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The impact of African elephants on *Acacia tortilis* woodland in northern Gonarezhou National Park, Zimbabwe

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ABSTRACT

We investigated the impact of African elephants (*Loxodonta africana*) on the structure and composition of *Acacia tortilis* woodland in northern Gonarezhou National Park, southeast Zimbabwe. *A. tortilis* woodland was stratified into high, medium and low elephant utilisation categories based on evidence of elephant habitat use as determined through dung-count surveys in relation to distance of woodland patches from perennial and natural surface water sources. The following variables were recorded in each study plot: tree height, species name, number of species, plant damage, basal circumference and number of stems per plant. A total of 824 woody plants and 26 woody species were recorded from the sampled *A. tortilis* woodland patches. Mean tree densities, basal areas, tree heights and species diversity were lower in areas with medium and high elephant utilisation as compared to low elephant utilisation areas. Plants damaged by elephants increased with increasing elephant utilisation. The study findings suggest that *A. tortilis* woodland is gradually being transformed into an open woodland. We 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 *A. tortilis* woodlands and (ii) establishing long-term vegetation monitoring programmes.

1. Introduction

Top-down regulation of ecosystems by large herbivores is a topic of active debate between scientists and managers, and a prime example is the interaction between the African elephants (*Loxodonta africana*) and trees in African savannas (Moe et al., 2009). The structure and composition of savannas are typified by the coexistence of woody plants and grasses, whose proportions are influenced by water availability, nutrients, fire and herbivores (Scholes and Archer, 1997). While herbivores and fire have altered the structure and composition of many African landscapes (Van Langevelde et al., 2003), the elephant can radically change an ecosystem through its feeding behaviour (Pellew, 1983).

The African elephant is a highly valuable species, which has major ecological influence on savanna dynamics, playing significant roles in nutrient cycling, seed dispersal and as a result they are considered as keystone or flagship species (Shoshani et al., 2004). Elephants are water-dependent, bulk feeders that are not very selective, preferring grazing to browsing (Van Wijngaarden, 1985). However, elephants tend to shift diets from grass to browse in response to seasonal changes in food quality (Miller and Coe, 1993). Browsing occurs mainly in woodlands and scrubland areas. 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).

As the largest living land mammals, elephants have attracted human attention for millennia (Riddle et al., 2009). In Gonarezhou

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National Park (GNP), southeast Zimbabwe, there is an increasing concern from park management due to the degradation of *Acacia tortilis* woodland patches in the northern section of the park largely attributed to elephant browsing. The elephant population in GNP was first estimated at 3100 in 1969 (Department of National Parks and Wildlife Management [DNPWLM], 1998). The elephant population was estimated to be 9100 in GNP during 2009 with a density of 1.84 per km^2 (Dunham et al., 2010). These changes in elephant population are likely to have been associated with some negative impact on some woodlands in GNP. Earlier studies in GNP have attributed herbivores, particularly elephants, as a major factor in the modification of woodlands. For example, Tafangenyasha (1997) mentioned that *A. tortilis* woodland is one of the woodland that appears to be affected by elephants in GNP. Zisadza (2008) attributed the increase in landcover changes in GNP to increasing wildlife population density and spatial distribution, particularly elephants. Investigating the impacts of elephant abundances on the structure and composition of *A. tortilis* woodland in relation to perennial and natural surface water sources in a semi-arid environment such as GNP may assist in better understanding of the complexity of some of the factors altering *A. tortilis* woodland. Our main objective was to establish the extent to which *A. tortilis* woodland structure and composition differed in areas with contrasting elephant utilisation in relation to distance from perennial and natural surface water in northern GNP.

2. Material and methods

2.1. Study area

GNP is located in the southeast lowveld of Zimbabwe, 21° 00′–22° 15′ S and 30° 15′–32° 30′ E, bordering the Gaza District of Mozambique and covering 5053 km^2. GNP lies between 165 and 575 m above sea level and falls within the 400–600 mm mean annual rainfall range (Gandiwa and Kativu, 2009). The climate of GNP therefore, may be regarded as semi-arid. Average monthly maximum temperatures are 25.9 °C in July and 36 °C in January. Average monthly minimum temperatures range between 9 °C in June and 24 °C in January.

Few patches of *A. tortilis* woodland occur in the northern GNP, some of which were mapped by Farrell (1968). Some of the *A. tortilis* patches in GNP represent some successional stages in the woodland dynamic processes. Our study sites were located in *A. tortilis* woodland patches occurring only in the northern part of GNP. Acacia trees are key elements in African savannas (Loth et al., 2005). Midgley and Bond (2001) provided a comprehensive review of the demography of acacias. The African acacias are important in vegetation succession and provision of goods and services (Chidumayo, 2008).

2.2. Sampling design

Systematic-cluster sampling design was used to study the impacts of elephant utilisation in treatments that varied in elephant utilisation in relation to distance of *A. tortilis* woodland patches from perennial and natural surface water sources in the northern section of GNP. A reconnaissance survey which included walking along line transects of variable length employing the dung-count method were used to have a fair idea of the measure of utilisation of an area by elephants. Dung counts have the advantage that they give data not only on numbers but also on distribution and differential habitat use (Barnes, 2001). In each woodland patch, a transect of at least 5 km length and 10 m wide was used. Both fresh and old dung-piles were counted. After the reconnaissance, each of the three *A. tortilis* woodland patches were stratified into sites with low elephant utilisation (5 km traversed and 29 dung-piles recorded), medium elephant utilisation (5 km traversed and 44 dung-piles recorded) and high elephant utilisation (7 km traversed and 71 dung-piles recorded).

The high elephant utilisation sites were characterised by *A. tortilis* vegetation patches occurring near the Save-Runde confluence and two of GNP's major natural pans, i.e., the Tambohata and Machaniwa Pans; medium elephant utilisation sites were characterised by *A. tortilis* vegetation patches occurring far away from the Save-Runde confluence and away from large natural water pans whereas low elephant utilisation sites were characterised by *A. tortilis* vegetation patches occurring in the interior of the Pombadzi Wilderness Area far away from the Runde and Save Rivers and large natural water pans. All the selected study sites occurred in areas with no recent history of artificial water provision. We assumed that elephant utilisation in the study sites were primarily determined by distance from perennial and natural surface water with areas near the Save-Runde confluence having higher elephant utilisation particularly during the drier periods of the year.

Depending on the spatial extent of *A. tortilis* woodland patches for each of the three elephant utilisation categories designated in this present study, at least five replicate plots, total of 25 plots were identified as a way of maximising representation of the vegetation. The high elephant utilisation category had 10 study plots, and these were numbered 1 to 10, medium elephant utilisation category had 5 plots, numbered as 11 to 15, and the low elephant utilisation category had 10 plots, numbered as 16 to 25. Study plots were placed in the selected *A. tortilis* woodland patches at 500 m intervals in a random pattern. The initial plot position was selected using random number tables based on the topographical map grid system. We identified the *A. tortilis* woodland patches in the field through considering the dominant tree species, height and cover.

2.3. Data collection

Floristic composition and structure of woody vegetation component were assessed in May 2009. At this time of the year, species composition is most conspicuous. Plot sizes of 20 m × 50 m were used. These plot sizes were determined following Walker's (1976) method of having at least 15 to 20 trees inside a plot. In each study plot, the following variables were recorded or measured: tree height, stem circumference, plant damage, woody vegetation species and number of stems per plant (Table 1). Trees were defined as woody plants greater than 3 m in height and greater than 6 cm basal diameter, above buttress swelling (Ben-Shahar, 1998). All woody plants rooted within a plot were recorded and measured. Woody plants occurring along plot margins were included if at least half of the rooted system was inside the plot (Walker, 1976). For multi-stemmed plants located at edges of plots, only stems with more than half their base inside the plot were measured and recorded.

2.4. Data analyses

Plant heights for all trees were averaged for each plot. The total number of stems for all trees in each plot was divided by number of plants to give an average number of stems per plant. Stem circumference data were used in calculating stem basal areas for each woody stem using the formula:

$$\text{Basal area}\left(m^2\right) = \left(C^2/4\Pi\right)$$

where C is stem circumference.

Tree densities for each plot together with woody plants affected by elephants were calculated using the formula:

Table 1
Variables measured or recorded and assessment methods used in this study.

Variable	Assessment method
Tree height	Woody vegetation height was measured by placing a 6 m pole that was calibrated to read height values when held against a tree. For trees greater than 6 m, the pole was manually lifted and tree height visually estimated. For multi-stemmed plants, only the height of the tallest stem was recorded.
Stem circumference	Circumference for each stem was measured just above the buttress swelling to the nearest centimetre. In cases where a tree or shrub was forked close to the ground, circumference was measured below the fork. Where the fork was too low to permit a measurement, stem circumferences were measured separately.
Elephant damage	Elephant damage was considered as any noticeable form of vegetation utilization by elephant. Damage to woody plants was estimated for individual plants within each study plot as being one of the two types; new elephant and old elephant damage. New damage is that which had occurred since the recent rainy season. Damage becomes characteristically greyish in colour after rain soaks into the exposed inner plant parts (Ben-Shahar, 1998).
Plant species	Woody plant species were identified using a field guide (Coates-Palgrave, 1997), and where unknown species were encountered, samples were taken and later identified with the assistance of botanists.
Number of stems per plant	Numbers of stems per plant were determined through direct counting. Multi-stemming was considered only when stems started underground.

Density (e.g. trees or plants affected by elephants ha^{-1}) = $[(x \times 10{,}000\ m^2)/(\text{plot area, } m^2)]$, where x is the recorded number of trees or plants affected by elephants.

In order to determine the changes in species composition in different study sites due to elephant utilisation, we calculated the Shannon Index (H'). The Shannon Index for each plot was calculated using the following formula (Ludwig and Reynolds, 1988):

$H' = -\sum (p_i \times \ln(p_i))$, where p_i is the fraction of the entire population made up of species i, and ln is the natural logarithm.

We conducted statistical tests using STATISTICA for Windows, version 6 (StatSoft, 2001). Vegetation survey data were tested for normality using the Shapiro–Wilk test (Shapiro and Wilk, 1965). Data on tree heights, number of stems per plant, basal areas and tree densities were $\log_{10}(y+1)$ transformed, where y is the vegetation variable quantity, in order to satisfy the assumptions of normality and equality of variance. In order to test the impact of elephants on the *A. tortilis* woodland structure and composition, we performed Two-level Nested ANOVA with unequal sample sizes tests. Significant effects were further analysed using the Fisher's Least Significant Difference (LSD) *post-hoc* tests to detect significant differences between elephant utilisation categories. We considered to be no significance when the value of the probability of significance (P) was greater than 0.05. In order to determine whether different *A. tortilis* woodland patches, specifically study plots, could be distinguished from each other based on impact of elephant utilisation on woody vegetation, we performed two different analyses, i.e., first, a Principal Component Analysis (PCA) and second, a Hierarchical Cluster Analysis (HCA). The PCA was performed using the following variables: tree heights, number of species per plot, species diversity, basal areas, tree densities, number of plants damaged by elephants and number of stems per plant. We performed the HCA using the weighted pair-group average amalgamation rule with a matrix of 25 plots and only recorded woody species abundance data.

3. Results

3.1. Changes in woody vegetation structure and composition in relation to elephant utilisation

A total of 824 individual woody plants were assessed in the 25 study plots and 26 woody plant species were recorded. Elephant utilisation altered woodland structure and composition of *A. tortilis* woodland in northern GNP in the different elephant utilisation categories as follows: (1) mean tree height was significantly higher in the low elephant utilisation category as compared to the medium and high elephant utilisation categories (Table 2; Fisher's LSD *post hoc* test, $P < 0.0001$ and $P < 0.0001$ for medium and low elephant utilisation categories respectively compared with the high elephant utilisation category. There was however, no significant difference between the medium and low utilisation categories, Fisher's LSD *post hoc* test, $P = 0.142$); (2) mean basal area was significantly higher in the low elephant utilisation category compared to the medium and high elephant utilisation categories (Table 2; Fisher's LSD *post hoc* test, $P < 0.0001$ and $P < 0.0001$ for medium and high elephant utilisation categories respectively compared with the low elephant utilisation category. There was no significant difference between the medium and high utilisation elephant categories, Fisher's LSD *post hoc* test, $P = 0.663$); (3) mean tree density was significantly higher in the low elephant utilisation category compared to the medium and high elephant utilisation categories (Fisher's LSD *post hoc* test, $P < 0.0001$ and $P < 0.001$ for medium and high utilisation elephant categories respectively compared with the low elephant utilisation categories. There was no significant difference between the medium and high elephant utilisation categories, Fisher's LSD *post hoc* test, $P = 0.371$).

Furthermore, (4) woody species diversity was higher in the low elephant utilisation category as compared to the medium and high elephant utilisation categories (Table 2; Fisher's LSD *post hoc* test,

Table 2
Attributes of the entire woody vegetation for all study plots in *A. tortilis* woodland in relation to elephant utilisation (mean ± standard errors, SE) and significant levels from Two-level Nested ANOVA with unequal sample sizes tests.

Woody vegetation variable	Elephant utilisation category			$F_{2,\ 22}$	P
	Low	Medium	High		
Height (m)	7.30 ± 0.08	6.85 ± 0.22	5.51 ± 0.23	28.50	0.0003^{***}
Number of stems per plant	1.73 ± 0.06	1.67 ± 0.03	1.67 ± 0.06	0.32	$0.726^{n.s.}$
Basal area ($m^2\ ha^{-1}$)	2.84 ± 0.14	1.26 ± 0.05	1.36 ± 0.14	40.52	0.0001^{***}
Number of species per plot	7.00 ± 0.49	7.00 ± 1.18	6.50 ± 0.43	0.25	$0.782^{n.s.}$
Density (trees ha^{-1})	272 ± 12	247 ± 16	191 ± 11	13.49	0.0008^{***}
Species diversity (H')	1.62 ± 0.07	1.46 ± 0.03	1.20 ± 0.04	6.59	0.006^{**}
Plants affected by elephants (plants ha^{-1})	67 ± 5	80 ± 3	92 ± 4	4.73	0.037^{*}

Sig. = statistical significance (P value), n.s. = not significant ($P > 0.05$), * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

$P < 0.01$ for low elephant utilisation category compared to high elephant utilisation category. There were no significant differences between the medium and low elephant utilisation categories, Fisher's LSD *post hoc* test, $P = 0.283$ and between the medium and high elephant utilisation categories, Fisher's LSD *post hoc* test, $P = 0.074$); and (5) mean plants affected by elephants were significantly higher in the high elephant utilisation category as compared to the low elephant utilisation category (Table 2; Fisher's LSD *post hoc* test, $P < 0.001$ between low elephant utilisation category compared with high elephant utilisation category. There were no significant differences between the medium and high elephant utilisation categories, Fisher's LSD *post hoc* test, $P = 0.152$ and between the medium and low elephant utilisation categories, Fisher's LSD *post hoc* test, $P = 0.203$).

In contrast, there were no significant differences in mean number of stems per plant and number of species per plot in relation to the different elephant utilisation categories (Table 2). Woody plants with fresh elephant damage were mostly recorded in the medium and high elephant utilisation categories. The nature of damage recorded was as follows: (i) in high elephant utilisation categories; breaking of branches, stressing of trees seen by rotting stems and stripping of bark whereas (ii) in the medium and low elephant utilisation categories; tree stressing as evidenced by rotting stems and branches.

3.2. Study plots association in relation to woody vegetation

Fig. 1 shows a PCA-biplot with 25 study plots from *A. tortilis* woodland. Principal component 1 defines a gradient from sites with higher woody plant species diversity to sites with lower woody plant species diversity. Principal component 2 defines a gradient from sites with higher basal areas and tree heights to sites with higher woody plant densities and damaged trees. There were similarities of study plots from the medium and high elephant utilisation categories as these consisted of lower woody plant species diversity and numerous damaged trees. However, study plots occurring in the low elephant utilisation areas were characterised by high woody plant species diversity, higher basal areas and tall trees, however, with few damaged trees.

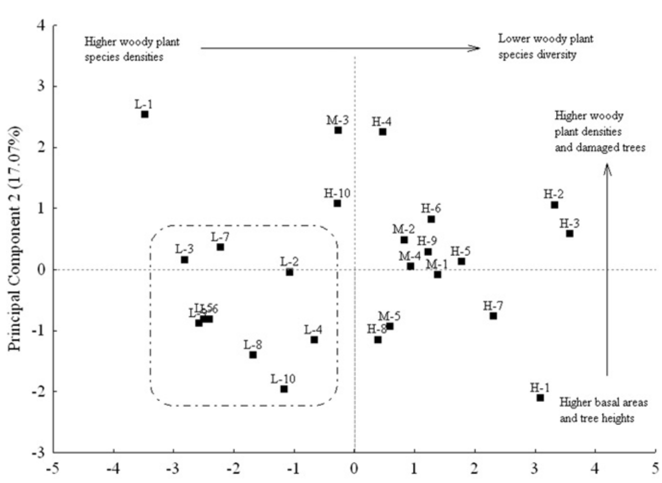

Fig. 1. Principal component analysis biplot of investigated study plots in *A. tortilis* woodland. Principal Component 1 explained 45.73% and Principal Component 2 explained 17.07% of the variance in the data. Notes: H-denotes plots drawn from the high elephant utilisation category; M-denotes plots drawn from the medium elephant utilisation category and L-denotes plots drawn from the low elephant utilisation category.

3.3. Study plots classification based on vegetation composition

A total of 18 woody plant species were common in *A. tortilis* woodland patches sampled and these were *A. tortilis*, *Albizia harveyi*, *Acacia nigrescens*, *Acacia senegal*, *Acacia xanthophloea*, *Afzelia quanzensis*, *Berchemia discolor*, *Colophospermum mopane*, *Combretum apiculatum*, *Combretum imberbe*, *Combretum molle*, *Dichrostachys cinerea*, *Diospyros mespiliformis*, *Hyphaene coriacea*, *Kigelia africana*, *Lannea discolor*, *Philenoptera violacea* and *Sclerocarya birrea*. The HCA dendrogram to a greater extent distinguished plots from the different elephant utilisation categories based on species composition and abundance. The 25 study plots were grouped into three sub-clusters (Fig. 2). First, sub-cluster A was composed of 89% of study plots drawn from areas sampled in the low elephant utilisation areas. Study plots in this category comprised of the following dominant species: *A. tortilis*, *A. nigrescens*, *A. xanthophloea*, *C. mopane*, *H. coriacea*, *P. violacea* and *S. birrea*. Second, there was a high similarity of study plots drawn from the high and medium elephant utilisation areas in sub-clusters B. Sub-cluster B comprised of 33% and 44% of the study plots drawn from the medium and high elephant utilisation areas respectively and the following common woody plant species were recorded in these study plots: *A. tortilis*, *A. nigrescens*, *B. discolor*, *C. molle*, *D. mespiliformis*, *P. violacea*, *L. discolor* and *Terminalia sericea*. Third, sub-cluster C consisted of 86% of the study plots from the high elephant utilisation area. Common woody plant species in these study plots included: *Azanza garckeana*, *A. tortilis*, *A. nigrescens*, *A. harveyi*, *C. mopane*, *C. imberbe*, *Diplorhynchus condylocarpon*, *P. violacea* and *S. birrea*.

4. Discussion

We recorded a decreasing trend in mean tree heights, tree densities, basal areas and species diversities with increasing elephant utilisation in *A. tortilis* woodland patches in northern GNP. Elephant damage was mostly in the form of breaking of branches and stripping of tree barks. Observations on the ground showed that *A. tortilis* species had the most damaged trees. This may presumably

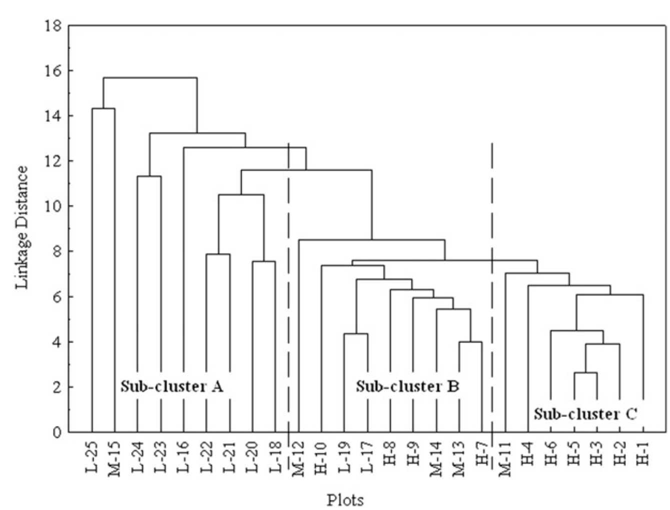

Fig. 2. Hierarchical cluster analysis dendrogram showing study plots drawn from categories with different elephant utilisation in *A. tortilis* woodland. Study plots were grouped into three sub-clusters. Sub-cluster A represents study plots largely drawn from low elephant utilisation category; Sub-cluster B represents plots drawn largely from both medium and high elephant utilisation categories and Sub-cluster C represents study plots mostly drawn from high elephant utilisation category. Notes: H-denotes plots drawn from high elephant utilisation category; M-denotes plots drawn from medium elephant utilisation category and L-denotes plots drawn from low elephant utilisation category.

be due to its high crude protein content (Du Toit, 1990). Elephant browsing affected the woody species composition of the *A. tortilis* woodland in this present study. We recorded a relatively high number of elephant damaged trees in all the study sites. This may probably be a result of similar elephant bull densities, i.e., 0.11–0.20 elephants per km^2, in all the study sites (Dunham et al., 2010). Additionally, elephant cow densities for both the high and medium elephant utilisation categories were 2.01–3.00 elephants per km^2 whereas it was 1.01–2.00 elephants per km^2 for low elephant utilisation category. The overall elephant density in all the study sites was 2.01–3.00 elephants per km^2 (Dunham et al., 2010). Elephant bulls and family groups might impact the vegetation in different ways and utilise range at different rates with bulls removing more trees than females (Duffy et al., 2002).

Observations throughout the African savannas show that elephants prefer *Acacia* species over other woody species as a source of browse during critical dry periods (Owen-Smith, 1988). In Lake Manyara National Park, Tanzania, Kalemera (1989) found that *A. tortilis* was generally taken in proportion to abundance by elephants. Elephants cause vegetation change in structure and composition through their varied seasonal choice of food items that include debarking in the dry season (Holdo, 2003). Our findings support the assertions of Guldemond and Van Aarde (2008) that herbivores, in this case elephants, influence arid and semi-arid savannas.

It is possible that the structural and compositional changes in *A. tortilis* woodland patches in northern GNP may lead to woodland degradation making such areas less visually appealing and unattractive to tourists. Additionally, changes in *A. tortilis* woodland may affect the biodiversity and ecosystem functioning in GNP. Saayman and Saayman (2009) stated that ensuring quality service and products guarantees repeat visits to national parks. An example of a product can be woodland structural and compositional integrity that can be an attraction to a national park, for example, mature *A. tortilis* population produce an attractive flat-topped canopy (Pellew, 1983).

Controversy surrounds the management of Southern Africa's burgeoning elephant population (Owen-Smith et al., 2006). A total of 5572 elephants were culled in 1971, 1972, 1983, 1986, 1992 and 1993 in periodic population reduction exercises in GNP (DNPWLM, 1998). However, there have been no recent culls, partly because the ivory trade ban prevents tusks from culled elephants being sold to offset the costs of management and protection (Dunham, 2008). The 1991/92 drought is estimated to have accounted for 1500 elephant deaths in GNP (DNPWLM, 1998). Sherry (1975) recorded an annual mean calving interval of about 4 years and annual recruitment of 7% for GNP elephants. The management objective of GNP is to reduce and maintain elephants at an overall density of 0.2–0.6 elephants per km^2 (DNPWLM, 1998). Zimbabwe's elephant policy calls for elephant density in protected areas to be kept below levels that 'compromise biodiversity' and in practise about 0.75 elephants per km^2 (Dunham, 2008).

Elephant browsing alone may however not be solely responsible for inducing the recorded vegetation changes in *A. tortilis* woodland in GNP. Other factors that may affect the *A. tortilis* woodland structure and composition are droughts, frost, fire, disease, edaphic factors, topography and past human activities (e.g. Guldemond and Van Aarde, 2008; Chafota and Owen-Smith, 2009). These factors may be interrelated and when they occur simultaneously, probably act in concert to exert a stronger effect. For example, (i) the influence of former land use practises in GNP (O'Connor and Campbell, 1986), (ii) bush clearing in anti-tsetse fly (*Glossina* spp.) operations (Tafangenyasha, 1997) and (iii) vegetation fires (Gandiwa and Kativu, 2009) may also have to some extent influenced the structure of the *A. tortilis* woodland in GNP.

The present study focussed only on the changes influenced by elephants on *A. tortilis* woodland in northern GNP. Our results could have been affected by the fact that we only sampled once. The impact of elephants on the woody vegetation 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 our study is that our sampling plots where relatively close to each other since the *A. tortilis* woodland patches studied were too small and could not allow us to have wide distribution of our sampling plots to capture for much variability. Therefore, the small vegetation patches and resultant small distances between our plots may have had some influence on our 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). Additionally, the differences in the woody vegetation attributes may also be influenced by other confounding factors such as differences in soil types. For instance, our low elephant utilisation category occurred largely on granophyres and the medium and high elephant utilisation categories occurred largely on alluvial soils. However, Duffy et al. (2002) reported that elephant impact appears non-homogeneous even in regions with very similar characteristics, i.e. elevation, species composition and distance from water.

It is therefore, likely that continued elephant browsing on the *A. tortilis* species would lead to thinning of the *A. tortilis* woodland and possible threat of local extirpation of this species particularly in areas near perennial and natural surface water sources, e.g. Runde River, in northern GNP. *A. tortilis* does not coppice well following uprooting, pollarding, debarking or even defoliation (MacGregor and O'Connor, 2004). However, the resilience of the *A. tortilis* population in *A. tortilis* woodland to elephant-induced decline will depend on its recruitment and regeneration potential (MacGregor and O'Connor, 2004). We end by recommending the following: (a) the need for formulation of clear thresholds of potential concern against which woodland structural and compositional changes can be continuously measured so that proper management can be taken to conserve sensitive woodlands such as *A. tortilis* woodlands and (b) the need for continued monitoring and long-term research on the variation of interactions between large herbivores and woodlands in arid and semi-arid areas.

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