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Wire Netting Reduces African Elephant (*LOXODONTA AFRICANA*) Impact to Selected Large Trees in South Africa

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WIRE NETTING REDUCES AFRICAN ELEPHANT (*LOXODONTA AFRICANA*) IMPACT TO SELECTED LARGE TREES IN SOUTH AFRICA

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Master of Science

By
Kelly Derham

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WIRE NETTING REDUCES AFRICAN ELEPHANT (*LOXODONTA AFRICANA*) IMPACT TO SELECTED LARGE TREES IN SOUTH AFRICA

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Directed by: Dr. Bruce A. Schulte, Dr. Carl W. Dick, and Dr. Albert Meier

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African elephants (*Loxodonta africana*) are ecosystem engineers in that they substantially alter the environment through their unique foraging and feeding habits. At high densities, elephants potentially have negative impacts on the environment, specifically to large trees. Because of this, recent increases of elephants in the Associated Private Nature Reserves (APNR) on the Western Boundary of Kruger National Park, South Africa have caused concern regarding the health of several species of tree. My objective was to assess the effectiveness of wrapping protective wire netting around the trunk of the tree in preventing and reducing bark stripping by elephants. 2,668 trees, 1352 marula (*Sclerocarya birrea)*, 857 knobthorn *(Acacia Nigrescens),* and 459 false marula (*Lannea schweinfurti),* were assessed for elephant impact in the APNR, 1387 (52%) of which had previously been wrapped in protective wire netting (789, 548, and 50 respectively). For knobthorn and marula, wire netting significantly decreased the number of the trees that were bark stripped. For all trees, wire netting decreased the level of bark stripping especially for the highest impact levels. No trees wrapped with wire were ringbarked, compared to 23 unwired trees. In addition, wire netting had an effect on the distribution of damage for the highest impact class incurred regardless of type. A higher relative frequency of wired trees were found in lower impact categories compared to unwired trees. Wire netting is a low maintenance and ecologically valuable technique that alleviates bark stripping for some species. The judicial use of wire netting on trees could

serve to maintain elephant and trees populations in areas of heavy confinement with locally high densities of elephants.

Introduction

Elephants are allogenic ecosystem engineers in that they substantially modify the environment through their unique foraging and feeding habits (Laws, 1970; Jones, Lawton & Shachak, 1994). In areas where elephants are confined by fences and human settlements, their numbers can increase locally, leading to extensive modification of habitat that can potentially have negative consequences on ecosystem processes and many other organisms (Dublin & Hoare, 2004; Guldemond & Van Aarde, 2008). Large trees are of particular concern, since elephants are one of only a few biotic forces that can directly and rapidly modify this key feature of the savanna landscape (Laws, 1970). These trees play an important role in the biogeochemical cycles of the savanna as well as indirectly affect the distribution of numerous other sympatric species that use the trees for refuge, shade, nesting areas, food, and other services (Bernhard-Reversat, 1982; Bonnington, Weaver & Fanning, 2007; Nasseri, McBrayer & Schulte, 2010).

Elephants can affect trees in a variety of ways including bark stripping and branch breaking, as well as breaking the main stem or uprooting the tree entirely (Henley, 2007; Boundja & Midgley, 2009). In the wet season, African elephants primarily feed on grass, while browse makes up a significant amount of their diet in the dry season (Barnes, 1982; Owen-Smith & Chafota, 2012). Because of their large body size and hindgut digestion, elephants can consume a variety of plant parts including bark, branches, leaves, and roots and therefore can impact trees in a multitude of ways (Owen-Smith & Chafota, 2012). Bark stripping and branch breaking expose trees to insect attack and greater damage from fire, either of which may contribute to their mortality (Helm *et al*., 2011). Trees are particularly vulnerable to ringbarking, when bark has been removed around the entire circumference of the tree (Gadd, 2002; Ihwagi *et al*., 2009; Helm *et al*., 2011). Although extensive branch breaking and felling can alter the form of a tree, species that readily recoppice after such events can survive and continue to grow if their roots remain intact (Eckhardt, Van Wilgen & Biggs, 2000; Gadd, 2002; Henley, 2007, Ihwagi *et al*., 2009). However, the continuing loss of habitat for elephants confines them to areas for unnaturally long periods of time, resulting in high amounts of damage and persistent attack that alone or in combination with other factors leads to increased risk of mortality (Van Aarde, Jackson & Ferriera 2006; Boundja & Midgley, 2009; Mapaure & Moe, 2009; Helm *et al*., 2011).

Elephants are often selective when feeding and, therefore, tree species vary in vulnerability to increasing elephant densities (Ihwagi *et al*., 2009; Owen-Smith & Chafota, 2012). In the Associated Private Nature Reserves (APNR) in South Africa, residents expressed concern about the marula (*Sclerocarya birrea*) and knobthorn (*Acacia nigrescens*) through a survey conducted in 2003 (Henley, 2007). In addition, false marula (*Lannea schweinfurthii*) are known to be heavily impacted by elephants in the area (Greyling, 2004). All three species of trees can grow very large, ranging from 5 to over 18 m (Palgrave & Keith, 2003). Marula trees have a characteristic grey, rough, and flaky bark that is often bark stripped by elephants (Jacobs & Biggs, 2002a). Elephants frequently uproot marula trees, either to consume their roots or purely as a behavioral display (Jacobs & Biggs, 2002a). Knobthorn is a preferred species for elephants, which typically bark strip the species but only infrequently fell trees (Boundja & Midgley, 2009). False marula trees are heavily impacted in the APNR, yet are known to grow in many different habitats and recover well from damage (Henley, 2007).

In addition to species differences, elephant impact can also differ depending by location (Ben-Shahar, 1993; Nellemann, Moe, & Rutina, 2002; Guldemond & Van Aarde, 2008). For example, in Kruger National Park (KNP), several marula populations are unstable and threatened, and one population is virtually extinct primarily due to elephants (Jacobs & Biggs, 2002b). However, other populations in the KNP, as well as populations in three private properties near the APNR, appear to be healthy (Gadd, 2002; Jacobs & Biggs, 2002b). Trees of all three species in areas with high densities of elephants often experience greater damage than trees in other areas (Guldemond & Van Aarde, 2008).

In order to maintain both elephant and large tree populations, several ideas have been proposed that focus on reducing elephant numbers. These suggestions include culling, hunting, or altering surface-water availability (Van Aarde, Jackson & Ferriera, 2006; Chamaille-Jammes, Valeix & Fritz, 2007). Alternatively, other strategies focus on protecting the trees themselves. Wrapping wire netting around the bark of the tree is one such technique that has been previously employed by Save the Elephants (Gordon, 2003), a non-profit conservation organization in Africa. The same technique was used by Save the Elephants- South Africa with results indicating that the occurrence of bark stripping and survival rates of trees with wire netting protection differ from those of unprotected trees (Henley, 2013). To determine the potential success of wire netting as a long-term solution to heightened elephant activity, studies at larger scales and over longer periods are necessary. If wire netting prevents bark stripping, then it could serve as a cost-effective and ecologically valuable way to prevent some negative impact to trees caused by elephants.

The primary aim of my study was to assess bark stripping in the APNR as well as the effectiveness of wire netting in reducing both the number of trees that were bark stripped and the degree of bark stripping. In addition, I wanted to determine if wire netting influenced branch breaking or felling by elephants. Finally, I examined whether species, property, and tree size were important factors influencing the impact on trees by elephants. For property, I was especially interested in whether relative distance from KNP influenced elephant impact. I hypothesized that properties closer to the KNP border would experience higher levels of impact due to the high densities of elephants found there before the fences between the APNR and KNP were removed in 1993/1994 (Greyling, 2004).

Material and Methods

Study Site

This study was conducted from 1 July to 1 December 2012 in the Associated Private Nature Reserves (APNR) adjacent to Kruger National Park (KNP), South Africa (Fig. A1). The APNR is a conserved area of approximately 180,000ha (1,800 km^2) of private lands on the western boundary of KNP (Greyling, 2004). In 1993 and 1994 the fences separating the APNR and KNP were removed creating a large conservation area of over 2.3 million ha (23,000 km^2). The APNR includes Balule, Klaserie, Timbavati and Umbabat Private Nature Reserves (Fig. A2). Each Private Nature Reserve is made of many private properties that have adopted the management plan of the APNR. This study was conducted on Klaserie, Timbavati, and Umbabat Private Nature Reserves on the individual properties of Charloscar, De Luca, Ntsiri, Sumatra, Vlakgezicht and Zebenine (Fig. A2).

The APNR is characterized by a savanna ecosystem with a continuous grass understory and isolated trees (Scholes & Archer, 1997). The vegetation within the APNR varies regionally. The eastern areas, including the properties of De Luca and Sumatra, have dense mopane (*Colophospermum mopane)* woodland as well as isolated knobthorn and marula. On the properties of Charloscar, Ntsiri, and Zebinine, red bush willow (*Combretum apiculatum)* occurs regularly. Other common trees species in the APNR include false marula and silver cluster leaf (*Terminalia sercea)* (Venter & Gertenbach, 1986; Henley, 2007).

The climate in the APNR consists of a mild dry season generally lasting from April to October and a wet season from November to March. Mean annual rainfall is less than 600 mm and temperatures average 22° C throughout the year (Greyling, 2004). The study area is dominated by igneous rock with granite occurring in the north and gabbro in the central and southern areas. Soils weathered from these rock formations consist of well-drained coarse soil with low fertility (Venter & Gertenbach, 1986).

Study history

Elephant numbers in the APNR have increased from 952 in 2002 to 1528 in 2012, warranting concern about their effect on vegetation and leading to a long-term impact monitoring study initiated by Dr. Michelle Henley and Save the Elephants- South Africa (M. Henley, pers.comm.). The study began in 2004 when 63 marula were mapped and tagged on Vlakgezicht, 37 of which had been wrapped in wire netting in an attempt to protect them from elephant impact, a technique that had been successfully used by Save the Elephants in Kenya (Gordon, 2003). As the study was expanded, properties were chosen because their owners expressed interest in participating. Workers on each property were instructed to tag marula, knobthorn, and false marula trees greater than 2 meters tall. Other selection criteria are largely unknown and varied by property. By 2008 the study grew to include the monitoring of 2975 trees on six properties within the APNR with nearly half (1446) being wrapped in wire netting (Table A1).

Netting procedure

Wire netting was wrapped around the trunk of the tree (defined as single-stemmed woody plants taller than two meters (Fig. 1) (Greyling, 2004)) and secured with fencing staples. When nests were present, holes were cut in the netting to allow animals such as squirrels and birds continued access to the trees. Wire netting was sometimes applied to trees that were already bark stripped by elephants and new impact was recorded.

Three types of wire netting were used for protecting the trees. At the Vlakgezicht, Ntsiri, and Zebenine study sites bird wire was used (mesh size 13 mm). At the De Luca study site larger bird wire was used (mesh size 50 mm). At Charloscar mesh size was also 50 mm but wire was somewhat thicker than that on the De Luca study site. In 2008 both 13 mm mesh and 50 mm mesh bird wire were used when trees on the Sumatra property were added to the study.

Assessment of elephant impact

Marked trees had previously been assessed for elephant impact in 2004, 2005, and 2008 (M. Henley, pers.comm.). In 2012, they were reassessed using the same procedure. For each marked tree the impact type was recorded as BS (bark stripping), BBA (primary branch breaking), MS (main stem breaking, where the main stem had been broken off), or UR (uprooting, where the main stem had been pushed over). Because of their rare occurrences, MS and UR were combined into a single category called F (felling) for analysis. In instances where multiple impact types occurred, each event was recorded separately. Two or more instances of the same type were recorded and scored separately. These trees were recorded once in the given impact category and the highest impact level was used in analyses. Damage from other animals such as rhinoceros (*Diceros bicornis*) or cape buffalo (*Syncerus caffer*) was differentiated based on the height and type of stripping or branch breaking and recorded separately from elephant impact. For each impact type a class number was given based on the severity of each event as adapted from Anderson & Walker (1974) and used by Henley (2013). Bark stripping severity was determined based on the proportion of the circumference of the tree that had been bark stripped, which is a method commonly used in other studies (Table A2) (Anderson & Walker, 1974; Gadd, 2002; Ihwagi *et al*., 2009; Helm *et al*., 2011; Henley, 2007). For primary branch breaking, the class was determined based on the percentage of all branches that had been broken by elephants (Table A2). Impact classes were assigned to trees that had their main stem snapped or had been uprooted based on particular categories (Tables A3 & A4) Recoppice was defined as new growth after a main stem snapping or uprooting event (Henley, 2007). Stem diameter at breast height was also measured and recorded (in cm) for each of the trees. In addition, height and volume were calculated with the program VolCalc developed by Barrett & Brown (2012). Additional methods are provided in Appendix A.

Statistical analysis

Elephant impact data were analyzed using R statistical software (R core Development Team 2012). Of the 2975 trees tagged in 2008, 2772 (93%) were relocated in 2012. Of the 2772, 57 were dead and unable to be assessed because only remains of the tree were found. Of the remaining 2715 trees, 2668 were marula, knobthorn, or false marula and had complete data. These trees were used for analysis. To determine differences in tree size between species, properties, I performed randomization ANOVAs and pairwise comparisons with 10,000 permutations. The assumption of heteroscedasticity was met for randomization ANOVAs.

To assess differences in size between wired and unwired trees, as well as between trees with bark stripping, branch breaking, and felling compared to undamaged trees, I performed unpaired Welch's t-tests to address unequal variance. DBH was used as a measure of tree size because DBH, height, and volume were determined to be highly correlated and DBH is commonly used in other studies (Table A6). DBH is reported as mean ± 1 SD.

In order to determine if wire netting affected the likelihood that a tree would be bark stripped or incur any other type of damage by elephants, log linear analyses were performed with wire netting and species as independent variables and DBH as a covariate. DBH was log transformed to address the assumption of linearity between a covariate and bark stripping. Property was not included in log linear analyses due to small sample sizes.

Likelihood ratio tests for goodness-of-fit (G-tests) with William's continuity corrections were used to further examine significance found in log linear analyses. A G-test was also performed with wire netting (2 levels) and highest impact category (10 levels) in order to determine if the distribution of the level of impact changed with wire netting. For this analysis, the highest impact class was recorded for each tree regardless of the type of that impact. Although sample size was too small for property to be included in log linear analyses, property tests were performed with G-tests of independence for the three properties with the most trees: Charloscar, Sumatra, and Vlakgezicht for wired and unwired trees separately. These three properties were used because they had sufficient sample size and were differing distances from KNP (Fig. A2). A type I error rate of 0.05 was used for all analyses. I used a Bonferroni correction to maintain an experimentwise alpha value of 0.05 for multiple comparisons because they can increase the likelihood of obtaining a significant p-value when there is not necessarily a difference between the groups.

Results

General results and tree characteristics

In total, 25% of unwired trees were bark stripped by elephants, making it second to branch breaking (69%) as the most common type of damage by elephants (Table A5). In comparison, bark stripping from rhinoceros or buffalo was evident on only 26 of the 1281 unwired tagged trees (2.0%). Main stem breaking (11%) and uprooting (20%) were the least frequent forms of damage. For wired trees, percentages for all impact types decreased. Only 1.7% of wired trees were bark stripped by elephants, making it the least common type of impact for trees wrapped with wire. Branch breaking (64%) was still the most frequent category of impact. One wired tree (< 0.1%) was bark stripped by rhinoceros or buffalo.

The average DBH of tagged trees was 39.2 ± 13.5 cm but this was significantly different among species (F = 129.1, df = 2, 2578, p-value < 0.001) and properties (F = 23.8, df = 2, 2582, p-value < 0.001). All three species were significantly different from each other (Table A7). Knobthorn were generally the largest (mean DBH = 44.9 ± 15.2 cm, n = 845), compared to marula (37.9 ± 13.4 cm, n = 1347) and false marula (32.3 ± 14.0 cm, n = 458). For the three properties that were analyzed, Charloscar had significantly different average DBH compared to Sumatra and Vlakgezicht (Table A8). In general, tagged trees on Charloscar were larger (mean DBH = 43.5 ± 12.4 cm, n = 596) compared to Sumatra (mean DBH = 37.4 ± 15.1 cm, n = 1221) and Vlakgezicht (mean DBH = 37.6 ± 15.4 cm, n = 687). In addition, mean DBH differed significantly between trees that were and were not wired (t = -17.9, df = 2, 418, p-value < 0.001). Trees that were wired (mean DBH = 44.0 ± 13.5 cm, n = 1380) were significantly larger than trees that were not (mean DBH = 33.8 ± 14.1 cm, n = 1270).

Effectiveness of wire netting in reducing bark stripping

Wire netting and species type were important in determining the likelihood of bark stripping once DBH was accounted for (Table 1). Wire netting significantly decreased the number of trees that were bark stripped for knobthorn (G=48.9, df = 1, p-value < 0.001) and marula (G=4.14, df = 1, p-value 0.04), with fewer trees having been bark stripped than expected with wire netting (Fig. 2). However, wire netting did not significantly reduce the occurrence of bark stripping for false marula (G=1.84, df = 1, p-value 0.17). The number of trees in all impact categories was reduced with wire netting and no trees wrapped with wire experienced damage in the highest two categories, 9 and 10 (Fig. 3). Only three trees with wire were bark stripped more than 50% of the circumference of their trunk, compared to 85 without wire. In addition, no trees wrapped with wire were ringbarked, compared to 23 unwired trees.

Influence of wire netting on branch breaking, main stem breaking, and uprooting

DBH had a significant effect on whether a tree had its branches broken from elephants (Table 1). Trees that had their branches broken were significantly smaller than those not impacted in this way by elephants (t = 3.80, df = 1788, p-value < 0.001). After DBH was accounted for, species was an important factor for determining branch breaking but wire netting was not. Knobthorn had significantly fewer branches broken compared to marula (G = 346, df = 1, p-value < 0.001) and false marula (G = 208, df = 1, p-value <

0.001) (Fig. 4). DBH was also an important factor related to the occurrence of felling by elephants (Table 1). For all threes species, felled trees were significantly smaller than trees that remained standing (t = 11.3, df = 954, p-value < 0.001). After DBH was taken into consideration, neither species nor wire were important factors in determining whether or not a tree was felled. Regardless of the type of impact, wire netting had an influence on the distribution of the level of impact (G=73.8, df = 9, p-value < 0.001) (Fig. 5). Wired trees were more likely to experience lower levels of elephant impact than unwired trees.

Property analysis

Pairwise comparisons indicate differences in the type of elephant impact depending on property. The Charloscar and Sumatra properties differed in the likelihood of bark stripping for unwired trees (G = 19.6, df = 1, p-value < 0.001) but not for wired trees (G =1.15, df = 1, p-value = 0.29). The Charloscar and Vlakgezicht properties differed for all trees (Unwired: G = 50.5, df = 1, p-value < 0.001; Wired: G = 49.1, df = 1, p-value < 0.001) as did the Vlakgezicht and Sumatra properties (Unwired: G = 171.2, df = 1, p-value < 0.001; Wired: G = 70.5, df = 1, p-value < 0.001). The likelihood of branch breaking by elephants was lower on Charloscar compared to Sumatra for both unwired (G = 151.7, df = 1, p-value < 0.001) and wired trees (G = 47.7, df = 1, p-value < 0.001). There was not a significant difference in branch breaking between Charloscar and Vlakgezicht for unwired trees (G = 0.64, df = 1, p-value = 0.42) but these properties were significantly different for wired trees (G = 47.7, df = 1, p-value < 0.001). With wire, Vlakgezicht experienced more branch breaking than expected when compared to

Charloscar. The Sumatra and Vlakgezicht properties did not differ for unwired (G = 0.26, df = 1, p-value = 0.61) or wired trees (G = 4.29, df = 1, p-value = 0.04) following the pairwise Bonferroni correction. The occurrence of tree felling was significantly less at Charloscar than Sumatra for all trees (Unwired: G = 132, df = 1, p-value < 0.001; Wire: G = 5.29, df = 1, p-value = 0.002). Felling was also less likely at the Charloscar property compared to the Vlakgezicht property for unwired trees (G = 254, df = 1, p-value < 0.001) but not for wired trees (G = 10.0, df = 1, p-value = 0.02) following the pairwise Bonferroni correction. Sumatra and Vlakgezicht had significant differences for the likelihood of felling for unwired (G = 17.9, df = 1, p-value < 0.001) but not for wired trees (G = 0.01, df = 1, p-value 0.91).

Discussion

In this study, bark stripping by elephants was frequent and wire netting was effective at reducing the relative number of trees that were bark stripped. Similar patterns resulted for all three species, but significant reductions were only evident for knobthorn and marula. Wire netting also reduced the frequency of high levels of bark stripping. High levels of bark stripping, and especially ringbarking, are known to affect tree survival (Gadd, 2002; Ihwagi *et al*., 2009; Helm *et al*., 2011). Therefore, wire netting could prevent mortality by decreasing both the number of trees that are bark stripped by elephants and the occurrence of high levels of bark stripping. Regardless of the type, a higher relative frequency of wired trees were found in lower impact categories compared to unwired trees. O'Connor, Goodman, & Clegg (2007) hypothesized that species likely to experience ringbarking, main stem breaking or uprooting were vulnerable to extirpation in areas of increasingly high elephant densities. Therefore, wire netting could lower the risk of extirpation in these species and others that are frequently damaged by elephants.

Differential success of wire netting across the species was hypothesized to be a result of elephant preference. I hypothesized that marula and knobthorn would be preferred for bark stripping for two reasons. These two species have bark that is more easily stripped and their larger size compared to false marula makes them more attractive to elephants (Gadd, 2002; Jacobs & Biggs, 2002a; Moncrieff, Kruger & Midgley, 2008; Boundja & Midgley, 2009; Ihwagi *et al*., 2009). Therefore, I further hypothesized that wire netting would reduce bark stripping for marula and knobthorn but not for false marula. Contrary to my first hypothesis, in this study elephants were equally likely to bark strip false marula and marula trees. This suggests that for false marula, efficacy of wire netting may depend more on the protection it offers rather than elephant preference. Only 11% (50/409) of false marula trees in this study were wrapped with wire, which is a relatively small proportion and total number compared to 64% of knobthorn (548/857) and 58% of marula (789/1352). This small sample size may have contributed to the lack of significance affected by wire wrapping. Alternatively, the effect could be real and some species might benefit more from wire wrapping than other.

Elephant impact differed by location for the comparison of three properties that differed in their proximity to KNP. Other studies have reported elephant impacts vary by location (Ben-Shahar, 1993; Nellemann *et al*., 2002; Guldemond & Van Aarde, 2008). In general, trees on Charloscar experienced less branch breaking, and felling compared to those on Sumatra and Vlakgezicht. Charloscar was located the furthest from KNP, lending support to the hypothesis that elephant density, varying by distance to KNP, could be influencing the amount of elephant impact. Three notable differences in damage between unwired and wired trees were found. With wire, there was no longer a significant difference between Charloscar and Sumatra for likelihood of bark stripping. This was also the case for the likelihood of felling between Charloscar and Vlakgezicht. Compared to the other two properties, Charloscar has a higher proportion of trees with heavier wire netting, yet impact decreased on Sumatra and Vlakgezicht compared to Charloscar. This suggests that the mesh size and thickness of wire netting, at least to the degree they differed in this study, may not have an influence on its efficacy. The likelihood of branch breaking between Charloscar and Vlakgezicht was different for unwired and wired trees. In this case, unwired trees showed no significant difference while wired trees on Vlakgezicht were significantly more likely to have branches broken compared to Charloscar. This could be due to the relatively high proportion of marula trees found on Vlakgezicht. Of these three properties, Charloscar was closest to a major water source and had larger trees than the other two properties. These factors often increase elephant impact, which suggests that elephant densities might be more important in determining tree damage than either distance from water or tree size (Ben-Shahar, 1993; De Beer *et al*., 2006).

Differential elephant impact and success of wire netting among species highlights the need for context-dependent elephant management policies within the APNR. Species that experience significant reductions in bark stripping by elephants would benefit more from wire netting than others. O'Connor *et al.* (2007) hypothesized that increased probability of an encounter with an elephant is one factor that can predispose a species to local extirpation. Therefore, properties that are located closer to KNP might benefit more from wire netting since these trees are likely to be repeatedly damaged by elephants. The APNR has a history of heavy confinement of elephants through fencing as well as a large number of artificial water sources, which are factors known to influence elephant impact (Chamaille-Jammes *et al.*, 2007; Guldemond & Van Aarde, 2008; Loarie, Van Aarde, & Pimm, 2009). Wire netting could therefore be a beneficial management strategy in areas with a similar history. Addo Elephant National Park in South Africa has high densities of elephants that have been found to have substantial impact on the environment (Lombard *et al*., 2001). In this area wire netting could alleviate elephant impact to trees. Although elephant numbers have remained low in South Africa's Tembe Elephant National Park, wire netting could be employed if elephant densities increase in coming years

(Guldemond & Van Aarde, 2007). Outside of South Africa, wire netting could be used in areas where either residents and/or tourists are interested in seeing large trees and elephants, which are both characteristic features of the savanna ecosystem. This strategy might be particularly useful in areas where elephant frequently visit and therefore inflict more damage, such as near rivers (Nellemann *et al*., 2002). Overall in the current study, wire netting was effective at reducing the prevalence of bark stripping and at lowering the proportion of trees that received severe damage of any type. Compared to other management alternatives, wire netting is a relatively low maintenance and ecologically valuable strategy to promote the coexistence of both elephants and trees into the future.

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Table 1 Results of log linear analysis for presence of (a) bark stripping (b) branch breaking, and (c) felling by elephants in the APNR, South Africa

(a)

Model	Df	Residual Deviance	p-value
Null		39.6	
DBH	1	36.6	0.08
Species	2	4.88	< 0.001
Wire	1	0.10	0.03
Wire:Species	1	0.00	0.75

(b)

Model	Df	Residual Deviance	p-value
Null		31.8	
DBH	1	21.7	0.001
Species	2	1.39	< 0.001
Wire	1	0.92	0.49
Wire: Species	1	0.00	0.34

(c)

Model	Df	Residual Deviance	p-value
Null		19.6	
DBH	1	0.94	< 0.001
Species	2	0.54	0.82
Wire	1	0.11	0.51
Wire: Species	1	0.00	0.74

Fig 1 13 mm mesh wire netting around a *S. birrea* used to reduce elephant bark stripping

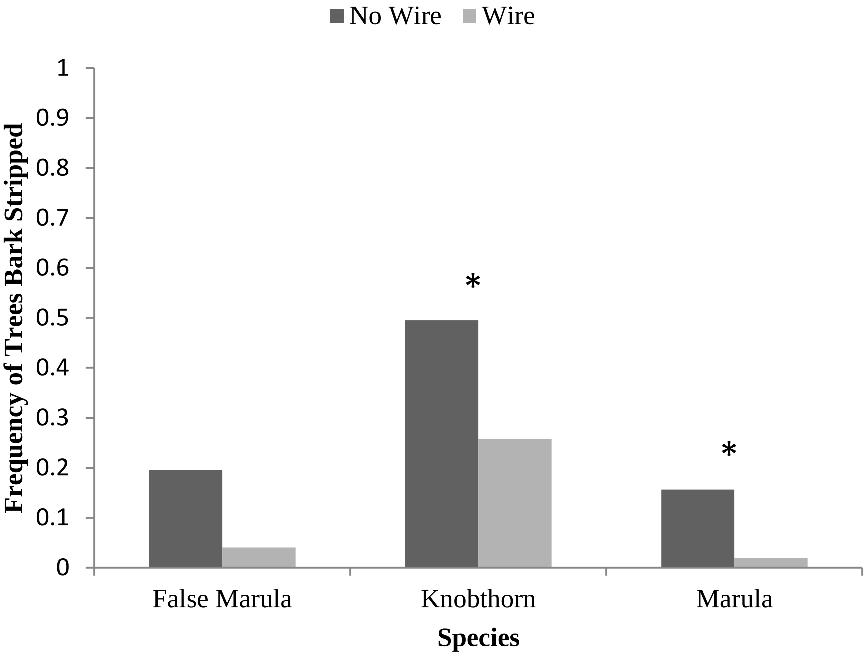

Fig 2 The relative frequency of False Marula, Knobthorn, and Marula with bark stripping caused by elephants in the APNR, South Africa (2012)

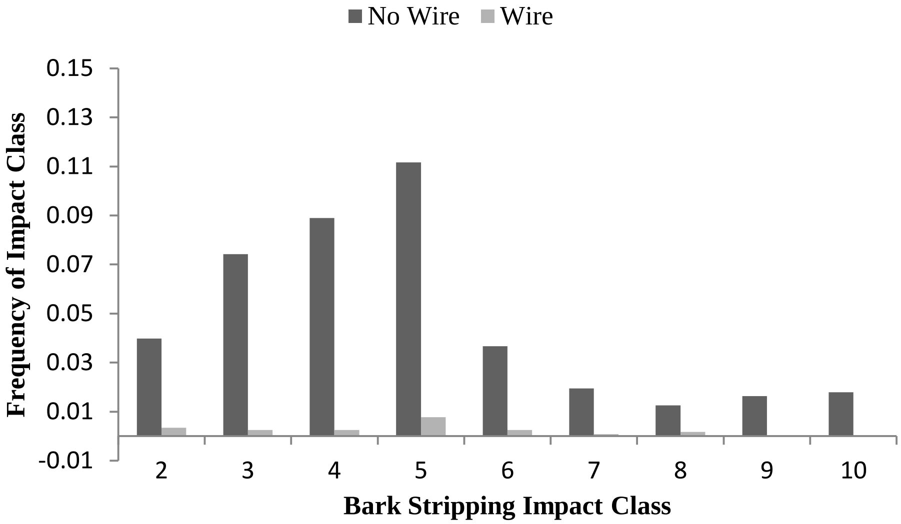

Fig 3 The relative frequency of each bark stripping class for trees with and without wire wrapped around their trunk in the APNR, South Africa (2012) (Class 2 < 1% of circumference of tree bark stripped; Class 3 = 1-5%; Class 4 = 5-10%; Class 5 = 10-25%, Class 6 = 25-50%; Class 7 = 50-75%; Class 8 = 75-90%; Class 9 = 90-99%; Class 10 = 100%)

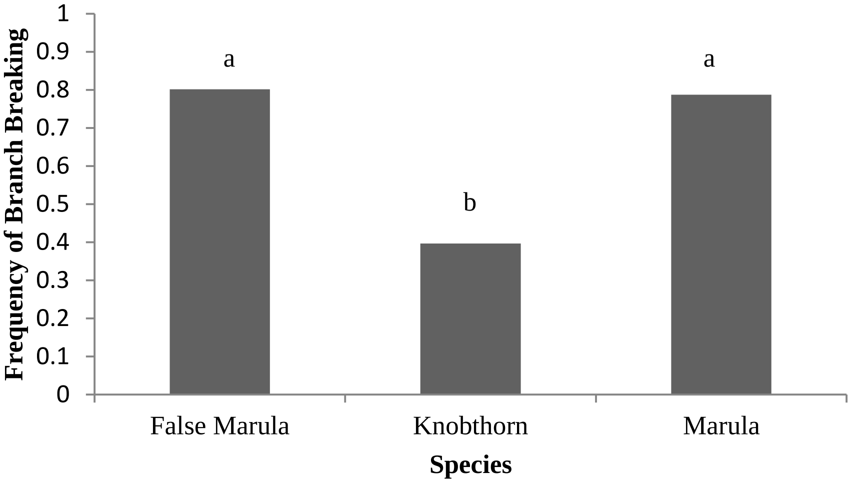

Fig 4 Relative frequency of branch breaking caused by elephant for False Marula, Knobthorn, and Marula in the APNR, South Africa (2012)

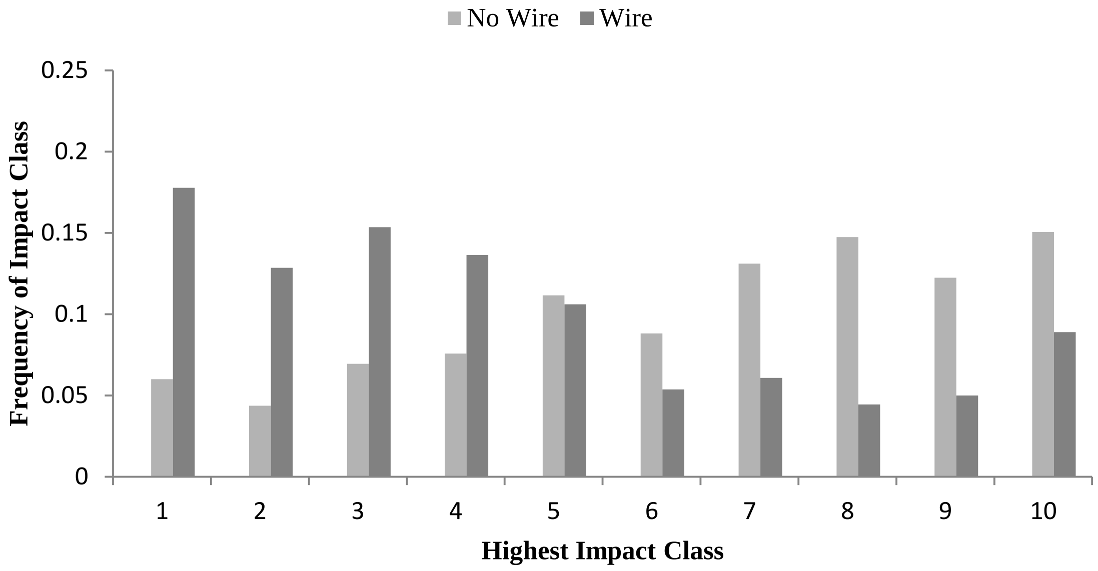

Fig 5 The relative frequency of impact classes where trees are recorded at the highest level of impact they incurred regardless of impact by elephants in the APNR, South Africa (2012). Over all classes, branch breaking was the highest impact for 1745 of the trees, felling was the highest impact for 1270 of the trees, and bark stripping was the highest impact for 742 of the trees (some trees had more than one type that were both the highest impact)

APPENDIX A:

Additional Methods & Results

Relabeling trees

Trees were not assessed since 2008, thus, some of the tags had fallen off. To make sure I was looking at the correct tree I compared the GPS coordinates and notes from previous years to my present location. In some cases the trees had distinct impact or comments in notes from previous years. For example, if the tree had been uprooted in 2008 it could not be standing in 2012. The presence/ absence of wire netting provided another means to correctly identify a tree. If a tree had lost a label a new label was hammered into the tree.

Wire condition

The treatment for each tree (netting type or no netting) was recorded and wire condition was noted as the following: fine, tested, rubbed open or up, penetrated, or open from natural expansion of the tree. The wire was considered tested if entry from a tusk was evident but no subsequent bark stripping had occurred. The wire was considered penetrated if entry from a tusk was evident and subsequent bark stripping occurred (Henley, 2013).

Height estimation

In addition to calculating the height and volume with VolCalc (Barrett & Brown, 2012), height of the tree was estimated within the following categories: <1m, 1-2m, 2-

3m, 3-5m or >5m. Height in previous years had been estimated by using a 3-meter pole. In 2012 all field personnel were trained to estimate the height of the tree by people who had originally used the pole method. In addition to the current height of the tree, the height the tree would have been before any damage from elephants occurred was estimated and recorded in the same height categories. For example, if a tree that was taller than 5 meters had been felled by elephants and was now < 1 m tall it would be placed in the > 5 m category for the height before damage and in the < 1 m category for its current height.

Age estimation

An increment bore was used to estimate the age of a subset of the marula species. Only one species was used because of time constraints. An increment bore must be manually inserted into a tree. Therefore, to avoid breaking the bore instrument marula trees were selected because the composition of their bark makes them relatively easy to bore. It was planned to age five randomly picked trees in each of the diameter categories chosen (0 to 9, 10 to 19, 20 to 29, 30 to 39, 40 to 49, 50 to 59, 60 to 69, and 70 cm and up) on each of the main three properties (Vlakgezicht, Sumatra, and Charloscar). When more than five trees were available in a size category, five trees were selected at random using a random number generator. In categories that had less than five samples available, typically 0 to 9 cm and on occasion some of the larger diameter classes all of the samples possible were bored. Trees that were hollow were not bored because they would not provide age information. In addition to Vlakgezicht, Sumatra, and Charloscar, all of the marula on the Ntsiri study site were bored. Unfortunately the increment bore jammed before completion of the sampling process. Charloscar was the only study site where the full sample set was bored. In total 14 trees were bored on Ntsiri, 14 on Sumatra, 38 on Charloscar and 7 on Vlakgezicht after discarding rotten or partial samples. After returning from South Africa, I was denied a permit from the United States Department of Agriculture to import the core samples and the trees could not be aged.

Table A1 Number of wire and unwired trees by property within the APNR in the study of elephant impact in 2012 (M – Marula, K – Knobthorn, FM – False Marula, NW- No wire, W – wire)

	M NW	M W	K NW	K W	FM NW	FM W	Total	Percentage
Charloscar	91	105	134	183	55	28	596	22.3
De Luca	6	11		3			20	0.8
Ntsiri	43	15	26	39			97	3.6
Rock Fig	2	5	2	25			32	1.2
Sumatra	451	485	30	278	107	11	1225	45.9
Vlakgezicht	499	168	117	20	247	11	698	26.2
Total	563	789	309	548	409	50	2668	100

Table A2 Bark stripping and branch breaking classes for elephant impact to trees in the APNR July to December 2012. Adapted from Anderson & Walker (1974) and used by Henley (2013)

Class	Percentage of circumference bark stripped
1	0%
2	<1%
3	1-5%
4	5-10%
5	10-25%
6	25-50%
7	50-75%
8	75-90%
9	90-99%
10	100%

Table A3 Main stem classes for elephant impact to trees in the APNR July to December 2012

Class	Main Stem (MS) Classification
1	No main stem impact
7	MS snapped part way or entirely, recoppice material makes up 2/3 of the tree or more
8	MS still attached part way, tree still alive or recoppice present
9	MS fully snapped, tree still alive or recoppice material present
10	Tree is dead, MS snapped part way or entirely

Table A4 Uprooting classes for elephant impact to trees in the APNR July to December 2012

Class	Uprooted (UR) classification
1	No uprooting impact
6	No roots exposed, tree bending partially over
7	No roots exposed, tree bending all the way over
8	Roots partially exposed, recoppice material present or tree still alive
9	Roots entirely exposed, recoppice material present or tree still alive
10	Tree that has been uprooted and subsequently died

Table A5 The number and percentage of total trees in each category of elephant impact in the APNR, South Africa (Bark Stripping (BS), Branch Breaking (BBA), Main Stem Breaking (MS), and Uprooting (UR))[1]

Impact	Number of trees – No wire	Percentage – No wire	Number of trees- Wire	Percentage- Wire
No impact	74	5.8%	213	15%
BS	321	25%	24	1.7%
BBA	878	69%	894	64%
MS	146	11%	80	5.8%
UR	253	20%	119	8.6%
Total	1281		1387	

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[1] Percentages do not add to 100% since a tree could have more than one type of elephant impact

Table A6 Correlation table for tree characteristics of DBH (cm), height (m), and volume (m^3) for 1674 of the tagged trees showing r^2 values in the left lower corner and p-values in the upper right corner. Height and volume were calculated with the program VolCalc developed by Barrett & Brown (2012).

	DBH	Height	Volume
DBH		<0.001	<0.001
Height	0.64		<0.001
Volume	0.62	0.78	

Table A7 Results of randomization multiple means comparisons of ANOVA comparing trees characteristics (DBH (cm) by species. Distances shown in lower left corner and p-values shown in upper right corner

	Marula	Knobthorn	False Marula
Marula		<0.001	<0.001
Knobthorn	7.09		<0.001
False Marula	5.52	12.6	

Table A8 Results of randomization multiple means comparisons of MANOVA comparing trees characteristics (DBH (cm), height (m), and volume (m^3)) by property. Distances shown in lower left corner and p-values shown in upper right corner

	Charloscar	Vlakgezicht	Sumatra
Charloscar		< 0.001	< 0.001
Vlakgezicht	0.55		0.33
Sumatra	0.60	0.10	

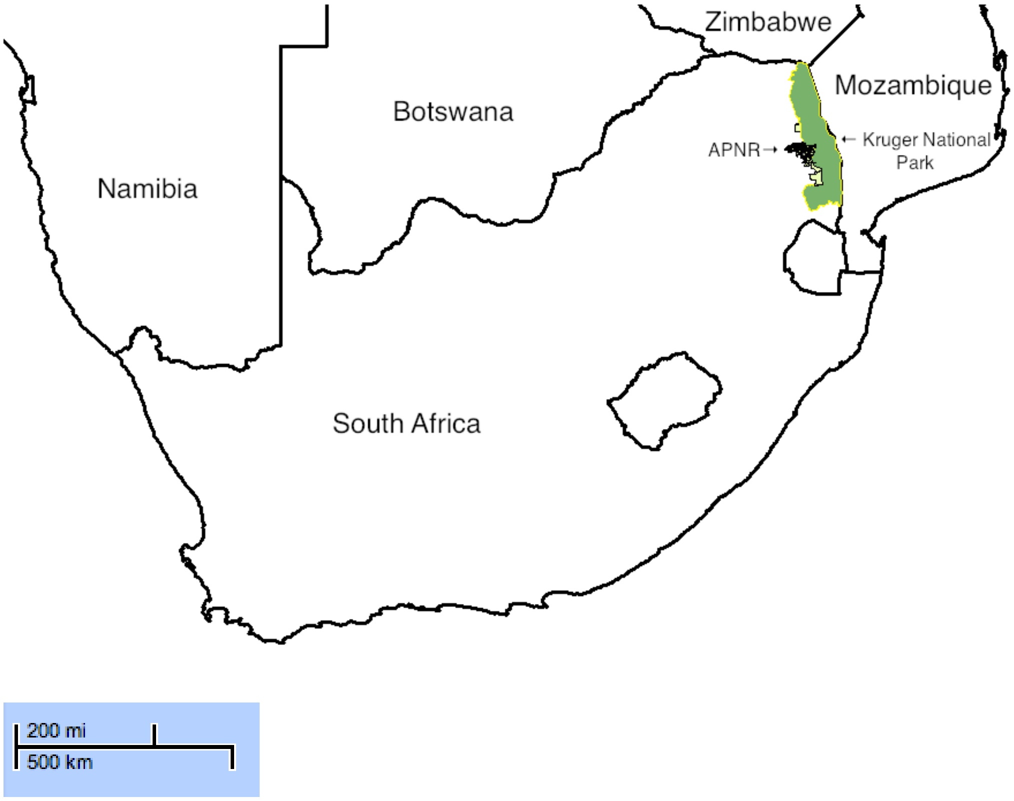

Fig A1 Map of South Africa, highlighting Kruger National Park in green and the APNR in black. Map credit of M. Henley.

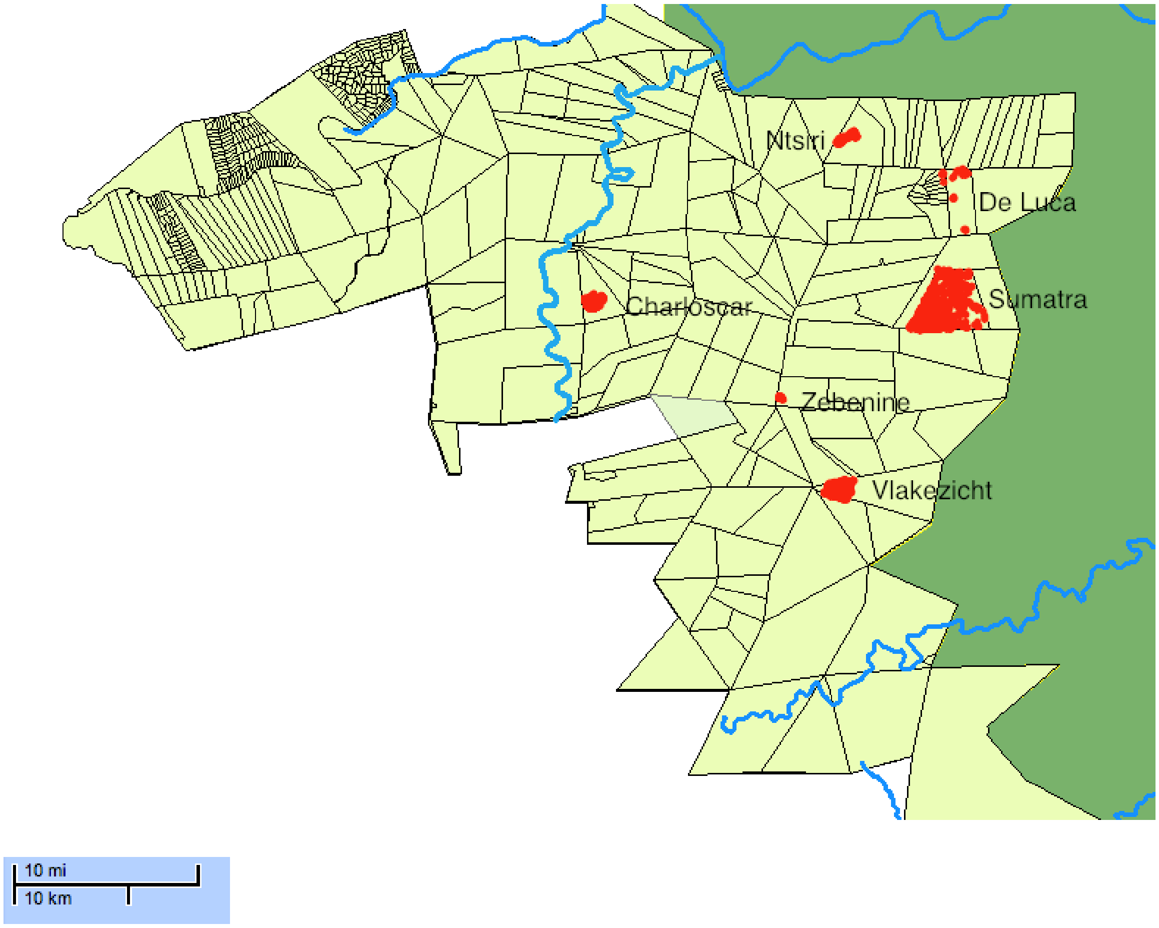

Fig A2 Location of the six study sites within the APNR. Red dots show the relative amount of trees tagged on each property. Kruger National Park is shown in dark green and major rivers in the area are shown. Map credit of M. Henley.

APPENDIX B

Grass Surveys

Introduction

Many studies have assessed the effect of standing trees on grasses, but few have focused on trees felled by elephants. Because of this, I devised methods and completed a preliminary study assessing the quality of grasses found under a felled tree compared to outside of it. I predicted differences in grass height under the canopy of felled trees (henceforth referred to as a “cage” of branches) compared to outside of them. I also predict that herbivores would be excluded from the cage, leading to lower utilization of grasses and creating a unique habitat. Originally, I had hoped to assess grass species composition but since some species had not come into inflorescence by the end of my study I was unable to identify all species. Because of this I focused on guinea grass (*Panicum maximum*) and stinking grass (*Bothriochloa radicans*), two species that are easily recognizable. Guinea grass is a highly valuable grazing grass and an indicator of good habitat, while stinking grass is unpalatable and generally grows in poorer soil conditions (Van Oudtshoorn 1999). I hypothesized that guinea grass would be present in the cage more often than outside of it, indicating a higher soil and habitat quality. On the other hand, I expected stinking grass to be found more in the control areas outside of the down canopy.

Material and methods

Study site

This study was conducted from 1 October 2012 to 16 November 2012 on the Sumatra property, located within the Timbavati Private Nature Reserve in South Africa (Figs. A1 & A2). On the Sumatra property there was dense *Colophospermum mopane* woodland in some areas as well as scattered *Acacia nigrescens* and *Sclerocarya birrea* (Henley, 2007). Soils in the area were generally sandy and tended to have relatively low levels of nitrogen and phosphorous (Treydte *et al*., 2007).

Tree selection

Knobthorn were used for this study because their down canopy branches produce a “cage” structure that protects vegetation within (Fig. B1). In the original study of elephant impact, a total of 325 knobthorns were surveyed on the Sumatra property of which 60 had their main stem snapped or had been uprooted by elephants. Of these, 40 knobthorns were randomly selected for this study.

Grass surveys

Grass surveys began with a pilot study on 1 October 2012 and data were initially collected on 16 October 2012. Transects for the 40 trees were resurveyed twice: two weeks after the initial surveys were completed and one month after the initial surveys. Transects were resurveyed in order to determine growth rates of the grasses within the study period and to identify grass species that had not come into inflorescence at the beginning of the survey. At each tree, two intersecting transects going through the felled tree as well as two intersecting control transects in the opposite direction were surveyed

(Fig. B2). Every 50 cm a stick was placed on the ground and any grass touching the stick was recorded. Grass species were identified according to Van Oudtshoorn (1999) as well as local expertise. At the time of the study, some species were not in inflorescence and thus it was difficult to identify to species. During later surveys these species could often be identified as they inflorescence later into the wet season. In addition to species, the height at the point the grass touched the stick was estimated in the following categories: Class 1 (0 to 25 cm), Class 2 (25 to 50 cm), Class 3 (50 to 75 cm), Class 4 (75 to 100 cm), Class 5 (100-125 cm), and Class 6 (125-150 cm). If the grass was green the highest leaf of the tuft of grass was pulled up vertically and this height was estimated. This method allowed assessment of new growth during the study period. It was often hard to trace a blade of grass back to the original tuft if it was not green and therefore height was recorded where the grass touched the stick.

The grass at each sample point was assessed for consumption by a grazer and was determined to be grazed if five blades of grass or more on the plant were cut horizontally (Treydte, Riginos & Jeltsch, 2010). The ground cover at each point was recorded as follows: grass, bare ground, grass litter, leaf litter, or other such as a forb, tree, or shrub. Mammal dung was identified and recorded when in the transect.

I also noted when the canopy from a neighboring tree (defined as greater than 1 meter high) was shading the study plot from overhead sunlight. The neighboring tree's canopy had to be directly above the sample point to be recorded as having an additional shade effect since trees were surveyed at different times of the day. The number of trees in the vicinity of the felled tree and control area (< 5 m from the center of the cage or control) were recorded. In addition to the number, an estimate of each of the tree's DBH

(0 to 20 cm, 20 to 40 cm, and 40 cm and up), height (<1 m, 1-2 m, 2-3m, 3-5m, and > 5 m) and distance from the center of the cage (<1 meter, 1-5 meters, or > 5 meters) were recorded.

Statistical analysis

Likelihood ratio tests for goodness-of-fit (G-tests) with William's continuity corrections were performed in order to determine if the distribution of height classes differed under the down canopy compared to outside the canopy. These tests were also used to determine if guinea grass and stinking grass were more likely to be found under or outside the down canopy. All assumptions for G-tests were met and a type I error rate of 0.05 was used.

Preliminary results

I found several differences between the area directly under the canopy of the felled tree compared to the area outside of it. The grass height distribution was significantly different in the two areas (G = 220, df = 1, p-value < 0.001) (Fig. B3). Grasses were, on average, slightly taller under the down canopy compared to outside of it. Overall, very little grass was utilized by grazers (1.3%) (Fig. B4). However, of the grasses that were utilized by grazers, 95% were found outside the canopy (Fig. B3). In fact, only 2 of 37 (5%) points located under the cage of the tree were utilized by grazers (Fig. B5). Guinea grass was more likely to be found inside the cage (G = 126, df = 1, p-value < 0.001) (Fig. B6), while stinking grass was more likely to be found outside of the cage (G = 33.4, df = 1, p-value < 0.001) (Fig. B7).

Grass surveys references

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Fig B1 Felled knobthorn (*Acacia nigrescens*) with standing marula in the background

ET_1- Experimental Transect 1- Length of the felled tree + 2 meters
ET_2- Experimental Transect 2- Starting at the middle of the cage right until end of cage + 2 meters
ET_3- Experimental Transect 3- Starting at the middle of the cage left until end of cage + 2 meters
CT_1- Control Transect 1- 180 degrees from ET_1, same length of ET_1
CT_2- Control Transect 2- Starts at same distance away from base of tree as ET_2, same length as ET_2
CT_3- Control Transect 3- Starts at same distance away from base of tree as ET_3, same length as ET_3

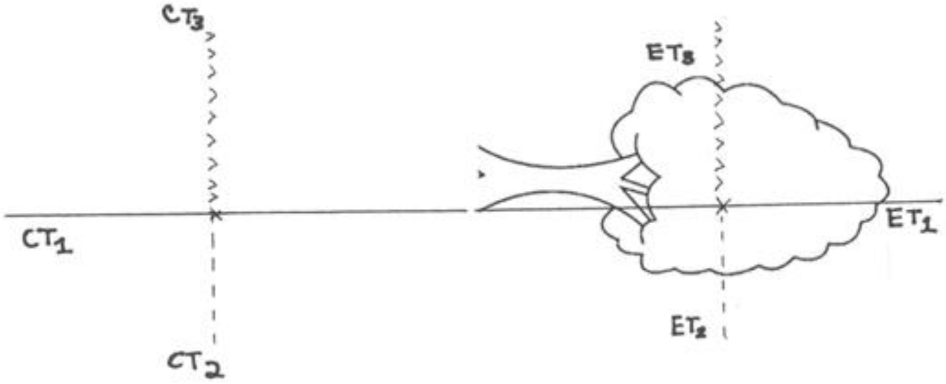

Fig B2 Diagram of transects surveyed in a study of effect of elephant felling in the APNR in October to November 2012

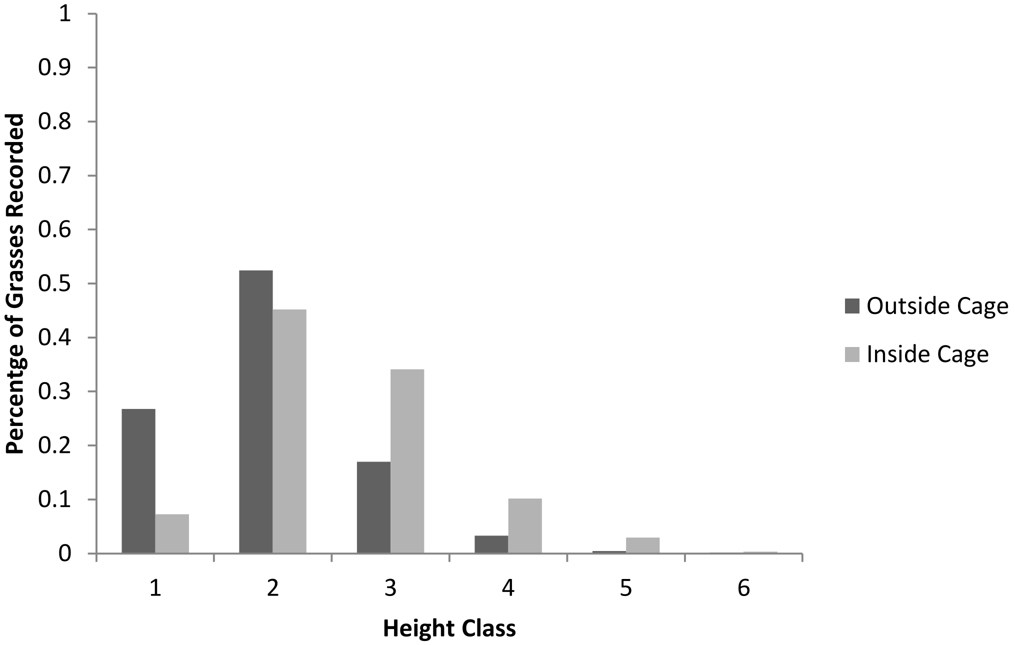

Fig B3 Distribution of grass height classes in a study of the effects of elephant felling in the APNR in 2012 (Class 1 0-25 cm; Class 2 = 25-50 cm; Class 3 = 50-75 cm; Class 4 = 75-100 cm, Class 5 = 100-125 cm; Class 6 = 125-150 cm)

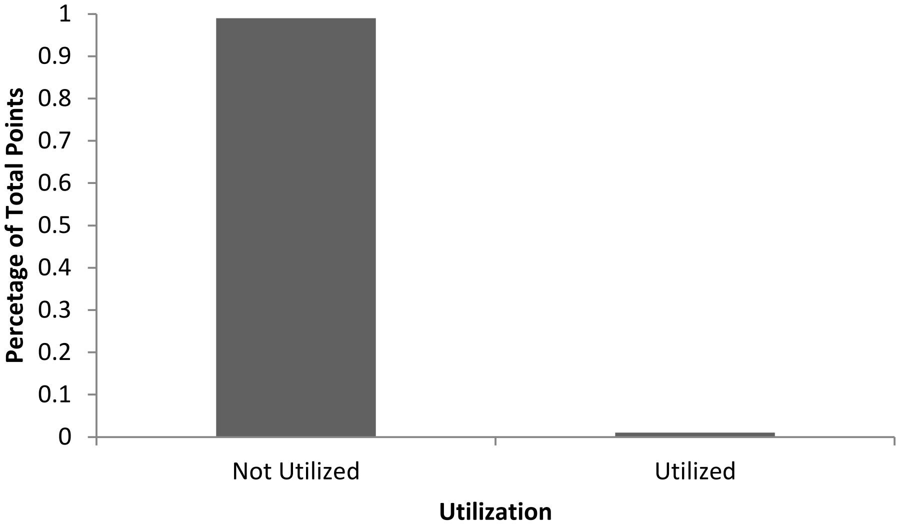

Fig B4 Percentage of grazer utilization inside and outside of the cage in a study of the effects of elephant felling trees in the APNR in 2012.

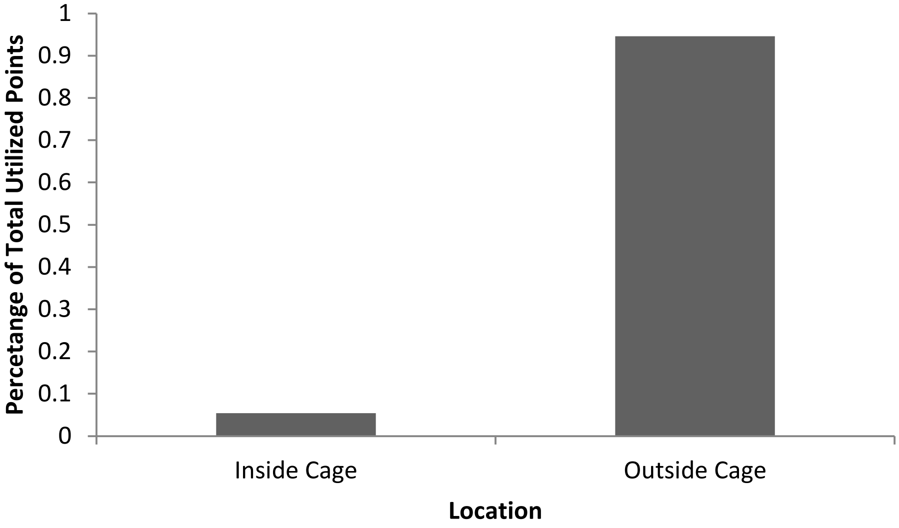

Fig B5 Location of grasses utilized in a study of the effects of elephant felling trees in the APNR in 2012

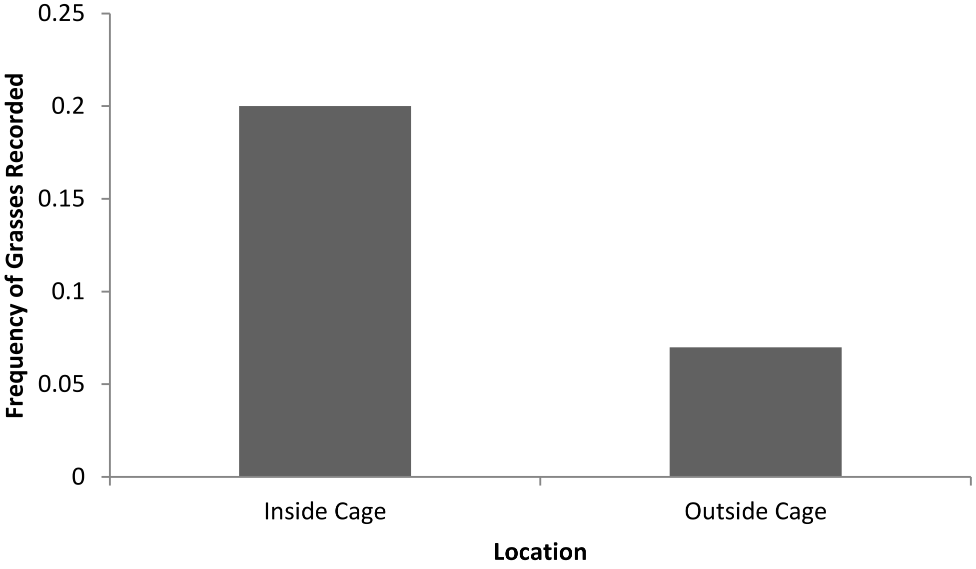

Fig B6 Frequency of guinea grass (*Panicum maximum*) by location in a study of the effects of elephant felling in the APNR in October to November 2012

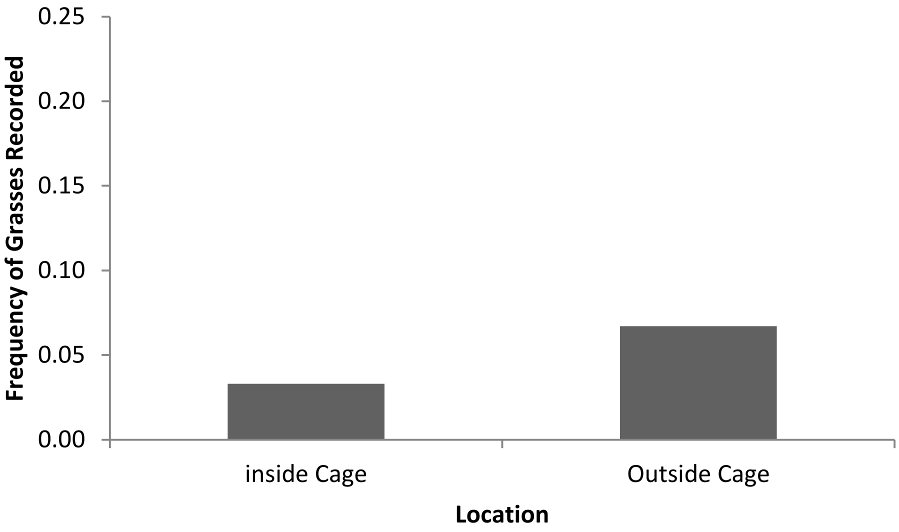

Fig B7 Frequency of stinking grass (*Bothriochloa radicans*) by location in a study of the effects of elephant felling in the APNR in October to November 2012. Y-axis is scaled to 0.25