African Journal of Ecology

Elephant (*Loxodonta africana*) impact on trees used by nesting vultures and raptors in South Africa

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Abstract

Negative influences on the establishment and persistence of large trees used by tree-nesting birds as nesting sites represent a potential threat to vultures and raptors. We monitored large trees and their surrounding vegetation and analysed whether trees with nesting sites are at risk due to elephant impact. Trees with nests did not differ in elephant impact from control trees without nests, and the survival rates of trees with nests and the actual nests within the trees showed that nests decreased at a faster rate than the trees themselves. Elephant damage did not affect the persistence of nests over the 5-year monitoring period. However, the presence of insects and fungus on large trees was negatively related to tree survival, thereby indicating that elephant impact could indirectly facilitate insect and fungus attack and shorten the lifespan of a tree.

Key words: Acacia nigrescens, African elephant, bark stripping, nesting trees, raptor, vulture

Résumé

L'influence négative des oiseaux qui utilisent les arbres pour y faire leur nid sur le recrutement et la persistance de grands arbres fréquentés constitue une menace potentielle pour les vautours et autres rapaces. Nous avons suivi de grands arbres et la végétation qui les entoure et nous avons vérifié si les arbres avec sites de nidification couraient plus de risques à cause de l'impact des éléphants. Les arbres avec nids ne différaient pas des arbres contrôle sans nid pour ce qui est de l'impact des éléphants, et le taux de survie des arbres avec nids et des nids eux-mêmes dans ces arbres montrait que les nids diminuaient à un rythme plus rapide que les arbres. Les dommages causés par les éléphants n'ont pas affecté la persistance des nids pendant les cinq années de suivi, mais la présence d'insectes et de champignons sur les arbres était liée négativement à la survie des arbres, ce qui indique que l'impact des éléphants pourrait faciliter indirectement les attaques d'insectes et de champignons et raccourcir la durée de vie des arbres.

Introduction

Elephants are known ecosystem engineers, capable of altering landscapes by reducing plant biomass, changing species composition and increasing landscape patchiness (White & Goodman, 2009). The ability of elephants to transform landscapes is of major concern in elephant-dominated areas (Herremans, 1995; Boundja & Midgley, 2010; Kalwij *et al.*, 2010), as the impact of elephants on the vegetation could have negative consequences for species that require a particular vegetation structure (Skarpe *et al.*, 2004; Pringle, 2008; Valeix *et al.*, 2008). Increased elephant densities are related to severe declines in large tree abundance (Shannon *et al.*, 2008; Kalwij *et al.*, 2010). Tree damage by elephants is caused by browsing, breaking of branches, debarking (Calenge *et al.*, 2002; Shannon *et al.*, 2008; Nasseri, McBrayer & Schulte, 2011) and by tree uprooting (Shannon *et al.*, 2008; White & Goodman, 2009;

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Nasseri, McBrayer & Schulte, 2011). Debarking makes trees more susceptible to other damages such as fires (Ihwagi *et al.*, 2010) and diseases and can even cause direct mortality (White & Goodman, 2009). It also makes the tree more susceptible to termites (*Coptotermes* species), wood-borers (*Cerambycidae* species) or other insect activity, shortening the trees' lifespan (Hatcher, 1995).

Hence, an increasing elephant density could negatively affect the availability of potential nesting sites of large tree-nesting species, such as raptors (referring to hawks and eagles in this paper) and vultures, causing concern for the decline in the population numbers of raptors and vultures due to increasing elephant numbers (Monadjem & Garcelon, 2005; Henley *et al.*, 2008). For instance, both the loss and formation of nesting sites for the Southern Ground Hornbill (*Bucorvus leadbeateri*) are affected by elephants (Morrison & Kemp, 2005). Henley & Henley (2005) however found that elephants preferentially used trees with smaller stem diameters and of different species than those preferred by Southern Ground Hornbills as nesting sites, with the exception of common marula trees (*Sclerocarya birrea*) preferred by both animals, indicating that elephant impact on large trees might not negatively affect the availability of potential nesting sites for the southern ground hornbill (Henley & Henley, 2005; Morrison & Kemp, 2005). Moreover, elephants could even facilitate the availability of potential nesting sites, by creating cavities when breaking primary branches (Henley *et al.*, 2008; Pringle, 2008). However, both elephants and vultures, like the white-backed vulture (*Gyps africanus*; Ferguson-Lees & Christie, 2001), positively select knob thorns (*Acacia nigrescens*) as food resource and nesting sites, respectively, and hence, elephant impact to these trees could decrease their suitability as nesting sites (Henley *et al.*, 2008). Shannon *et al.* (2008) showed that in Kruger National Park, signs of elephant utilization were present on more than half of the knob thorn trees (>5 m) and on 75% of the marula trees, both known vulture and raptor nesting trees. Managers of conservation areas are therefore concerned about the impact of elephants on marula and knob thorn trees, which could negatively affect the availability and suitability of nesting sites for large tree-nesting birds (Henley & Henley, 2007). The ultimate question is whether elephants have an impact on vulture and raptor populations, and in this paper, we therefore investigated whether elephants affected the availability, suitability and survival of their nesting trees. We tested whether elephant impact on nesting sites of vultures and raptors influenced the persistence of their nests. We also recorded the size class distribution of woody species in proximity to nesting sites and studied the elephant impact on the different height and diameter classes. We tested the hypothesis that the intensity of elephant impact on a tree affected the probability that the tree contained a vulture or raptor nest. Subsequently, we tested whether there was a difference in choice of nesting sites between vultures and raptors. Finally, we examined whether the intensity of elephant impact determined the probability of abandoning a nest.

Material and methods

Study site

Trees were monitored in the Klaserie Private Nature Reserve (KPNR), centre at 24.302° south and 31.179° east as part of the Associated Private Nature Reserves, bordering Kruger National Park, South Africa. The dominant vegetation types were knob thorn and red bushwillow (*Combretum apiculatum*) open woodland or mopane (*Colophospermum mopane*) woodland.

Field methods

We visited 100 large trees with nests, of which 95 trees were revisited annually since 2008 and five were new additions in 2011 (totalling 95 knob thorn and five leadwood, *Combretum imberbe*, trees). The diameter breast height (DBH) of these trees was between 34 and 127 cm and height ranged from 8.8 to 18.4 m. In 2012, we also studied 185 knob thorn control trees: trees without nests in close proximity to the trees with nests, with a DBH of at least 34 cm and/or a minimum height of 8.8 m. During this survey, we also studied three trees that we did not find in 2011, which we included in some of our data analyses when appropriate, as data on these trees were incomplete.

The 95 revisited trees were located by GPS coordinates. Of these trees, we examined the current state of elephant impact of which we recorded: type of impact, impact intensity, impact age, whether the tree was dead or alive, according to the methods used by Henley & Henley (2007) and Rode (2011). We distinguished between four elephant impact types: bark stripping (BS), broken primary branch (BPB), main stem broken (MS) and pushed over (PO). We recorded the impact intensity class on a scale of 10 (1 = no impact, 2 = <1%, 3 = 1–5%, 4 = 5–10%, 5 = 10–25%, 6 = 25–50%, 7 = 50–75%, 8 = 75–90%, 9 = 90–99%

and 10 = 100%) and determined the age of the impact (<1 month, <6 months, <1 year, >1 year). We recorded whether there was a nest present and whether it was active, that is presence of bird or fresh bird droppings. We also recorded whether shelf fungus (phylum *Basidiomycota*), termite (*Coptotermes* spp.) or other insect activity was present. Shelf fungus is recognized as shelf-like structures, termite damage by red tunnel-like structures (5 mm in diameter), whereas other insect damage showed as holes into the inner bark.

To study the effect of tree height and DBH on elephant impact, we measured the stem circumference and height of all knob thorn, leadwood, tamboti (*Spirostachys africana*), marula and apple leaf (*Philenoptera violacea*) trees in a 20 m radius around the main stem of each large tree with a nest and recorded the elephant impact on these trees. These tree species are known to be used by vultures and raptors as nesting sites within the KPNR and thus potential nesting trees. We measured the height of each tree using a height measurement pole of 4 m length. The stem diameter was measured at a distance of 50 cm from the ground, as DBH was inappropriate for some of the younger age classes of trees.

Data analysis

Due to small sample sizes, we individually grouped each of the four types of elephant impact based upon impact intensity into low (1–6, <50%)- and high (7–10, ≥50%)-impact classes. Of these four types of elephant impact, only BS has both a low- and high-impact class; therefore, we could only analyse the distribution of the BS impact.

To determine the relationship between elephant impact and nesting sites as well as the abandonment of a tree previously used as a nesting site, we used binary logistic regression, with a backward selection of significant variables: tree height, DBH, type of impact, and termite, fungus or insect presence. For the analysis of tree selection, we combined the data of the 100 trees with nests and the 185 control trees, while for the abandonment of trees previously used as nesting sites, we analysed only the 100 trees with nests.

Raptor and vulture trees have dissimilar nesting characteristics (Rode, 2011). Therefore, we used the chi-square test to compare raptors and vultures on the occurrence of the high- and low-impact classes and of the different types of impact. For these tests, we used the data on all 103 nest trees we studied. We also used the chi-square test to compare BS with stem impact and no impact, for which we grouped pushed over, main stem broken and bark stripped as stem impact, due to low samples sizes. Unfortunately, data for this test were complete for only 96 of the 103 trees.

For the analysis of the nest and tree persistence, we constructed survival curves for both the trees with nests and for the presence of the nests themselves, and compared these using a Mantel-Cox test. For this test, data throughout the years were complete for only 90 trees. We used this nonparametric test for the analysis of survival curves on the basis of the hazard rate of the trees and nests (Cox & Oakes, 1984). The distributions of height and diameter classes in the surrounding vegetation were analysed with chi-square tests. For this analysis, we pooled all trees with a diameter >30 cm.

Results

Selection of trees for nesting sites

The binary logistic regression showed that trees with nests were taller than control trees ($Wald_1 = 12.32$, $P_{height} < 0.001$, $\bar{x}_{height\ nest\text{-}control} = 0.90$ m. At the same time, trees with nests had a lower probability of recording termites ($Wald_1 = 6.15$, $P_{termite} = 0.013$, Exp(B) = 2.060) and fungus ($Wald_1 = 5.45$, $P_{fungus} = 0.020$, Exp(B) = 2.194). Elephant impact intensity was equal between trees with nests and control trees in a binary regression with a single and with multiple predictors. However, a high elephant impact increased the likelihood of recording insects and fungus on trees ($Wald_1 = 5.27$, $P_{insect} = 0.022$; $Wald_1 = 5.57$, $P_{fungus} = 0.018$, respectively). The presence of encountering insects, other than termites, was positively correlated with the presence of termites ($\chi^2_1 = 20.275$, $P < 0.001$, $n_{total} = 285$).

Elephant impact on trees with nests

When analysing the nesting trees, a significant difference was found in types of elephant impact over the different stem diameter classes and the different height classes across all tree species that were used as nesting sites (diameter: $\chi^2_{12} = 71.45$, $P < 0.0001$; height: $\chi^2_{22} = 73.61$, $P < 0.0001$) as well as for knob thorn trees only (diameter: $\chi^2_{12} = 68.61$, $P < 0.0001$; height: $\chi^2_{22} = 65.22$, $P < 0.0001$). Figure 1 shows the distribution of elephant impact on the potential nesting trees. As regards impact types, a broken main stem mainly occurred in the

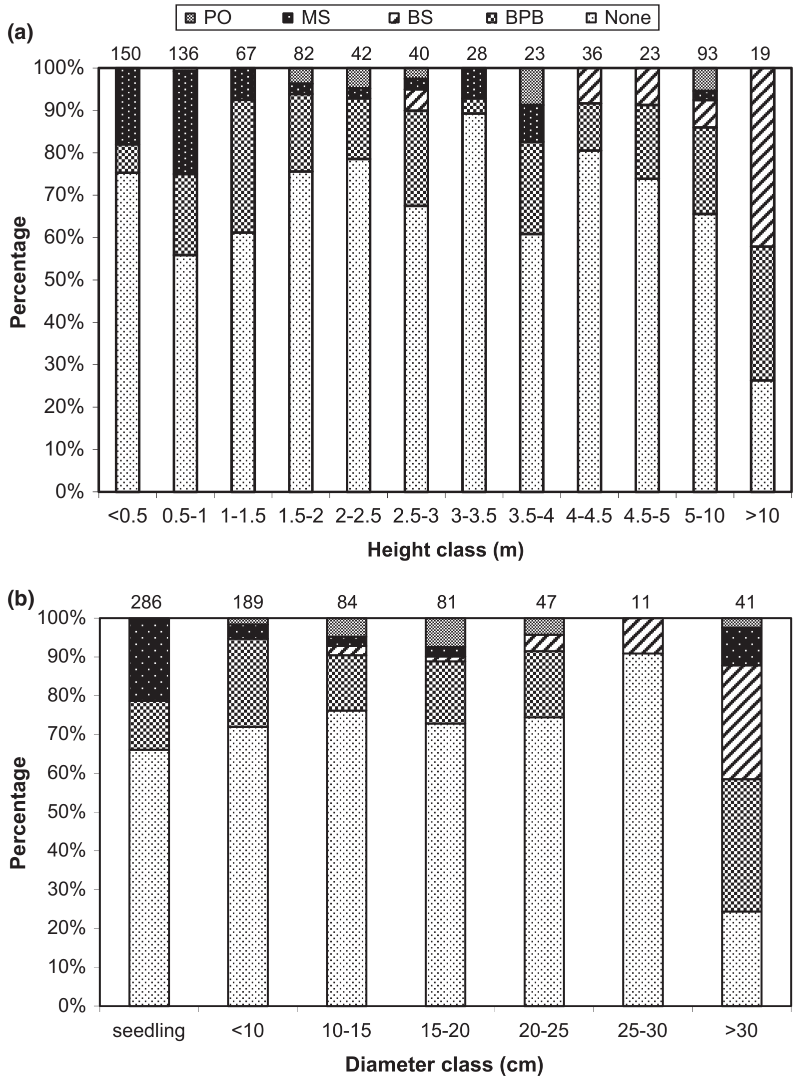

Fig 1 The distribution of the different types of elephant impact over the trees' height (a) and diameter (b) classes for all *Acacia nigresence* trees surrounding (<20 m) the focal nest tree. The number of trees per class is reported above each bar (N = 739). In this figure, broken primary branch stands for the breaking of primary branches (126 trees), bark stripping (BS) stands for BS (18 trees), MS for main stem broken (75 trees), PO for pushed over (seventeen trees) and 503 trees were without damage

lowest diameter and height classes, whereas the breaking of primary branches appeared to be spread evenly across both diameter and height classes. Bark stripping mainly occurred in the larger diameter and height classes. Trees with a diameter >30 cm and a height >10 m showed a relatively high elephant impact, especially in BS and breaking of primary branches.

Difference in selection between raptors and vultures for nesting sites

Trees with vulture nests had relatively lower elephant impact compared to trees with raptor nests, with 90.4% of the trees in the low elephant impact category, compared with 70.6% for raptors ($\chi^2_1 = 6.449$, $P = 0.011$, $n_{vulture} = 52$, $n_{raptor} = 51$, $n_{low} = 83$, $n_{high} = 20$). Figure 2 shows the distribution of the trees over the impact intensity classes for raptors and vultures separately. The elephant impact types of branch breaking, stem impact (BS, main stem broken and pushed over), no impact and the combined effect of both impact types did not differ significantly between raptor and vulture nesting trees ($\chi^2_3 = 5.960$, $P = 0.114$, $n_{no} = 14$, $n_{stem} = 34$, $n_{branch} = 30$, $n_{both} = 18$).

Abandonment of trees with nests

In the year 2008, all 90 monitored trees with nests were still alive and active as nesting sites. From 2008 to 2012, the survival rate of the trees and the nests differed, with a lower survival for nests compared with the survival of trees with the nests (Mantel-Cox test, $\chi^2_1 = 131.2$, $P < 0.0001$; Fig. 3). The survival curve of the nests showed an initial decrease of 16% in the first year, but decreased by as much as 39% between 2010 and 2011 and just over 65% by the year 2012.

The binary logistic regression showed that the probability of nest persistence was larger with a larger DBH ($\text{Wald}_1 = 5.00$, $P_{\text{DBH}} = 0.025$, $\bar{x}_{\text{DBH nest persist-nest lost}} = 4.0$ cm). Besides this, the absence of insects also increased the probability of nest persistence ($\text{Wald}_1 = 5.28$, $P_{\text{insect}} = 0.022$, Exp(B) = 2.827). Damage does not come alone, the probability of recording other insects increased under the presence of termites ($\text{Wald}_1 = 7.86$, $P_{\text{termite}} = 0.005$, Exp(B) = 0.250). At the same time, high elephant impact (category 50–100%) increased the probability of encountering insects ($\text{Wald}_1 = 4.79$, $P_{\text{impact cat.}} = 0.029$, Exp(B) = 0.208) and termites ($\text{Wald}_1 = 4.39$, $P_{\text{impact cat.}} = 0.036$, Exp (B) = 0.099). Next to this, termites have a higher probability of occurring on trees with a larger DBH ($\text{Wald}_1 = 5.02$, $P_{\text{DBH}} = 0.025$, Exp(B) = 1.043). The presence of other insects also increased the probability of encountering termites ($\text{Wald}_1 = 6.25$, $P_{\text{insect}} = 0.012$, Exp (B) = 0.281). Unlike the presence of insects, the presence of termites did not correlated to the abandonment of nesting trees. Fungus and tree height did not show an effect on the abandonment of the trees with nests, but height may play a role as DBH and height were correlated (Pearson $r = 0.380$, $P < 0.001$, n = 84). Elephant impact was not correlated with nest abandonment, also if it was included as a single term in the model.

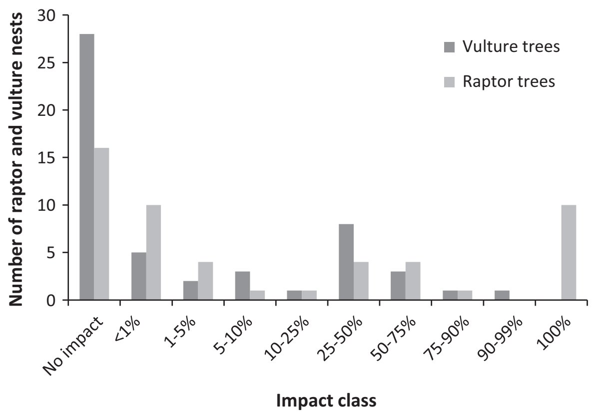

Fig 2 The distribution of raptor and vulture nests across the elephant impact intensities for bark stripping

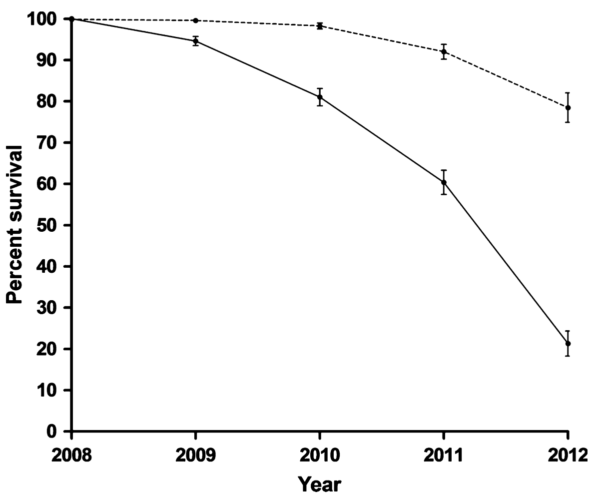

Fig 3 Survival curves for nests (solid line) and trees with nests (broken line) from 2008 to 2011 for the 90 trees with nests, with error bars for the 95% confidence intervals

Discussion

Elephant impact could negatively affect the suitability of large trees as vulture and raptor nesting sites (Henley *et al.*, 2008). However, this research shows that elephant impact intensity on trees was low, irrespective of the type of tree and nesting bird. It also showed that elephant impact intensity is not different between trees with nests and control trees, even though trees with nests were taller than control trees. The distribution of the elephant impact types did not differ between the vulture and raptor nesting sites, but trees with vulture nests showed relatively lower elephant impact compared with trees with raptor nests. This could be due to differences in required tree characteristics for nesting between raptors and vultures. Raptors are known to build their nests lower in the canopy in the forks of larger branches while vultures breed on the very top of the canopy (Rode, 2011). Therefore, vultures could be more susceptible to the die-back of branch tips compared with raptors. Vultures would consequently need to rely more on a supporting mesh of finer branches that should be alive to have sufficient buoyancy to carry their nests, while raptors are less affected by changes higher in the canopy. However, to determine whether this is the case, further investigation is needed.

Raptors are known to reuse nests for generations, and nests sites have been defined as ecological magnets

(Burnham, Burnham & Newton, 2009). The survival curves showed that large trees die at a slower rate than the raptor and vulture nests disappear, with different patterns for the trees with nests and the nest survival curves. Hence, changes in nesting sites cannot be attributed to changes in tree survival alone. A number of trees (6%) have disappeared with signs of fire scaring in the immediate vicinity of where the monitored trees once were. Although these trees may have been more susceptible to fire to elephant impact (Ihwagi *et al.*, 2010), the disappearance of these nests cannot be attributed directly due to elephant impact. However, fire is known to be a critical determinant of tree abundances and could have a negative impact on seedling establishment (Goheen *et al.*, 2010; Kalwij *et al.*, 2010). The disparate decline in nest survival in comparison with tree survival indicates that other factors may be at play that could affect the available number of bird breeding pairs more directly, such as poisoning, electrocution on electricity pylons and drowning in farm reservoirs (Murn, Anderson & Anthony, 2002). However, vultures and raptors might also abandon their nest in an effort to reduce the parasite load in their nests (Heeb, Kölliker & Richner, 2000).

We found that the impact of insect and shelf fungus was more common on trees with higher elephant impact. Hence, elephants could be influencing the survival of the tree indirectly by facilitating the colonization of the trees by fungus and insects through opening the bark or breaking branches (Hatcher, 1995). A larger proportion of nests were present on trees with lower elephant impact while trees with nests showed a lower survival when invaded by either insects or fungus. Finally, trees with nests appeared less affected by termites and fungus than trees without nests, which could be due to the selection of healthy trees for nesting by birds. These results correspond with the findings of Monadjem & Garcelon (2005) who found that white-backed vultures do not nest in areas where there is severe elephant impact on trees. What requires further investigation is whether raptors and vultures are selecting trees with low elephant impact – thus avoiding trees with signs of a shortened lifespan – or even abandon trees when elephant impact increases over time. Raptor and vulture selection criteria are probably more complex than to be directly related to the level of elephant impact, as we found that of the new trees with nests first surveyed in 2011, 40% were established on trees with high elephant impact.

When considering the age class distribution of the surrounding vegetation, there was a high number of trees in low diameter and height classes. The surrounding tree types we measured all belonged to species that are known to be preferred as nesting sites, which indicates that there is a high regeneration rate of nesting sites. This is in line with several articles that suggest that elephants do not have a large negative impact on the regeneration of trees (Augustine & McNaughton, 1998; Boundja & Midgley, 2010; Goheen *et al.*, 2010). It is also supported by the presence of the 200 control trees that were all qualified for vulture and raptor nesting, which shows that the knob thorn regeneration is able to reach the height and diameter required to qualify as nesting trees.

Elephant impact type differed over the tree age classes; the majority of the younger age classes (smaller heights and diameters) were not heavily impacted by elephants. However, the oldest tree classes contained relatively few trees with no elephant impact and had the highest accumulated elephant impact. Trees that were pushed over were typically found in the medium height classes, main stems were mainly broken in the lower classes, and most of the BS occurred in the older age classes. The highest and broadest tree class stands out, as it has a few trees with no impact and many bark-stripped trees. Bark stripping is probably profitable only when trees are large enough for elephants to easily remove bark and obtain an appreciable food reward. These results are in agreement with Calenge *et al.* (2002), who claimed that elephants mainly impact high trees. However, other browsers can have equally dramatic effects, and retrospective inference of elephant impact is limited (White & Goodman, 2009). Moreover, the browsing effects we measured for the younger age classes could also be attributed to the effects of other small herbivores such as impala (*Aepyceros melampus*; Western & Maitumo, 2004; Ihwagi *et al.*, 2010).

Our results indicate that elephants are not directly threatening the regeneration of knob thorn, one of the main tree species chosen by raptors and vultures as nesting sites. However, the accumulated elephant impact on older trees could render them unsuitable as potential nesting sites if arthropod and fungus invasions increase over time, which deserves further investigations.

Acknowledgements

We would like to thank Colin Rowles for his support and assistance with field rangers. Blair Zoghoy, Lamson Monarig, Prince Nakuna, Roni Makukule, Sarah Bergs, Kelly Derham and Adam Edge are thanked for their contributions towards the data collection. We also thank Save the Elephants – South Africa and Tanda Tula Safari Camp for their logistical support and the U.S. Fish and Wildlife Service for their financial support.

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(*Manuscript accepted 13 December 2013*)

doi: 10.1111/aje.12140