**Bothalia - African Biodiversity & Conservation**
ISSN: (Online) 2311-9284, (Print) 0006-8241



# Vulnerability of vulture populations to elephant impacts in KwaZulu-Natal

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**Dates:**
Received: 03 Nov. 2017
Accepted: 12 June 2018
Published: 19 July 2018

**How to cite this article:**
Rushworth, I.A., Druce, D., Craigie, J. & Coverdale, B., 2018, 'Vulnerability of vulture populations to elephant impacts in KwaZulu-Natal', *Bothalia* 48(2), a2327. https://doi.org/10.4102/abc.v48i2.2327





Elephant were previously widespread in savanna and coastal systems of KwaZulu-Natal (KZN), but were virtually extirpated by 1870. Over time, elephant have been reintroduced into their former range in KZN, but always onto small fenced systems (mean size 191.3 km$^2$ ± 87.8 km$^2$, median size 107.0 km$^2$, range 14 km$^2$ – 900 km$^2$). These populations have increased rapidly (8.4% per annum), and although a number of populations are now being managed using contraception, the majority of the populations (66.7%, 14 out of 21) are stocked above the 'preferred density' as defined in their approved management plans, while others will soon exceed the preferred density. Vulture populations in KZN are small, declining and already at risk of extinction. In KZN, 94.2% of tree-nesting vulture nests occur in areas with elephant; this could increase to 99.5% in the near future if proposed land-use change takes place. Anthropogenic impacts in the broader landscape mean that there are limited opportunities for vultures to nest elsewhere, and we hypothesise that loss of suitable nesting habitat in existing areas, including through impact of elephant on large trees, could result in declines and even extirpation of these species as breeding residents. Given the demonstrated and potential impacts of elephants on large trees necessary for vulture nesting, it is essential that the role of protected areas and extensive wildlife systems for vultures be adequately taken into account when managing elephant populations. It is important that a precautionary and adaptive management approach is taken regarding management of elephant in areas important for vultures, at least until the ecological interactions between vultures, vegetation, elephant and other drivers are better understood, and until the willingness and ability to manage elephant numbers and impact according to the elephant management plans are demonstrated.

## Background

### Elephant

Elephant (*Loxodonta africana*) once occurred widely across South Africa and the entire savanna and the Indian Ocean Coastal Belt biomes of KwaZulu-Natal (KZN) (Birss et al. 2015; Rushworth 2017a; Skinner & Chimimba 2005). They were largely extirpated from KZN by 1870 barring a small migratory population in northern Maputaland, eventually fenced into Tembe Elephant Park. Over time, elephant have been reintroduced into their former range, both into state protected areas and now, increasingly, into private and communally owned properties.

In South Africa as a whole, the reintroduction of elephant following previous extirpation has been extremely successful, with elephant now occurring in at least 79 areas (Selier et al. 2016), with an average rate of increase in the early 2000s of 8.3 ± 1.1% per annum, but with a number of populations showing an increase of over 13% per annum (Slotow et al. 2005). The average annual growth rate declined to an estimated 6.9% for the period 2001 to 2013 (ESAG 2015). Many areas were likely to have been stocked at over 0.5 animals per km$^2$ by 2006 (Slotow et al. 2005). A combination of factors has resulted in a high population growth to date, and importantly, a high future growth potential and requirement for active management of population sizes.

In KZN, elephant have been reintroduced to 20 properties (and occur in 21 including the naturally occurring population at Tembe Elephant Park). All reintroductions in KZN have been into relatively small fenced systems (mean size 191.3 km$^2$ ± 87.8 km$^2$, median size 107.0 km$^2$, range 14 km$^2$ – 900 km$^2$), making up a total of 4018 km$^2$ or 4.3% of the province. The mean and median size is significantly smaller than the threshold of 1000 km$^2$ below which an area is considered to be 'small' for elephant, and displays landscape characteristics that would make plant species vulnerable to extirpation (Scholes & Mennell 2008). In KZN protected areas, the population has grown consistently at 6.9% per annum from 685 in 2004 to 1317 by 2015; on private and communal land the population grew rapidly between 2004 (148) and 2006 (420), primarily owing to introductions. Since 2006 the population on private and communal land has shown a slower growth (3.7% per annum) to 590 at the end of 2015. The combined provincial elephant population growth rate over the same period is 8.4% per annum (Goodman & Craigie 2016). Many populations (15 out of 21) are now being managed using immunocontraception, and growth rates are expected to slow, with some having stopped growing already (Ezemvelo KZN Wildlife records).

All properties in KZN with elephant have developed, or are in an advanced stage of developing, management plans in terms of the requirements of the National Norms and Standards for the Management of Elephant in South Africa (Notice 251, Government Gazette 30833, 2008). All elephant management plans for state protected areas have been approved by the Department of Environmental Affairs, and the provincial conservation authority has approved 10 for private and communally owned conservation areas, while the remainder are undergoing final review prior to sign off. These management plans specify the preferred management density for elephant, and the properties are then obliged to manage towards these densities, where 'preferred management density' means 'a stocking rate, or an acceptable range of densities within which a population may be allowed to fluctuate naturally' (Notice 251, Government Gazette 30833, 2008). These densities are set using multiple criteria, but are primarily based on an attempt to achieve a balance between elephant numbers and other biodiversity or social objectives, including in many instances[1] concern regarding maintenance of large trees for vulture and other raptor nesting sites. Preferred density is therefore not necessarily synonymous with the concept of ecological carrying capacity. It is important to note that the purpose of the National Norms and Standards for the Management of Elephant in South Africa is to provide for the ethical and humane treatment of elephant, but equally to make sure that elephant do not have unacceptable impacts on ecosystem functioning or other land management and biodiversity objectives.

## Vultures

African vultures are increasingly restricted to protected areas (BirdLife International 2017; Brandl, Utschick & Schmidtke 1985; Herremans & Herremans-Tonnoeyr 2000; Sorley & Andersen 1994; Thiollay 2006). Thiollay (2006) suggested that this apparent dependence on protected areas is a recent phenomenon, with vulture populations outside protected areas having declined markedly in recent decades as human populations have increased. Monadjem and Garcelon (2005) hypothesised that the unusually high nest density of African White-backed Vulture (*Gyps africanus*) in a protected area in Swaziland was in part because of immigration of long-lived birds following recent and ongoing habitat clearing taking place outside the protected area. Likewise, Whateley (1986) proposed that the increase in African White-backed Vulture nests in Hluhluwe–iMfolozi Park in the 1980s was owing to immigration of birds from areas that had become unsuitable following rapid human population growth. The same pattern of dependence on protected areas or other extensive systems for nesting has been noted by others (Bamford, Monadjem & Hardy 2009a; Rushworth 2008; Rushworth & Piper 2004). The most likely explanation for the observed distribution of nesting vultures (concentration in protected areas, absence of nests from apparently suitable habitat outside protected areas) is direct and indirect anthropogenic disturbance (Bamford et al. 2009a).

There are four species of tree-nesting vultures in KZN: African White-backed Vulture (*Gyps africanus*), Lappet-faced vulture (*Torgos tracheliotos*), White-headed Vulture (*Aegypius occipitalis*) and Palm-nut Vulture (*Gypohierax angolensis*). Palm-nut Vultures occur marginally in this region with fewer than 15 pairs occurring along the northern coastal strip (Rushworth & Chittenden 2004) and are not considered further in this analysis. Being obligate tree nesters, the breeding range of all these vulture species is limited to where suitable large trees occur within the savanna biome; foraging range however extends significantly further. Vulture populations in KZN have declined significantly from historical levels principally owing to anthropogenic use of poisons, collisions and electrocutions on electrical infrastructure, collections for belief-based use and habitat loss (Rushworth 2008). Remaining vulture populations are small and vulnerable to extirpation – in 2015, there were 566 nests of African White-backed Vulture, 21 nests of Lappet-faced Vulture and three nests of White-headed Vulture in KZN (Rushworth 2017b). All three species considered in this analysis have recently been uplisted in both the global and regional Red Lists (IUCN 2017; Taylor, Peacock & Wanless 2015) (African White-backed and White-headed Vultures now feature as Critically Endangered, Lappet-faced Vulture as Endangered). All three of these vulture species were also recently added to Appendix 1 of the Convention on Migratory Species, which requires signatories to the convention (South Africa is a signatory) to take measures to protect the species and their habitat.

## Tree selection by vultures

A brief summary of vulture tree selection for nesting based on local studies is provided. In Hluhluwe–iMfolozi Park, the following trees are selected by Lappet-faced and White-headed vultures within which to nest: *Senegalia* (*Acacia*) *nigrescens*, *Senegalia* (*Acacia*) *burkei*, *Vachellia* (*Acacia*) *robusta* and at times *Schotia brachypetala*, *Balanites maughamii* and *Ficus* sp. (D. Druce pers. obs.). African White-backed Vultures utilise *Ficus sycomorus* (36.4% of nests, $n$ = 242), *Vachellia* (*Acacia*) *robusta* (33.1%), *Schotia brachypetala* (14.9%), *Spirostachys africana* (9.9%), *Senegalia* (*Acacia*) *nigrescens* (2.5%) and *Senegalia* (*Acacia*) *burkei* (1.7%) (Whateley 1986).

In Phongolo Nature Reserve, there is a definite preference by African White-backed Vultures for *Senegalia* (*Acacia*) *nigrescens* trees with 27 of 28 recorded nests occurring in mature *Senegalia* (*Acacia*) *nigrescens* trees, and one nest in an *Vachellia*

1. At least nine KZN elephant management plans refer to vultures as elements of concern.

(*Acacia) tortilis* (James Wakelin, unpublished data). The single Lappet-faced Vulture nest at Ithala Game Reserve in 2005 was in a *Vachellia* (*Acacia) tortilis* tree (Rushworth, Wakelin & Bawden 2007).

In the Kruger National Park, the heights of the nests of African White-backed Vultures were 10 m – 25 m above ground (large trees), with the most important species used being *Senegalia* (*Acacia) nigrescens* 29%, *Vachellia* (*Acacia) robusta* 19%, *Senegalia* (*Acacia) welwitchii* sub sp. *delagoensis* 17%, *Ficus sycamorus* 12% and *Diospyros mespiliformis* 9% (*n* = 106) (Kemp & Kemp 1975).

Vogel et al. (2014) found that a larger proportion of vulture nests were present on trees with lower elephant impact. However, they observed that further investigation is required as to whether vultures are selecting trees with low elephant impact – thus avoiding trees with signs of a shortened lifespan – or are abandoning trees when elephant impact increases over time. They did observe however that some new vulture nests were established in trees with high elephant impact. Vulture nests are more likely to persist for longer in larger trees (Vogel et al. 2014).

African White-backed Vultures tend to nest in large trees close to perennial rivers and smaller drainage lines but also nest away from watercourses (Howells, Craigie & Nänni 2010; Kemp & Kemp 1975; Whateley 1986). After massive floods destroy favoured nesting trees on perennial rivers, vultures may relocate their nests to unaffected tributaries (Whateley 1986). Lappet-faced and White-headed Vultures tend to nest in the interfluves away from drainage lines (Howells et al. 2010; Kemp & Kemp 1975).

## Elephant–tree interactions

Concern has been expressed over an observed decline in large tree abundance in protected savannah areas linked to the destruction of vegetation by large herbivores, particularly elephant (e.g. Coetzee et al. 1979; Cumming et al. 1997; Eltringham 1980; Jacobs & Biggs 2002; O'Connor, Goodman & Clegg 2007). It is not the intention here to provide an extensive review of elephant–vegetation interactions, but some key local studies investigating elephant impacts on large trees are summarised.

In Hluhluwe–iMfolozi Park in KZN, elephant are having a marked impact on certain less common tree species and larger tree size classes (Boundja & Midgley 2010). However, the nature of the elephant impact data currently available does not allow a clear differentiation between various factors (elephants, fire, shrub encroachment and interactions between fire and elephant) driving vegetation change (Druce et al. 2017). Total woody plant density between 1999 and 2007 remained little changed, but there was a shift in representation of different height classes. Density in trees taller than 8 m remained unchanged between 1999 and 2007. Representation of trees between 4 m and 8 m declined by 31%, while the representation of trees less than 4 m increased from 61% to 71% over the same time period (Druce et al. 2017). Among the common trees species, a decline in the number of trees in the taller height classes (4 m – 10 m) was observed for *Senegalia* (*Acacia) burkei*, *Senegalia* (*Acacia) nigrescens*, *Sclerocarya birrea* and *Vachellia* (*Acacia) robusta* (Druce et al. 2017). *Senegalia* (*Acacia) burkei* declined from 1.55 individual trees per plot in 1999 to 0.76 trees per plot in 2007, while *Senegalia* (*Acacia) nigrescens* declined from 2.96 to 1.59 trees per plot, *Vachellia* (*Acacia) robusta* declined from 1.41 to 0.60 trees per plot and *Sclerocarya birrea* declined from 0.69 to 0.29 trees per plot in the same period (unpublished data). The most selected tree species in Hluhluwe–iMfolozi Park include *Cussonia* spp. (0.60 Jacobs index), *Albizia versicolor* (0.53) and *Ficus* spp. (0.53) (Druce et al. 2017). Species selected by Lappet-faced and White-headed vultures as nesting trees also show high levels of selection by elephant, for example *Senegalia* (*Acacia) burkei* (0.37 Jacobs index), *Vachellia* (*Acacia) robusta* (0.35) and *Schotia brachypetala* (0.35) (Druce et al. 2017). Although *Senegalia* (*Acacia) nigrescens* does not show high selection by elephant overall, this species falls within the list of trees with the highest percentage of bark stripping by elephant, with 1.1% of all individuals recorded showing signs of debarking by elephant; 1.1% of all *Vachellia* (*Acacia) robusta*, *Senegalia* (*Acacia*) *burkei* and *Vachellia* (*Acacia*) *nilotica* had been toppled by elephant by 2007 (Druce et al. 2017). In summary, in addition to evidence of elephant selecting some preferred nesting trees, there has been an overall decline in density of some preferred nesting trees and there are indications of a recruitment bottleneck into the mature size class developing (intermediate size trees declining).

In Ithala Game Reserve (KZN), elephant had a disproportionately large impact on tree mortality, with elephant responsible for 38% of all tree mortality at a time when elephant density was one-third of current levels; damage accumulated over the years as elephants revisited the trees (Wiseman, Page & O'Connor 2004). In Tembe Elephant Park (KZN), elephant may be affecting the sand forest and they have already changed plant cover significantly, but not the species composition (Gaugris et al. 2004).

In the Kruger National Park (South Africa), the interaction between elephant browsing and fire is resulting in a decline in large tree density (Trollope et al. 1998), with mortality higher than recruitment into the ≥ 5 m height class (Shannon et al. 2011). In Swaziland, high densities of elephant in small fenced enclosures resulted in mortality of virtually all *Senegalia* (*Acacia) nigrescens* trees, and the absence of African White-backed Vulture nests in these enclosures was attributed to this mortality of preferred nesting trees (Monadjem & Garcelon 2005). In Chobe National Park (Botswana), tree density, cover and volume had increased over time throughout the area, caused by a combination of an increase of trees in lower size classes and a decrease in larger size classes; the decrease of large trees is attributed to a growing elephant population (Kalwij et al. 2010).

Elephant impact on large trees is often mediated through synergistic interaction effects with fire (Moncrieff, Kruger & Midgley 2008; Shannon et al. 2011; Trollope et al. 1998) and browsing by other herbivores (O'Kane et al. 2011; Wiseman et al. 2004), while in other cases it is not possible to clearly disentangle the drivers (Druce et al. 2017). Trees with high elephant impact have a higher likelihood of insect and fungus establishment (Vogel et al. 2014). Hence, in addition to making trees more susceptible to fire, elephant could be influencing the survival of trees indirectly through opening the bark and facilitating the colonisation by fungus and insects (Hatcher 1995; Vogel et al. 2014). Older trees had more accumulated elephant damage, and the accumulated elephant impact on older trees could render them unsuitable as potential nesting sites if arthropod and fungus invasions increased over time (Vogel et al. 2014).

## Objectives

It has been previously noted that elephant have been reintroduced into several protected areas where vultures nest and that there may be a risk to the persistence of vulture populations if elephant impact gets to the point where the availability of suitable nesting trees may be reduced (e.g. Rushworth 2008). The objectives of this paper are to: (1) assess the potential vulnerability of tree-nesting vulture populations, as resident breeding species in KZN, to elephant impact by quantifying the extent of overlap of elephant populations and vulture nesting sites, (2) evaluate the ability to manage elephant populations by assessing current elephant densities of all KZN elephant populations against preferred densities as defined in the various elephant management plans, thereby indirectly assessing the effectiveness of the National Norms and Standards for the Management of Elephant in South Africa to protect other elements of concern where there are elephant, and (3) to provide management recommendations to reduce the vulnerability of tree-nesting vultures to elephant.

## Methods

Systematic aerial surveys of tree-nesting vultures in Zululand have taken place biannually since 2004 (Howells & Goodman 2013a, 2013b, 2013c; Howells et al. 2010; Rushworth 2017b). While these surveys have focused on protected areas and known nesting areas, they have targeted other suitable habitat outside protected areas, and have been supplemented by ground-based observations, including *inter alia* (1) reporting of nests by patrolling rangers, (2) landowner reporting of vulture activities and nests (there have been significant vulture awareness activities conducted with landowners in Zululand) and (3) reporting of nests by avifaunal experts during Environmental Impact Assessment activities. The pilot of the Ezemvelo aircraft routinely surveys for vulture nests during other monitoring or transport flights. Each nest was mapped using a GPS while flying and so is accurate to within 100 m of the true ground position. While it is undoubtable that some nests have not been accounted for, there is a high degree of confidence that more than 95% of tree-nesting vulture nests in the province are known. It is reasonably assumed that the map of nesting sites represents an unbiased assessment of the current distribution of vulture nests in KZN.

All elephant populations in KZN are known and all properties have, or are in the final stages of completing, elephant management plans in terms of the requirements of the National Norms and Standards for the Management of Elephant. Ezemvelo KZN Wildlife (Ezemvelo), as the biodiversity regulatory authority for KZN, approves all elephant management plans for non-state areas and maintains a database of all properties with elephant. Numbers are updated annually based on censuses in Ezemvelo protected areas and reports received by Ezemvelo from other properties. The boundaries of all elephant properties as demarcated in the elephant management plans are kept in GIS format by Ezemvelo. There are some challenges in providing the exact areas available to elephant because the fenced and legal boundaries are not always completely the same; however, the most accurate fenced boundaries available were used in this assessment, captured at a 1:50 000 scale or better. In some cases, natural features make up part of the boundary (e.g. the eastern boundary of the Phongolo Nature Reserve and the Pongola Game Reserve East Association, referred to as the Phongolo/Pongola Complex in this paper, is the Pongolapoort Dam) and these were digitised off aerial photographs or satellite images.

Each property with elephant is required to specify the preferred management density of elephant. In most cases, these have been approved as part of the approval of the elephant management plans; in some cases, these remain as recommendations, while the plan goes through the approval process. In some cases, this is expressed as a density (elephants per $km^2$) and in other cases as a number of elephant, in which case these were converted to densities based on the property size. Where the preferred number was provided as a range, the upper limit of the range was used to calculate preferred density.

We used GIS to compare vulture nest distribution from the 2016–2017 surveys, with boundaries of properties with elephant to quantify the proportion of nesting sites occurring within areas occupied by elephant. In addition, we quantified the proportion of properties currently (2016) stocked above the 'preferred density' as defined in the respective elephant management plans. Where properties were still stocked below the preferred density, we calculated the time (years) to reach the preferred density based on the growth rate for each specific population as reported or calculated from annual reports provided to Ezemvelo.

Given that (1) other extraneous factors such as poisoning events influence the number of pairs and/or nesting attempts in any particular year and subsequent years, and (2) there is a lag effect between current elephant density and vegetation response, it is not possible to use this data to determine the relationship between elephant density and vulture nest density or change in density.

### Ethical considerations

Vulture populations in KwaZulu-Natal are monitored according to monitoring plans approved by Ezemvelo KZN

Wildlife: Ezemvelo KZN Wildlife Monitoring Plan: Lappet-faced Vulture (*Torgos tracheliotos*); Ezemvelo KZN Wildlife Monitoring Plan: White-backed Vulture (*Gyps africanus*); and Ezemvelo KZN Wildlife Monitoring Plan: White-headed Vulture (*Aegypius occipitalis*). The research was approved by the Ezemvelo KZN Wildlife Scientific Services Operations Committee. No permits were required.

# Results

Not all areas with elephant have vultures, but the majority of vulture nests occur in areas with elephant. A total of 623 active vulture nests were recorded in KZN in 2016/2017. Only 36 of these nests occurred in areas where no elephant were present, whereas 587 (94.2%) of all vulture nests occur in areas where elephant occur (Figure 1, Table 1). When analysed by species, 100% of Lappet-faced ($n$ = 17), 100% of White-headed ($n$ = 2) and 94.0% of African White-backed Vulture ($n$ = 568) nests co-occur with elephant. However, the imminent dropping of fences between the 'Big 5' properties (which have 12 pairs of African White-backed Vultures and no elephant) and the neighbouring Hluhluwe–iMfolozi Park will result in the immigration of elephants, thereby increasing the overall proportion of vulture nests co-occurring with elephant to 96.1%. If a recent proposal for the development of a large open cast coal mine goes ahead in the Thula Thula area, 58 African White-backed Vulture breeding pairs would be displaced, resulting in 99.5% of remaining nests co-occurring with elephant.

The three most important properties for tree-nesting vultures (in terms of total number of vulture nests of all species combined) are the Hluhluwe–iMfolozi Park (73.2% of all vulture nests in KZN), the Phongolo/Pongola Complex (8.8%) and Thula Thula (5.9%). It should be noted that the current number of nests in uMkhuze Game Reserve is significantly reduced compared to the recent past owing to ongoing poisoning events; otherwise, uMkhuze would have been in the top three most important sites and should be regarded as one of the most important sites in the province in terms of efforts to recover vulture populations as per the targets in the provincial vulture conservation strategy (Rushworth 2008). Both the Phongolo/Pongola Complex (second most important) and Thula Thula (third most important) are under threat of land-use change, further emphasising the importance of Hluhluwe–iMfolozi Park and uMkhuze.

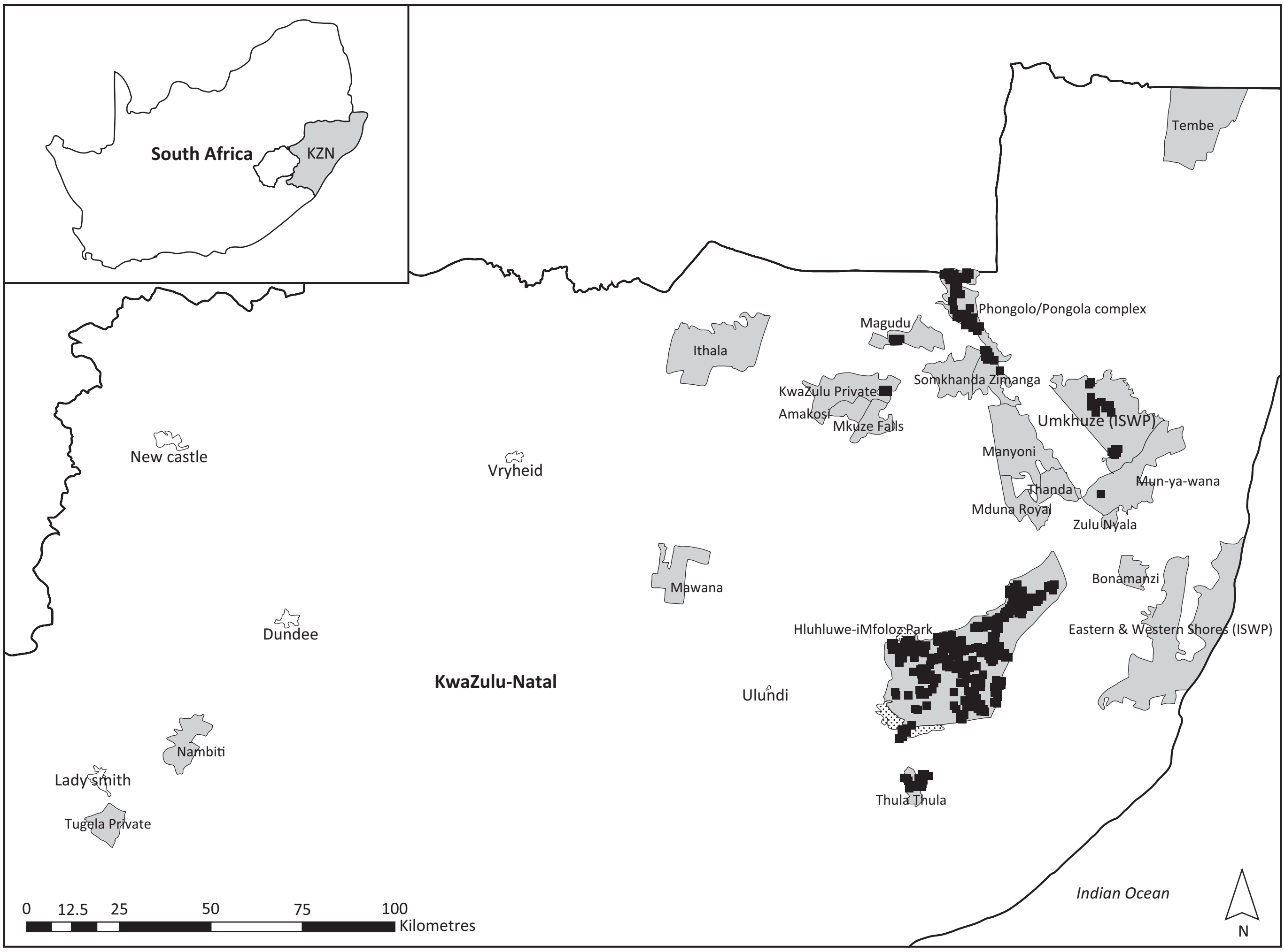


**FIGURE 1:** Location of all known tree-nesting vulture nests from 2016 and 2017 (black squares) and boundaries of properties with elephant (grey); the boundaries of the properties show the areas that elephant have access to and are not necessarily the proclaimed or managed area; 'Big 5' properties where immigration of elephant is imminent shown as stippled area on south-western boundary of the Hluhluwe–iMfolozi Park; ISWP, iSimangaliso Wetland Park.

TABLE 1: Number and proportion of vulture nests in KwaZulu-Natal in areas with and without elephant based on 2016/2017 survey data.

| Variables | African White-backed Vulture (%) | Lappet-faced Vulture (%) | White-headed Vulture (%) | Total (%) |
|---|---|---|---|---|
| With elephant | 568 (94.0) | 17 (100.0) | 2 (100.0) | 587 (94.2) |
| Without elephant | 36 (6.0) | 0 (0.0) | 0 (0.0) | 36 (5.8) |
| **Total** | **604 (100.0)** | **17 (100.0)** | **2 (100.0)** | **623 (100.0)** |

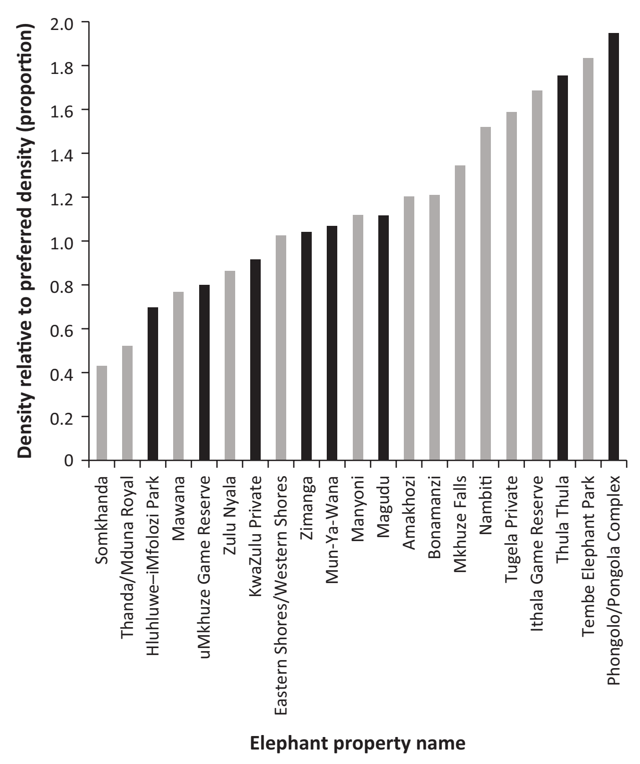


FIGURE 2: Stocking density of 21 elephant properties in KwaZulu-Natal as a proportion of preferred or recommended stocking densities as recorded in the respective elephant management plans; 14 properties were stocked above the preferred stocking density in 2016; black bars indicate areas with vulture nests in 2016 and 2017.

The majority of areas, including half of those with vultures, are stocked at densities above the preferred density recorded in the elephant management plans. Fourteen out of 21 properties (66.7%) were already over the preferred or recommended stocking density by 2016 (Figure 2, Table 2), with one property being stocked at almost double the preferred stocking density. Of the remaining seven properties currently below the preferred stocking density, three (Mawana, uMkhuze Game Reserve, KwaZulu Private) will be over the preferred stocking density within 5 years, one in 5–10 years (Hluhluwe–iMfolozi Park), one in 10–15 years (Somkhanda) and one (Thanda/Mduna Royal) will take over 15 years (based on current growth rates, incorporating effects of contraception, and assuming no further introductions) (Table 2). The last (Zulu Nyala) is a female-only population. Five of the eight properties where elephant and vulture nests co-occur are currently stocked above the preferred density specified in the elephant management plans; three are marginally (less than 10%) above, while two (representing 14.7% of all vulture nests) are stocked significantly above the preferred density (Figure 2).

# Discussion

Given that 94.2%, and potentially up to 99.5%, of nests of tree-nesting vultures in KZN occur in areas now occupied by elephant, and the potential for elephant to impact on large trees in general and specifically those selected by vultures, we propose that the way in which elephant and elephant impacts are managed will be an important factor affecting vultures in the medium to long term. While there is no evidence at this stage to suggest that suitable nesting trees are becoming limiting, there is evidence of a reduction in density, and further evidence of a developing recruitment bottleneck, of preferred nesting trees in the most important areas for vultures in KZN. Although it is complex to fully understand the interacting drivers of change, there is evidence that elephant are at least a contributory factor in these vegetation changes. We predict that if an appropriate balance between elephant numbers and vegetation is not achieved in existing areas with elephant, this could conceivably lead, in the long term, to the complete or almost complete loss of tree-nesting vultures as breeding residents from KZN.

Given that many elephant populations are still growing (i.e. the impacts are increasing over time at a range of scales), and that there are significant lag effects in vegetation response to herbivory, there is a need for a concerted effort to model or predict future scenarios of vegetation composition and structure so that management interventions can take place early enough. In particular, planning for elephant management should not consider average conditions, but should explicitly incorporate the impact of elephant during prolonged periods of drought. While several authors have advocated implementing measures to protect individual trees, we believe that this approach is not practical in protected areas and largely fails to recognise that the key issue is allowing for ongoing recruitment into the adult size classes as individual protected trees will eventually senesce. This interventionist approach is also largely incompatible with the process-based management philosophy adopted by conservation agencies and that is entrenched in management plans. A risk-averse approach in relation to setting preferred management densities for elephant, or other thresholds of potential concern, should be adopted in the Hluhluwe–iMfolozi Park given that 73.2% of vulture nests occur in this area.

Two-thirds of properties with elephant, including two of the three most important vulture nesting areas, were stocked above their preferred densities by 2016. Preferred densities of elephant in these confined areas were set in relation to multiple factors, one of which may have been concern over maintaining nesting sites or opportunities for vultures. It is not the intention here to review the logic for the setting of preferred densities or to question whether they were set appropriately for vultures where vultures were listed as an element of concern. However, the key thesis is the seeming inability to manage according to the preferred densities, whether these were set correctly or not. What this could mean for vultures is that even if threshold densities were set

**TABLE 2:** Preferred (as per elephant management plan) versus actual (based on reported numbers) density of elephant in Kwazulu-Natal (KZN) in 2016; number of vulture nests (of all three species combined), and proportion of the total number of nests in KwaZulu-Natal, are provided for each property based on the most recent surveys; years until preferred density exceeded is calculated based on growth rates reported by each property; property size rounded to the nearest km².

| Area | Size (km²) | Reported elephant number 2016 | Elephant density 2016 (elephants per km²) | Preferred elephant density (elephants per km²) | Percentage of preferred density | Years till preferred density exceeded | Number of vulture nests and proportion of KZN total (%) |
|---|---|---|---|---|---|---|---|
| Somkhanda† | 120 | 13 | 0.11 | 0.25 | 43.3 | 10–15 | 0 (0.0) |
| Thanda/Mduna Royal† | 143 | 41 | 0.29 | 0.55 | 52.1 | > 15 | 0 (0.0) |
| Hluhluwe–iMfolozi Park† | 900 | 796 | 0.88 | 1.27 | 69.6 | 5–10 | 456 (73.2) |
| Mawana† | 107 | 27 | 0.25 | 0.33 | 76.5 | < 5 | 0 (0.0) |
| uMkhuze Game Reserve† | 348 | 120 | 0.34 | 0.43 | 80.0 | < 5 | 18 (2.9) |
| Zulu Nyala‡ | 14 | 3 | 0.21 | 0.25 | 85.7 | Never | 0 (0.0) |
| KwaZulu Private† | 153 | 63 | 0.41 | 0.45 | 91.5 | < 5 | 3 (0.5) |
| Eastern Shores/Western Shores† | 573 | 102 | 0.18 | 0.17 | 102.0 | Already exceeded | 0 (0.0) |
| Zimanga† | 39 | 26 | 0.67 | 0.64 | 104.0 | Already exceeded | 7 (1.1) |
| Mun-Ya-Wana† | 231 | 106 | 0.46 | 0.43 | 106.7 | Already exceeded | 1 (0.2) |
| Manyoni† | 212 | 33 | 0.16 | 0.14 | 111.2 | Already exceeded | 0 (0.0) |
| Magudu | 103 | 62 | 0.60 | 0.54 | 111.5 | Already exceeded | 10 (1.6) |
| Amakhosi | 41 | 28 | 0.68 | 0.57 | 119.8 | Already exceeded | 0 (0.0) |
| Bonamanzi | 45 | 19 | 0.42 | 0.35 | 120.6 | Already exceeded | 0 (0.0) |
| Mkhuze Falls | 61 | 41 | 0.67 | 0.50 | 134.4 | Already exceeded | 0 (0.0) |
| Nambiti† | 92 | 21 | 0.23 | 0.15 | 152.2 | Already exceeded | 0 (0.0) |
| Tugela Private† | 62 | 19 | 0.31 | 0.19 | 158.3 | Already exceeded | 0 (0.0) |
| Ithala Game Reserve† | 293 | 172 | 0.59 | 0.35 | 167.7 | Already exceeded | 0 (0.0) |
| Thula Thula† | 30 | 30 | 1.00 | 0.57 | 175.4 | Already exceeded | 37 (5.9) |
| Tembe Elephant Park† | 300 | 220 | 0.73 | 0.40 | 183.3 | Already exceeded | 0 (0.0) |
| Phongolo/Pongola Complex | 125 | 85 | 0.68 | 0.35 | 194.3 | Already exceeded | 55 (8.8) |

†, Population size currently being managed using immunocontraception; ‡, female-only population.

specifically and appropriately to allow for the long-term persistence of suitable nesting trees for vultures, based on a good scientific understanding of vegetation dynamics and ecological processes, the socio-political factors related to elephant population reduction may still mean that these thresholds are exceeded. For example, the management authority of Ithala Game Reserve has been trying without success for more than 6 years to find homes for excess elephant, all the time being over the density approved in the elephant management plan (currently stocked at nearly 170% of the preferred density in the elephant management plan).

The failure to manage at preferred densities is probably the result of a combination of factors, notably limited opportunities to translocate live elephants, including the limitations imposed by the Norms and Standards regarding translocation of previously translocated elephants, coupled with a reluctance to invoke the culling option given the continued opposition from some quarters. Interacting with the aforementioned reasons, there is still a level of uncertainty regarding the ecological interactions between browsing, vegetation and other drivers, creating both uncertainty in setting the preferred density and possibly a reluctance to face scrutiny of these estimates in the face of challenges to overturn decisions[2]. The Norms and Standards and elephant management plans have clearly been successful in securing ethical and humane treatment of elephants, but seemingly there is a significant risk in failing to achieve other equally important key purposes of the Norms and Standards which are to ensure that elephant are managed in a way that 'promotes broader biodiversity and socio-economic goals that are ecologically, socially and economically sustainable' and 'does not disrupt the ecological integrity of the ecosystems in which elephants occur'. There is seemingly a risk that short-term elephant welfare considerations may take precedence over long-term ecosystem and biodiversity management considerations, particularly for smaller properties.

The Norms and Standards require a rigorous process of evaluating all possible management options to manage elephant density or impact. Only if all other management options have been attempted and densities or impact are still too high will the culling option be considered. In this case, in addition to the management plan, a separate culling plan has to be prepared, submitted and approved prior to permits being issued. All of these processes can introduce significant lag effects in managing elephant numbers and complicate the adaptive management approach advocated in the same document. The Norms and Standards also prohibit selective culling from within family groups. For small properties that can only hold one family group, and where contraception has not been used or has not contained the population size, this may mean an 'all or nothing' approach where the entire family group has to be removed and a new smaller group introduced. Properties in this category are at present choosing to allow the population density to exceed the preferred density.

The National Norms and Standards for the Management of Elephant refer to an adaptive management approach, defined as 'integrated research, planning and monitoring in repeated cycles of learning in order to better define and achieve objectives, and is built on the assumption that natural

2. Management authorities routinely manage, through live removals or culling, populations of other large herbivores in an attempt to manage the relationship between herbivores and other elements of concern. None of these management interventions is subject to the level of regulation and scrutiny as for elephants in terms of either setting the preferred management densities/carrying capacities or in terms of the methods of removal.

extensive wildlife systems are complex, our knowledge is imperfect but we can learn from purposeful, documented objectives and actions'. They go on to state that 'measures to manage elephants must be informed by the best available scientific information, and where the available scientific information is insufficient, adaptive management forms the cornerstone of the management of elephants and adaptive decision-making tools must be adopted'. What this actually means in practice is unclear. However, in the case of managing for vulture nesting opportunities, we believe that adaptive management should be interpreted as setting relatively conservative elephant stocking densities, and then monitoring the impact of that density on the recruitment and availability of suitable large trees over an appropriate ecologically meaningful time frame. If the impacts are within acceptable limits, the elephant density could be allowed to increase. The process of monitoring and re-assessment is then repeated until an acceptable stocking density that is compatible with all objectives is reached. It may take several decades to then arrive at a final agreed preferred density using this approach. Advances in immunocontraception would allow this approach to be implemented without the need for, or at least significantly reducing the need for, removals. The likelihood of exceeding the acceptable density would be diminished by adopting this approach. It would however require specific emphasis on, and resources allocated to, monitoring. The tendency at present, by and large, seems to be to try and estimate the maximum density of elephant that an area may support and manage towards that target. This creates a significant risk that if the target was set incorrectly, then incompatible changes in habitat, or other impacts on objectives, may have been initiated or may take place prior to the preferred density being reached.

The vulnerability of vultures to elephant impact should be seen in the context of both rapid habitat loss outside protected areas as well as the unsuitability of otherwise suitable habitat owing to anthropogenic disturbance effects. Natural vegetation in KZN is decreasing at 1.2% per annum (Jewitt et al. 2015), while human population densities are increasing at 1.61% per annum (Statistics South Africa 2017). In communal areas, which cover a significant portion of the savanna biome, there is an ongoing loss of larger trees (e.g. see Higgins, Shackleton & Robinson 1999). If vultures are lost from protected areas and other extensive wildlife systems, then there are extremely limited opportunities for them elsewhere. The opportunities to expand or increase the number of protected areas suitable for vulture nesting are also decreasing rapidly, and there are no targets set for protected area expansion in the province. There is a strong push to grow the 'wildlife economy' in KZN, and this is likely to translate in the medium term to some increase in extensive wildlife systems, but at the same time also likely to see introduction of elephant to more areas. There is also a growing tendency to subdivide extensive ranches into smaller, intensively managed camps to breed high-value game species (Taylor, Lindsey, Davies-Mostert & Goodman 2015), and this may further reduce the extent of suitable nesting habitat for vultures.

We have shown for KZN that (1) a high proportion of vulture nests occur in areas with elephant, (2) there is evidence of elephant selection for tree species preferred by vultures for nesting, as well as of actual declines in density and recruitment of preferred species, (3) there are challenges in managing elephant populations according to preferred densities and (4) there are limited and reducing opportunities for vultures to use other areas for breeding. We conclude that retaining adequate habitat in protected areas and extensive wildlife systems with the appropriate structural attributes for vulture nesting and foraging is essential. We also conclude that retaining vultures as breeding residents in KZN would be dependent on appropriate ecological management of these areas, including managing the relationship between elephant and their habitat. Loss of vultures from the areas where they currently breed could result in the loss of vultures as breeding residents from KZN, even if other anthropogenic factors influencing vulture mortality could be managed. While many of the anthropogenic threats to vultures are difficult to manage and may largely be outside of the control of conservation programmes, managing elephant impact on vegetation structural attributes and hence the availability of vulture breeding habitat is directly within the control of land managers. It is important to note that the recruitment of trees into adult size classes is affected by the presence of multiple browsers and fire (O'Kane et al. 2011; Staver et al. 2009), and can be slow especially where both processes act together. For example, there has been essentially no regeneration of riverine forest, once the preferred nesting habitat of African White-backed Vultures in the Hluhluwe–iMfolozi Park, more than three decades after Tropical Cyclone Domoina (Staver, Beckett & Graf 2017). While it can be debated whether elephant and vegetation may reach a new stable state or that vegetation may eventually recover in a cyclical process (Scholes & Mennell 2008), in the time taken for this recovery to take place vultures could end up with significantly reduced or no suitable breeding habitat and could largely or completely disappear as breeding residents, with a low probability of eventual population recovery.

An indirect impact of elephant on vultures may be mediated through the competitive release of small shrubs and trees in response to reduced competition from large trees. A reduction in large trees has been associated with an increase in smaller size classes in several areas containing elephant (e.g. Druce et al. 2017; Kalwij et al. 2010). The increasing density of shrubs may reduce foraging ability of vultures, both in terms of carcass detectability and ability to take off after feeding (Bamford, Monadjem & Hardy 2009b; Brown 1985). While vultures can and do forage over large areas, loss of foraging habitat in protected areas and other extensive wildlife systems would result in vultures spending more time foraging in areas where they are more susceptible to mortality from poisons, power lines and direct human persecution.

The recent addition of all three tree-nesting vulture species occurring in KZN to Appendix 1 under the Convention on Migratory Species in 2017 makes the management of vultures, including the management of breeding habitat, not merely a provincial or national issue, but an international obligation.

We propose that the most important management actions to reduce vulnerability of vulture populations are:

- Sustained implementation of existing vulture monitoring programmes in KZN, and initiation and/or expansion of systematic vulture nest monitoring across larger areas of South Africa, particularly in areas where elephant occur.
- Long-term monitoring of tree density, structure, mortality and recruitment in all areas where elephant occur.
- Initiation of a detailed, focused and funded national research programme to, at a minimum, (1) develop ecological models to predict the outcomes of different browsing, fire and global change scenarios on vegetation composition and structure, (2) further document vulture nest site selection in terms of tree species, tree size and structural attributes, and landscape position, and (3) understand when nest site availability may become a limiting factor for vulture breeding. It is important that the models allow for scenario planning and forecasting of future state in terms of tree species composition, distribution and structural attributes.
- Adopt a precautionary approach regarding introduction of elephants to additional areas important for vulture nesting until the ecological interrelationships between elephants, vegetation and other ecological processes are better understood.
- Adopt an adaptive management approach to setting preferred stocking densities, with densities being held at conservative levels until there is reasonable certainty that these densities are not detrimental, prior to allowing densities to increase, that is, a progressive approximation towards identifying appropriate stocking densities.
- Hold protected area authorities and other land managers more accountable for managing elephant population densities and impact in accordance with the purpose of the National Norms and Standards for the Management of Elephant and approved elephant management plans.
- Initiate contraception early in new elephant populations.
- Review and potentially modify or remove provisions in the National Norms and Standards for the Management of Elephant that may introduce lag effects into decision-making processes.

Based on what we have observed in KZN, we hypothesise that tree-nesting vultures in the rest of South Africa could be vulnerable to elephant impact in the medium to long term. Loss of suitable breeding habitat in protected areas and extensive wildlife systems would result in significant negative effects on vulture populations. Unlike vegetation that can potentially recover in the medium to long term following perturbations, vulture populations would not be able to persist for the length of time that this recovery would take.

## Acknowledgements

The Zululand Tree Nesting Vulture Surveys that provided much of the vulture nest site data for this analysis were initiated and undertaken for the last 13 years by Bill Howells, John Craigie and pilot Greg Nänni, with more recent assistance by Geoff Clinning; John Craigie extracted and manages the vulture data used in this analysis. Heidi Snyman, Brent Coverdale, Greg Martindale and Kirsten Oliver assisted with the boundary maps of elephant properties in GIS format. We thank Andy Blackmore, Pieter Ruinard and three anonymous reviewers for their constructive comments that significantly improved an earlier draft. We thank Ezemvelo KZN Wildlife for providing permission to use these data. The ideas, arguments and opinions expressed in this paper are the authors' own and do not necessarily represent those of Ezemvelo KZN Wildlife.

### Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

### Authors' contributions

I.A.R. was in charge of conceptualisation, analysis, writing and property boundary mapping, while D.D. was involved in conceptualisation, elephant data collation and writing. J.C. was responsible for vulture data collection and property boundary mapping and B.C. was involved in property boundary mapping, elephant data collation and comment on text.

## References

Bamford, A.J., Monadjem, A. & Hardy, I.C., 2009a, 'Nesting habitat preference of the African White backed Vulture *Gyps africanus* and the effects of anthropogenic disturbance', *Ibis* 151(1), 51–62. https://doi.org/10.1111/j.1474-919X.2008.00878.x

Bamford, A.J., Monadjem, A. & Hardy, I.C., 2009b, 'An effect of vegetation structure on carcass exploitation by vultures in an African savanna', *Ostrich* 80(3), 135–137. https://doi.org/10.2989/OSTRICH.2009.80.3.2.965

BirdLife International, 2017, *Trigonoceps occipitalis* (amended version of assessment), The IUCN Red List of Threatened Species 2017, e.T22695250A118632735, viewed 24 February 2018, from https://doi.org/10.2305/IUCN.UK.2017-3.RLTS.T22695250A118632735.en

Birss, C., Rushworth, I., Collins, N., Pienkie, D. & Buijs, D., 2015, *Natural distribution ranges of large mammals in South Africa*, Version 1, Unpublished GIS coverage, Stellenbosch.

Boundja, R.P. & Midgley, J.J., 2010, 'Patterns of elephant impact on woody plants in the Hluhluwe iMfolozi Park, KwaZulu Natal, South Africa', *African Journal of Ecology* 48(1), 206–214. https://doi.org/10.1111/j.1365-2028.2009.01104.x

Brandl, R., Utschick, H. & Schmidtke, K., 1985, 'Raptors and land-use systems in southern Africa', *African Journal of Ecology* 23, 11–20. https://doi.org/10.1111/j.1365-2028.1985.tb00707.x

Brown, C.J., 1985, 'The status and conservation of the Cape Vulture in South-West Africa/Namibia', *Vulture News* 14, 4–15.

Coetzee, B.J., Engelbrecht, A.H., Joubert, S.C.J. & Retief, P.F., 1979, 'Elephant impact on *Sclerocarya caffra* trees in *Acacia nigrescens* tropical plains Thornveld of the Kruger National Park', *Koedoe* 22, 39–60. https://doi.org/10.4102/koedoe.v22i1.650

Cumming, D.H., Fenton, M.B., Rautenbach, I.L., Taylor, R.D., Cumming, G.S., Cumming, M.S. et al., 1997, 'Elephants, woodlands and biodiversity in southern Africa', *South African Journal of Science* 93(5), 231–236.

Druce, D.J., Druce, H., Te Beest, M., Cromsigt, J.P.G.M. & Van Rensburg, S., 2017, 'Elephant management in the Hluhluwe-iMfolozi Park', in J.P.G.M. Cromsigt, S. Archibald & N. Owen-Smith (eds.), *Conserving Africa's mega-diversity in the Anthropocene*, The Hluhluwe-iMfolozi Park Story, pp. 336–357, Cambridge University Press, Cambridge.

Eltringham, S.K., 1980, 'A quantitative assessment of range usage by large African mammals with particular reference to the effects of elephants on trees', *African Journal of Ecology* 18, 53–71. https://doi.org/10.1111/j.1365-2028.1980.tb00270.x

ESAG, 2015, *Elephant database*, Elephant Specialist Advisory Group, Pretoria.

Gaugris, J.Y., Matthews, W.S., Van Rooyen, M.W. & Bothma, J.D.P., 2004, 'The vegetation of Tshanini Game Reserve and a comparison with equivalent units in the Tembe Elephant Park in Maputaland, South Africa', *Koedoe* 47(1), 9–29. https://doi.org/10.4102/koedoe.v47i1.67

Goodman, P.S. & Craigie, J., 2016, 'KZN Biodiversity Status Assessment Report 2015: African Elephant (*Loxodonta africana*)', in I.A. Rushworth (ed.), *KwaZulu-Natal State of Biodiversity Report 2015*, pp. 145–147, Ezemvelo KZN Wildlife, Pietermaritzburg.

Hatcher, P.E., 1995, 'Three-way interactions between plant pathogenic fungi, herbivorous insects and their host plants', *Biological Reviews of the Cambridge Philosophical Society* 70, 639–694. https://doi.org/10.1111/j.1469-185X.1995.tb01655.x

Herremans, M. & Herremans-Tonnoeyr, D., 2000, 'Land use and the conservation status of raptors in Botswana', *Biological Conservation* 94, 31–41. https://doi.org/10.1016/S0006-3207(99)00166-4

Higgins, S.I., Shackleton, C.M. & Robinson, E.R., 1999, 'Changes in woody community structure and composition under contrasting landuse systems in a semi-arid savanna', *South Africa Journal of Biogeography* 26(3), 619–627. https://doi.org/10.1046/j.1365-2699.1999.t01-1-00317.x

Howells, W.W., Craigie, J. & Nänni, G., 2010, *Aerial survey of Zululand tree nesting vultures, 2010*, Unpublished report, Ezemvelo KZN Wildlife, Pietermaritzburg.

Howells, W.W. & Goodman, P.S., 2013a, *Ezemvelo KZN Wildlife Monitoring Plan: Lappet-faced vulture* (Torgos tracheliotos), Unpublished monitoring document, Ezemvelo KZN Wildlife, Pietermaritzburg.

Howells, W.W. & Goodman, P.S., 2013b, *Ezemvelo KZN Wildlife Monitoring Plan: White-backed vulture* (Gyps africanus), Unpublished monitoring document, Ezemvelo KZN Wildlife, Pietermaritzburg.

Howells, W.W. & Goodman, P.S., 2013c, *Ezemvelo KZN Wildlife Monitoring Plan: White-headed vulture* (Aegypius occipitalis), Unpublished monitoring document, Ezemvelo KZN Wildlife, Pietermaritzburg.

IUCN, 2017, *The IUCN Red List of Threatened Species. Version 2017-3*, viewed 05 December 2017, from http://www.iucnredlist.org

Jacobs, O.S. & Biggs, R., 2002, 'The impact of African elephant on marula trees in the Kruger National Park', *South African Journal of Wildlife Research* 32, 13–22.

Jewitt, D., Goodman, P.S., Erasmus, B.F.N., O'Connor, T.G. & Witkowski, E.T.F., 2015, 'Systematic land-cover change in KwaZulu-Natal, South Africa: Implications for biodiversity', *South African Journal of Science* 111(9–10), 1–9. https://doi.org/10.17159/sajs.2015/20150019

Kalwij, J.M., De Boer, W.F., Mucina, L., Prins, H.H.T., Skarpe, C. & Winterbach, C., 2010, 'Tree cover and biomass increase in a southern African savanna despite growing elephant population', *Ecological Applications* 20(1), 222–233. https://doi.org/10.1890/09-0541.1

Kemp, A.C. & Kemp, M.I., 1975, 'Observations on the White-backed Vulture *Gyps africanus* in the Kruger National Park, with notes on other avian scavengers', *Koedoe* 18(1), 51–68. https://doi.org/10.4102/koedoe.v18i1.914

Monadjem, A. & Garcelon, D.K., 2005, 'Nesting distribution of vultures in relation to land use in Swaziland', *Biodiversity and Conservation* 14(9), 2079–2093. https://doi.org/10.1007/s10531-004-4358-9

Moncrieff, G.R., Kruger, L.M. & Midgley, J.J., 2008, 'Stem mortality of *Acacia nigrescens* induced by the synergistic effects of elephants and fire in Kruger National Park, South Africa', *Journal of Tropical Ecology* 24(6), 655–662. https://doi.org/10.1017/S0266467408005476

O'Connor, T.G., Goodman, P.S. & Clegg, B., 2007, 'A functional hypothesis of the threat of local extirpation of woody plant species by elephant in Africa', *Biological Conservation* 136, 329–345. https://doi.org/10.1016/j.biocon.2006.12.014

O'Kane, C.A., Duffy, K.J., Page, B.R. & Macdonald, D.W., 2011, 'Are the long-term effects of mesobrowsers on woodland dynamics substitutive or additive to those of elephants?', *Acta Oecologica* 37(5), 393–398. https://doi.org/10.1016/j.actao.2011.05.005

Rushworth, I. & Chittenden, H., 2004, 'Palm-nut Vulture *Gypohierax angolensis',* in A. Monadjem, M.D. Anderson, S.E. Piper & A.F. Boshoff (eds.), *The Vultures of Southern Africa–Quo Vadis? Proceedings of a workshop on vulture research and conservation in southern Africa*, pp. 46–50, Birds of Prey Working Group, Johannesburg.

Rushworth, I. & Piper, S.E., 2004, 'Status and conservation of vultures in KwaZulu-Natal, South Africa', in A. Monadjem, M.D. Anderson, S.E. Piper & A.F. Boshoff (eds.), *The Vultures of Southern Africa–Quo Vadis? Proceedings of a workshop on vulture research and conservation in southern Africa*, pp. 87–95, Birds of Prey Working Group, Johannesburg.

Rushworth, I., Wakelin, J. & Bawden, G., 2007, 'Lappet-faced vulture (*Torgos tracheliotos*) breeding in Ithala Game Reserve, KwaZulu-Natal, South Africa', *Vulture News* 57(1), 65–67.

Rushworth, I.A. (ed.), 2008, *KZN Vulture Conservation Strategy, 2008–2012*, Unpublished document, Ezemvelo KZN Wildlife, Pietermaritzburg.

Rushworth, I.A., 2017a, *Natural distribution ranges of large herbivores in KwaZulu-Natal*, South Africa. Unpublished report, Ezemvelo KZN Wildlife, Pietermaritzburg.

Rushworth, I.A. (ed.), 2017b, *KwaZulu-Natal State of Biodiversity Report 2015*, Ezemvelo KZN Wildlife, Pietermaritzburg.

Scholes, R.J. & Mennell, K. (eds.), 2008, *Elephant management: A scientific assessment for South Africa*, Wits University Press, Johannesburg.

Selier, S.A.J., Henley, M., Pretorius, Y. & Garai, M., 2016, 'A conservation assessment of *Loxodonta africana'*, in M.F. Child, L. Roxburgh, E. Do Linh San, D. Raimondo, J. Sellier & H.T. Davies-Mostert (eds.), *The red list of mammals of South Africa, Swaziland and Lesotho*, South African National Biodiversity Institute and Endangered Wildlife Trust, South Africa, viewed 01 June 2018, from https://www.ewt.org.za/reddata/reddata.html

Shannon, G., Thaker, M., Vanak, A.T., Page, B.R., Grant, R. & Slotow, R., 2011, 'Relative impacts of elephant and fire on large trees in a savanna ecosystem', *Ecosystems* 14(8), 1372–1381. https://doi.org/10.1007/s10021-011-9485-z

Skinner, J.D. & Chimimba, C.T., 2005, *The mammals of the southern African sub-region*, Cambridge University Press, Cambridge.

Slotow, R., Garaï, M.E., Reilly, B., Page, B. & Carr, R.D., 2005, 'Population dynamics of elephants re-introduced to small fenced reserves in South Africa', *South African Journal of Wildlife Research* 35(1), 23–32.

Sorley, C.S. & Andersen, D.E., 1994, 'Raptor abundance in south-central Kenya in relation to land-use patterns', *African Journal of Ecology* 32, 30–38. https://doi.org/10.1111/j.1365-2028.1994.tb00552.x

Statistics South Africa, 2017, *Mid-year population estimates 2017*, Statistical Release P0302, Statistics South Africa, Pretoria.

Staver, A.C., Bond, W.J., Stock, W.D., Van Rensburg, S.J. & Waldram, M.S., 2009, 'Browsing and fire interact to suppress tree density in an African savanna', *Ecological Applications* 19(7), 1909–1919. https://doi.org/10.1890/08-1907.1

Staver, A.C., Beckett, H. & Graf, J.A., 2017, 'Long-term vegetation dynamics within the Hluhluwe-iMfolozi Park', in J.P.G.M. Cromsigt, S. Archibald & N. Owen-Smith (eds.), *Conserving Africa's mega-diversity in the Anthropocene*, The Hluhluwe-iMfolozi Park Story, pp. 56–79, Cambridge University Press, Cambridge.

Taylor, A., Lindsey, P.A., Davies-Mostert, H. & Goodman, P.S., 2015, *An assessment of the economic, social and conservation value of the wildlife ranching industry and its potential to support the green economy in South Africa*, The Endangered Wildlife Trust, Johannesburg.

Taylor, M.R., Peacock, F. & Wanless, R.M. (eds.), 2015, *The 2015 Eskom red data book of birds of South Africa, Lesotho and Swaziland*, BirdLife South Africa, Johannesburg.

Thiollay, J.M., 2006, 'The decline of raptors in West Africa: Long-term assessment and the role of protected areas', *Ibis* 148, 240–254. https://doi.org/10.1111/j.1474-919X.2006.00531.x

Trollope, W.S.W., Trollope, L.A., Biggs, H.C., Pienaar, D. & Potgieter, A.L.F., 1998, 'Long-term changes in the woody vegetation of the Kruger National Park, with special reference to the effects of elephants and fire', *Koedoe* 41(2), 103–112. https://doi.org/10.4102/koedoe.v41i2.255

Vogel, S.M., Henley, M.D., Rode, S.C., Vyver, D., Meares, K.F., Simmons, G. & Boer, W.F., 2014, 'Elephant (*Loxodonta africana*) impact on trees used by nesting vultures and raptors in South Africa', *African Journal of Ecology* 52(4), 458–465. https://doi.org/10.1111/aje.12140

Wiseman, R., Page, B.R. & O'Connor, T.G., 2004, 'Woody vegetation change in response to browsing in Ithala Game Reserve, South Africa', *South African Journal of Wildlife Research* 34(1), 25–37.

Whateley, A., 1986, 'Response of White-backed Vultures *Gyps africanus* to environmental change in the Hluhluwe and Umfolozi Game Reserves, Natal', *Lammergeyer* 37(5), 5–10.