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Short duration overnight cattle kraaling in natural rangelands leads to increased tree damage by elephants

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Abstract

Elephants are attracted to nutrient hotspots created through short duration overnight cattle corralling (hereafter kraaling) in natural rangelands at Debshan, a mixed cattle-wildlife private ranch in central Zimbabwe, causing severe tree damage. We determined the effect of age of nutrient hotspot (i.e., time after kraal use) on elephant use and the extent of tree damage. Elephant use and tree damage were assessed in nutrient hotspots of varying ages (6, 12, 24, 36 and 48 months after kraal use) and in surrounding landscape. We also compared *Acacia karroo* bark nutrient and soil nutrient concentration between nutrient hotspots (24 months after kraal use) and the surrounding landscape. Elephant use of nutrient hotspots was highest at 12 and 24 months after kraaling. The most severely damaged trees were in the 12-, 24- and 36-month-old nutrient hotspots. *Acacia karroo* bark nutrient concentrations (nitrogen, potassium, calcium, magnesium and iron) were higher in nutrient hotspots than surrounding vegetation, while soil nutrients (nitrogen, phosphorus, calcium and potassium) were higher in nutrient hotspots than surrounding landscape. We concluded that elephants mostly used nutrient hotspots 12 and 24 months after kraaling, while severe tree damage occurred 12, 24 and 36 months after kraal use.

Introduction

African elephant (*Loxodonta africana* Blumenbach 1797) damage is a major cause of tree mortality and exerts selection pressure on preferred species (Abraham *et al.* 2021), such as *Acacias* (alt. *Senegalia* or *Vachelia*) in African savanna ecosystems (Owen-Smith *et al.* 2006). Manipulation of rangelands to create nutrient hotspots with plentiful foraging resources for herbivores could result in selective and repeated elephant damage to preferred tree species leading to their extirpation. For instance, at Debshan ranch in central Zimbabwe, short duration overnight cattle (*Bos taurus*) corralling (hereafter kraaling) is used to create nutrient hotspots (Huruba *et al.* 2017, 2018), which are attractive to both domestic and wild herbivores, including elephants (Huruba *pers. obs.*, Riginos & Grace 2008, Veblen 2013). Livestock, particularly cattle, are considered 'ecosystem engineers' that can be used to create habitat heterogeneity in rangelands (Lipsey & Naugle 2017). However, elephant use of newly created nutrient hotspots and subsequent tree damage has not been studied to better understand the effects of rangeland modification through short duration overnight cattle kraaling. Elephants prefer foraging in nutrient hotspots than surrounding vegetation in search of nutritive forage (Veblen & Young 2010).

Debshan ranch is home to migrant bull elephants from Hwange National Park (HNP) in western Zimbabwe. They immigrate in March and emigrate in November every year. A group of older males (25% of the elephants) goes back to HNP in May and comes back to Debshan ranch in August and then leaves with the rest in November (Huruba *pers. obs.*). The elephants travel a distance of approximately 500 km from HNP to Debshan ranch. The presence of these bull elephants at Debshan ranch is of concern to the management because of the damage they cause to trees, particularly in nutrient hotspots (*alt.* previously kraaled sites). Elephants cause severe tree damage through their feeding in most savanna ecosystems (Morrison *et al.* 2016). They damage trees by breaking stems and branches, bark stripping and/or uprooting the whole tree (Moncrieff *et al.* 2017, Wigley *et al.* 2019). Bark damage could be in the form of ring barking, that is, the stripping of bark around the entire circumference of the trunk or stem (Wigley *et al.* 2019). Elephants use their tusks to gouge trees and then strip bark using their trunks (Vesey-Fitzgerald 1973). Elephants tend to ring bark *Acacia* species leading to high tree mortality (Watson *et al.* 2020). Bark stripping is more pronounced during the dry than wet season as grass quality declines (Owen-Smith & Chafota 2012, Styles & Skinner 2000). At Debshan ranch, the dry season is between May and October, and wet season is from

November to April. The presence of bull elephants at Debshan ranch between March and November leads to high bark stripping.

Elephant use and tree damage is expected to vary with age of newly created nutrient hotspots, due to differing availability of tree foliage. Tree foliage availability is influenced by soil moisture and nutrient concentration among other factors. For example, soil nutrient concentration is relatively high just after kraal use and thereafter declines with time (Huruba, unpublished data). Thus, elephant use and tree damage is predicted to follow soil nutrient trends which influence foliage availability. Short duration overnight cattle kraaling improves water infiltration through loosening the soil and also increases soil nutrient concentration via dung and urine deposition leading to the production of nutritive tree foliage (shoots and leaves) (Huruba *et al.* 2017) and presumably bark. Elephants generally prefer to forage on trees with high shoot and leaf density (Gaylard 2015), making nutrient hotspots targets for increased and repeated foraging, which could lead to severe tree damage. Elephant preferential foraging in nutrient hotspots could modify these sites, for example, from woodlands to shrublands through destruction of large trees (du Toit *et al.* 2014, Holdo 2007). Elephants break mature trees stimulating coppicing that creates shrubland (Dublin *et al.* 1990). Shrubs compete with grass for soil moisture and nutrients leading to a decline in grass biomass, which negatively affect grazing herbivores. The presence of bull elephants that tend to cause more damage to large trees than females (O'Connor *et al.* 2007), at Debshan ranch, could lead to the loss of most large trees, particularly in nutrient hotspots. Elephant use and tree damage in newly created nutrient hotspots of varying ages has not been previously studied.

Elephant tree damage varies with height and diameter, that is, tree size (Abraham *et al.* 2021, Vogel *et al.* 2014). For instance, elephants damage the crown of small trees and severely damage large trees, altering vegetation structure (Thornley *et al.* 2020). Although previous studies have shown that large trees are more vulnerable to elephant damage (Abraham *et al.* 2021, Thornley *et al.* 2020, Vogel *et al.* 2014), there is need for further research to ascertain which tree height and diameter classes are more vulnerable to elephant damage.

Tree bark stripping by elephants is influenced by nutrient concentration (Ihwagi *et al.* 2011). For example, Hiscocks (1999) reported elephant bark stripping as positively correlated with bark nitrogen (N), calcium (Ca) and magnesium (Mg). Improved soil nutrient concentration in nutrient hotspots, presumably, increases bark nutrient concentration leading to increased elephant bark stripping. However, the effect of short duration overnight cattle kraaling on soil nutrient and bark mineral concentration has not been tested. At Debshan ranch, elephants have been observed mostly stripping bark from *Acacia karroo* in nutrient hotspots, presumably, in response to improved bark nutrient concentration (Huruba *pers. obs.*). However, causes of higher bark stripping in nutrient hotspots than surrounding vegetation remain unclear. In this study, we collected bark samples from *A. karroo* in nutrient hotspots (24 months after kraal use) and surrounding vegetation for nutrient analysis. Twenty-four months after kraaling was ideal because bark nutrient concentration would have, presumably, responded to improvements in soil nutrients. During the dry season, bark is rich in protein and minerals translocated from senescing leaves, making it attractive to elephants (Bloom *et al.* 1985). Bark can contribute up to 40% of elephant diets during the dry season (Seloana *et al.* 2018). However, elephant consumption of bark is thought to be determined mostly by shortage of alternative good quality forage rather than to its high nutritional value, particularly during the dry season (Verheyden *et al.* 2006). For instance, O'Connor *et al.* (2007) suggested that bark stripping was a response to nutritional stress. Nutrients (elements) are important constituents of body tissues and therefore need to be consumed in adequate amounts as part of the animal diet. For example, sodium (Na), potassium (K) and Mg are important for buffering pH and osmoregulation, while manganese (Mn), zinc (Zn) and copper (Cu) are major constituents of enzymes (Groenewald and Boyazoglu 1980).

Here we studied the relationship between elephant use/tree damage and age of nutrient hotspots created through short duration overnight cattle kraaling in a savanna ecosystem. In addition, we determined the nutrient concentration of *A. karroo* bark to ascertain if it had an influence on the observed higher elephant bark stripping in nutrient hotspots than surrounding vegetation. Furthermore, soil nutrient concentration was determined to explain the higher *A. karroo* bark nutrient concentration in nutrient hotpots as compared to surrounding vegetation. We hypothesized that i) elephant use of nutrient hotspots and tree damage was influenced by time after kraaling (age of nutrient hotspot), ii) elephant tree damage was influenced by tree height and diameter at breast height (DBH), iii) *A. karroo* bark and soil nutrient concentration was higher in nutrient hotspots (24 months after kraal use) than in surrounding landscape.

Methods

Study site

The study was carried out at Debshan, an 800 km^2 private ranch located in central Zimbabwe (29°13′E, 19°36′S; 1230 m elevation). Rainfall averages 612 mm y^{-1} (average of twenty years) and falls mostly between October and April (Dunham *et al.* 2003). Rainfall for the period 2010 to 2020 ranged from 213 to 1225 mm (Figure 1). Temperatures range between 8.5°C and 31.4°C.

The landscape is gently undulating and covered in yellowish brown, medium- to coarse-grained loamy sands derived from granite and relatively infertile (Frost 1999). On flatter ground, sandy clay loams derived from quartzite or epidiorite are moderately fertile, fine-textured and reddish brown or yellowish red. The vegetation shows a catenal pattern, with most areas consisting of grassed bushland on the more fertile low lying areas and Miombo woodland on the less fertile high ground further away from the drainage system (Dunham *et al.* 2003). The major browse species are *Grewia monticola* Sond., *Terminalia sericea* Burch. ex DC., *Dichrostachys cinerea* (L.) Wight & Arn., *Combretum hereroense* Schinz and *Acacia karroo* Hayne. The dominant grass species are *Hyperthelia dissoluta* (Nees ex Steud.) C., *Hyparrhenia filipendula* (Hochst.) Stapf., *Eragrostis rigidior* Pilg., *Eragrostis curvula* (Schrad.) Nees., *Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult., *Bothriochloa insculpta* (Hochst. ex A. Rich.), *Digitaria milanjiana* (Rendle) Stapf. and *Panicum maximum* Jacq.

Debshan is a mixed ranch with both cattle and wildlife. Cattle are managed as eleven herds, each with an average 350 cattle, by eight herders. Apart from African elephants, wild herbivores found in the ranch include plains zebra (*Equus quagga* Boddaert, 1785), hare (*Lepus capensis* Linnaeus, 1758), warthog (*Phacochoerus africanus* Gmelin, 1788), common duiker (*Sylvicapra grimmia* Linnaeus, 1758), northern giraffe (*Giraffa camelopardalis* Linnaeus, 1758), bushpig (*Potamochoerus larvatus*

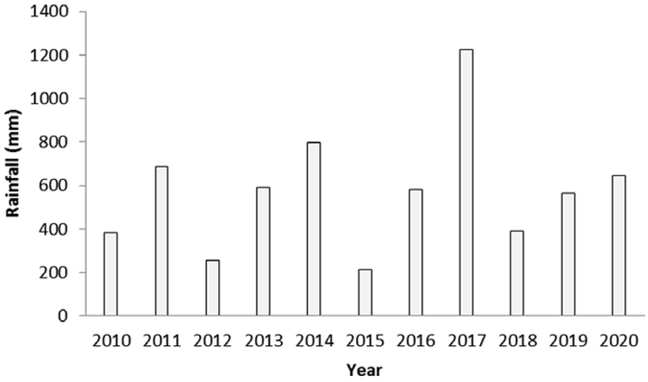

Figure 1. Annual rainfall (mm) for Debshan ranch for the period 2010–2020.

F.Cuvier, 1822), common eland (*Taurotragus oryx* Pallas, 1766), bohor reedbuck (*Redunca redunca* Pallas, 1767), sable antelope (*Hippotragus niger* Harris, 1838), steenbuck (*Raphicerus campestris* Thunberg, 1811), tsessebe (*Damaliscus lunatus* Burchell, 1823) and waterbuck (*Kobus ellipsiprymnus* Ogilby, 1833).

Experimental design

Nutrient hotspots (alt. previously kraaled sites) of five different ages (6, 12, 24, 36 and 48 months after cattle removal) were randomly selected for elephant use and tree damage assessments. All previously kraaled sites measured 70 m × 100 m and quadrats of similar size were marked 500 m from each previously kraaled site to represent surrounding vegetation. Each age group had three replicates. Sampling was carried out in June 2018 in a once-off survey. The short duration overnight cattle kraaling system which created the nutrient hotspots (alt. previously kraaled sites) was introduced to Debshan ranch in 2012 and is described in detail by Huruba *et al.* (2018). A herd of cattle was kept in a kraal (70 m by 100 m) set up in the natural rangelands for seven days before being moved to a new location. The newly created nutrient hotspots are attractive to both domestic and wild herbivores (Huruba *pers. obs.*). The rainfall received during kraal use was as follows: six months after cattle removal (used in 2018) – 391 mm; twelve months after cattle removal (used in 2017) – 1225 mm; twenty-four months after cattle removal (used in 2016) – 580 mm; thirty-six months after cattle removal (used in 2015) – 213 mm and forty-eight months after cattle removal (used in 2014) – 796 mm. The thirty-six- and twelve-month-old previously kraaled sites were used during a drought (213 mm rainfall) and unusually high precipitation (1225 mm rainfall) years, respectively.

Tree damage assessments

Tree species' nomenclature is according to Coates Palgrave (2002). We used the genus *Acacia* rather than the recently proposed *Vachellia* and *Senegalia* as these changes are still being debated. Within each nutrient hotspot (alt. previously kraaled site) and surrounding vegetation, we identified all woody species and assessed elephant damage. The number of individual trees of a species (and genus for *Acacia*, *Combretum* and *Grewia*) assessed and damaged by elephants was expressed as a percentage of all trees assessed and damaged, respectively. Tree damage by elephants was characterized by breaking of branches and stems, uprooting, pushing over, bark striping and scarring of woody species. Thus, tree damage by elephants was also presented according to the five damage categories above. Elephant feeding is distinctive in that they tear off entire branches with their trunks, leaving characteristic scars on damaged stems (Holdo 2003). Tree damage by elephants was assessed per tree in nutrient hotspots (70 m × 100 m) and marked plots (70 m × 100 m) representing surrounding vegetation. Old and new tree breakages by elephants are characterized by grey and yellow coloration, respectively (Ben-Shahar 1993, Nellemann *et al.* 2002). In this study, we recorded tree damage by elephants for the current year, that is, with predominantly yellow coloration. We classified tree damage by elephants into three categories *viz.* no damage, moderate damage and severe damage according to the extent of observed damage. No damage was assigned to trees without any apparent elephant damage, moderate damage for trees with parts of canopy destroyed and severe damage for trees with canopy severely destroyed. For example, a tree with most branches and stems broken, uprooted or with serious bark stripping was considered to be severely damaged. In addition, tree damage by elephants was categorized into five classes *viz.* breaking of branches and stems, total uprooting of trees, bark stripping, pushing over of trees and scarring with individual trees only assigned to one damage category that was the most apparent. For each individual tree within the sampling site; species identity, height (m) and diameter at breast height (DBH, cm) were recorded. Furthermore, we compared the proportion of trees damaged by elephants across all tree species and in each of three height (<1 m, 1–3 m, >3 m) and diameter at breast height (DBH) (<7 cm, 7–20 cm, >20 cm) classes. The number of trees in each category was recorded and expressed as a percentage.

Elephant use of nutrient hotspots and surrounding vegetation

We estimated elephant use by counting dung piles and then crushing them to avoid double counting in nutrient hotspots and surrounding vegetation (control) sites. Dung counts are considered a reliable method of estimating relative animal use of rangelands (Barnes 2001; Young *et al.* 2005; Porensky and Veblen 2015). Elephant dung counts were done in nutrient hotspots 6, 12, 24, 36 and 48 months after cattle removal and surrounding vegetation. The population of elephants from aerial census counts at Debshan ranch during the kraaling period was as follows: 2014 – 174 elephants; 2015 – 198 elephants; 2016 – 217 elephants; 2017 – 223 elephants and 2018 – 231 elephants (Huruba, unpublished data).

Bark nutrient analysis

Acacia karroo bark samples were collected from five trees in previously kraaled sites (24 months after cattle removal) and five trees in the surrounding vegetation for nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), zinc (Zn), boron (B) and iron (Fe) analysis and air-dried prior to transport to the Department of Research and Specialist Services (DR & SS), Harare, Zimbabwe laboratory for analysis. The bark samples were then oven-dried at 60°C for 48 h and ground with a Wiley Mill to pass through a 1 mm sieve. The ground bark samples were then first digested with a mixture of hydrogen peroxide, sulphuric acid, selenium and salicylic acid. About 0.5 g of bark sample was placed in a dry digestion tube. Then 2.5 ml of a digestion mixture (3.2 g salicylic acid in 100 ml sulphuric acid-selenium mixture) was added. The samples were digested for one hour at 110°C, removed, cooled and three successive 1 ml portions of hydrogen peroxide were added to each tube. Heating then continued at 330°C till the colour cleared, and the contents were allowed to cool again. Twenty-five ml of distilled water was then added and mixed until it was saturated with hydrogen peroxide, cooled, topped up to 50 ml with water and allowed to settle before taking clear solutions for element analysis. Nitrogen, K, Ca, Mg, Mn, Cu, Zn, B and Fe concentration was then determined using standard methods (Anderson and Ingram 1993).

Total N was determined calorimetrically. The digested solution was diluted to a ratio of 1:9 (v/v) with distilled water, mixed with 0.5 ml of a reagent (34 g sodium salicylate, 25 g sodium citrate and 25 g sodium tartrate dissolved in 750 ml water plus 0.12 g sodium nitroprusside) and vortexed. Then, 0.5 ml of another reagent (30 g of sodium hydroxide dissolved in 750 ml water; cooled, 10 ml of sodium hypochlorite) was added and topped up to 1000 ml with water and vortexed. Total N absorbance was then read at 650 nm after allowing the mixture to stand for 2 h (Anderson and Ingram 1993).

Potassium, Mg, Ca, Mn, Fe, Cu, Zn and B were determined using an atomic absorption spectrophotometer (AAS). Two ml of digested sample solution was poured into a 50-ml volumetric flask, and distilled water was added up to 50 ml. Potassium concentration was determined using an AAS at 766.5 nm wavelength. Ten ml of digested sample solution was poured into a 50-ml volumetric flask, 10 ml of 0.15% lanthanum chloride added and then flask was topped to the 50 ml mark with distilled water. The flask contents were shaken thoroughly and Ca absorbance read at 422.7 nm in an AAS. Five ml of digested sample solution was poured into a 50-ml volumetric flask and topped up to 50 ml with distilled water. Magnesium concentration was read from an AAS. Similarly, Mn, Fe, Cu, Zn and B concentrations were read from an AAS at 279.5 nm, 248.3 nm, 324.7 nm, 213.9 nm and 249.8 nm, respectively (Anderson and Ingram 1993).

Soil nutrient analysis

Five soil samples each were collected using a 6-cm diameter stainless steel soil auger in randomly selected positions in previously kraaled sites (24 months after cattle removal) and surrounding vegetation. The samples were collected up to a depth of 10 cm. At each sampling location, soil cores were collected in the four cardinal directions (N, E, S and W), bulked, and mixed thoroughly before a composite sample was drawn. Soil was then passed through a 2-mm mesh sieve before air-drying. The samples were then packed in polythene bags and transported to the Department of Research and Specialist Services, Chemistry and Soil Research Institute soil testing laboratory in Harare, Zimbabwe. Soil samples were analysed for N, P, K, Ca and Mg according to Anderson and Ingram (1993). Total N was determined using semi-micro Kjeldahl procedure of acid-digestion, distillation and titration. Available P was estimated by colorimetry using the ascorbic acid–molybdate method. Extractable K, Ca and Mg were determined using atomic absorption spectroscopy.

Data analysis

Data analyses were conducted in SPSS version 23 (IBM Corp., Armonk, NY) using an alpha value of 0.050. The relationship between tree damage and abundance was tested using the Pearson correlation test. The effect of time after kraal use (age of nutrient hotspot), tree height and diameter at breast height (DBH) on tree damage levels (no damage, moderate damage and severe damage) was tested using the chi-square test of independence (Zar 2010). Data on number of dung piles, *A. karroo* nutrient concentration and soil nutrient concentration was tested for the assumptions of normality and homogeneity of variance using Shapiro–Wilk and Levene's tests, respectively. The assumptions of normality and homogeneity of variance were not violated allowing one-way analysis of variance (ANOVA) and the independent *t*-test to be carried out. The effect of time after kraal use on the number of dung piles (proxy for elephant use) was tested using ANOVA. A Bonferroni *post hoc* test was used for multiple comparisons following a significant ANOVA. The relationship between amount of rainfall received during the year of kraal use and the number of elephant dung piles (proxy for elephant use) was tested using the Pearson correlation test. The nutrient concentration of *A. karroo* bark and soil nutrient concentration in previously kraaled sites (24 months after kraal use) and surrounding vegetation at Debshan ranch was compared using the Independent *t*-tests.

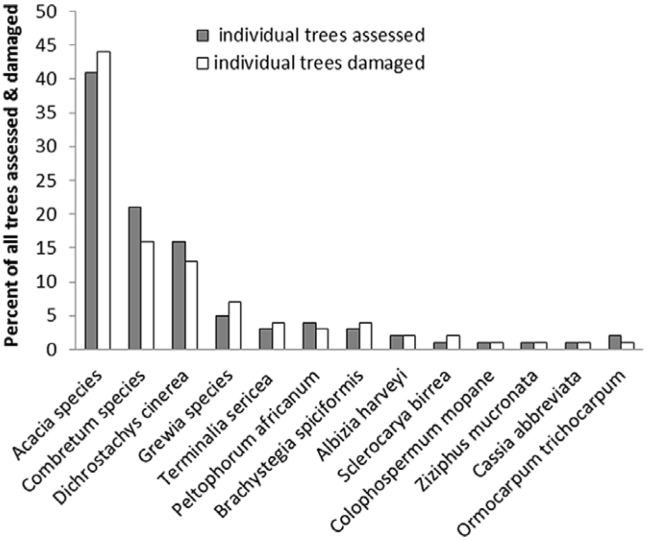

Figure 2. Percent of individual trees assessed and damaged by elephants at Debshan ranch according to tree species.

Results

A total of 1216 trees were examined for damage by elephants in nutrient hotspots (alt. previously kraaled sites) and surrounding vegetation. Data for *Acacia* (*A. karroo, A. robusta, A. nilotica, A. rehmanniana, A. galpinii, A. gerrardii, A. tortilis, A. senegalensis* and *A. nigrescen*), *Combretum* (*C. hereroense, C. molle* and *C. imberbe*) and *Grewia* (*G. bicolor* and *G. flavescens*) were pooled for all the species identified within each genus. *Acacia* species were the most assessed and damaged by elephants (Figure 2). Tree damage by elephants was significantly correlated to their abundance (Pearson correlation coefficient $(r) = 0.99$, $p < 0.001$, $n = 13$). Most undamaged trees were found in the surrounding vegetation and kraaled sites six and forty-eight months after kraal use, while severe tree damage occurred 12, 24 and 36 months after kraal use (Figure 3; $\chi^2 = 27.72$, $df = 10$, $p < 0.001$). Generally, trees were moderately damaged in all nutrient hotspots and surrounding vegetation. Most tree damage occurred through breaking of branches and stems, and bark stripping (Figure 4). Elephant tree damage was influenced by height (Figure 5; $\chi^2 = 217.5$, $df = 4$,

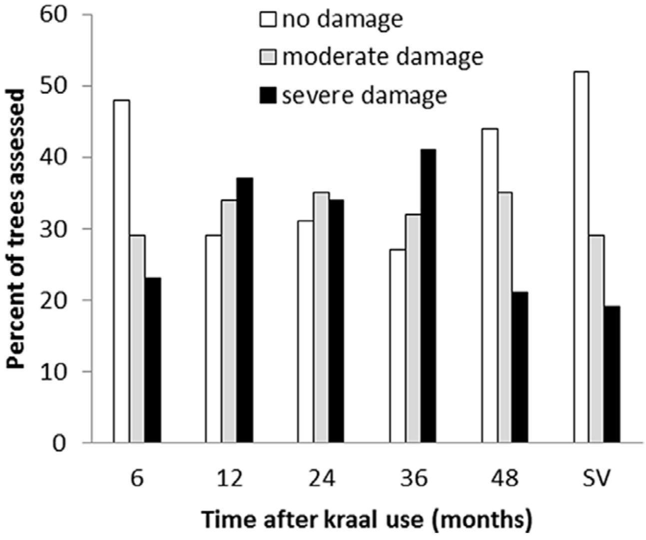

Figure 3. Elephant tree damage in previously kraaled sites of varying ages and surrounding vegetation (SV) at Debshan ranch.

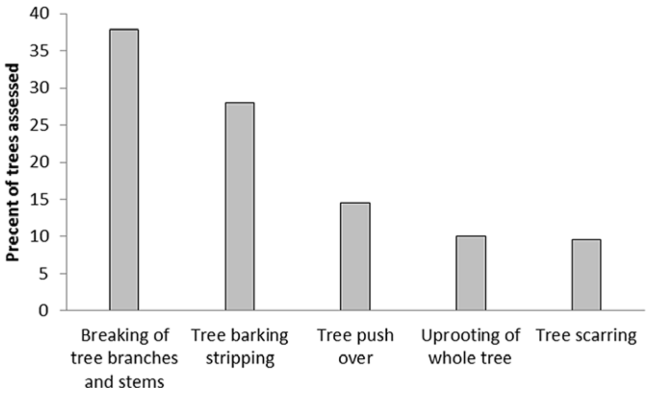

Figure 4. Elephant tree damage at Debshan ranch in five damage categories.

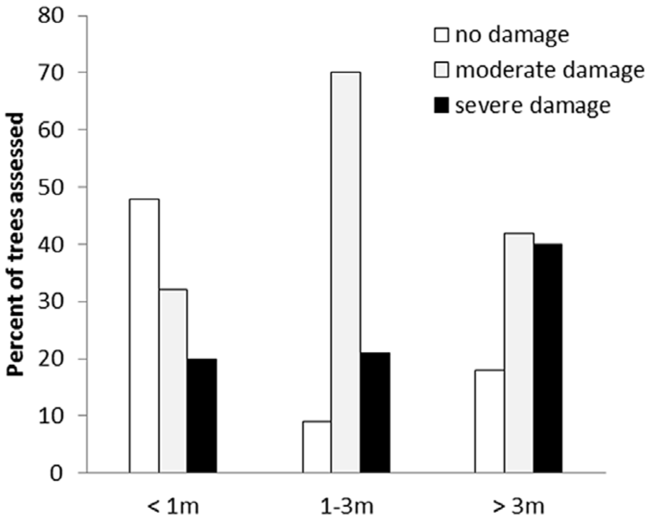

Figure 5. Elephant tree damage at Debshan ranch according to tree height.

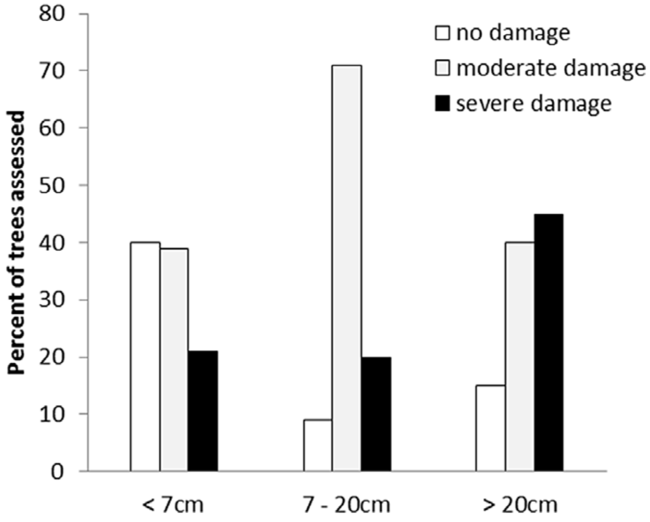

Figure 6. Elephant tree damage at Debshan ranch according to tree diameter.

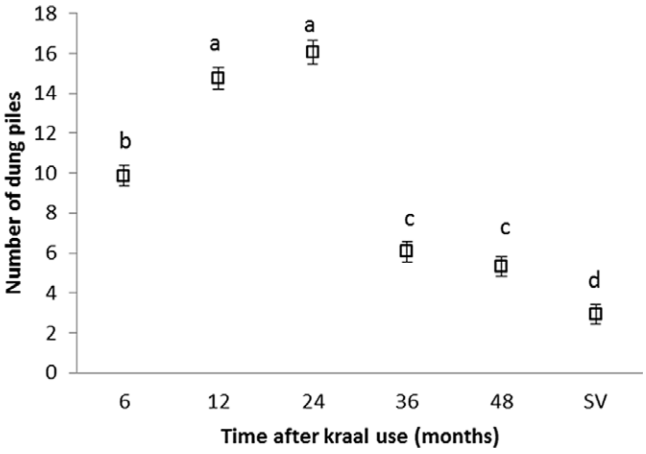

Figure 7. Number of dung piles (mean ± SE) in previously kraaled sites and surrounding vegetation (SV) at Debshan Ranch. Means with the same lower case letters are not significantly different ($p > 0.05$).

$p < 0.05$) and DBH (Figure 6; $\chi^2 = 240.9$, df = 4, $p < 0.05$). The most severely damaged trees were taller than 3 metres and had a DBH greater than 20 cm, while most undamaged trees were in the <1 m height class and the <7 cm DBH diameter class.

The highest number of dung piles (proxy for elephant use) was recorded twelve and twenty-four months after kraal use (i.e., after cattle removal from kraaling sites) and the least in surrounding vegetation (Figure 7; $F_{5,24} = 187.79$, $p < 0.001$). Among nutrient hotspots (alt. previously kraaled sites), elephant use was low six months after cattle removal, peaked 12 and 24 months, and then declined 36 months after kraal use. The amount of rainfall received during the year of kraal use was not significantly correlated to the number of elephant dung piles (proxy for elephant use) (Pearson correlation (r) = 0.44, $p = 0.456$, $n = 5$). Nitrogen, K, Ca, Mg and Fe concentrations of *A. karroo* bark were significantly higher in nutrient hotspots than surrounding vegetation, while manganese, zinc, boron and copper concentrations were similar between nutrient hotspots and surrounding vegetation (Table 1). Soil N, P, Ca and K were significantly higher in nutrient hotspots than in the surrounding landscape, while Mg did not vary with kraaling (Table 2).

Table 1. Nutrient concentration of *Acacia karroo* bark in previously kraaled sites (24 months after kraal use) and surrounding vegetation at Debshan ranch and results of independent *t*-tests

	Previously kraaled sites	Surrounding vegetation	*t*-value	*p*-value
Nitrogen (%)	0.70 ± 0.03	0.58 ± 0.02	8.10	***
Potassium (%)	0.59 ± 0.04	0.46 ± 0.03	8.35	***
Calcium (%)	0.42 ± 0.02	0.34 ± 0.03	5.66	***
Magnesium (%)	0.22 ± 0.04	0.15 ± 0.02	6.34	***
Iron (ppm)	79.00 ± 1.34	56.80 ± 0.86	13.93	***
Manganese (ppm)	7.92 ± 0.24	7.44 ± 0.25	1.41	0.96 (ns)
Zinc (ppm)	17.44 ± 1.01	20.40 ± 1.50	−1.64	0.14 (ns)
Boron (ppm)	22.80 ± 2.31	17.40 ± 1.72	1.87	0.10 (ns)
Copper (ppm)	4.68 ± 0.45	3.46 ± 0.39	2.06	0.07 (ns)

Significance levels are indicated by: ns = not significant, $^{***}p < 0.001$.

Table 2. Soil nutrient concentration in previously kraaled sites (24 months after kraal use) and surrounding landscape at Debshan ranch and results of independent *t*-tests

	Previously kraaled sites	Surrounding landscape	*t*-value	*p*-value
Nitrogen (%)	0.35 ± 0.01	0.16 ± 0.01	13.44	***
Phosphorus (ppm)	11.36 ± 0.52	7.89 ± 0.40	5.31	***
Calcium (me per 100 g)	5.20 ± 0.24	3.27 ± 0.15	6.81	***
Potassium (me per 100 g)	6.20 ± 0.38	3.89 ± 0.30	4.73	***
Magnesium (me per 100 g)	4.21 ± 0.49	4.43 ± 0.44	−0.33	0.749 (ns)

Significance levels are indicated by: ns = not significant, $^{***}p < 0.001$.

Discussion

Short duration overnight cattle kraaling was introduced in 2012, and since then, bull elephant migrants to Debshan ranch continue to increase. Tree damage by elephants was influenced by their abundance, with *Acacia* species the most abundant and damaged. Previous studies have reported elephants as damaging trees in proportion to their abundance (Shannon *et al.* 2008; Strauss & Packer 2015). Overall, *Acacia* species damage was high (44% of total tree damage), in agreement with previous studies (Chafota & Owen-Smith 2009, Gandiwa *et al.* 2011, Thornley *et al.* 2020). The high *Acacia* species damage could reduce its abundance (Owen-Smith & Chafota 2012, Scogings *et al.* 2012, Shrader *et al.* 2012), leading to changes in vegetation composition (Weber 2014). Tree damage by elephants and dung counts (proxy for elephant use) in nutrient hotspots (alt. previously kraaled sites) varied with time after kraal use (i.e., age of nutrient hotspot).

The purpose of setting up short duration overnight kraals in natural rangelands is to improve availability of forage for grazing and browsing large herbivores by creating nutrient hotspots. Forage availability to large herbivores after kraal use is dependent on the season (dry or wet) of kraaling and amount of rainfall. For example, sites kraaled during the wet (rainy) season respond by producing nutritive tree resprouts immediately after cattle removal with no grass growth (Huruba *et al.* 2017), while those kraaled during the dry season remain as bare patches with no resprouting trees until the next rainy season (Huruba pers. obs.). Thus, grass growth on sites kraaled during the rainy season only occurs in the next rain period (approximately 7–12 months later), while in sites kraaled during the dry season grass growth and tree resprouting occurs during the next rains (1–6 months later). The year of kraaling could have legacy effects on amount of grass and tree foliage produced. For instance, kraaling during a drought year and a year with high precipitation could result in low and high plant biomass production in that and subsequent years, respectively. In our study, the 36- and 12-month-old nutrient hotspots (alt. previously kraaled sites) were established during a drought year (2015: annual rainfall received was 213 mm) and a year of unusually high precipitation (2017: annual rainfall received was 1225 mm), respectively. Thus, the 36- and 48-month-old nutrient hotspots (alt. previously kraaled sites) could have been negatively affected by the drought in 2015 in terms of reduced plant growth, while the unusually high precipitation in 2017 may have resulted in increased plant growth in all previously kraaled sites, with the 24- and 12-month-old nutrient hotspots benefitting the most as they still had relatively high nutrient-rich dung deposits. Our results showed that most severely damaged trees were in the 12-, 24- and 36-month-old nutrient hotspots, while the largest elephant dung piles were in the 12- and 24-month-old nutrient hotspots. The high utilization of 12- and 24-month-old nutrient hotspots were, presumably, in response to the legacy effects of the high rainfall in 2017. While the drought in 2015 could have negatively affected plant growth in the 36- and 48-month-old nutrient hotspots leading to their poor utilization by elephants (few elephant dung piles). The high utilization of nutrient hotspots 12 and 24 months after kraal use, presumably, resulted in severe tree damage. Elephants prefer foraging on trees with plentiful foliage (Gaylard *et al.* 2003). These findings have important implications for the use of short duration overnight cattle kraaling in natural rangelands to create nutrient hotspots. The benefits of this innovative practice, in terms of improved grass production (Huruba *et al.* 2018), could be negated by the attraction of elephants to these newly created nutrient hotspots which results in increased tree damage. Consistent with previous studies, most tree damage was in the form of branch and stem breakages and bark stripping (Asner & Levick 2012, Gandiwa *et al.* 2011, Guldemond & van Aarde 2008, Kohi *et al.* 2011, O'Connor *et al.* 2007, Young *et al.* 2021). The higher use of nutrient hotspots than surrounding vegetation and subsequent tree damage was, presumably, due to elephants tracking availability of nutritive forage (Anderson *et al.* 2010, Huruba *et al.* 2017).

Our results showed that tall (>3 m) and thick (DBH >20 cm) trees were more severely damaged than short (<3 m) and thin (<20 cm) trees. Previous studies have reported elephants as severely damaging trees taller than 4 m (Abraham *et al.* 2021, Thornley *et al.* 2020) and having a DBH >30 cm (Vogel *et al.* 2014).

Bark stripping by elephants followed a similar trend to that of severe tree damage with most occurring 12 and 24 months after kraal use (Huruba, unpublished data). Thus, the higher *A. karroo* bark N, K, Ca, Mg and Fe in nutrient hotspots (24 months after kraal use) than in surrounding vegetation, presumably, resulted in the higher elephant bark stripping. Elephants strip bark from trees, particularly *Acacia* species, with high bark N, K and Zn content (Ihwagi *et al.* 2011, Santra *et al.* 2008, Wanderi 2007). *Acacia* bark nutrients, particularly N, remain high throughout the year (Ihwagi *et al.* 2011), making bark attractive for stripping by elephants, especially during the dry season. However, elephants strip bark to meet other requirements. For example, they strip off tree leaves to feed on stems to reduce intake of plant secondary metabolites (Owen-Smith & Chafota 2012). In addition, bark stores water and carries photosynthates making it attractive to elephants (Ryan *et al.* 2014, Wigley *et al.* 2019). Previous studies stated that bark was consumed mainly for its sugar containing phloem tissue (Barnes 1982, Owen-Smith 1988). *Acacia karroo* bark N content of 0.70% in nutrient hotspots was comparable to that of *A. tortilis* (0.70%), *A. gerrardii* (1.04%) and *A. nigrescens* (1.14%) at the Kruger National Park, South Africa reported by Wigley *et al.* (2019). Further studies are required to relate bark nutrient concentration with age of nutrient hotspots and to determine bark nutrient concentration of other tree species.

Our results showed that twenty-four months after kraaling, soil mineral concentration was higher (N – twice; P – 1.4 times; while both Ca and K – 1.6 times) compared to the surrounding landscape. Porensky and Veblen (2015) also reported increases in soil nutrients eighteen months after kraaling. The increase in soil nutrients, presumably, improved *A. karroo* bark nutrient concentration. Wanderi (2007) reported a positive relationship between soil nutrient and bark nutrient concentration. Elephants selectively forage on browse species in nutrient rich patches as compared to nutrient poor surrounding vegetation (Pretorius *et al.* 2011).

Conclusions

Short duration overnight cattle kraaling is an innovative way of creating nutrient hotspots in natural rangelands. However, the attraction of elephants to these nutrient hotspots and severe tree damage, particularly 12 and 24 months after kraal use, creates a dilemma for ranch owners interested in this practice. We conclude that this practice will only be beneficial in rangelands without elephants limiting its use in mixed cattle-wildlife ranches.

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