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African Elephant (*Loxodonta africana*) Impact on Selected Tree Species and Assessment of Piosphere Gradients in Venetia-limpopo Nature Reserve

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ABSTRACT

Trees utilised by elephants often undergo a significant amount of damage compared to trees utilised by other browsers. Woody plants play a crucial role in plant community dynamics, species composition, and the savannah system's functioning. As drivers of ecosystems, elephants are capable of transforming habitats in terms of structure and species composition. In this paper, the damage caused by elephants on different selected tree species in Venetia-Limpopo Nature Reserve was studied following a field-based approach. Field data collected for trees included the species name, GPS location, tree height class, extent, and type of damage resulting from elephant foraging. The Normalized Difference Vegetation Index (NDVI) was used to evaluate vegetation's vigour using Landsat-5 imagery. A Multiple Ring Buffer Tool was used to extract mean NDVI values of buffer rings spread around waterholes at 400-metre intervals. The impact on woody vegetation along the vegetation gradient, 'Piosphere', was evaluated. NDVI values extracted for the different years indicate that the impact on woody vegetation degradation along the Piosphere gradient is negligible. There was no statistically significant relationship (Pearson correlation r_3= –0.500, P = 0.391), trend or pattern between the number of damaged trees and the type of damage. Different trees at different height classes were utilised inconsistently by elephants. The dominant (45%) type of damage was for Broken Main Stem (BMS), with the lowest (1%) damage being for Bark Stripping (BS). Overall, there was a statistically significant difference (Pearson correlation r_3= 0.973, P = 0.146) between the number of trees selected by elephants in the various height classes. Trees between 3 m and 4 m were the most selected and the impact seemed to be stabilising at these tree heights. Additional studies need to be focused on the recruitment rates of elephant foraged trees in the reserve to prevent local extirpation of these species in the future.

Key words : *Keystone species, tree height classes, Priority species, Local extirpation, Vegetation gradient, NDVI*

Introduction

Elephants are generalist-mixed bulk feeders found in dense tropical rain forests, open and closed savannah, grasslands (Advani, 2014). Elephants switch between woody and herbaceous vegetation components while feeding. They often feed on low-quality food characterised by low-protein and high fibre content, which means that they must consume large amounts of vegetation material per day

(Eckhardt *et al*., 2000). Elephants feed on as many as 173 different plant species, including grasses, leaves, fruits, tree bark, and roots (Sukumar, 2003). On average, an adult bull elephant consumes 300 kg of forage per day, while an adult cow consumes 170 kg (Laws, 1970). They are highly dependent on water and drink 150 – 300 litres per day, in addition to bathing and playing (Bothma, 2002; Bothma and van Rooyen, 2005).

As water-dependent animals, elephants forage not far from water bodies. During the dry season, elephants concentrate near drinking spots and disperse to more comprehensive ranges during the wet season when water pools are more widely distributed (Owen-Smith, 1996; Kerley and Landman, 2006; Simon Chamaillé-Jammes *et al*., 2007). Elephant concentrations near water bodies during dry seasons contribute to the vegetation gradient that develops around the 'Piosphere' (Lange, 1969; Andrew, 1988; Thrash, 1998). Piospheres occur mainly around artificial water bodies such as pools, troughs and boreholes (Ben-Shahar, 1993; Owen-Smith, 1996). In these areas, there is a high amount of bare ground as a result of increased dung deposition; increased soil nutrients; high trampling activities; increased soil compaction and erosion; as well as increases in annual and unpalatable herbs (Bax and Sheldrick, 1963; Weir, 1971; Ben-Shahar, 1993; Owen-Smith, 1996; Thrash, 1998; James *et al*., 1999). The development of Piosphere effects in savannah areas is mainly due to changes in the woody vegetation structure resulting from elephant foraging (Kerley *et al*., 2008). Trees growing along river edges recover from floods and damage from elephants, whereas trees growing elsewhere do not (Rogers and O'Keefe, 2003).

Elephants are considered 'keystone species', defined as important species for ecosystem integrity (Scholes and Mennell, 2008). They are ecosystem engineers that drive ecosystem processes and are capable of changing habitats due to their feeding habits (Scholes *et al*., 2007). Destructive feeding habits include debarking and pushing over large trees, thereby changing the structure and composition of vegetation (Lessing, 2007; Scholes *et al*., 2007), encouraging the establishment and growth of grass species and preventing savannah habitats from becoming woodlands. According to Cowling and Kerley (2008), elephants also contribute positively towards ecosystems by acting as potential seed dispersers while feeding on large quantities of forage and travelling long distances searching for food. Lessing (2007) states that elephant impacts on vegetation depend on habitat variables such as climate, soil type, vegetation type, and the presence of other herbivores. According to Rutina *et al*. (2005), when woodland habitats are converted to shrublands, dry season browse availability improves for other species such as Impala (*Aepyceros melampus*).

If elephant foraging activities are excessive due to large elephant densities, they affect other plants, other animals, and the soil, especially in small-protected areas. African elephants have a negative impact on woody vegetation by reducing tree height and density, which leads to structural changes in the woody layer (Ben-Shahar, 1998; De Boer and Kohi, 2008), and changes to overall vegetation composition resulting in ecosystem degradation (Kelly, 2000). Studies investigating *Adansonia digitata* and *Aloe* spp. found that the densities of these plants decreased when elephant density increased (Ben-Shahar, 1998; De Boer and Kohi, 2008). Guldemond (2006) found that elephant impacts in closed woodlands created canopy gaps, leading to reduced recruitment of young trees. Impacts in open woodland, coupled with hot fire, can lead to altered tree canopies, reduced grass biomass and underdeveloped sapling establishment. The consequences of these impacts often create habitats for alien plant invasions.

Several authors have studied elephant impact on different tree species such as *Vachellia tortilis* (MacGregor and O'Connor, 2004), *Adansonia digitata* (Ndoro *et al*., 2016), and *Sclerocarya birrea* (Coetzee *et al*., 1979; Jacobs and Biggs, 2002; Gadd, 2002; Seloana *et al*., 2017). Species such as *A. digitata* and *S. birrea* are vulnerable to elephant impact and tend to grow further away from water as impact near waterholes tends to intensify (Owen-Smith *et al*., 2006). According to Mukwashi *et al*. (2012), the availability of surface water influences the impact of elephants on woody vegetation. This is evident in arid and semi-arid regions where surface water availability constrains the distribution of elephants, especially during the dry season (Chamaillé-Jammes *et al*., 2007; Loarie *et al*., 2009). Animals tend to congregate around artificial waterholes during the dry season when seasonal waterholes have dried up (Thrash and Derry, 1999), modifying the vegetation structure in these areas (Laws, 1970). Venetia Limpopo Nature Reserve (VLNR) is in a semi-arid region and experiences a mean annual rainfall of

~366 mm (O'Connor, 1992; O'Connor, 1999). Artificial waterholes sustain the animals throughout the dry seasons as the reserve only has seasonal rivers. O'Connor and Page (2014) found that elephant foraging was spread along riverine and non-riparian dryland vegetation. Elephant impact may cause local extirpation of certain plant species (O'Connor *et al*., 2007), threatening animal diversity supported by these ecosystems (O'Connor, 2017).

O'Connor and Associates (2007) reported changes in vegetation in Venetia Limpopo Nature Reserve (VLNR) as mainly the loss of perennial grasses and an increase in the woody component, meaning that the reserve became less suitable for the diverse abundance of large mammalian grazers that once roamed the area, and more suitable for the higher biomass of browsing species. It was also reported that the most affected grazing species were those with narrow habitat requirements and those that were migratory. Although the reserve still allowed some degree of seasonal movement among vegetation types at the time, most grazers were mainly distributed in areas where there is good quality graze, which is influenced mostly by fertile soil types. Elephants are, no doubt, essential browsers and patch creation agents in ecosystems. Smaller enclosed protected areas may experience persistent and sustained elephant browsing pressures, ultimately leading to decreased woody biomass(Kerley *et al*., 1995) and local extirpation of plant species (O'Connor *et al*., 2007). Enclosed protected areas of South Africa with high elephant numbers may see an increase and an almost irreversible impact of elephants on vegetation (Blanc *et al*., 2007).

South Africa's elephants are confined in fenced-off areas and this necessitates the need for the implementation of various management strategies. It is essential for conservation managers to identify the effects of elephants within ecosystems and how secondary factors such as fire and herbivory contribute towards habitat modification. It is also important that we understand elephant feeding behaviour to negate and minimise the negative impacts on the landscapes they inhabit. Collecting biological data regularly from large and inaccessible areas using field-based methods can be challenging to achieve. Limitations relate to accessing rugged and sometimes dangerous terrains, large areas to traverse, time and financial constraints. By using remote sensing techniques integrated with traditional field-based approaches, we can identify the biophysical characteristics of landscapes, predict species distribution, determine spatial variability in species richness, and monitor species' impact on their environment (Kerr and Ostrovsky, 2003). Remote sensing techniques provide various types of imagery known for their different spectral, spatial, radioactive and temporal characteristics and are applicable for use in broad-scale vegetation classification and mapping (Xie *et al*., 2008). This technology offers a practical and economically sound way of studying vegetation structure and change, especially for large, protected areas (Nordberg and Evertson, 2003).

Several multispectral satellites such as the IKONOS, QuickBird, SPOT-5, GeoEye-1 and Landsat-7 have produced images that have been used to calculate the NDVI (Normalized Difference Vegetation Index) ratio. NDVI ratios are extracted from two bands: the near-infrared (NIR) and the red band (RED) (Digital Globe, 2010). These two bands discriminate between healthy trees (greenness) and trees impacted by disease. Landsat imagery provides medium spatial resolution (30 m pixels) with seven bands ranging in wavelength and four bands in the spectrum's infrared part. These images have been used since the launching of Landsat-1 in 1972. Several authors have used Landsat images (Fernandez-Buces *et al*., 2006; Gao and Liu, 2008; Elnaggar and Noller, 2010; Dehni and Lounis, 2012; Jin *et al*., 2014) and they are generally popular. These images are well suited for detecting land cover changes at a patch dimension of ~1 ha and may not be sufficient to detect finer scale landscape changes (Powers *et al*., 2015).

NDVI ratio estimates vegetation's vigour (greenness) using the Near-Infrared (NIR) that reflects vegetation and the Red band that absorbs vegetation. NDVI also provides valuable information on specific vegetation species' dynamic changes when temporal images are analysed (Xie *et al*., 2008). Previous studies (Harris *et al*., 2008; Loarie *et al*., 2009; Young *et al*., 2009; Duffy and Pettorelli, 2012) have indicated that the greenness of a patch drives elephants' foraging, and higher greenness levels equate to higher nutritional quality and vegetation productivity as compared to surrounding areas (Shrader *et al*., 2012). The trampling impact caused by elephants leads to geomorphic landscape alterations more than any other herbivorous species. However, NDVI is not a direct indicator of elephant damage but rather an index used to evaluate vegetation greenness. NDVI values have been used as an indicator of vegetation cover along Piosphere gradients in this study.

According to O'Connor *et al*. (2007), plant species that are susceptible to local extirpation from elephant impact are those that are predisposed to pollarding, uprooting or ringbarking; whose adults coppice poorly, hence the rate of mortality; whose mortality is not compensated by regeneration and recruitment; species with restricted distribution; and those whose dispersal abilities and recolonization abilities are poor. The loss of woodland due to high elephant densities has persisted in southern Africa (Conyebeare, 2004), demanding a greater understanding of the impact caused by elephants on vegetation (Gillson and Lindsay, 2003). Reserves located in semi-arid regions like the study area experience variable grass production resulting in the heightened levels of woody material utilisation by elephants and woody species forming the main part of elephant diets (O'Connor *et al.*, 2007). This paper investigates the type and extent of damage on different tree height classes and tree species found in VLNR. The Piosphere effect around waterholes was evaluated using NDVI values as indicators of the vegetation's gradient of degradation.

Materials and Methods

Study area

Venetia-Limpopo Nature reserve is privately owned by the De Beers Group of Companies and was established in 1991 through the amalgamation of several local livestock farms. The livestock in the area was removed at the time of purchase and was replaced with wildlife. A total of 43 elephants were introduced as four separate groups into the reserve between 1991 and 1994 from Kruger and Gona-Re-Zhou National Parks (O'Connor and Page, 2014). According to O'Connor and Page (1997), the elephants introduced onto Venetia-Limpopo Nature Reserve utilise the entire reserve with a pronounced preference for specific vegetation types, particularly vegetation in the northern section of the reserve. Venetia-Limpopo Nature Reserve is a ~39 000-hectare reserve located in the Limpopo Province of South Africa (Figure 1), slightly south of South Africa's convergence with Zimbabwe and Botswana (22°08´ – 27´South and 29°13´ – 28´East). The reserve is located in the summer rainfall region with very dry, frost-free winters and receives a mean annual precipitation of 366 mm (Mucina and Rutherford, 2006). There are only two major seasonal rivers in the reserve, the Kolope that runs from south to the north, and the Setonki that runs from the west to the north of the reserve (Smallie and O'Connor, 2000). Summers are hot (monthly maximum temperature of 32 ºC between October and December), and winters are warm (monthly minimum temperature of 24.7 ºC in June).

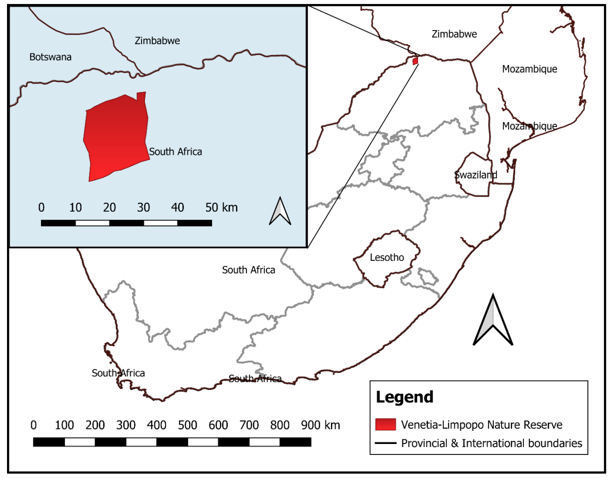

Fig. 1. A map of Venetia-Limpopo Nature Reserve in the Limpopo province, South Africa

The reserve is dominated by mopane trees (*Colophospermum mopane*) and named by Mucina and Rutherford (2006) as "Mopane veld". Other commonly found woody species include the *Boscia foetida*, *Salvadora angustifolia* and *Lycium austrinum*. Dundee, Oakleaf, Swartland, and Valsrivier are the predominant soil forms in the area with an average content of 20% clay and 19% silt (Botha, 1994). The herbaceous layer is not well developed, leading to sheet and rill erosion prevalent throughout the reserve (O'Connor, 1999). The reserve's topography is relatively flat and the vegetation is broadly described as Musina Mopane Bushveld (SVmp 1), with small hills covering approximately 20% of the reserve representative of the Limpopo Ridge Bushveld (SVmp 2) (Mucina and Rutherford, 2006).

Data collection, acquisition and processing

Damaged tree species

Eight survey plots of 400 m^2 (20 x 20 m) were systematically placed out on the reserve for field sampling of elephant impact on woody vegetation (Buckland *et al.*, 2001). These plots were placed within homogenous vegetation areas, at least 100 metres away from water points and roads. The following data was collected within each plot: the: (i) name of tree species; (ii) tree height (TH): TH1: <1 m, TH2: 1 – 2 m, TH3: 2 – 3 m, TH4: 3 – 4 m, and TH5: >4 m; (iii) type of elephant damage (DT): DT1: Bark Stripping (BS), DT2: Broken Primary Branch (BPB), DT3: Broken Main Stem (BMS), DT4: Uprooted Main Stem (UMS), DT5: Tree Pushed Over (TPO); (iv) extent of elephant damage (DE): DE1: none, DE2: <1%, DE3: 1 – 5%, DE4: 5 – 10%, DE5: 10 – 25%, DE6: 25 – 50%, DE7: 50 – 75%, DE8: 75 – 90%, DE9: 90 – 95%, DE10: 95 – 100%.

Remote sensing data acquisition

Landsat-Thematic Mapper (TM) images from 1990, 2000 and 2011 containing scenes for July and October (Table 1) were acquired from the United States Geological Survey website (USGS, http://glovis.usgs.gov/). Venetia-Limpopo Nature Reserve is in a semi-arid region and experiences rainfall between the summer months of November to March (O'Connor, 1992; O'Connor, 1999; O'Connor and Goodall, 2017). This means that the month of October is still relatively dry. No Landsat-TM images met the study's search criteria of 'cloud free' to a maximum of 10% close to July in 2010. Only in October 2011 was an image that met this criterion found. The acquired images were also based on the availability of cloud-free images and the scenes were split into three decades. Dry season images were acquired to identify the vegetation cover density. Landsat-TM images have a spatial resolution of 30 m (120 m thermal) and spectral resolutions of 60 m with seven bands (United States Geological Survey, 2021). Landsat datasets are well documented with rich archival data for short-and medium-term landscape monitoring (Jombo *et al*., 2017).

Image pre-processing

Atmospheric conditions, earth-sun distance, zenith angle and view, topography and temporal resolution pre-processing procedures were performed. Radiometric calibration coefficients supplied in the metadata were used to convert the images into top-of-atmosphere (TOA) radiance. The radiance calibration was processed using the Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) module in Environment for Visualizing Images (ENVI) software using the MODTRAN4 radiation transfer code. All images were projected to Universal Transverse Mercator (UTM) projection, World Geodetic System (WGS) 1984 – Zone 35 South.

Data analysis

The frequencies of the different tree species foraged by elephants were analysed to determine the most frequently foraged woody species in the study area. The selected tree height class in terms of forage intensities was evaluated and the extent and type of damage caused to the different trees were recorded. A *Chi*-square test was computed for the Damage type (DT) and Tree height (TH) categories to determine whether there is an association between these categorical variables. A Pearson's correlation coefficient (r) test was computed to measure the linear association between the type of elephant damage and the number of individual trees in the five different height classes (Freedman *et al*., 2007).

The Normalized Difference Vegetation Index (NDVI) for vegetation cover over the selected years (1990, 2000 and 2011) was calculated based on the Multiple Ring Buffer (MRB) function in Quantum Geographic Information System (QGIS) software. This tool was used to place multiple ring buffers around waterholes (QGIS Development Team, 2012). The NDVI values were extracted to assess the Piosphere effect around the sampled waterholes. A zonal statistical analysis was computed to extract the means ($\bar{x}$) for the NDVI values of the multiple buffers that were placed at intervals of 400 m, 800 m, 1 200 m, 1 600 m and 2 000 m around the sampled waterholes for all the years. These are waterholes that are known to not dry up during the dry season. NDVI uses the Near-infrared (NIR) and the red bands to calculate vegetation's health (Tucker, 1979). NDVI values generated by the results range between -1 and +1. A low NDVI value (-1) represents

Table 1: Image acquisitions and characteristics for the study area

Acquisition date	Sensor and spectral range	Path/row	Resolution (metres)
09/07/1990	Landsat-5 TM	170/75 and 76	30
20/07/2000	Landsat-5 TM	170/75 and 77	30
23/10/2011	Landsat-5 TM	170/75 and 78	30

low vegetation cover, while a high NDVI value (+1) represents healthy vegetation cover.

Results

Tree species damaged by elephants

A total of 16 tree species represented by 211 individuals were recorded. *Colophospermum mopane* is a dominant species on the reserve. The top three tree species recorded to have the highest number of trees damaged by elephants include *C. mopane* (63%), *Vachellia tortilis* (14%) and *Vachellia stuhlmannii* (10%) – Figure 2. Ten tree species recorded less than

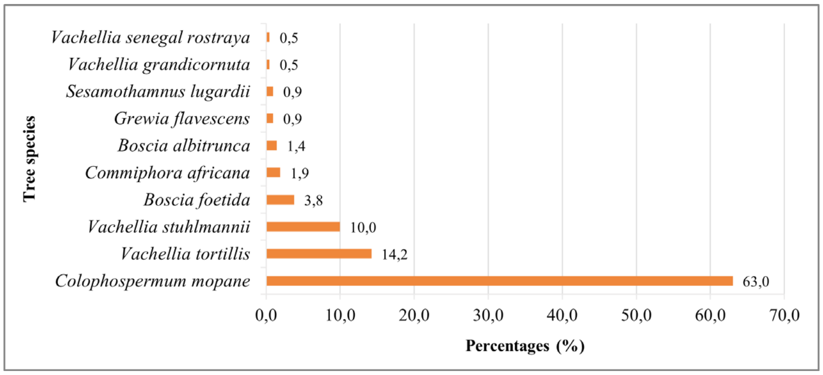

Fig. 2. Frequencies (%) of the different tree species damaged by elephants

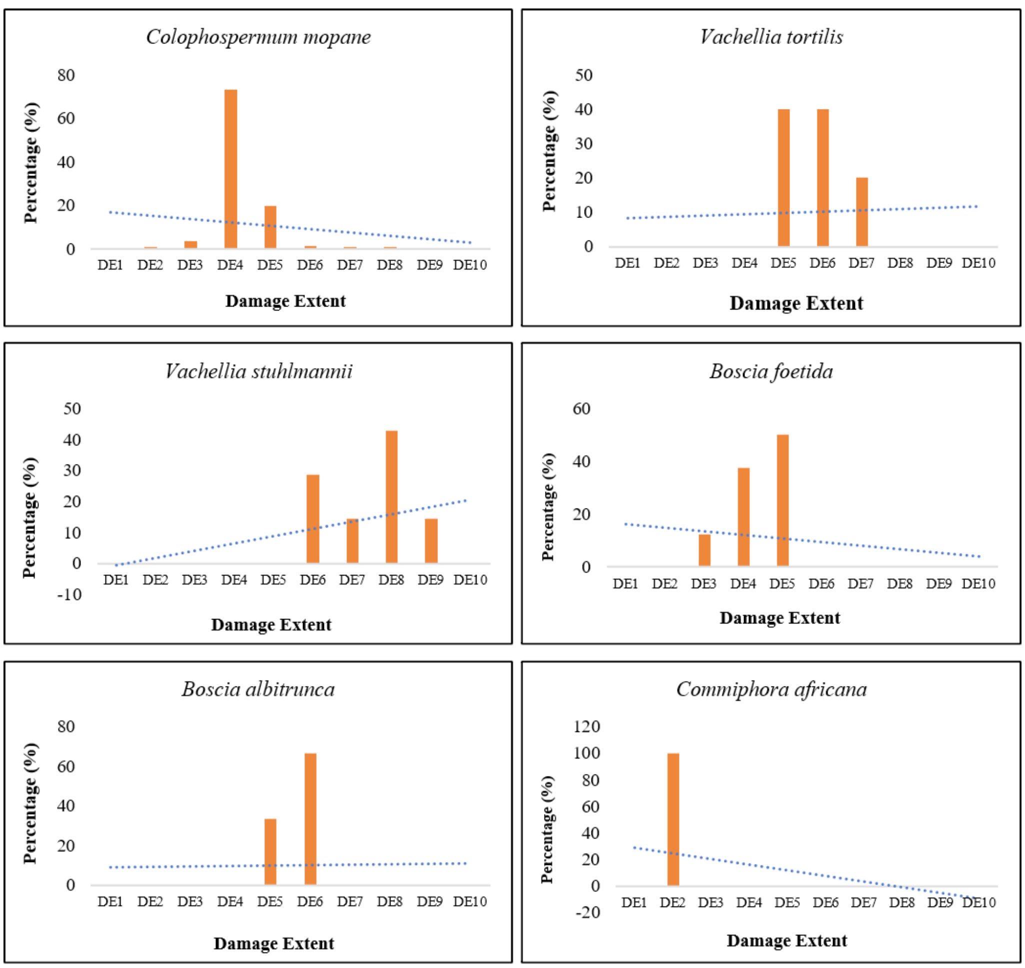

Fig. 3. Summaries of estimated damage caused to the six most selected tree species by elephants

1% of elephant damage: *Grewia flavescens*, *Sesamothamnus lugardii*, *Vachellia grandicornuta*, *Vachellia senegal* subsp. *rostrata*, *Commiphora glandulosa*, *Commiphora merkeri*, *Commiphora pyracanthoides*, *Commiphora* spp., *Dichrostachys cinerea* and *Euphorbia ingens*.

Only the top six (6) tree species with over 1% elephant impact were considered for further analysis in terms of the following categories: Damage extent (DE), Damage type (DT) and Tree height (TH). The *Chi*--square test result indicated a statistically significant association (two-way classification chi-square: $X^2 = 230.18$, $N = 466$, $P<0.05$) between the DE and the TH for the different tree species selected by elephants.

Damage extent

Estimations were made in terms of the amount of material removed from each tree as a result of elephant foraging. *Colophospermum mopane* recorded the highest number of 97 individuals (73%) at DE4 (5 – 10%) and 26 (20%) at DE5 (10 – 25%). For *C. africana*, a total of four (100%) individuals foraged at DE2 (<1%). Figure 3 indicates the summaries of the six species and the extent to which each tree was foraged. No damage was recorded in the first TH1 (0%) and the last TH10 (95 – 100%) classes.

Damage Type

Summaries of the type of damage recorded for the six tree species are presented in Figure 4. Broken

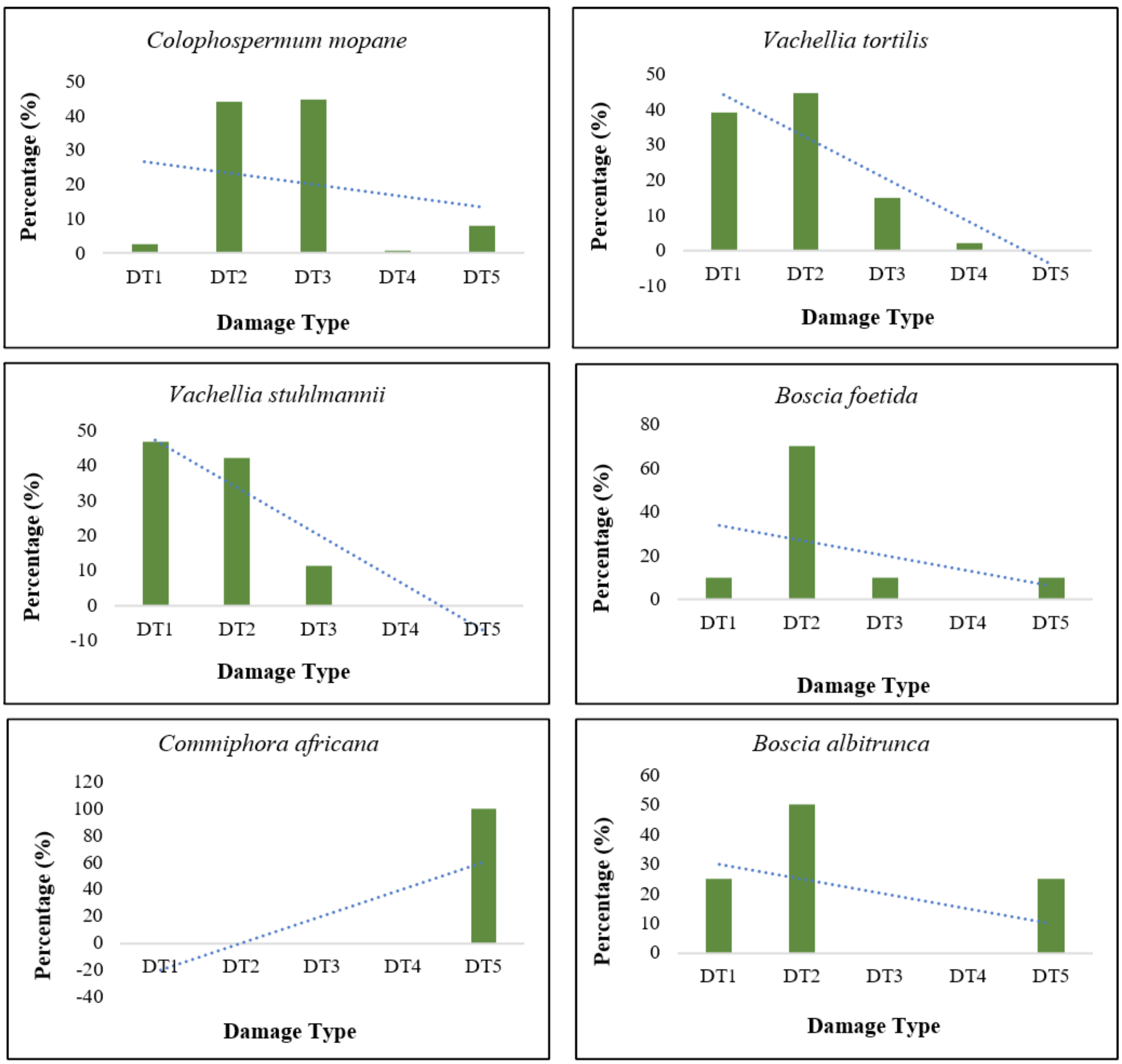

Fig. 4. Summaries of elephant damage types on the six most selected tree species

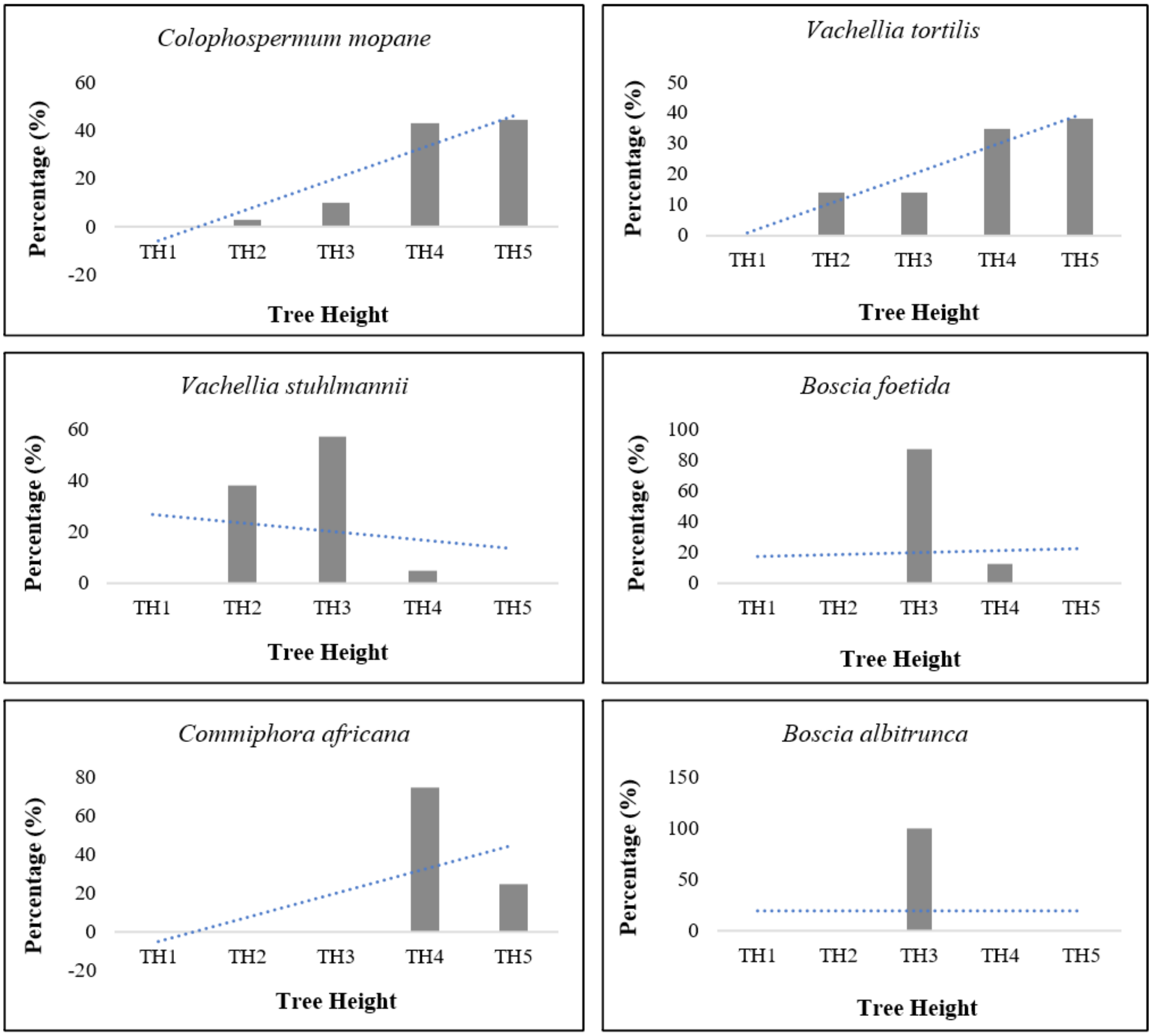

Fig. 5. Summaries of tree heights for the six most selected tree species by elephants

main stems (45%) and uprooted main stems (44%) represented by 67 and 66 individuals were recorded. A total of 54 individuals were recorded for *V. tortilis*, 45 individuals for *V. stuhlmannii*, ten for *B. foetida*, *C. africana* and *B. albitrunca,* recording an equal number of four individual trees each.

Tree heights

Colophospermum mopane recorded the highest number of 59 individual trees at TH5 (> 4 m) and 57 at TH4 (3 – 4 m). No foraged trees were recorded at TH1 (< 1 m) for all six tree species. Summaries indicating the height of trees selected by elephants for the six most selected tree species are represented in Figure 5.

Damage type versus Tree height

A comparison was made between the type of dam-

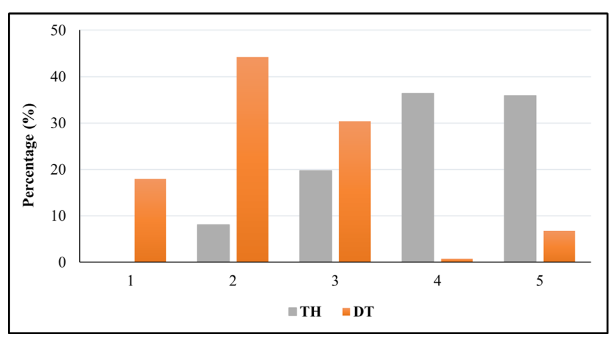

Fig. 6. Comparison between Damage Type and Tree heights of the top six tree species

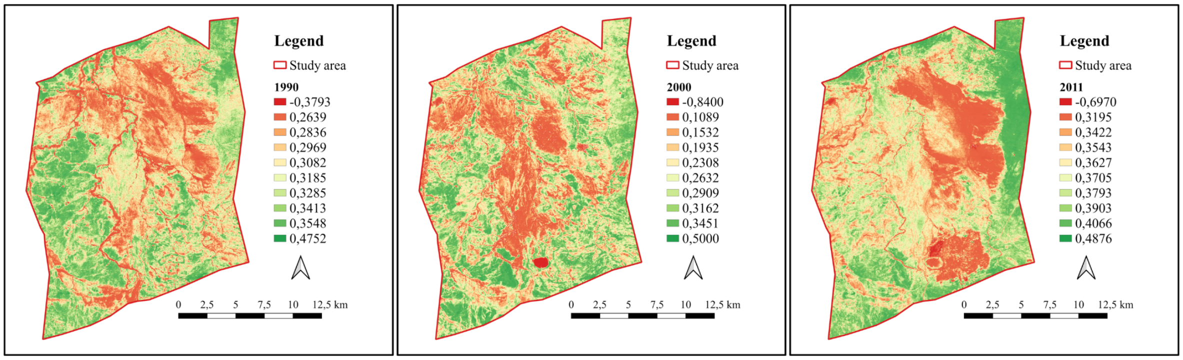

Fig. 7. NDVI on the vegetation distribution in 1990, 2000 and 2011 calculated from Landsat-5 TM

age (Class 1 to Class 5) and the height classes (TH1 to TH5) for the six most selected tree species (Figure 6).

The Pearson's correlation coefficient indicated a negative correlation between the number of trees and the type of damage (Pearson correlation $r_3 = -0.500$, $P = 0.391$). The correlation between the number of trees and the height of damaged trees was positive (Pearson correlation $r_3 = 0.973$, $P = 0.146$), which indicates a significant result.

Landsat-TM – NDVI

The NDVI trends over the three study years were compared to assess the vegetation cover and map the habitat changes over time (Figure 7).

Piosphere

Multiple ring buffers were placed around the waterholes on the reserve (Figure 8). The spatial distribution of vegetation around the Piosphere gradient for the sampled waterholes was analysed by comparing the mean values (($\bar{x}$)) at the different distance intervals along the Piosphere gradient to determine the extent of degradation around these areas over the years (Figure 8).

The results indicate a varying Piosphere gradient difference for the different years at different intervals. A higher NDVI value indicates high vegetation health compared to a lower index. There was a relatively small vegetation health increase (0.270) observed at 800 m distances in 2000 and a gradual decrease at 1 200 m (0.245), 1 600 m (0.240) and 2 000 m (0.230) (Figure 8).

Discussion

Colophospermum mopane is the most abundant tree species in VLNR and a staple food for elephants. It is not surprising that this species recorded the highest number of foraged individuals compared to all other species, especially for trees taller than four metres. Similar results were found by Smallie and

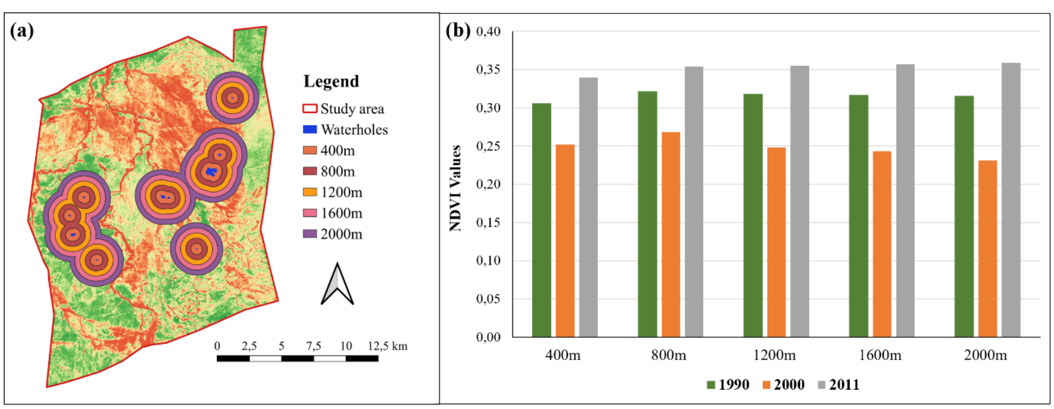

Fig. 8(a). Location of the sampled waterholes and the extended buffer zones at 400 m distance intervals; (b) NDVI mean ($\bar{x}$) values indicating vegetation health along the Piosphere gradient at different distance intervals for 1990, 2000 and 2011

O'Connor (2000). They reported that elephant utilised *C. mopane* branches, foliage, and main stems for trees <4 m and bark stripping accounted for the majority of the trees >4 m. It was noted in the field and from the collected data that the majority of the *C. mopane* trees sustained between 5 and 10% damage, a result that has also been confirmed by Smallie and O'Connor (2000) in their study. The dominant type of damage includes BMS as well as UMS. *Vachellia tortilis* is one of the prominent tree species in the reserve, especially along riverine habitats. *Vachellia tortilis* is a widespread species selected by elephants. Bark stripping, Broken Primary branches and Uprooted Main Stem were some of the forage approaches used by elephants foraging on the species (Croze, 1974). An equal number of 12 individual trees (40% each) sustained damage at DE5 (10 – 25%) and DE6 (25 – 50%) classes, with only six (6) trees in DE7 (50 – 75%) class. *Vachellia tortilis* trees' damage was the most for DT2 (44%), BPB and DT1 (39%) for BS. Bark stripping and broken primary branches are forms of damages consistent with a study done by MacGregor and O'Connor (2004). *Vachellia tortilis* does not coppice well after uprooting, pollarding, debarking or even defoliation. Although it is a resilient species, its recruitment and regeneration potential may be influenced by the level of browsing pressure placed on the species by elephants in the reserve (MacGregor and O'Connor, 2004). Debarking or bark stripping by elephants is suspected to be a seasonal phenomenon associated with wet climatical phases (Coetzee *et al*., 1979) and is possibly linked to increased levels of polysaccharides exuded from the branches of various species.

Bark stripping (DT1) and broken primary branches (DT2) for *V. tortilis* were forms of damages shared with the *V. stuhlmannii* species, recording 21 (47%) and 19 (42%) trees with similar damage caused by BS and BPB, respectively. *Vachellia stuhlmannii* is a multi-stemmed spreading shrub that usually grows 1 – 3 m in height, with young branches covered in dense golden hairs. This species sustained the most damage at DE8 (75 – 90%) for nine individuals followed by DE6 (25 – 50%) for six individuals, with the lowest 14% represented by three individuals at DE7 (50 – 75%) and DE9 (90 – 95%). There was an example of a tree with an estimated damage extent between DE6 (25 – 50%) or DE7 (50 – 75%). It was not surprising that the main type of impact recorded for the species was in the DT1 (bark stripping), DT2 (broken primary branch) and DT3 (broken main stem) classes, with no damage recorded at DT4 (uprooted main stem) and DT5 (tree pushed over) classes, an observation that warrants further research (Figure 9).

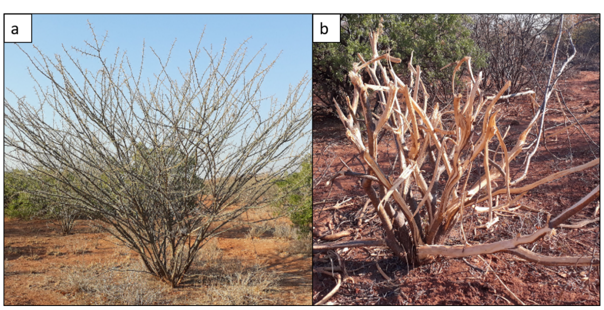

Fig. 9. *Vachellia stuhlmannii* not browsed (a) and browsed (b) by elephants.

Strip barking (DT1) and broken primary branches (DT2) were forms of damage observed for the top two utilised *Vachellia* spp. in the top six. *Vachellia tortilis* is regarded as a keystone savannah species adapted to a wide range of browsing pressures. The species exude a water-soluble sugary polysaccharide from their branches, which could be the reason for strip barking by elephants. Gandiwa *et al*. (2011)found that continued browsing on *V. tortilis* by elephants may lead to thinning of woodlands dominated by this species. This is a threat that may result in local extirpation of the species.

Boscia foetida species is number four of the six mostly damaged woody trees on the reserve. It is one of the common species in VLNR (MacGregor and O'Connor, 2002). The highest number of seven (70%) were recorded for DT2 (BPB) and one (10%) individual for DT1 (BS), DT3 (BMS) and DT5 (TPO), with none for DT4 (UMS). Broken primary branches (DT2) were recorded as the most prevalent form of damage for *B. foetida*. The most selected tree height recorded for *B. foetida* was at TH3 (2 – 3m), equivalent to 88% of the species, and one individual (13%) at TH4 (3 – 4 m). Elephant impact on *B. foetida* accounted for 59% (4th place) of the number of individual species recorded to have their bark removed due to elephant foraging activities (O'Connor and Page, 1997). Another species of this genus, *B. albitrunca* was recorded in this study as the sixth (1.4%) most highly browsed species in VLNR, representing 26% of the total species whose bark was removed from elephant feeding (O'Connor and Page, 1997).

Elephants were responsible for decreasing *Commiphora* woodlands in Tsavo National Park, Kenya (Leuthold, 1996) and 95% of *Commiphora* shrubs over ten years in Ruaha National Park, Tanzania (Barnes, 1985). *Commiphora* spp., based on their utilisation pattern in Tuli Block, Botswana and evidence in the literature, are also generally selected by elephants in VLNR (O'Connor and Page, 1997). Kuiper and Parker (2014) reported that *Commiphora* spp. have poor re-sprouting abilities after sustaining damage caused by elephants. From our results, DT5 (trees pushed over) was the recorded type of impact for the only four *C. africana* individuals (100%) within this height class recorded in this study.Only three (75%) individual trees at TH4 (3 – 4 m) and one (25%) at TH5 were recorded. Smallie and O'Connor (2000) found that trees <4 m were selected mainly by elephants over trees >4 m for the *C. africana*. Although most *C. africana* trees were mostly at DT5, elephants only utilised less than 1% of the pushed over trees (DE2).

Commiphora africana is a priority species on the reserve due to its slow growth and recruitment rate and is a typical Limpopo valley species (O'Connor and Page, 1997). A high mortality rate for these trees was observed, mainly because of being pushed over by foraging elephants. Their spatial distribution is mostly on sandy-loam soils, which could be the reason that they are easily pushed over and, in some instances, uprooted from the ground. Monitoring these species is essential as there were not many juveniles observed in the field. The results also indicate that the main tree height class selected by elephants for *Commiphora africana* were for trees taller than 3 m, while trees between 2 m and 3 m foraged at different intensities depending on the species.

Overall, there was a statistically significant difference (r = 0.973, P = 0.146) in height and the number of trees selected by elephants in VLNR. Trees between 3 m and 4 m were the most selected and the impact seemed consistent at these tree heights. No trees in the first height class (TH1) were recorded as damaged or foraged on by elephants. From field observations, the reserve does not seem to have many trees at TH1, resulting from high elephant densities or low establishment rates of seedlings. There was no statistically significant relationship (r = –0.500, P = 0.391), trend or pattern between the number of damaged trees and the type of damage. Different trees at different height classes were utilised inconsistently. However, the most dominant type of damage was DT3 (BMS) and the lowest damage type, with only 1% of the trees, was for DT1 (BS).

The health status of woody vegetation along the Piosphere gradient was evaluated by spreading multiple ring buffers around the waterholes (Figure 8). Although there were no significant changes in the NDVI values for the different buffer zones, the results in 2000 indicated the lowest NDVI mean value (= 0.23) at a 2 000 m distance compared to all other years. This may be attributed to possible rainfall that may have been experienced in the study area other than elephant impact. Chamaille-Jammes *et al*. (2009) found that the woody vegetation cover was strongly affected within the first 2 km of the Piosphere gradient. Based on the extracted NDVI values, the impact on woody vegetation within the 2 km distance in 1990 and 2011 for this study was negligible. The highest and similar recorded NDVI values (=0.36) were for the 1 600 and 2 000 m distances. This may be attributed to the fact that the available Landsat-5 image for 2011 was later in the dry season. This is at the initial stage of vegetation growth during spring.

According to Jachmann and Croes (1991), elephants selected feeding height class is estimated at trees between 2 m and 3 m tall. Our results also support the findings by Jachmann and Bell (1985), who found that trees taller than 3 m were mainly pushed over or felled by elephants. Although the recorded variations in the type of damage for the six tree species' overall results correspond with what other researchers found, there were still variations in how different tree species were utilised or foraged at individual levels (Figure 3 and 4). According to Anderson and Walker (1974), elephants move to the next selected tree species when forage becomes less available and this process keeps repeating itself. Tall trees provide a wide range of habitats and promote biodiversity (Cumming *et al*., 1997) and the ecological functioning of ecosystems (Belsky, 1994). Levick *et al*. (2009) alluded to researchers needing to understand the tree height classes that are most important for an elephant to utilise. Shannon *et al*. (2008) found that elephants utilise trees in proportion to their abundance in the different height classes; however, tree size and tree species influence the intensity and utilisation approach. Barnes (1983) also found that the influence of elephants on tree density was species-specific.

Although there is a high elephant impact on *Vachellia* species, these species are persistent due to their regeneration ability (Vesey-FitzGerald, 1973;

Croze, 1974; Pellew, 1983). *Colophospermum mopane* is a resilient species with strong coppicing abilities (Lewis, 1991; Ben-Shahar, 1996) compared to *V. tortilis* with relatively low coppicing abilities (MacGregor and O'Connor, 2004) and *Commiphora* spp. that seems not to coppice at all (O'Connor *et al*., 2007) after elephant impact. *Colophospermum mopane* is also a staple food item of elephants and can tolerate relatively high browser impact (Smallie and O'Connor, 2000; Styles and Skinner, 2000).

Conclusion

This study aimed to evaluate the impact of elephants on woody vegetation, a complex subject that is yet to be understood. It is unknown whether elephants utilise tree species as they come into contact with them, or whether the abundance of various tree species affects selection, or whether they target specific height classes based on the tree species. Unfortunately, elephant impact becomes more prominent over time on large trees that produce seeds, stabilise the soil, and provide macro and microhabitats to other plants animals. Their destruction negatively affects biodiversity, making it important for protected area managers to implement monitoring interventions. Further studies are necessary to understand the recruitment rates of trees in high elephant density areas such as VLNR. Elephants are free-ranging animals that require large areas and they are capable of increasing in population size, having an annual growth rate of approximately 5% to 7% (Cumming, 1981; Gibson *et al*., 1998). Determining whether elephants are overpopulating a protected area depends on the size of the area, the objectives for the area, the population growth rate, and whether high elephant densities will have negative impacts on the environment or not. Deleterious impacts trigger some form of intervention to reduce such impacts (Balfour *et al*., 2007). According to the extracted NDVI values, there was insufficient evidence to suggest an increase in vegetation degradation around the Piosphere gradient in the reserve (Figure 9), regardless of the cause. From the results of this study, there is a negligible impact of woody vegetation within the 2 km distance from the waterholes in 1990 and 2011, except for the lowest NDVI mean value result at a 2000 m distance in 2000.

Colophospermum mopane is the most abundant tree species on the reserve. The most prominent and dominant type of damage to this species was broken main stems and pushed over individuals. Although these trees were mostly lying flat, the extent of their impact ranged between classes 4 (5 to 10%) and 5 (10 – 25%). Conversely, the proportion of *V. stuhlmannii* utilisation by elephants from our observations seemed to be at interestingly high intensities. Elephants in VLNR seem fond of this species and in some cases, it is browsed down to ground level (Figure 7). It is assumed that this form of browsing could be influenced by the multi-stemmed growth form of the species resulting in softer branches being easily accessible to elephants, or due to gum production from the plants since it is of a genus: *Vachellia*, or as a result of the possibly high nutritional value for the species, or due to reduced chemical defence (tannins) capability within the plants. All factors that warrant further research.

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