*. 2006). For instance, some of the management options include manipulating water supply and/or increase elephant hunting quota in wildlife areas surrounding Mana Pools National Park, especially in areas with high baobab damage.

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