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Rainfall pattern and nutrient content influences on African elephants' debarking behaviour in Samburu and Buffalo Springs National Reserves, Kenya

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Abstract

The magnitude of debarking by elephants was investigated in Samburu and Buffalo Springs National Reserves. About 1617 plants were monitored for debarking intensities for 6 months spanning through dry and wet seasons. Debarking indices ranged from no debarking at all during the wet months to complete stem girding at the height of the dry season. A negative correlation was found between rainfall and debarking indices. It was hypothesized that nutrient content of the bark influenced the magnitude to which trees were debarked. Bark samples were collected from least, moderate and intensely debarked plants throughout the 6 months. These were analysed for calcium (Ca), sodium (Na), phosphorus (P), magnesium (Mg), potassium (K), nitrogen (N), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn). Significant positive correlations were found between debarking intensity and each of the nutrients N [crude protein (CP)], P, K and Zn. Bark was found to be richest in CP and Calcium. Neutral detergent fibre content was on average 67%. Monthly variations in nutrient composition were minimal. *Acacia elatior*, the most preferred species had significantly higher quantities of each of the four elements N, P, K and Zn than *Acacia tortilis*, the second most preferred woody species.

Key words: elephants, debarking, rainfall, nutrient content

Résumé

Nous avons étudié l'importance de l'arrachage des écorces d'arbres par les éléphants dans les Réserves Nationales de Samburu et de Buffalo Springs. Quelque 1617 plants furent ainsi suivis pendant six mois couvrant saison sèche et saison des pluies. Les indices d'arrachage allaient de zéro pendant les mois de pluie à une mise à nu complète du tronc au pic de la saison sèche. Nous avons trouvé une corrélation négative entre les chutes de pluies et l'indice d'arrachage des écorces. Nous avons émis l'hypothèse que le contenu nutritionnel de l'écorce influençait la mesure dans laquelle les arbres étaient écorcés. Nous avons récolté des échantillons d'écorce de plants les moins touchés, modérément touchés et intensément touchés tout au long des six mois. Ils furent analysés pour leur contenu en calcium (Ca), sodium (Na), phosphore (P), magnésium (Mg), potassium (K), azote (N), fer (Fe), cuivre (Cu), manganèse (Mn) et zinc (Zn). Des corrélations significativement positives furent découvertes entre l'importance de l'écorçage et chacun des nutriments suivants : N (protéine brute), P, K et Zn. Nous avons découvert que l'écorce était surtout riche en protéine brute et en calcium. La teneur globale en éléments pariétaux était en moyenne de 67%. Les variations mensuelles de la composition nutritionnelle étaient minimes. *Acacia elator*, l'espèce préférée contenait des quantités significativement plus élevées qu'*Acacia tortilis*, l'espèce ligneuse choisie en second lieu, pour chacun des quatre éléments N, K, P et Zn.

Introduction

Elephants consistently strip bark from woody species as part of their dietary requirements (Ben-Shahar, 1993). The protein concentration of browse can be up to twice that of grass during the growing season and is more constant over the annual cycle (Dougall, Drysdale & Glover, 1964;

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Barnes, 1982). Protein content in browse materials selected by elephants ranges from 6.7% in the dry season to 10.7% in the wet season (Meissner & Spreeth, 1990). Elephants favour food types that permit a rapid rate of nutrient intake (O'Connor, Goodman & Clegg, 2007). When green grass is less available during drought periods, elephants are forced to increase the consumption of bark earlier in the season when they are relatively the most palatable (Styles & Skinner, 2000). Despite its higher lignin levels, browse offers higher levels and diversity of nutrients (Jachmann, 1989). Large-bodied herbivorous mammals survive on food of lower quality owing to their higher absolute metabolic needs, higher digestive efficiency and lower specific metabolic rate (Belovsky, 1997). Monitoring of Illegal Killing of Elephants programme reveals the two reserves as safe refuges (Kahindi *et al.*, 2009). As elephants lose habitat, it will become more and more important for us to understand their nutritional requirements in the refuges.

Buechner & Dawkins (1961) observed that the most severely damaged trees are the ones for which elephants have developed a predilection; consequently, elephant seek out these trees until they become completely girdled and die within 2 years. Barnes (1982) and Owen-Smith (1988) suggested that bark is consumed mainly for its sugar-containing phloem tissue, as it is most consistently utilized during early spring when sap flow through phloem is most active for flowering or leaf flush. Elephants have been observed to fell trees, sample them for <5 min and then proceed to fell another of similar species and size nearby which they devour for hours (Croze, 1974; Gadd, 2002). Such observations suggest that there exist differences between species and amongst trees of the same species, and elephants can possibly detect those differences through the sense of taste. Mature bark of different species differs largely in chemical and structural composition but their physical structure alone cannot explain preference (Malan & Van Wyk, 1993). Relations between bark consumption by elephants and nutrients in past studies have been inconsistent most of them showing high debarking intensity to be positively correlated with crude protein (CP), calcium or magnesium (e.g. Croze, 1974; Hiscocks, 1999). Despite the knowledge that elephants feed on tree bark in everywhere, studies on the chemical composition of bark as part of elephant's diet are few for most African trees (e.g. Malan & Van Wyk, 1993; Smallie & O'Connor, 2000). Ihwagi (2007) found that elephants in Samburu and Buffalo Springs National Reserves (BSNRs) debark trees selectively and have varying preferences for bark from the different tree species. While theories have been proposed suggesting that selective debarking is a consequence of physiological changes in the elephants and the trees (e.g. Barnes, 1982), the factors underlying bark utilization have not been investigated (Holdo, 2003) save for observations by Gadd (2002) that elephants are able to distinguish desirable trees by the sense of taste. This study investigated the possible influences of rainfall pattern and bark dietary content on foraging behaviour.

Study area

Samburu National Reserve (SNR) and BSNR lie opposite each other at 0°30′N, 37°30′E and are separated by the Ewaso Nyiro River. The area is typically a dry savannah, which is characteristically hot and dry for most of the year with highly variable bimodal rainfall of <400 mm per annum (Jaetzold, 1983). About 90% of the mean annual rainfall occurs in the peak months of April–May and November–December (Barkham & Rainy, 1976). Large migrant animals congregate in the reserves during the long dry season because of permanent availability of green riverine vegetation along Ewaso Nyiro River (Rainy, 1975, in Barkham & Rainy, 1976). Detailed flora and fauna of the reserves have been described by Ihwagi (2007) and Ihwagi *et al.* (2009). To the north of the river is SNR whose surface geology is dominated by ancient basement complex rocks, which consist of horn-blend gneisses and schists, and banded biotite gneisses (Jennings, 1966 in Barkham & Rainy, 1976). Between these are the more or less gently sloping pediments covered with recent deposits of red sand (Barkham & Rainy, 1976). South of the river is BSNRs whose landscape and geology is dominated by tertiary and more recent flows of olivine basalt giving rise to a plateau of poorly structured and excessively drained volcanic soils.

Materials and methods

Rainfall pattern and debarking behaviour

Debarking by elephants was assessed on individual woody plants in 15 one hectare randomly placed plots within the two reserves between October 2006 and March 2007. Ten of the plots were situated along either sides of the Ewaso River. The initial survey involved assessment of debarking intensity, measuring of stem circumferences and mapping out of individual woody plants within the plots using a Garmin 3.2 Global Positioning System (GPS) unit. A GPS enabled HP personal digital assistant (PDA) (h2200 series) with a BC-337 receiver and external AT-65 GPS antenna was used for increased accuracy approximately 2 m where trees were very close to each other. The GPS unit's horizontal position error (accuracy) was approximately 6 metres. Each plot was visited at least twice a month, and additional fresh debarking marks on individual plants were recorded. These wounds dry up and begin changing to pale colour by the next round of sampling. The stem area with maximum bark removed around the circumference was regarded to as 'worst damage height'. The proportion of the stem debarked at worst damage height was rated as a percentage of the circumference according to a six-point indices 0–5 described by Walker (1976) and latter adopted by Ihwagi (2007) each corresponding to the six utilization classes: 0%; 1–25%; 26–75%; 75%; 76–99% and 100%, respectively (Table 1). To avoid bias in the calculation of debarking indices where multiple stemmed trees were utilized to different degrees, the number of stems within each utilization score was multiplied by a weighting factor corresponding to midpoint of the above-mentioned utilization classes and expressed on a scale of 0–1 for ease of averaging. The results were collated every month and used to compute monthly mean debarking index. Mean monthly debarking indices of trees were calculated by averaging the indices of the individual tree damage scored as earlier expressed on a scale of 0–1 corresponding to 0–100% debarking at height of worst damage.

Rainfall data were obtained from a rain gauge stationed at Save the Elephant's Research Camp situated within the study area. Pearson's correlation was used to test whether monthly mean debarking indices varied with monthly rainfall.

Bark sampling

For the purpose of bark sampling, the six indices mentioned earlier were simplified into three levels of debarking. These were as follows: (i) the less debarked or avoided corresponding to the categories 0 and 1; (ii) moderately debarked corresponding to the categories 2 and 3; and (iii) heavily debarked corresponding to the categories 4 and 5. Bark sampling regime targeted to collect six samples every month from trees suffering each of the three debarking levels, for 6 months. Routine fortnightly visits were made to the each of the plots when debarking activity was assessed. When more trees were debarked than could be sampled, their location marks in the GIS database were noted and a random set picked from a hand held GPS enabled PDA loaded with Arcpad 7.0. A bark sample of approximately 15 g was collected from the loose debris remaining from the elephants' wasteful feeding. To collect a sample from a less debarked or avoided tree, a sharpened 2.5×2.5-cm square metal tube was gently hammered onto the stem and three pieces gouged out. A vertical alignment was adopted to keep damage on the bark's translocative tissues minimal. For trees with greater debarking indices, loose remnants of elephants' feeding behaviour were collected. If necessary, the dry collenchymatous tissue was sloughed off first with a machete as elephants were observed to meticulously devour inner live tissues often leaving behind a heap of the dry tissues. Bark samples were transported to the laboratory for oven drying and further processing for analysis of nutrient composition.

Laboratory analysis of nutrient content

Nutrient content of the bark samples was analysed at Kenya Agricultural Research Institute laboratory in Nairobi. Each of the bark samples was analysed for total calcium (Ca), sodium (Na), phosphorus (P), magnesium (Mg), potassium (K), nitrogen (N), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn). Bark samples were oven-dried, ground and digested with a mixture of hydrogen peroxide, sulphuric acid, selenium and salicylic acid. The content of each of the nutrient elements were

Table 1 Description of bark damage assessment criteria, utilization classes and weighting factors

Category	Description of damage assessment	Utilization class	Weighting factor
0	No clear damage	0%	0.00
1	Up to 1/4 bark debarked at worst height	1–25%	0.13
2	1/4 to 3/4 debarked at worst height	26–74%	0.50
3	3/5 debarked at worst height	75%	0.75
4	Total ringing somewhere at worst height	76–99%	0.88
5	Total barks stripping all the way around and up main stem	100	1.00

determined using standard methods described by Anderson & Ingram (1989). Nitrogen content was primarily recorded as per cent, and CP was calculated from total nitrogen by multiplying by 6.25 (Kane, 1987). The expected set of 18 samples from plants under each of the three utilization levels was not attained in all months except for March. Nutrient detergent fibre (NDF) was analysed in these 18 samples as an indication of the overall indigestible proportion of bark.

Statistical analysis

Data were analysed using SYSTAT 9.0 (SYSTAT, 1998). ANOVA was used to test whether there were significant differences in the debarking intensities and nutrient composition between the months. Bonferroni adjustment was used to determine the sources of differences. Laboratory measurements of nutrient content were normalized by log transformation $[X' = \log(X + 1)]$ before applying parametric analysis because some of the values were very small. Hypotheses were tested at $\alpha = 0.05$. The nonparametric Mann–Whitney test with tied ranks was used to determine whether there existed differences between the two most abundant and also highly preferred species, *Acacia elatior* Brenan and *Acacia tortilis* Hayne with respect to each of the four nutrient elements that had significant positive correlations with debarking intensity: N, P, K and Zn. Ihwagi *et al.* (2009) had found these two species to be the most preferred. A nonparametric test was preferred because the differences between the two samples' sizes (*A. elatior* = 38, *A. tortilis* n = 27) were over 10% (=28.9%), and the smaller variances were associated with the larger sample; the latter of which would compromise the robustness of *t*-test (Ramsey, 1980). Considering that the smaller sample size exceeded 20, the normal approximation to the Mann–Whitney test was employed in this analysis and the Z-statistic calculated (Zar, 1996). Pearson's correlation was further used to test whether debarking intensity was correlated with each of the mineral elements analysed in the bark samples. Student's *t*-test was used in evaluating the significance of the correlation coefficient *r* at $\alpha \leq 0.05$ (Zar, 1996). One-way ANOVA was used to test whether the proportion of NDF in bark samples varied in the three sets of six bark samples collected for each of the three debarking levels.

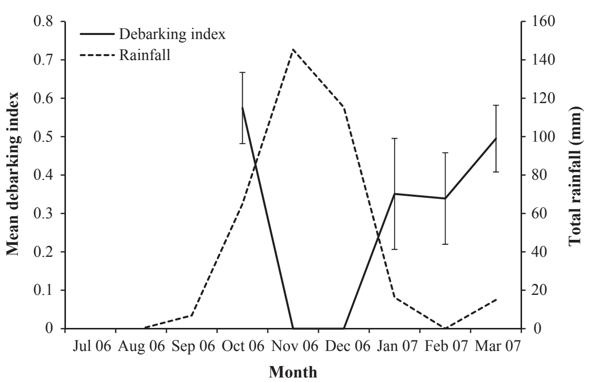

Fig 1 Monthly mean debarking indices (±SE) of trees (n = 1617) and monthly rainfall July 2006–March 2007

Results

A total of 1617 woody plants from 14 species were recorded. Of these, 1373 individuals were within the 10 riverine plots and the rest in plots away from the river. There was a marked inverse relationship between rainfall and debarking (Fig. 1) ($r = -0.745$). Debarking was least during the wet months of November and December. In October 2006, incidences of complete ring debarking were encountered and the highest mean monthly debarking indices of 0.6 (60%) was calculated.

The monthly target of six bark samples per utilization score was not attained in all months as the debarking incidences, and their intensities varied with some months exhibiting no debarking at all. A total of 67 bark samples were collected as opposed to the expected possibility of 108. These were from *A. elatior* (n = 38), *Acacia tortilis* (n = 27) and *Prosopsis chilensis molina* (n = 2). *Acacia elatior* and *A. tortilis* are the most preferred of the woody species in Samburu and BSNRs (Ihwagi, 2007). The two samples from *P. chilensis* were considered in the evaluation

Table 2 Coefficients of correlation between debarking intensity and the content of various mineral elements in 67 bark samples

Nutrient	*r*	Significance
N	0.575	Significant
Na	0.067	Not significant
P	0.310	Significant
K	0.336	Significant
Mg	−0.143	Not significant
Ca	−0.071	Not significant
Fe	−0.391	Significant
Zn	0.445	Significant
Mn	−0.060	Not significant

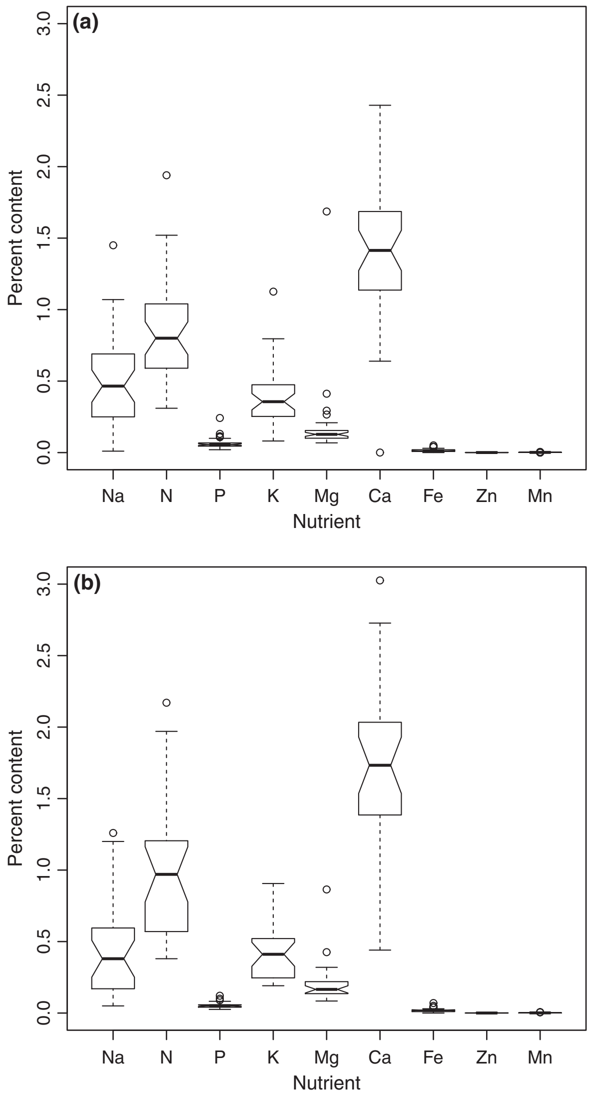

Fig 2 (a) Box plot of average content of various nutrients in 38 bark samples from the *Acacia elatior*. (b) Box plot of average content of various nutrients in 27 bark samples from the *Acacia tortilis*

of debarking indices versus dietary content but excluded in detailed analyses of temporal trends and species differences.

The monthly levels of debarking indices varied significantly from October 2006 to March 2007 ($F_{0.05\ (2)\ 5,\ 61}$ = 4.13, P = 0.003) (Fig. 1). Significant positive correlations were found between debarking intensity and each of the nutrients N (CP), P, K and Zn (Table 2). Elephants prefer bark of *A. elatior* more than *A. tortilis* (Ihwagi, 2007). The two species differed significantly in nutrient content with respect to N, P, K, Na, Mg, Mn and Zn (Z = 0.82, $P < 0.05$). Generally, the bark of *Acacia* spp. is rich in CP, Ca and Na (Fig. 2a,b). CP was the highest dietary content of all nutrients analysed for all 67 samples accounting for 5.7 ± 0.33 (SE) %. Considering total nutrient content of bark in general, there were only minimal monthly variations in nutrient content ($F_{0.05\ (1)\ 5,\ 61}$ = 2.94, P = 0.02). Monthly fluctuation of CP in particular was insignificant ($F_{0.05\ (1)\ 5,\ 61}$ = 1.763, P = 0.134). Only trace quantities of Cu were recorded.

The target of six samples from each of the three debarking level was attained only in March 2007. On this complete batch of samples, we analysed for NDF as a general indication of the digestibility of bark. The proportion of NDF varied from 60.0% to 80.14% with a mean of 67.42 ± 1.57 (SE) %. There was no significant difference in NDF content within the bark samples from plants under the three levels of debarking ($F_{0.05\ (1)\ 2,\ 15}$ = 0.841. P = 0.451).

Discussion

Debarking is a major concern for wildlife managers of protected areas in savannah ecosystems (Ruess & Halter, 1990; Ben-Shahar, 1996). Ihwagi (2007) established that elephants in Samburu and BSNRs are selective of the most abundant *A. elatior* trees. The exceptionally extensive debarking and subsequent death of mature trees raised a concern for the reserve managements and were highlighted in the recently adopted general management plan (SICA 2010). Such concern was raised around Lake Manyara, the Seronera woodlands and Sahelo-Soudanian region by Vesey-FitzGerald (1973), Ruess & Halter (1990) and Pamo & Tchamba (2001), respectively. Croze (1974) noted that from *Acacia* trees, the woody material ingested outweighs foliage. The riverine vegetation in Samburu and BSNRs offers a critical lifeline for a large breeding population of over 900 elephants (Wittemyer, 2001; Wittemyer *et al.*, 2005). Large grazing mammals must exploit a nutritional environment that is complex in composition and varies temporally and spatially with respect to density of nutrients and the nutritional value (McNaughton & Georgiadis, 1986). The nitrogen content of a plant is one of the many plant characteristics that are vitally important to herbivores (Mattson, 1980). Georgiadis & McNaughton (1990) noted that the quality of grass declines steadily as leaves age over the growing season. The barks of *Acacia* spp. forage were observed to exhibit only minimal temporal variations in the contents of most nutrient elements and relatively constant in CP content, making them an ideal source of nutrition for the elephants especially at critical times of the year when other forage items are not readily available. The influence of bark chemistry on foraging behaviour was confirmed as elephants fed extensively on the bark from plants with relatively higher quantities of CP, phosphorus, potassium and zinc.

McCullagh (1969) and Maplas (1977) found that the per cent CP in the stomach contents of elephants sampled during the dry season to be less than half that of the wet season value and suggested that the diet may be deficient in protein in the dry season. Despite its relatively low quantities, total N had a strong positive correlation with elephants debarking intensities in this study implying the elephants heavily relied on the bark as a source of nutrition in the dry months. McCullagh (1969) estimated the daily digestible protein requirement for a young growing elephant with a body weight of 1000 kg to be approximately 0.3 kg and that would require a mean of 6% CP in the food eaten. Incidentally, this is what the bark of *Acacia* spp. trees sampled in this study contained, 5.8 ± 2.64% protein. Therefore, the bark of *A. elatior* and *A. tortillas* could represent one of the richest sources of CP amongst other browse items.

Phosphorus is a constituent of the plant cell nucleus and plays an important part in cell division and development of meristematic tissues. Bark samples collected in this study had twice the amount of phosphorus found in *A. elatior* sampled from various other sites in Kenya by Dougall *et al.* (1964). Dougall *et al.*'s (1964) detailed analysis of Kenyan forage items from various other sites across Kenya showed that the average phosphorus content of leguminous browse is less than that of grasses. Sixty-five, 68 and 67% of the records of grasses, leguminous browse and nonleguminous browse, respectively, are distributed between 0.5% and 0.25% phosphorus while for the nonbrowse legumes, over 70% of the records are distributed between 0.15% and 0.35% phosphorus in the dry matter. These findings place the recorded mean of 0.06% phosphorus content in this study on the lower level compared with other forage items. As the bark of *Acacia* spp. is relatively not a rich source of phosphorus, it begs the question: are elephants limited in dietary phosphorus supply in the study area, to an extent of gleaning the little they can find from nutrient poor sources like the bark of *Acacia* spp.? Alternatively, elephants select the bark from *Acacia* spp. primarily for other nutritional constituents like CP. Hence, selection for phosphorus in particular may be compounded by the presence of other sought after nutrients. Further studies on the nutritional ecology of the herbivores in the ecosystem are warranted. Elephant populations in which the seasonal pattern shows an increasing proportion of bark being consumed during the early dry or even wet seasons is likely to be experiencing nutritional stress (O'Connor, Goodman & Clegg, 2007).

Large generalist herbivores such as elephants face a limit on how much material they can digest (Westoby, 1974). If elephant diet selection is largely driven by the necessity to meet a nutritional need, their response to availability of particular foods should show some level of forage preference. As a desired nutrient component becomes rarer in a plant community, grazing pressure on rich forage items would increase, at least until the necessary quantities are ingested. That debarking was minimal or completely absent in the wet periods suggests that the foraging behaviour changed from grazing as grass senesced to debarking until other forage items were available in the next wet season. O'Connor, Goodman & Clegg (2007) noted that foraging opportunities for elephants are compromised at a critical time of the year which forces them to rely on dry land browse earlier in the season and for a greater duration. That positive correlation found between various nutrients in relatively low quantities and debarking intensities on sampled trees suggests that the elephant population in the reserves and the wider ecosystem are most likely under nutritional stress, at least during the dry season.

This study brings us closer to understanding elephants' ability to detect minute quantities of nutrient elements. The systematic recording of various levels of debarking coupled with bark sampling and nutritional analyses by Ihwagi (2007) provided a platform to analyse what could be driving elephants selective debarking reported earlier. This individual-plant centred nutrient analysis is a step towards understanding the influence of the physiological changes of both elephants and trees on the debarking behaviour as proposed by Barnes (1982). Additional studies on tree population dynamics and physiological changes in trees and elephants because of seasonal effects would lead to a better understanding of the feeding ecology of the elephants.

Elephants' dependence during the dry season (with all associated impact) on the riverine woodland is fully appreciated by the reserves' managements. The 2010–2020 Samburu-Isiolo Conservation Area (SICA) general management plan identifies debarking as one of the major threats to the reserves. Although the national reserves are under a laisser-faire system, urgent human interventions are imperative to save the core habitat. Vollrath & Douglas-Hamilton (2002) established that elephants avoid feeding on acacia trees with beehives. Further studies (I. Douglas-Hamilton pers. comm.) have demonstrated that wire netting of mature tree stems limits elephants' success in their debarking attempts. These two measures should to be exploited to protect selected mature trees and ensure the seed bank is not depleted for regeneration. One of the identified information gaps for the implementation of the 2010–2010 SICA management plan is an accurate vegetation map. The study highlights the importance of a detailed vegetation map, because the only available one is a from very low resolution study by Barkham & Rainy (1976). This shall improve our understanding of the relative importance of particular vegetation types to elephants and serve as a reference to the managements in defining elephant exclusion zones.

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