

ELEPHANT IMPACT ON THE LARGE TREE COMPONENT AND ITS POTENTIAL
EFFECT ON SELECTED FAUNA

by

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submitted in accordance with the requirements

for the degree of

MASTER OF SCIENCE

in the subject

ENVIRONMENTAL MANAGEMENT

at the

UNIVERSITY OF SOUTH AFRICA

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NOVEMBER 2010

Declaration

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I declare that **ELEPHANT IMPACT ON THE LARGE TREE COMPONENT AND ITS POTENTIAL EFFECT ON SELECTED FAUNA** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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Date

ELEPHANT IMPACT ON THE LARGE TREE COMPONENT AND ITS POTENTIAL EFFECT ON SELECTED FAUNA

Summary

The aim of the study was to determine the consequences of elephant (*Loxodonta africana*) impact on selected nesting sites of avian fauna and other species in the Associated Private Nature Reserves. The study also aimed at answering key questions on how the architecture of trees influence nest site suitability and what landscape features affect nest site location. Furthermore the type of impact that elephants have on specific nesting sites was determined and how this would affect the short term persistence of these trees. The facilitatory role of elephants was examined by looking at the type of impact that produces gum exudants as well as what gum is selected for by primates and whether primary branch breaking may lead to the creation of nesting sites for species such as the southern ground hornbill (*Bucorvus leadbeateri*).

Key terms

Loxodonta africana, Vultures, Raptors, Southern ground hornbills (*Bucorvus leadbeateri*), Primates, Nesting sites, Elephant impact

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Acknowledgements

I would like to express my sincere gratitude and appreciation to:

- Prof. L.R. Brown and Dr. M.D. Henley, for the continued support, guidance, mentorship and encouragement throughout this project.
- Mr. Q. Hagens for his devoted assistance during field work and GIS analyses.
- The management (especially, Mr. C. Rowles and Mr. J. Brits) and staff (field rangers) of the APNR for allowing and supporting the research and for providing assistance when needed.
- Prof. P. Hockey for providing statistical analyses software.
- Ms. Merle Werbeloff for her assistance and mentorship during the statistical analyses.
- The South African Weather Service for providing climate data for the Hoedspruit area.
- The Transvaal Museum for allowing me to gather data from primate skulls in their collection.
- Riverside Wildlife Rehabilitation Centre for allowing us to conduct feeding trial experiments on vervet monkeys at the centre.
- Mr. A. Wood for generously providing six months of accommodation during the project.
- UNISA for the academic bursary awarded to me.
- To all my family and friends who encouraged and supported me throughout this project. And above all, to God who gave me this opportunity and the strength to complete it.

Chapter 1

Introduction

1.1 Elephants as modifiers of their environment

The African elephant (*Loxodonta africana*) has been described as an ecosystem engineer with the capacity to structurally modify the vegetation of the habitats within which they exist (de Beer *et al.*, 2006). The preservation of large populations of elephants as well as the maintenance of biodiversity in protected areas is becoming increasingly difficult. This is as a result of increasing human and elephant populations at rates of 3% and 5% respectively (Cumming *et al.*, 1997). The size and composition of most reserves in Africa are inadequate to absorb the considerable impacts of large numbers of animals (Conybeare, 2004). For most reserves and protected areas, biodiversity conservation remains a key mandate (O'Connor *et al.*, 2007). Not only are elephants an essential component of ecosystems, but they are also charismatic and considered vulnerable to extinction (Lombard *et al.*, 2001).

Historical data shows that elephant numbers and densities across Africa declined considerably due to the growth in the ivory trade which reached a peak in the mid nineteenth century, in many regions numbers are still decreasing to the point of real concern (Cumming *et al.*, 1997; Carruthers, 2010). In South Africa there has never been a reliable estimate of elephant numbers prior to 1652. The population decline took place in three phases; between 1652 and 1790 the decline was largely due to an increase in human population growth and settlements, ivory trade during this phase only played a small part. From 1790 – 1870 the primary force eliminating elephants was the growth of the ivory trade and the emergence of professional ivory hunters, the hunters operated as far as the Zambezi Valley. In third phase, by approximately 1870 the large elephant populations had been wiped out (Hall-Martin, 1992; Carruthers, 2010). In 1898 there

were no more than 10 – 20 elephants that remained in the Kruger National Park (Owen-Smith *et al.*, 2006). Elephant numbers reached their lowest when there were about 120 animals left in the 1920's (Hall-Martin, 1992). Numerous studies were conducted from the 1960's onwards, in East Africa (Buechner & Dawkins, 1961; Laws, 1969, Dublin *et al.*, 1990) as well as southern Africa (Van Wyk & Fairall, 1969; Caughley, 1976; Anderson & Walker, 1974; Guy, 1976; Coetzee *et al.*, 1979; Hall-Martin, 1990; Lindsay, 1993) and most of these suggested that woody vegetation responded negatively to elephants. Guldemon & Van Aarde (2008), found that there was a disproportionate citation (citation bias) of only a few published studies that concluded that woody vegetation responded negatively to elephants while others reveal the opposite. Responses of vegetation in transitional savannas where most elephants live range from negative to positive at different elephant densities. Long term studies (>20 years) in unfenced areas showed both positive and negative vegetation responses (Guldemon & Van Aarde, 2007). Currently the growing number of elephants and the management thereof remains a contentious issue. When large herbivores, especially elephants, are introduced into an area from which they have been absent or occurred in very low numbers, it is to be expected that a change in vegetation would occur (Owen-Smith *et al.*, 2006).

In combination with fire, drought and/or other browsers the effect of elephants on vegetation is amplified (De Beer *et al.*, 2006). The removal of trees from a woodland/savanna has been described by Fenton *et al.* (1998) as an apparent and dramatic disturbance that can alter biodiversity and change the structure of a system. By studying aerial photographs, Trollope *et al.* (1998) found that there has been a marked decline in the density of large trees in the major arid landscapes within the Kruger National Park (KNP), since 1960. High numbers of elephants in an area can reduce the abundance of large trees and therefore change the structure and functioning of ecosystems (Young *et al.*, 2009). African elephants are also regarded as the main drivers in determining savanna woody cover (Moe *et al.*, 2009). Large trees in arid or semi-arid regions generate habitat diversity (Dean *et al.*, 1999). Savanna ecosystems are defined by “a continuous herbaceous layer interspersed with trees.” Large trees are an important component of spatial heterogeneity in habitat structure (vertically and

horizontally) and they promote species diversity (Dean *et al.*, 1999; Druce *et al.*, 2008). The reduction of the number and density of large trees may lead to an increasing density of shrubs (Gadd, 2002), but it could also transform woodlands into mixed woodlands or even grasslands, which leads to an improved herbaceous layer (Guldmond & Van Aarde, 2007). Smit (2004) found that the rapid establishment of tree seedlings after the removal of some or all of the mature woody plants may in time develop into a bush encroachment problem. Bush encroachment is detrimental to grazers and in some cases may even be detrimental to some browsers (Smit, 2004). Large trees are also regarded as focal points for animal activity and provide resources that could be scarce in the environment such as, shade, shelter, nesting sites, observation posts for raptorial birds and specialized food or prey items. It has also been found that the size and spacing of the trees affects the spatial pattern of animal and plant assemblages (Dean *et al.*, 1999). Ecosystem engineers have the ability to influence ecological processes by altering the physical environment and this is believed to have positive effects at landscape-scale (Pringle, 2008; Goheen *et al.*, 2010; Kalwij *et al.*, 2010). Elephants as ecosystem engineers have the ability to increase habitat complexity by modifying the woody structure and in so doing they could potentially affect the suitability of the habitat for different animal (especially smaller animals) and bird species (Pringle, 2008; Palmer *et al.*, 2008; Nasser *et al.*, 2010). The study by Pringle (2008) showed that the local arboreal lizard population increased with the number of elephant-damaged trees increasing in an area. This interaction represents “an indirect effect initiated by elephants, transmitted by trees and received by lizards.” However, the substantial reduction of the large tree component in savanna systems would change the nature of the system and the system would then exist in a different successional state (Druce *et al.*, 2008). The elevated mortality of mature trees and the suppression of recruitment and regeneration may lead to the conversion of woodlands to scrubland or grassland states (O’Connor *et al.*, 2007; Lombard *et al.*, 2001). The loss of large trees is also likely to lead to the loss of large birds, frugivores and habitat-specific plants (Dean *et al.*, 1999). Depending on the scale at which data is gathered, browsers, especially elephants, therefore have the ability to noticeably alter system heterogeneity by reducing the number, structure and composition of woody species (Levick & Rogers, 2008). Relatively dense populations of large herbivores can elicit undesirable effects in protected areas, especially when the area is fenced and animal movements are restricted (Young *et al.*,

2009). These effects are exacerbated when found in conjunction with fire, herbivory and irregularities in rainfall (Eckhardt *et al.*, 2000; Wiseman *et al.*, 2004). By modifying habitats and removing or damaging adult trees, elephants might have a significant effect on certain avian fauna (i.e. vultures, raptors and ground hornbills) and other species, such as primates, and these effects need to be investigated.

1.2 Elephant feeding habits

Elephants forage in specific patches within a landscape. They also feed on specific individual plant species within those patches. Elephants may be attracted to certain patches for various reasons; a certain tree species, a combination of species, access and palatability or the presence of a certain species in a particular state. They may also have an increased impact on vegetation near waterholes and alongside rivers or next to roads which they frequently use (Gadd, 2002; Levick & Rogers, 2008). Elephants need to achieve maximum throughput of food per unit time due to their large energy requirement, they therefore select for items rich in cell soluble (the proteins, sugars, starches and lipids contained in the cytoplasm) relative to availability. Their diet consists predominantly of green grass and forbs in the wet season, green browse in the late wet and beginning of the dry season. Following leaf fall they feed mainly on bark and roots (O'Connor *et al.*, 2007). Elephants are forced to subsist on woody vegetation for longer periods in areas where there is degradation of grasslands, wetlands and riparian vegetation (O'Connor *et al.*, 2007). A wide variety of woody vegetation is utilized by elephant and they feed in several ways, by stripping leaves, clipping twigs, breaking branches, removing bark from stems and roots, as well as uprooting and felling trees (Stokke, 1999). Stokke & du Toit (2000) found that elephant browsing height was fairly low above the ground (<2 m) in the Chobe National Park, Botswana which is consistent with findings elsewhere and in South Africa (Jachmann & Bell, 1985; Owen-Smith, 1988). Family units are also generally more selective feeders; in terms of quality (feeding sites and woody plant species) and quantity than males. Bulls have a less diverse diet and consumed more tree parts in general (Stokke, 1999). A study conducted by Greyling (2004) in the APNR showed that impact on woody vegetation differs between sexes. Bull groups are more prone to tree felling and large branch breakage than family units, cows'

preferentially leaf-stripped woody plants. Bulls tend to utilize the bark and roots of trees that are felled (Greyling, 2004). In Pongola game reserve, Natal, tree utilization by reintroduced elephants was recorded and included, debarking, browsing and trees being pushed over. This study found however that elephants were destroying trees at rates within which trees could realistically regenerate (Duffy *et al.*, 2002).

Gadd (2002) found that elephants may reduce the survival rate of trees by extensive ring-barking. The breakage of stems and branches by elephants may transform tall trees to short trees (1 – 3 m tall) and create what is called “browsing lawns” (Makhabu *et al.*, 2006). It has been found that in some ecosystems, large mammals (such as elephants) affect vegetation structure and composition directly and this can have indirect effects on birds (Ogada *et al.*, 2008). It is therefore important to understand to what extent elephant feeding habits on large trees may influence the availability, creation and existence of nesting sites for bird species.

1.3 Elephants impact on vegetation and tree nesting raptors

Most large raptors, in southern Africa, start breeding in the dry winter season, in mature large trees (Herremans & Herremans-Tonnoeyr, 2000; Dean *et al.*, 1999). The availability of food is a major factor in determining raptor densities for an area. In less productive areas, the raptor pairs seem to be spaced further apart than in more productive areas (Hustler & Howells, 1990).

For certain tree nesting birds, elephants may be removing potential or existing nesting sites by felling large trees. Various tree nesting raptors which have been listed as vulnerable in the *Red Data Book of Birds of South Africa, Lesotho and Swaziland* (Barnes, 2000) are potentially susceptible to the loss of nesting sites due to elephant impact.

Vulture populations have shown a 10% decline in recent years (Murn *et al.*, 2002). Studies have shown that vultures select tall trees for nesting (Monadjem & Garcelon, 2005). It is generally accepted that raptors are sensitive to habitat changes; the main factors affecting raptor populations is the widespread prey reduction through grazing pressure, habitat loss and fragmentation (Herremans & Herremans-Tonnoeyr, 2000; Monadjem & Garcelon, 2005).

The White-backed vultures (*Gyps africanus*), particularly, were found by Murn *et al.* (2002) to have a preference for *Acacia* species as nesting trees. This is similar to data from Kemp & Kemp (1975) who found that 63% of nests for White-backed vultures were in *Acacia* trees, and the species used was the most common for the vegetation type. Lappet-faced vultures (*Torgos tracheliotus*) and White-headed vultures (*Trigonoceps occipitalis*) were found to nest in non riparian vegetation in the canopy of trees. Kemp & Kemp (1975) examined 106 White-backed vulture nests and all were in the canopy of trees except for four which were in the sub-canopy in large forks. There was an interchange of nests within the area and it was found that White-backed vultures used Whalberg's eagle (*Aquila wahlbergi*) nests, which could explain the presence of sub-canopy nesting by White-backed vultures. The nests ranged in diameter from 45 cm to 1 m and in depth from 15 cm to 90 cm. They were all constructed of sticks with a maximum diameter of 3 cm. Most of the nests were lined with grass, or a mixture of grass and sprigs, from vegetation in the immediate vicinity of the nest (Kemp & Kemp, 1975). They mostly nest singly or in loose colonies with nests between 200 m and 500 m apart. Larger aggregations of nests in the Kruger National Park appeared to be close to watering points (Kemp & Kemp, 1975; Hockey *et al.*, 2005).

Conflicting results have been obtained from studies investigating the effect of elephant presence on the diversity of bird communities (Herremans 1995, Cummings *et al.*, 1997). Herremans (1995) mentions that, changes in woody vegetation density and structure could have significant implications for bird species that could lead to a decline in their diversity, due to a more shrub like growth form. A study conducted in Hlane National Park, Swaziland, showed that vultures avoided nesting in two elephant enclosures. Within these enclosures tall trees had been debarked or killed by elephants, therefore it

was assumed that vultures avoided nesting there on account of the dead trees (Monadjem & Gracelon, 2005). Henley & Henley (2005) argued that elephant feeding habits could either be detrimental to the nesting sites of particular species of birds, have no effect at all or alternatively elephants could, by breaking primary branches, actually play a facilitating role in the creation of nests. Elephant impact could have positive or negative knock-on effects for tree nesting birds (Palmer *et al.*, 2008; Nasserri *et al.*, 2010).

1.4 Elephant vegetation impact and southern ground hornbills

Southern ground hornbills (SGH), *Bucorvus leadbeateri*, occur mainly in large conservation areas and the current population is thought to range over 160 000 km² in South Africa. Population estimates are between 1500 and 2000 birds, with numbers outside large conservation areas declining rapidly (Kemp, 2000). The birds live in cooperative breeding groups which vary in size from 2 – 11 individuals (Kemp & Kemp 1980; Kemp, 2000) and require a mosaic of habitat types to satisfy foraging and nesting requirements, including savanna, grassland and woodland areas (Vernon, 1986; Kemp, 1995). Nesting sites are usually large cavities in large trees with an internal diameter of at least 40 cm (Kemp & Begg, 1996). It was found in KNP that groups occupy large home ranges of up to 100 km² (Kemp & Kemp, 1980), where as in Zimbabwe and Botswana, the groups are more densely distributed with an average of 20 km² per group (Kemp & Begg, 1996). Kemp & Kemp (1980) suggested that the low density of southern ground hornbills in KNP could be as a consequence of lower habitat quality and therefore the birds need larger home ranges. There is also evidence that suggests that nesting sites are a significant limiting factor to the breeding success of the birds. It is estimated that there is a mean annual cavity loss of 7.7% in KNP (Kemp & Begg, 1996). It is unknown what the rate of cavity formation is, but is hypothesized that elephants and fire are likely to play a role in both cavity loss and formation (Spear *et al.*, 2005). SGH breeding is limited by availability of suitable nesting sites and this may influence population growth, it is therefore essential to understand what role elephants may play in the formation or loss of nesting sites.

1.5 Elephant vegetation impact and gum production

The impact of elephants on trees could play a facilitatory role in the production of a food source, i.e. gum, for primates. Facilitation occurs when “consumption by a consumer produces a flow of resources into another consumer and secondly, when the latter consumer specializes on consuming the produced resource” (Farnsworth *et al.*, 2002). Body size has been found to be an important aspect for food mediated interactions between small and large herbivore species. Small species often consume highly nutritious plant parts. Large herbivores can increase the production and/or availability of nutritious plant tissue (Makhabu *et al.*, 2006). Primates have been shown to eat gum exudates produced by trees after mechanical or insect damage (Nash, 1986). Because gum is living, photosynthetic tissue is often utilized by large herbivores (mainly elephants) which results in wounds that produce gum (Altmann, 1985). Gum may accumulate on trees as large “globs” or long “streaks” or even just small droplets on the tree. Although the gum is quickly depleted after a feeding event it is usually rapidly renewed (Nash, 1986). A study of *Acacia tortillis* and *Acacia xanthophloea* has shown that both species produced gum at sites of injury to the bark and that vervet monkeys (*Cercopithecus aethiops*) were found to inspect trees daily seeking for gum. Furthermore competition for especially *A. xanthophloea* gum was observed in vervet monkeys (Wrangham & Waterman, 1981). Field studies have shown that gum is an important aspect of primate diets and gum may be an important source of minerals (Bearder & Martin, 1980). According to a study by Altmann (1985) the primary benefit of gum for baboons (*Papio ursinus*) is energy. Certain primates have morphological features that allow them to harvest gum and by scraping or gouging trees they in turn stimulate gum flow. Consuming gum may give primates a competitive advantage (Nash, 1986). Nash (1986) suggested that gum is used extensively by some species year round or only in certain seasons as a dietary supplement. Vervets have been found to use all *Acacia* products for food throughout the year (Wrangham & Waterman, 1981). Bushbabies (*Galago moholi* and *Otolemur crassicaudatus*) are known to utilize gum throughout the year but gum usage was particularly prevalent during the dry season. Bearder & Martin (1980) found that gum flow increased steadily during summer but maximum gum flow did not coincide with spring or the appearance of new leaves. Indirectly, ecosystem

engineers such as elephants may initiate powerful trophic effects which necessitate further investigation (Pringle, 2008). Hence elephants could whilst feeding create a valuable dry season food source to a suite of primates which necessitates further investigation.

1.6 Aims

The main aim of the study is to determine the consequences of elephant impact on selected nesting sites of avian fauna and other species. The study also aims at answering key questions on how the architecture of trees influence nest site suitability and what landscape features affect nest site location. Furthermore the type of impact that elephants have on specific nesting sites will be determined and how this would affect the short term persistence of nesting trees. Aspects of the facilitatory role of elephant feeding habits is examined by looking at the type of impact that produces gum exudants as well as what gum is selected for by primates and whether primary branch breaking may lead to the creation of nesting sites for species such as the southern ground hornbill (*Bucorvus leadbeateri*).

1.7 Objective

To determine the impact of elephants on the large tree component in the savanna biome and its effect on nesting sites of selected avian fauna. Furthermore, I examine aspects of the indirect consequences of elephant feeding habits on primates.

1.8 Hypothesis

Elephants do have an impact on the nesting sites of avian fauna and their feeding habits do influence other species in other ways.

1.9 Predictions

1. Vultures, raptors and ground hornbills select for tall trees with particular morphological characteristics within the landscape.

2. Vultures and raptors vacate nesting sites after heavy impact by elephants.
3. Elephants play a role in facilitating the creation of ground hornbill nesting sites through primary branch breakage.
4. A secondary consequence of elephant impact leads to the creation of a food source i.e. gum for primates and other species.

1.10 Key questions

1. How does the architecture of a tree influence the nest site suitability?
2. What landscape features affect nesting site location?
3. What type of elephant impact was prevalent on the nesting trees and how does it affect the short term persistence of the tree?
4. Does breakage of large branches by elephants create suitable ground hornbill nesting sites?
5. What type of impact causes gum exudants?
6. What gum is selected for by primates?

1.11 Thesis structure

The following chapter (Chapter 2) gives a general description of the study area in terms of the location, size, topography, geology, soils, climate, vegetation and fauna. It also gives a description of the study animals. The study methods described in this chapter refer to the field methods and not the statistical analyses.

Chapter 3 describes the impact of elephants on the nesting sites of vultures and raptors as well as the morphological characteristics of the nesting trees and landscape features that affect nest site location. Chapter 4 describes the characteristics of ground hornbill nesting sites and the impact of elephants on these trees. Chapter 5 explores the facilitatory role of elephants in the possible creation of nesting sites for ground hornbills and the production of a food source for primates, with special reference to vervet monkeys and bushbabies.

Finally, chapter 6 represents a concluding discussion reviewing the above mentioned aspects, the limitations of the study as well as recommendations for management. Chapter 3 – 5 will follow the format of manuscripts with the consequence that some repetition might occur in the respective introductions of these chapters and this first chapter.

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Chapter 2

Study area and methods

2.1 Study area

2.1.1 Location and size

The study area is located in the approximately 180 000 ha of the Associated Private Nature Reserves (APNR) which is made up of the Timbavati, Klaserie, Balule and Umbabat Private Nature Reserve. The APNR is located in the Limpopo Province, South Africa, at a latitude of 24° 10.790 S and a longitude of 31° 10.514 E. The APNR (Fig. 2.1) is adjacent to the western boundary of the Kruger National Park (KNP). The fences between the Private Nature Reserves and the KNP were removed in 1993. Prior to this all internal fences were removed as the APNR is comprised of several privately owned properties which vary in size.

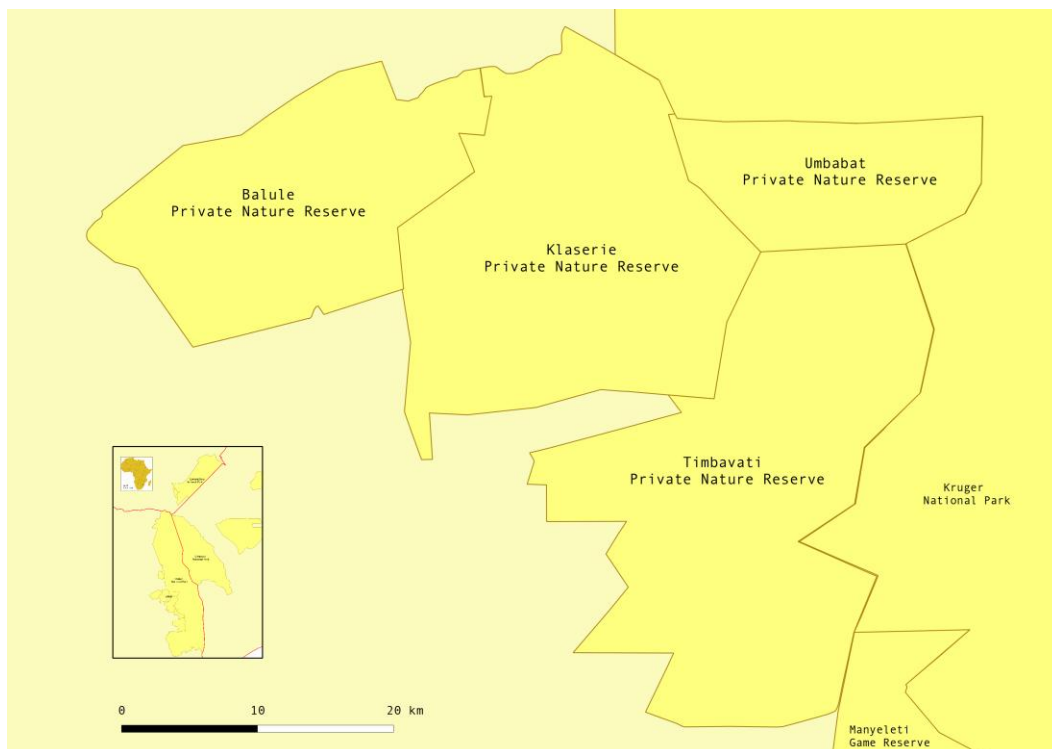


Fig. 2.1 Map of the study area (APNR).

Although the APNR is made up of four large amalgamated reserves, the focal study area consisted of the Timbavati, Klaserie and Umbabat Private Nature Reserves.

Within the Klaserie Private Nature Reserve (KPNR), vulture and raptor surveys were conducted. The KPNR was selected as it had the most comprehensive historical data of vulture and raptor nesting sites. Aerial surveys also indicated that the highest densities of vulture and raptor nests occurred within the KPNR; hence surveys were focused within this reserve. Southern Ground Hornbill (*Bucorvus leadbeateri*) nesting sites were surveyed throughout the APNR because nesting sites were more widespread albeit in lower numbers when compared to vulture and raptor nests.

2.1.2 Topography

The surface of the APNR is generally described as being flat or undulating. The northern areas of the KPNR are somewhat more rocky, with ridges, small hills and rocky outcrops (Zambatis, 1980). Altitude ranges from 232 m above sea level to approximately 535 m above sea level, at the Klaserie and Olifants River confluence the altitude is at 232 m above sea level (Fig. 2.2).

The main river systems are the perennial Olifants and Klaserie Rivers and the seasonal Timbavati River (Gertenbach, 1983). The KPNR is dissected by the Klaserie River which originates from the Drakensberg mountain range and which meets up with the Olifants River (de Villiers, 1994). The Olifants River forms the northern boundary of the KPNR. The Ntsiri River drains the Umbabat Private Nature Reserve (UPNR) as well as the eastern section of the KPNR. The seasonal Timbavati River runs for the most part through the southern section of the Timbavati Nature Reserve (TPNR) while the smaller seasonal Sesete River drains into the Timbavati River. The Nharalumi River dissects the TPNR and the UPNR and runs into the Olifants River in the Kruger National Park. The eastern section of the central TPNR is drained by the seasonal Machaton River (Fig. 2.2).

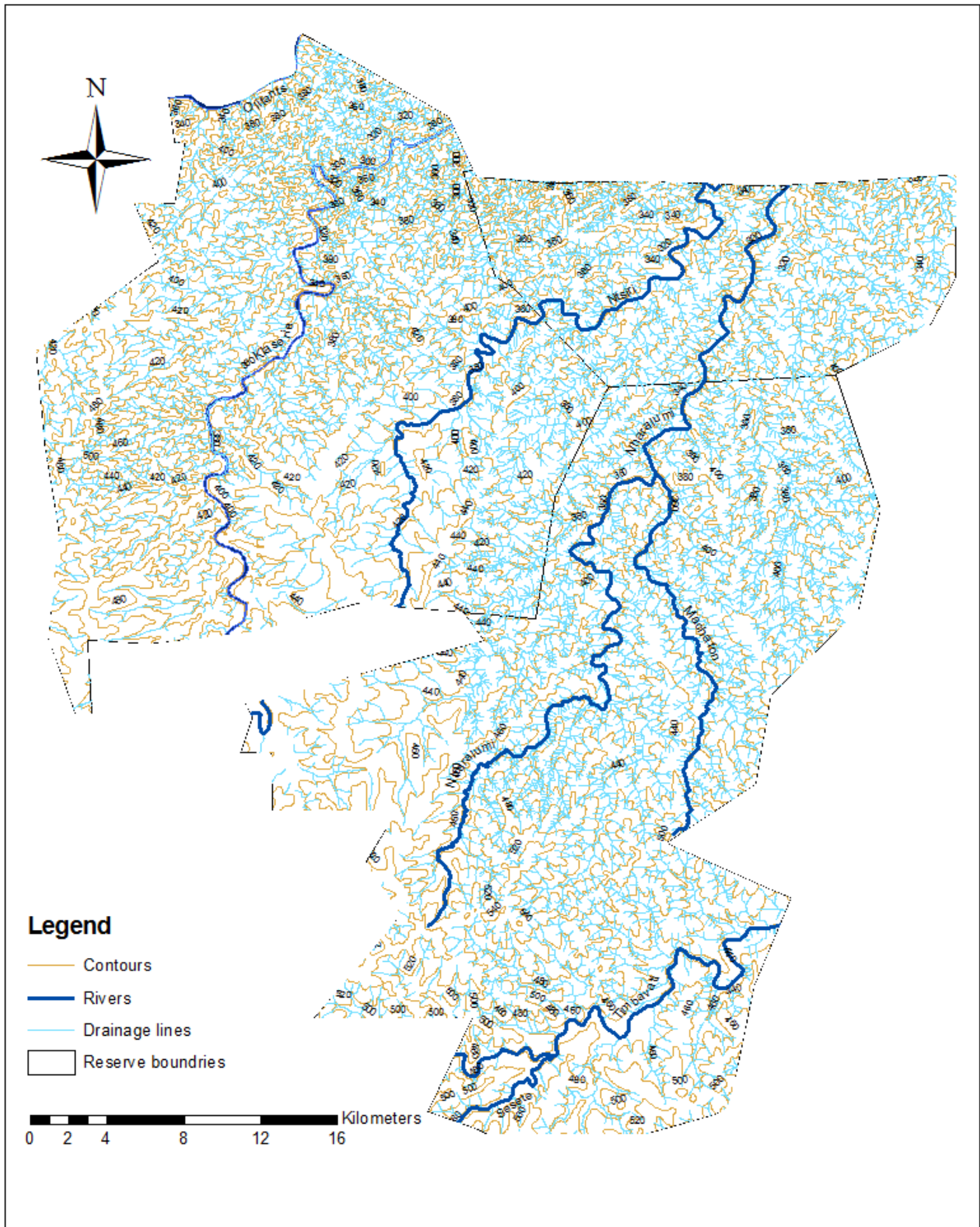


Fig. 2.2 Rivers, drainage lines and contours within the study area (APNR).

2.1.3 Geology and soils

The dominant geological formations in the study area consist of granite and gneiss, which are intersected by dolerite intrusions. Gabbro occurs only in the southern and central parts of the TPNR (de Villiers, 1994).

According to Gertenbach (1983), the main soil forms found within the APNR are shallow mispah and glenrosa forms. The dolerite intrusions give rise to changes in the soil. The main soils found within the intrusions are Hutton and Swartland. The terrain is very undulating with clayey and sometimes sodic soils found in the bottomlands. Leaching of soils occurs in the uplands and these soils therefore have very low fertility (Young, 1976).

2.1.4 Climate

The area has a subtropical climate with an annual rainfall that ranges between 450 – 700 mm per annum (Fig. 2.3). The summer months are hot and humid with day time temperatures in mid summer reaching temperatures of between 38° - 42 °C (Fig. 2.3). Winter is predominantly mild with day time temperatures of 20° - 25 °C. There has been no record of temperatures below 0 °C. The area has wet and dry periods which occur on approximately a 10 year cycle. Rainfall in the southern TPNR is higher than in the KPNR (de Villiers, 1994).

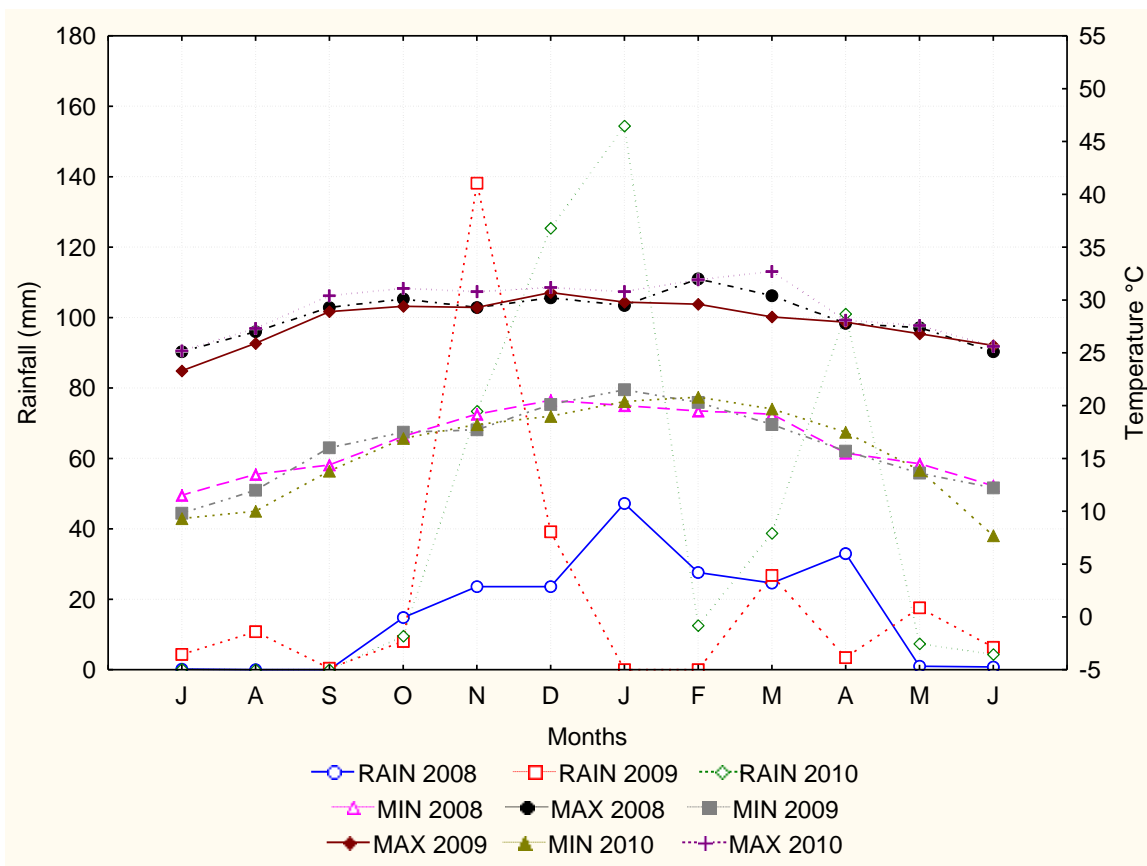


Fig. 2.3 Average monthly temperatures and rainfall for the Hoedspruit area from January 2008 – December 2010 (Data received from South African Weather Service).

2.1.5 Vegetation

The APNR is located within the savanna biome. Savanna is described as vegetation consisting of an herbaceous lower layer and a sparse to dense upper layer of woody plants (Edwards, 1983).

According to Mucina & Rutherford (2006) the vegetation occurring in the study area belongs to the Granite Lowveld (SVI 3), Phalaborwa-Timbavati Mopaneveld (SVmp 7) and Lowveld Rugged Mopaneveld (SVmp 6) vegetation units.

The veld type was also classified by Acocks (1988) as Arid Lowveld (Veld type 11) while Low & Rebelo (1996) classified the vegetation of the study area as a mixture of Mopane Bushveld (LR 10) and Mixed Lowveld Bushveld (LR 19). This veld type occupies the hot

Lowveld of Mpumalanga/Limpopo Province. It is characteristic of *Acacia nigrescens* – *Sclerocarya birrea* savanna as described by Mucina & Rutherford (2006).

The following plant communities have been classified by De Villiers (1994) within the study area:

1. *Acacia nigrescens*–*Combretum apiculatum* woodland
2. *Combretum apiculatum* open woodland
3. *Combretum* spp.–*Terminalia sericea* woodland
4. *Colophospermum mopane* veld
5. *Combretum* spp.–*Colophospermum mopane* woodland
6. Mixed *Combretum* spp.–*Terminalia sericea* woodland
7. Mixed veld on Gabbro
8. Olifants River Rugged veld
9. Shrub *Colophospermum mopane* veld

The vegetation throughout the study area comprises of a mixture of tall trees such as *Sclerocarya birrea*, *Acacia nigrescens*, *Combretum imberbe* and *Colophospermum mopane*. In the sandy uplands *Terminalia sericea*, *Combretum apiculatum* and *Colophospermum mopane* are mainly found, forming tall shrublands with few trees to moderately dense low woodlands. Dense thickets to open savanna are found in the bottomlands with *Acacia nigrescens*, *Sclerocarya birrea* and again *Colophospermum mopane* in the woody layer (Mucina & Rutherford, 2006). This study considered mainly the tall tree component of the vegetation as the occurrence of the nesting sites of raptors, vultures or ground hornbills are known to occur mostly within tall trees. Historical data from a study by Kemp & Kemp (1975) shows that vultures and most raptors select for tall trees with an estimated height of 10 m – 25 m. Southern Ground Hornbills also select for tall trees with large cavities for nesting (Kemp & Begg, 1996). Hence the plant community structure in general and large tree component specifically will be described in greater detail in relation to the occurrence of nesting sites for either raptors, vultures or ground hornbills in the chapters that follow.

2.1.6 Fauna

The APNR hosts a wide variety of animal species and since the removal of fences in 1993, animals can move freely between the APNR and KNP. Some of the more conspicuous species present in the APNR include buffalo (*Syncerus caffer*), elephant (*Loxodonta africana*), impala (*Aepyceros melampus*), white rhino (*Ceratotherium simum*), giraffe (*Giraffa camelopardalis*), blue wildebeest (*Connochaetes taurinus*), burchell's zebra (*Equus burchelli*), kudu (*Tragelaphus strepsiceros*), nyala (*Tragelaphus angasi*), and waterbuck (*Kobus ellipsiprymnus*). The cat species are also well represented within the APNR, with six of the seven true cat species of Africa occurring here. These include lion (*Panthera leo*), leopard (*Panthera pardus*) and cheetah (*Acinonyx jubatus*). There is also an abundance of birdlife consisting of approximately 364 species (Bornman, 1995).

2.1.7 Study animals

As this study specifically focused on the possible consequences of the feeding habits of African elephants (*Loxodonta africana*) on the nesting sites of vultures, raptors and southern ground hornbills, as well as the facilitatory role in food production for primate species, specifically vervet monkeys (*Cercopithecus aethiops*) and bushbabies (*Galago moholi*), I here explain specific aspects of feeding behaviour of elephants and primates as well as the biology of the avian fauna that are relevant to this study.

Elephants

Elephants in the APNR and elsewhere occur in family units led by a matriarch, in bachelor herds or as lone bulls (Owen-Smith, 1988). A study by Greyling (2004) within the same study area showed that family units and bull groups only utilized 9% of the 5 780 individual woody plants available to them in the study plots. Furthermore, elephants are mainly grazers during the wet season and browsers during the dry season, this may influence their impact on the tall tree component. The study also showed that bulls were more destructive feeders and were frequently responsible for uprooting, main stem and branch breakage of woody species. De Villiers (1994) found that elephants

preferred *Acacia nigrescens*, *Colophospermum mopane* and *Sclerocarya birrea* trees with a height taller than 7 m within the same study area.

Vultures, raptors and southern ground hornbills

The majority of nests that were surveyed were of White-backed vultures (*Gyps africanus*). The other vulture species that were found were the White-headed vultures (*Trigonoceps occipitalis*) and Hooded vultures (*Necrosyrtes monachus*). These species are locally common and are primarily scavengers. They search aerially for food and will follow other vultures or carnivores. They usually gather in large numbers at carcasses, with their diet consisting mainly of carrion. They nest singly or in loose colonies with nests between 200 m and 500 m apart. The breeding season starts with the laying of eggs from April till June, and an incubation period of approximately 56 to 58 days. The nestling period lasts between 108 to 140 days (Hockey *et al.* 2005.). Vulture nests are normally built on top of the canopy of tall trees (Kemp & Kemp, 1975).

Although numerous raptors occur within the APNR, the predominant raptor species whose nesting sites were surveyed during this study were Bateleur (*Terathopius ecaudatus*), Martial eagle (*Polemaetus bellicosus*), Tawny eagle (*Aquila rapax*), Wahlberg's eagle (*Aquila wahlbergi*) and African Hawk eagle (*Aquila spilogaster*). All these species are locally common and occur singly or in pairs. They are diurnal hunters except for the Bateleur which also scavenges. They are all solitary nesters and are territorial. Egg laying dates for Bateleur's is from December to January and for Wahlberg's eagle from August to January, but for the other species egg laying ranges from April to August. The incubation period ranges from approximately 39 days for the smaller species to 55 days for the larger species. Tawny eagle and African Hawk eagle chicks fledge at four weeks, the other species mentioned fledge between nine and ten weeks (Hockey *et al.*, 2005).

Southern Ground Hornbills are among the most long lived and slowest breeding terrestrial birds in the world. Groups are co-operative breeders that consist of a dominant breeding pair, with several non-breeding helpers (Kemp & Kemp, 1980). The ground hornbills require a mosaic of habitat types to meet their foraging and nesting

requirements (Vernon, 1986). Breeding is limited by suitability and availability of nest sites. Breeding commences after the start of the rainy season with an incubation period of approximately 40 days and the chick fledging after about 86 days. Natural nest cavities usually have an internal diameter of 40cm. It is estimated in the KNP that there is a mean annual cavity loss of 7.7% (Kemp & Begg, 1996). The rate of cavity formation is unknown and it is suspected that elephants play a role in cavity loss and formation (Spear *et al.*, 2005).

Vervet monkeys and bushbabies

Primates are omnivorous and have been shown to eat gum exudates produced by trees after mechanical or insect damage (Nash, 1986). Vervet monkeys (*Cercopithecus aethiops*) have been found to use all *Acacia* products for food throughout the year (Wrangham & Waterman, 1981). Bushbabies (*Galago moholi* and *Otolemur crassicaudatus*) are known to utilize gum throughout the year but gum usage was particularly prevalent during the dry season. A study by Bearder & Martin (1980) in the northern Transvaal, South Africa, confirmed that the diet of bushbabies consisted virtually entirely of *Acacia* gum exudates and arthropods. Bushbabies also have dental adaptations that allow them to scrape gum off the trees or gouge trees to stimulate gum flow. Vervets are less morphologically specialized but gum still forms a significant component of their diet (Nash, 1986).

2.2 Methods

The methods described in this chapter refer to the field methods and not statistical analyses which will be discussed in the chapters to follow.

2.2.1 Vulture, raptor and ground hornbill nesting site location and monitoring

The Klaserie Private Nature Reserve's (KPNR) annual aerial survey data for the period of 2003 to 2007 was collated to construct a Geographic Information System (GIS) database and map of known vulture/raptor nesting sites (Fig. 2.4). During the aerial surveys all visible nesting sites were marked with a Global Positioning System (GPS). These points

where then ground truthed to see if the nesting sites were still present. Only the KPNR was surveyed for vulture and raptor nesting sites as aerial survey data showed that this Reserve had the highest concentration of nesting sites.

The Associated Private Nature Reserves (APNR), with the exception of the Balule Private Nature Reserve, was surveyed for all southern ground hornbill nesting sites (Fig. 2.4), as these nesting sites occurred over a much larger area than the clustered nesting sites of vultures and raptors found primarily within the KPNR. Data for the southern ground hornbill nesting sites was collated from an existing research project of the Percy Fitzpatrick Institute for African Ornithology (PFIAO). Both natural and artificial nesting sites within the APNR are being monitored as part of an ongoing study by the PFIAO. The study by the PFIAO was started in 2003, during which time 28 artificial nest sites were put up and monitored, also eleven natural nest sites and 15 natural modified nests have been monitored. An artificial nest box was made out of a hollowed out pine trunk, which is about 1m high and has an internal diameter of 40cm.

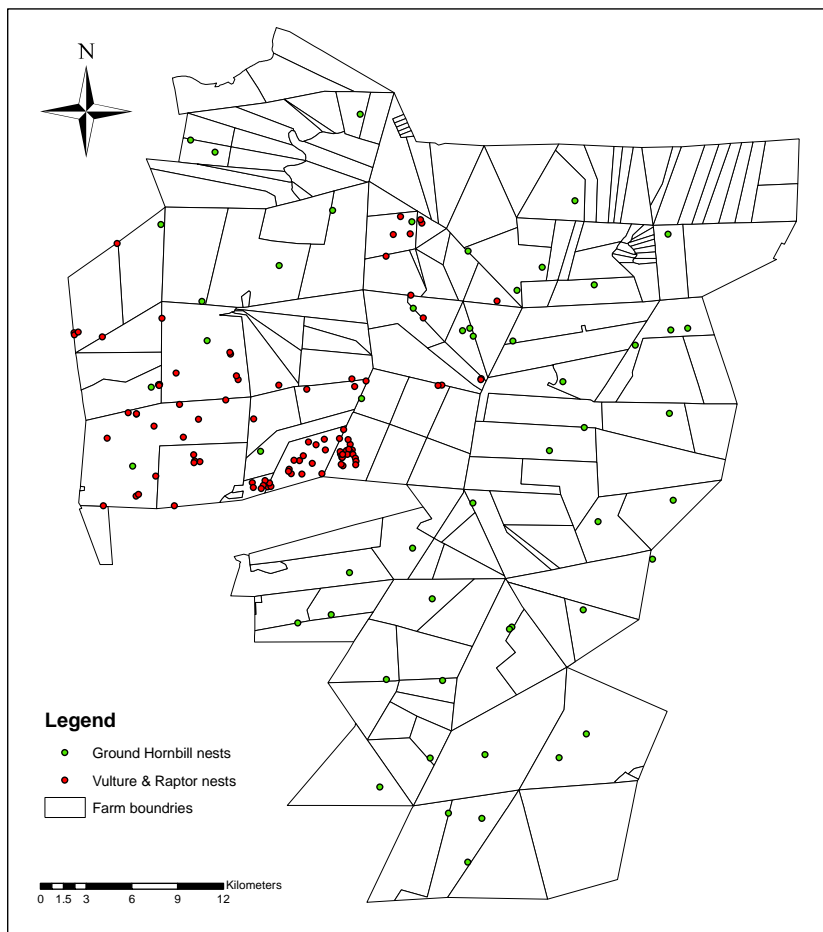


Fig. 2.4 Surveyed nesting sites within the APNR.

All trees were labelled with a metal washer with a unique number, and a full length photograph of each tree with a field worker as measurement of scale next to the tree, was taken. Surveys were conducted in August 2008, August 2009 and again in the beginning of September 2010. At each tree the following data were recorded:

- Tree species: The tree species was recorded at each labeled tree. If the tree was a marula (*Sclerocarya birrea*) tree, the sex was determined by looking for fruit kernels on the ground.
- Nest activity: For vultures and raptors, nests were recorded as active if there was a bird present in the nest or if there was white wash on the tree and surrounding area. Data on nest activity for ground hornbills was available through the PFIAO.
- Tree location: GPS co-ordinates were taken as close to the tree as possible.
- Altitude: was recorded at each labeled tree (in meters above sea level).
- Stem diameter: diameter of the stem measured at breast height (DBH) in cm.
- Tree canopy height: the height of the tree from the ground to the top of the canopy, was recorded in the following classes; <1 m, 1-2 m, >2-3 m, >3-5 m and >5 m using the same method as Henley & Henley (2007).
- Unknown impacts: such as, wind toppling, fire scarring of the main stem, impact by lightning or insect activity were recorded as unknown if no visible signs of elephant impact could be observed.
- Protection of tree: as natural protection by other plants, none or wire-netting.
- Distance to nearest tree: the distance from the labeled tree to the nearest woody tree species taller than 1.5 m.

2.2.2 Landscape features affecting nesting sites

It is generally accepted that raptors are sensitive to ecological changes (Herremans & Herremans-Tonnoeyr, 2000). Bridgeford and Bridgeford (2003) found that nesting vultures are very susceptible to disturbance, for instance; increased activity along a road may lead to vacation of nesting sites.

I therefore looked at all the nest sites in relation to certain predetermined anthropogenic and natural landscape features, these are as follows:

- Distance to the nearest drainage line/river
- Distance to the nearest waterhole
- Distance to the nearest road
- Distance to the nearest house/camp
- Distance from a nest to the nearest nest
- General vegetation type in which the nest sites occurred

The location of each of the nesting sites were over-layed with digitized vegetation maps of the APNR (Van Rooyen *et al.*, 2005) using ArcGIS 9.2 in order to determine in which vegetation types the nest sites occurred. The Hawth's Analysis Tool for ArcGIS (Beyer, 2004) was used to determine distances between nest sites and the aspects mentioned above.

2.2.3 Elephant impact on nesting sites

At each nesting tree the following data on elephant impact was collected, this was done in the 2008, 2009 and 2010 surveys according to the methods of Henley & Henley (2007).

- Elephant impact
 - Impact type: was recorded as bark stripping, primary branch breaking to access smaller plant parts, main stem breakage as the main stem has been snapped off and uprooting, when the entire tree was pushed over.
 - Extent of impact: was classified into the following classes; Class 1: none, Class 2: < 1%, Class 3: 1-5%, Class 4: >5-10%, Class 5: >10-25%, Class 6: >25-50%, Class 7: >50-75%, Class 8: >75-90%, Class 9: >90-99%, Class 10: 100%. The same field worker estimated the classes during each survey.
 - Age of impact: was assessed by looking at the colour of the impacted area, brown/reddish colour means recent impact and as the colour fades impact is older, grey/black would suggest old impact. It was then recorded as, recent (within the past month) <6 months, within the past dry season, within the past year (dry or wet cycle) >6 months, more than a year old.

- Healing after bark-stripping: measuring of debarked areas to determine the regrowth rate through edge development. Measurements were taken at the bottom, middle and top of the stripped area, once in each survey year.
- Estimated probability of survival of the tree: to the next monitoring cycle. By looking at the percentage of die-back on branches it would give an estimate of probability of survival. Die-back recorded does not necessarily mean that the tree will not survive, it is a conservative estimate.
- Tusk entry height: measured from the height above the ground to the fresh tusk entry point.

2.2.4 Facilitatory role of elephants

The feeding habits of elephants could be detrimental to the nesting sites of particular species of birds or have no effect at all. Elephants could also, by breaking primary branches play a facilitatory role in the creation of nests for ground hornbills (Henley & Henley, 2005). The impact of elephants on trees could also play a role in the production of a food source such as gum.

Facilitatory role in creation of nesting sites

Photographic evidence was taken of all branch breakage occurrences that could develop into potential nesting sites.

Facilitatory role in the production of a food source

A survey was conducted to determine the amount of gum that was produced by different tree species, the type of impact that would induce gum flow and whether this differed according to the late dry and early wet seasons. Feeding trials were conducted to determine which gum was preferred by primates, i.e. vervet monkeys.

A preliminary experiment was done using an *Acacia karroo* tree felled by an elephant and which subsequently produced gum. As the tree was located within the camp site, it

could be monitored on a regular basis (once a week). A camera trap was set up at the tree to take photographic evidence of any animal activity at the gum site.

Photographic evidence suggested that animals did visit the gum site and the experiment was then expanded to the following:

i. Tree surveys

- 14 trees were selected and elephant impact was simulated on these trees
 - Four *Acacia nigrescens*: two bark stripped & two branches broken
 - Four *Acacia tortillis*: two bark stripped & two branches broken
 - Four *Acacia xanthophloea*: two bark stripped & two branches broken
 - Two *Sclerocarya birrea*: both impacted upon with tusk entry wounds
- The bark stripping was done by using a panga to initially chop off pieces of the bark and then strip the bark off further as an elephant would to expose the white cambium. As *Acacia nigrescens* and *Acacia tortillis* has stringy bark (O'Connor *et al.*, 2007), simulating bark stripping by elephants was comparatively easy on these species.
- Branches were initially sawn and then torn down by hand in a motion simulating the feeding behavior of elephants.
- It was decided to only use the tusk entry wounds for *Sclerocarya birrea*, as field observations showed that bark stripping and branch breakage did not produce any gum in these trees, but tusk entry wounds did. To simulate tusk entry wounds of *Sclerocarya birrea* to initiate bark stripping, the tip of a broken off elephant tusk was gently hammered into the tree and the entry point opened further using the tip of the tusk in the same manner in which an elephant would do so until the tree started discharging a red substance.
- All the impacted trees were then wire netted to prevent animals from gaining access to the impact sites.
- Surveys were done on a weekly basis to determine if there was any gum flow.
- If there was gum, the gum was then collected and weighed with an electronic scale with a measuring accuracy of 0.1 g.
- Photographic evidence was also taken of all gum occurrences.

- Three additional trees were impacted in the manner mentioned above, a camera trap was placed at each of these trees and the impacted site was not protected. This was done to collect photographic evidence of the animals visiting the impacted sites. The following trees were selected:
 - *Acacia nigrescens*
 - *Acacia tortillis*
 - *Sclerocarya birrea*
- The first survey of 14 trees was initiated at the end of the dry cycle in August 2009 and the follow-up survey with an additional 14 trees was initiated in the wet cycle in December 2009. All trees were surveyed (on a weekly basis) until the end of February 2010.

ii. Cafeteria style experiments

- Cafeteria style experiments were conducted at Riverside Wildlife Rehabilitation and Environmental Education Centre, in Letsitele, Limpopo Province.
- Two vervet monkeys of same sex and similar age, in individual cages, were selected for the experiment. Both of these animals were in quarantine cages (1.2 m long x 1 m wide x 1 m high).
- Initially the study animals were first observed until they appeared disinterested in the observer. They were then presented with the empty feeding bowls which were to be used during the experiment in order to habituate them to the novel feeding receptacles.
- The feeding trials were conducted an hour after they had been fed to ensure that interest and attraction instead of hunger would drive their acceptance of a particular gum substance.
- At the start of each experiment using one study animal at a time, the control sample was presented in duplication to a vervet monkey during two consecutive occasions.
- Thereafter the control sample was presented in the right hand side bowl which was paired with an alternative tree species' gum which was placed in the left hand side bowl.

- *Acacia karroo* was used for the control and the following tree species (referred to as the treatment) were tested against the control:
 - *Acacia nigrescens*
 - *Acacia xanthophloea*
 - *Acacia nilotica*
 - *Acacia tortillis*
 - *Sclerocarya birrea*
- Due to the limited amount of *Sclerocarya birrea* gum, this gum could only be tested once with each animal. All other tree species' gum was tested in duplicate.
- There were thus in total 11 trials per animal.
- All gum pieces weighed 3 g and when presented the pieces in the control and experimental dish were mainly of same shape/size.
- Video recordings were made of each presentation.
- Gum was presented to the vervet monkey for 40 seconds at a time. The interval varied between presentations to ensure that the vervet monkey cleared her mouth before the next experiment. Gum pieces that fell during the presentation were removed after each trial.
- The observer presented the gum to the vervet from a distance of 1 m away.
- Interval periods between the trials were also recorded.
- A scoring system by Visalberghi *et al.* (2002) was used to score the animals behavior towards the gum presented. This was as follows:
 - Score 0 *Not taken.* The gum was not taken.
 - Score 1 *Discarding the gum.* Gum taken but not eaten, smelling it and taken close to the mouth.
 - Score 2 *Tasting.* Contact with gum is made, lips or teeth, but not ingested.
 - Score 3 *Nibbling.* Eating no more than half the piece of gum.
 - Score 4 *Eating.* Gum ingested and entirely consumed.

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Chapter 3

Elephant impact on the nesting trees of vultures and raptors

3.1 Introduction

The African elephant (*Loxodonta africana*) has been described as an ecosystem engineer with the capacity to structurally modify the vegetation of the habitats within which they exist (de Beer *et al.*, 2006). High numbers of elephants in an area can reduce the abundance of trees and therefore change the structure and functioning of ecosystems (Young *et al.*, 2009) that may have potential indirect effects on birds (Ogada *et al.*, 2008). Large trees are also regarded as focal points for animal activity and provide resources that could be scarce in the environment such as, shade, shelter, nest sites, observation posts for raptorial birds and specialized food or prey items.

Studies have shown that elephants have been found to reduce bird abundance and diversity in sites with high levels of impact (Herremans, 1995; Cumming *et al.*, 1997). A study conducted in Kenya found that the presence of megaherbivores reduced the overall bird diversity and species richness (of birds) by approximately 30% (Ogada *et al.*, 2008). This was mainly due to two aspects. Firstly, in the presence of megaherbivores, the subdominant trees had a lower mean canopy area and total canopy area. Secondly, megaherbivores reduced the biomass of ground-dwelling arthropods. The reduction in canopy area may lead to a reduction of available perching sites and possible nesting sites (Ogada *et al.*, 2008). Alternatively, elephants have the ability to increase habitat complexity by modifying the woody structure and in so doing they could potentially affect the suitability of the habitat for different animal (especially smaller animals) and bird species (Pringle, 2008; Palmer *et al.*, 2008; Nasser *et al.*, 2010).

For certain tree nesting birds, elephants may be removing potential or existing nesting sites by felling large trees. Various tree nesting raptors which have been listed as vulnerable in the *Red Data Book of Birds of South Africa, Lesotho and Swaziland* (Barnes, 2000) are potentially susceptible to the loss of nesting sites due to elephant

impact. Vulture populations have shown a 10% decline in recent years (Murn *et al.*, 2002) and all are currently listed as 'vulnerable' in South Africa (Monadjem & Gracelon, 2005). Studies have shown that vultures select tall trees for nesting (Monadjem & Gracelon, 2005).

The most common vulture found in the greater Kruger National Park area is the White-backed vulture (*Gyps africanus*) (Kemp & Kemp, 1975). The White-backed vultures, particularly, were found by Murn *et al.* (2002) to have a preference for *Acacia* species as nesting trees. This is similar to data from Kemp & Kemp (1975) who found that 63% of nests for White-backed vultures were in *Acacia* trees, and the species used was the most common for the vegetation type. They mostly nest singly or in loose colonies with nests between 200 m and 500 m apart, larger aggregations of nests in the Kruger National Park appeared to be close to watering points (Kemp & Kemp, 1975; Hockey *et al.*, 2005). Lappet-faced vultures (*Torgos tracheliotus*) and White-headed vulture (*Trigonoceps occipitalis*) occurred at far lower densities than White-backed vultures and were found to nest in the canopy of the trees of terrestrial vegetation (Kemp & Kemp, 1975; Monadjem & Gracelon, 2005). Kemp & Kemp (1975) examined 106 White-backed vulture nests and all were in the canopy of the tree except for four which were in the sub-canopy in large forks. There was an interchange of nests within the area and it was found that White-backed vultures used Whalberg's eagle (*Aquila wahlbergi*) nest, which could explain the sub-canopy nesting by White-backed vultures. Hence, bird of prey species composition was also monitored at the study site.

Most large raptors, in southern Africa, start breeding in the dry winter season, in mature large trees (Dean *et al.*, 1999; Herremans & Herremans-Tonnoeyr, 2000). During the breeding season, which spans well over half a year, vultures concentrate their activities around nesting sites (Monadjem & Gracelon, 2005). The availability of food is a major factor in determining raptor densities for an area. In less productive areas, the raptor pairs seem to be spaced further apart than in more productive areas (Hustler & Howells, 1990). The size and spacing of the trees affects the spatial pattern of animal and plant assemblages (Dean *et al.*, 1999). It is believed that the primary defining factors in bird communities is the structure of the vegetation, its complexity and the vertical arrangement. In the Hluhluwe-Umfolozi Park it was found that bird assemblages were

determined, to a degree, by vegetation structure (Skowno & Bond, 2003). Loiselle and Blake (1994) suggested that a range of successional stages is necessary to support a full complement of bird species.

This study builds on a broader and ongoing study of vegetation monitoring across landscapes, focussing on elephant impact on the large tree component of the APNR (irrespective if trees are occupied by avian fauna or not). The monitoring within the broader project, of SGH nesting sites, was started due to the concern that elephants could have an influence on the number of nesting sites available to SGH (Chapter 4). In this chapter the expansion of the SGH tree monitoring programme to incorporate vulture and raptor nesting sites, will be addressed. Through observations it seemed that there is an overlap in tree species used by elephants and utilized by vultures and raptors, further investigation was therefore required to determine the impact of elephants on these nesting sites. Finally, irrespective of elephant impact, landscape features that affect nest site location, the plant communities in which the nest sites occurred as well as the architecture of the trees that would make them suitable as nesting sites, were also considered.

In this chapter I investigated:

1. The type of impact that was prevalent on nesting trees.
2. The survival of nesting trees over the study period.
3. Which landscape features affected nest site location?
4. In which plant communities the nest sites occurred?
5. How the architecture of the tree affected nest site suitability?

3.2 Methods

3.2.1 Study area and field methods

For detailed description of the study area and methods please refer to Chapter 2.

3.2.2 Data Analyses

Data was analyzed using Statistica version 9.0 (Statsoft Inc, 2009).

The type of impact that was prevalent on the nesting trees

The type of impact at each nesting tree was recorded, the number of impacted trees were then quantified per impact type and per impact class. Bark stripping from the 2008 survey was then compared to bark stripping from the 2010 survey to see if there was any significant increase or decrease in the bark stripped area using cross tabulation.

Survival of nesting trees

I used the Kaplan-Meier (Product-limit) survival analysis to plot percent survival (of nesting trees) as a function of time. This analysis calculates the 95% confidence interval (CI) for fractional survival at any particular time. Trees 'at risk' involved a visual estimate of the persistence of the tree to the next survey season (please refer to the field methods section 2.2.3). Vulture and raptor nesting trees were plotted on one survival curve and ground hornbill nesting trees were plotted separately. Data for the vulture and raptor trees ranged from August 2008 till September 2010. I also used cross tabulation to determine the relationship between the persistence of the nesting trees and the nest activity (active or non-active).

Landscape features that affect nest site location

The multivariate (Hotelling's T^2) t-test was used to determine that; when the multivariate set of distance measurements of vultures and raptors were considered as a vector or variate or linear combination of variables weighted optimally to maximize the distances of the two groups of birds, the multivariate distances of the vulture/raptor nests to the selected features are different. The p-value tests whether the variances of the groups are equal (homoscedastic), or whether the variances are different (heteroscedastic).

A Principal Component Analyses (PCA) was conducted and this involves a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. The PCA therefore reveals the internal structure of the data in a way which best explains the variance in the data. The variable importance was quantified to measure how well a variable is represented by the principal components. This value is a quantity ranging from 0 to 1. Variables that are not well represented (i.e., have low values of power) are more likely to be insignificant (Statsoft Inc., 2009; Bishop, 1995). The variable importance was then plotted on a histogram, vultures and raptors were plotted separately.

Plant communities in which nest sites occurred

The Hawth's Analysis Tool for ArcGIS (Beyer, 2004) was used to count the points (nests) within the polygons (plant communities). A pie chart was used to display the contribution of each value to the total. Cross tabulation was then used to determine the percentages for vulture and raptor nest sites (separately) within each of the plant communities.

Architecture of the tree

Tree profile

Tree profile refers to the different shapes and heights of the trees, the following measurements were used to determine the tree profile; tree height, trunk height, canopy width, canopy length and the measurement from the base of the tree to the start of the canopy.

I assessed if there was a significant difference in tree profiles between vulture and raptor nests by conducting a multivariate t-test for independent samples (Hotelling T^2). Hotelling's T^2 is the multivariate equivalent of the univariate t-test and has the advantage of controlling the experiment-wise alpha level at 5% as it conducts only a single test of significance rather than multiple t-tests. Once the multivariate Hotelling's T^2 is significant,

one searches for the underlying univariate variables that contribute to the multivariate significance via the t-tests. A student's t-test was used to determine if there was a significant difference between vulture and raptor nest heights. A Cohen's *d* effect size was then computed to indicate the standardized difference between the two means (vulture and raptor) of nest height.

Correlations between tree dimensions and nest height

Pearson's correlation coefficient was used to measure the correlation between nest height and tree height, trunk height, canopy width, canopy height & start of the canopy. Pearson's correlation coefficient is the best method of measuring correlation, because it is based on covariance. Pearson's correlation coefficient gives information about the degree of correlation as well as the direction of the correlation. The Pearson correlation is +1 in the case of a perfect positive (increasing) linear relationship, as it approaches zero there is less of a relationship and therefore the degree of correlation can be described from low (closer to 0) to high (closer to +1). Therefore the following broad categories were defined using the *r*-value: low (0 – 0.49), moderate (0.5 – 0.79) and high (0.8 – 1.0). The correlations were then plotted on a categorized scatterplot.

Nest location within the tree

Cross tabulation was used to determine the relationship between the locality of a nest in the tree and the number of branching events (indicated as degrees with a first degree branching events referring to the first branch forking events of the main stem of a tree. Second degree branching events consequently refer to the subsequent branching of the first degree branches with third and fourth degree branching events following on these). The Pearson's *Chi*-square (χ^2) value was computed to test the significance of the relationship between the variables.

3.3 Results

3.3.1 The type of impact that was prevalent on nesting trees

The main impact types found on the nesting trees were bark stripping (Tab. 3.1) and branch breakage (Tab. 3.2). The highest proportion of bark stripping on nesting trees

was found between Class 6 – 10, for vulture nesting trees (67%) and for raptor nesting trees (61%). During the study period no trees were found with the main stem broken. During the study period only one tree was found (2010) to be uprooted. It is important to note that as the surveys only started in 2008, the numbers reflected for this year refer to accumulative bark stripping from previous years. Hence the annual bark stripping events from year to year are relatively low. There was a significant difference in proportions of raptor nesting trees and vulture nesting trees being impacted ($\chi^2= 9.52$, $N= 5$, $df= 4$, $p< 0.05$). There was a greater impact recorded on raptor nesting trees during 2008.

Tab. 3.1 Number of nesting trees bark stripped during the study period (these events are accumulative of previous years).

Impact type	Vulture nests	Raptor nests
Bark stripping 2008	23	27
Bark stripping 2009	29	29
Bark stripping 2010	33	33

Tab. 3.2 Number of nesting trees with primary branches broken during the study period (these events are accumulative of previous years).

Impact type	Vulture nests	Raptor nests
Branch breakage 2008	16	25
Branch breakage 2009	18	25
Branch breakage 2010	19	25

During the study period six vulture and two raptor nesting trees were found showing definite signs of healing at the bark stripped area. Several other nesting trees also started to show signs of healing. The average for the bottom, middle and top bark stripped measurements was calculated for both vulture and raptor nesting trees. For vulture nesting trees there was an average decrease (from 2008 – 2010) of 3.7 cm at the bottom and 0.1 cm at the top measurement, however there was an increase of 7.4 cm at the middle of the bark stripped area. For raptor nesting trees there was an overall

decrease (from 2008 – 2010) for all measurements, the top decreased by 8.4 cm, the middle by 1.2 cm and the bottom measurement by 5.3 cm.

3.3.2 Survival of nesting trees

Survival curves were calculated from time zero (when the study began) to 760 days when the last survey was conducted. The survival curves calculated survival proportions and number of subjects at risk (i.e. nesting trees). There was no significant difference between the two survival curves of vulture and raptor nesting trees ($\chi^2 = 0.21$, $df = 1$, $p > 0.05$). The percentage of trees surviving during the study period is very high with 96.30% of the vulture nesting trees surviving and 97.87% of raptor nesting trees surviving (Fig.3.1). During the study period 12 vulture nesting trees died and two raptor nesting trees. The number of nesting trees at risk at the end of the study period, was therefore 42 vulture nesting trees and 45 raptor nesting trees.

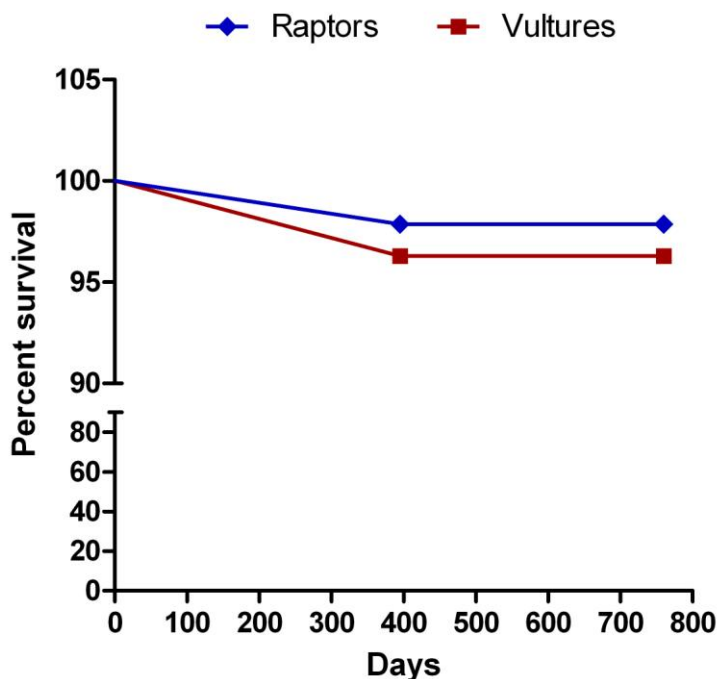


Fig. 3.1 Survival curve showing 96.30% survival for vulture nesting trees and 97.87% survival for raptor nesting trees.

The results from the cross tabulation showed that 87% of all the vulture nests and 89% of raptor nests were in trees that were classified as fine. Of the active vulture nests 77% were in trees that were classified as fine and 13% in trees that were recorded to have die-back. For the active raptor nests 87.5% were in trees that were fine and 12.5% in trees with die-back.

3.3.3 Landscape features that affect nest site location

The multivariate Hotelling's T^2 showed that there is a significant ($T^2= 51.32$, $F(5,97)= 9.857$, $p < 0.001$) difference between vulture and raptor nests with reference to the distance from nests to landscape features. The variances between raptor and vulture nests are significantly different for; distance to nearest nest, artificial water and rivers/drainage lines ($t(57.44)= 3.27$, $p < 0.01$) (Fig. 3.2).

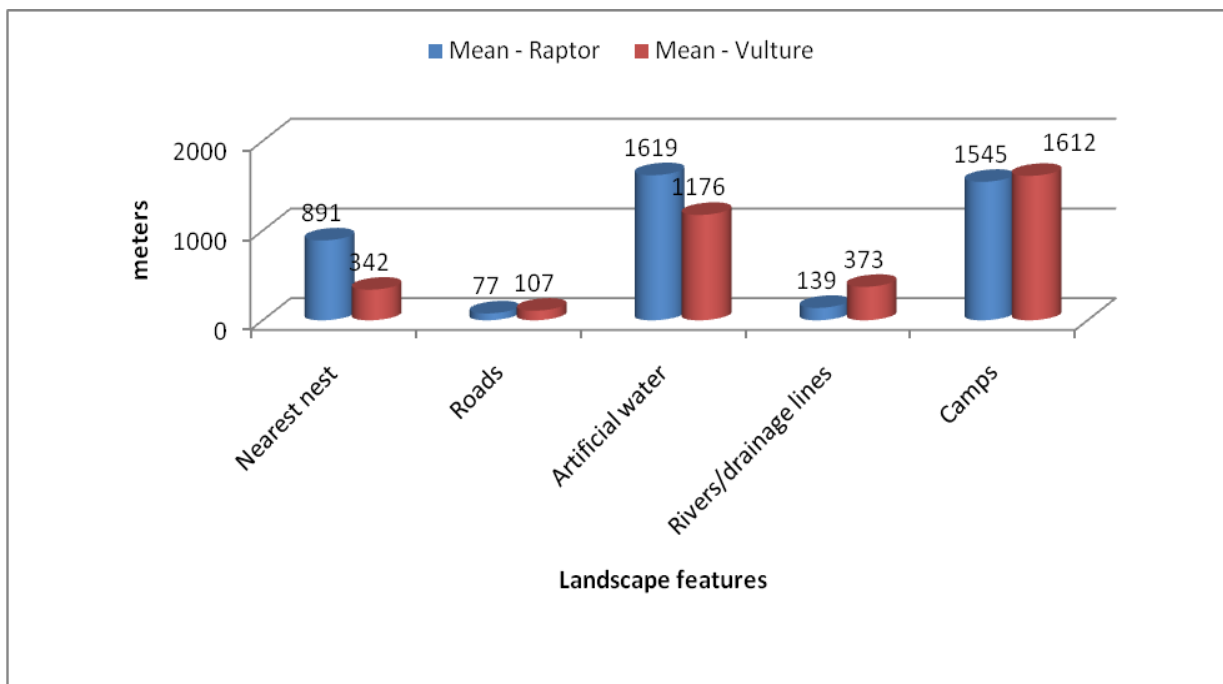
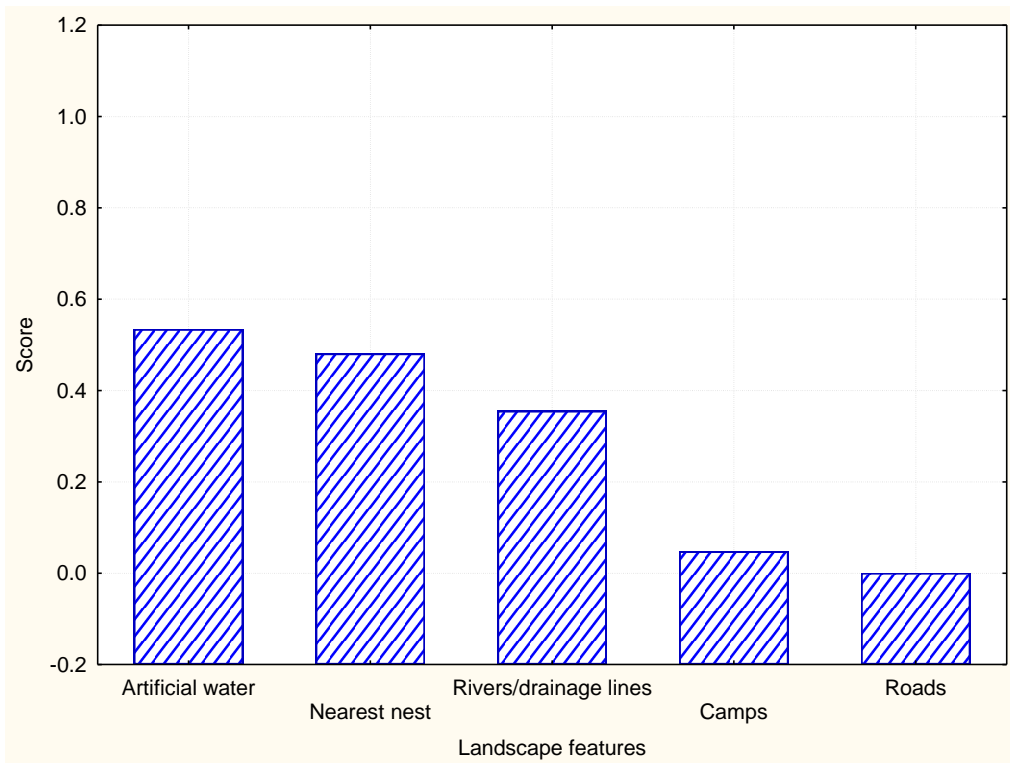
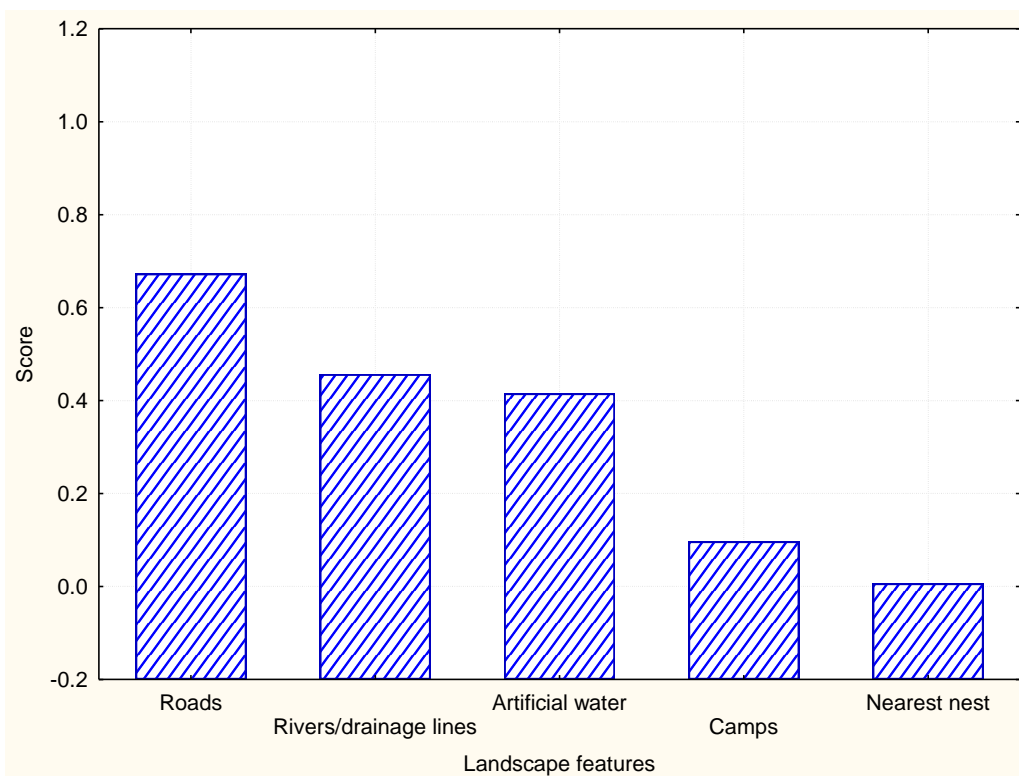


Fig. 3.2 Mean distances (m) from vulture and raptor nests to landscape features.

The PCA analysis showed that there is a difference in variable importance between vultures and raptors. The closer the variables are to 1 the greater the value of the variable. For vultures the most important variable is artificial watering holes and for raptors the most important variable is roads (Fig. 3.3 (a) and (b)).



(a)



(b)

Fig. 3.3 The variable importance shown for (a) vultures and (b) raptors.

3.3.4 Plant communities in which nest sites occur

In total 102 nests were surveyed, the nests occurred in 10 different plant communities. The two main plant communities in which the nests occurred was the *Acacia nigrescens*–*Combretum apiculatum* mixed woodland (47%) and the *Acacia nigrescens*–*Terminalia prunioides* woodland (32%). Vulture nests occurred predominantly in *Acacia nigrescens* trees (98%) and 91% of raptor nests were also found in *Acacia nigrescens* trees (Tab. 3.3). The *Chi*-square test could not be conducted to low or no tree counts in some of the plant communities.

Tab. 3.3 Representation (%) of vulture and raptor nests within the plant communities.

Plant community	Vulture nests	Raptor nests
<i>Acacia nigrescens</i> – <i>Combretum apiculatum</i> woodland	61%	29%
<i>Acacia nigrescens</i> – <i>Terminalia prunioides</i> woodland	26%	38%
<i>Acacia tortilis</i> lowland woodland	0%	2%
<i>Colophospermum mopane</i> - <i>Combretum apiculatum</i> woodland	0%	2%
<i>Colophospermum mopane</i> dense woodland	0%	9%
<i>Combretum apiculatum</i> - <i>Grewia bicolor</i> low thicket	4%	9%
<i>Combretum apiculatum</i> - <i>Sclerocarya birrea</i> - <i>Strychnos madagascariensis</i> open woodland	0%	2%
<i>Combretum apiculatum</i> - <i>Sclerocarya birrea</i> open woodland	7%	0%
<i>Combretum apiculatum</i> - <i>Xerophyta retinervis</i> low thicket	2%	4%
<i>Combretum apiculatum</i> , <i>Terminalia prunioides</i> , <i>Comiphora mollis</i> rugged veld	0%	4%

3.3.5 Architecture of tree

Tree profile

The multivariate Hotelling T² showed that there was no significant difference between tree dimensions (tree height, trunk height, canopy width, canopy length and the start of

the canopy) of vulture and raptor nests ($T^2=7.89$, $F(5,95)=1.5140$, $p < 0.05$) (Fig. 3.4). There was a significant difference ($p < 0.05$) of moderate size (Cohen's $d = 0.4392$) between the vulture and raptor nest heights (Fig. 3.5).

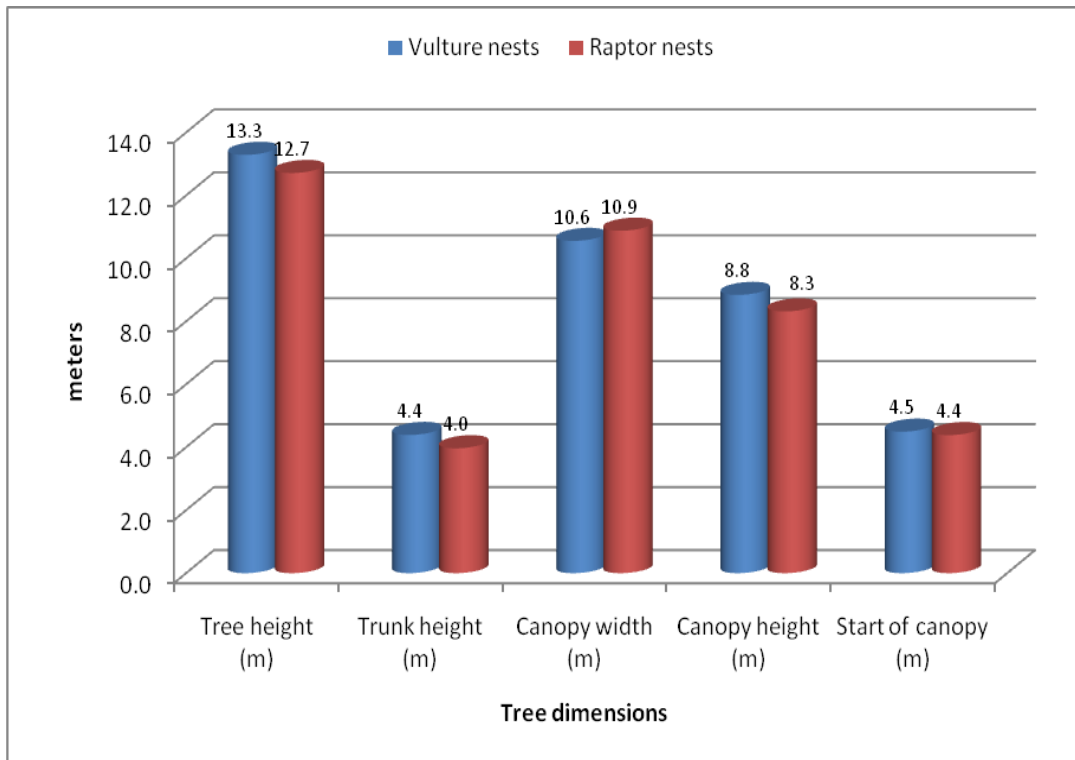


Fig. 3.4 Tree dimensions for vulture and raptor nests ($T^2=7.89$, $F(5,95)=1.5140$, $p < 0.05$).

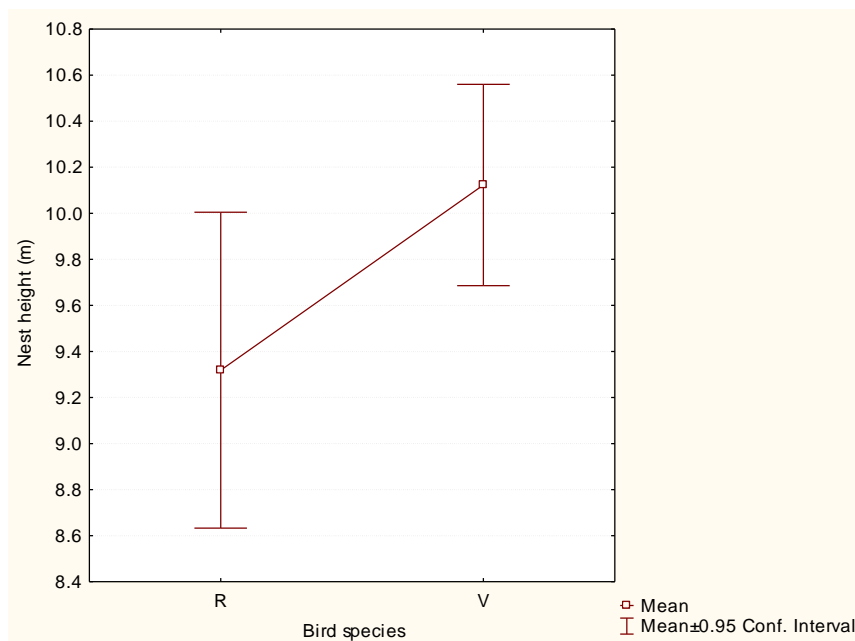
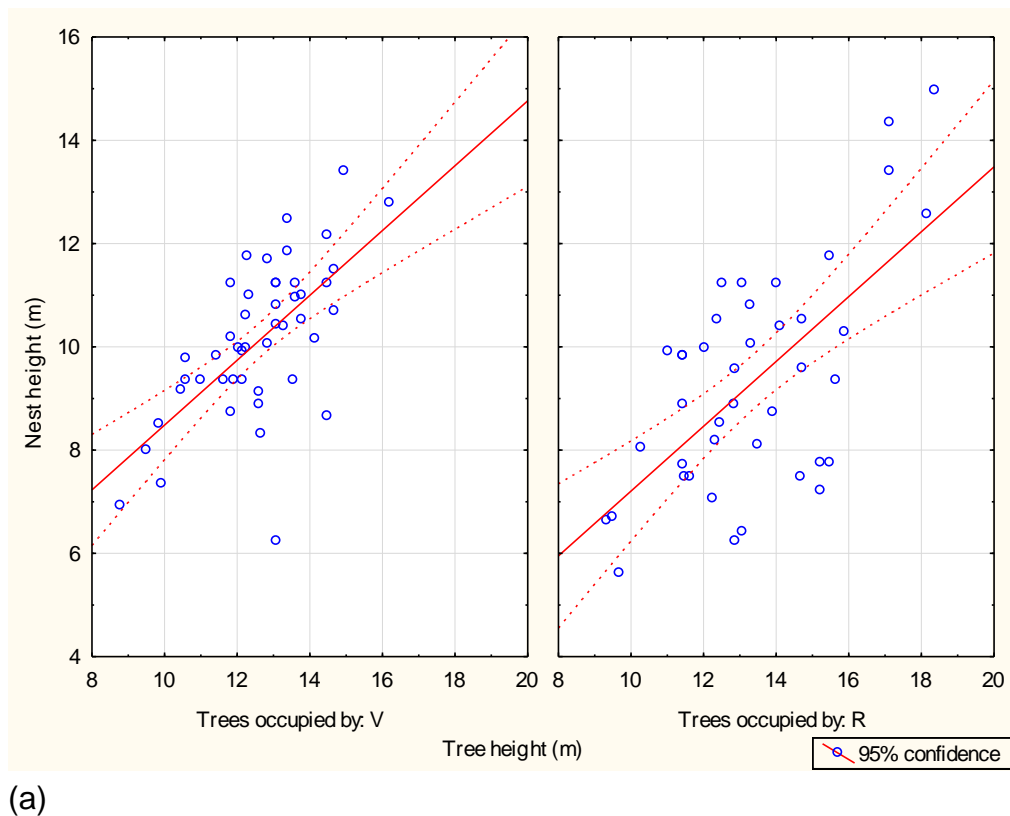
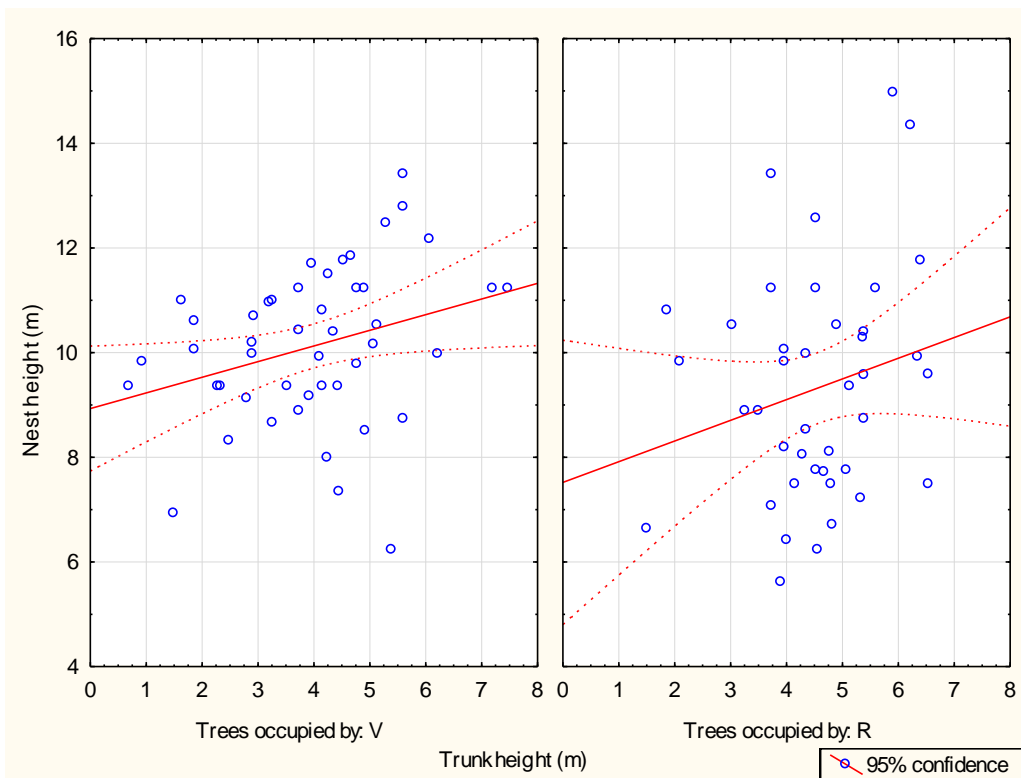


Fig. 3.5 Difference in mean nest height between raptor (R) and vultures (V) ($p < 0.05$).

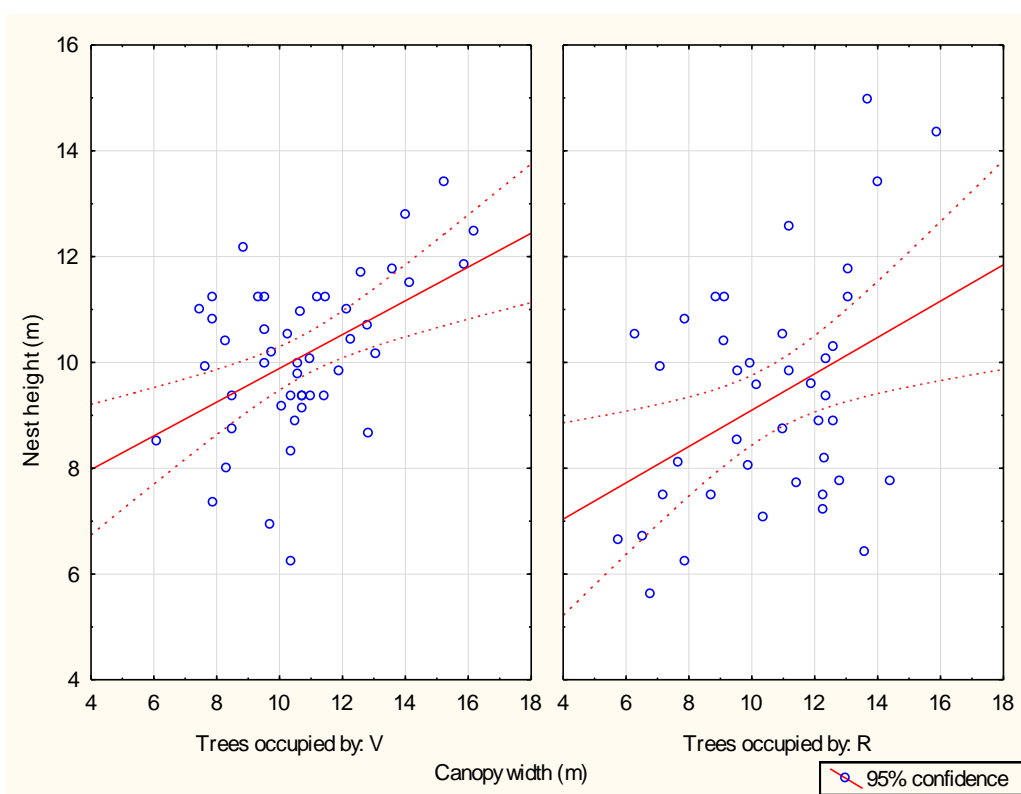
Correlations between tree dimensions and nest height

There was a significant correlation of moderate degree with positive linear relationships (Fig. 3.6) between raptor nest height and tree height ($r = 0.64$), canopy width ($r = 0.40$) and canopy height ($r = 0.56$) and a significant correlation of low degree between nest height and trunk height ($r = 0.22$) and start of the canopy ($r = 0.17$) ($N = 41$, $p < 0.05$). There was also a significant correlation of moderate degree between vulture nest height and all the measured tree dimensions ($N = 47$, $p < 0.05$).

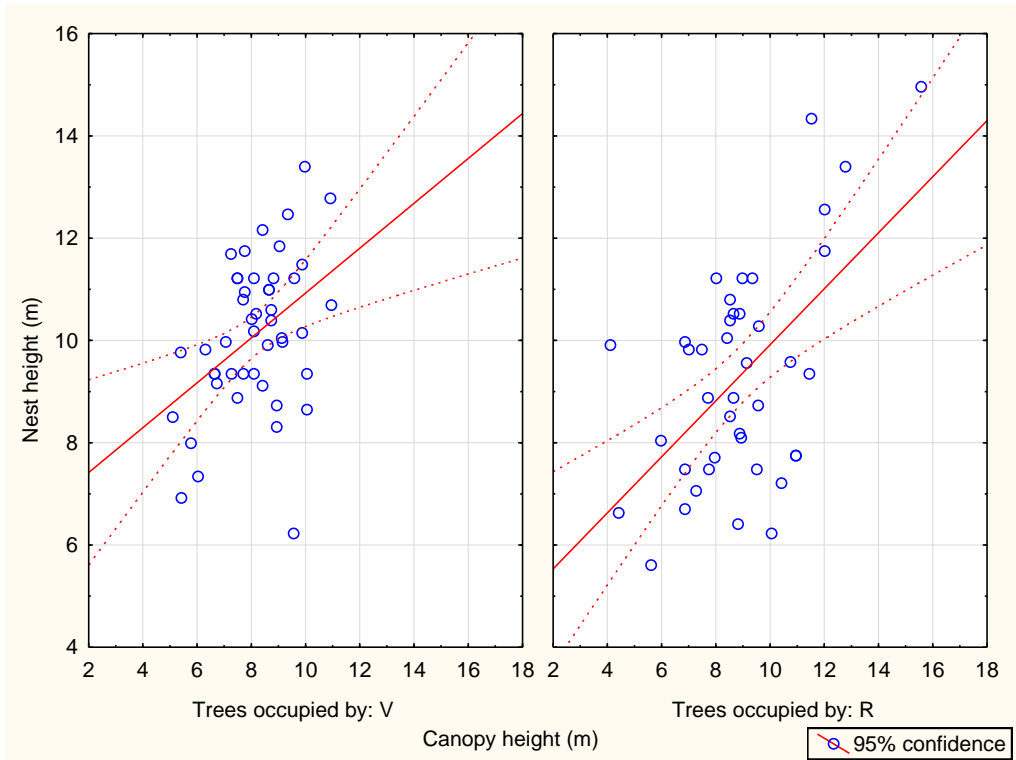




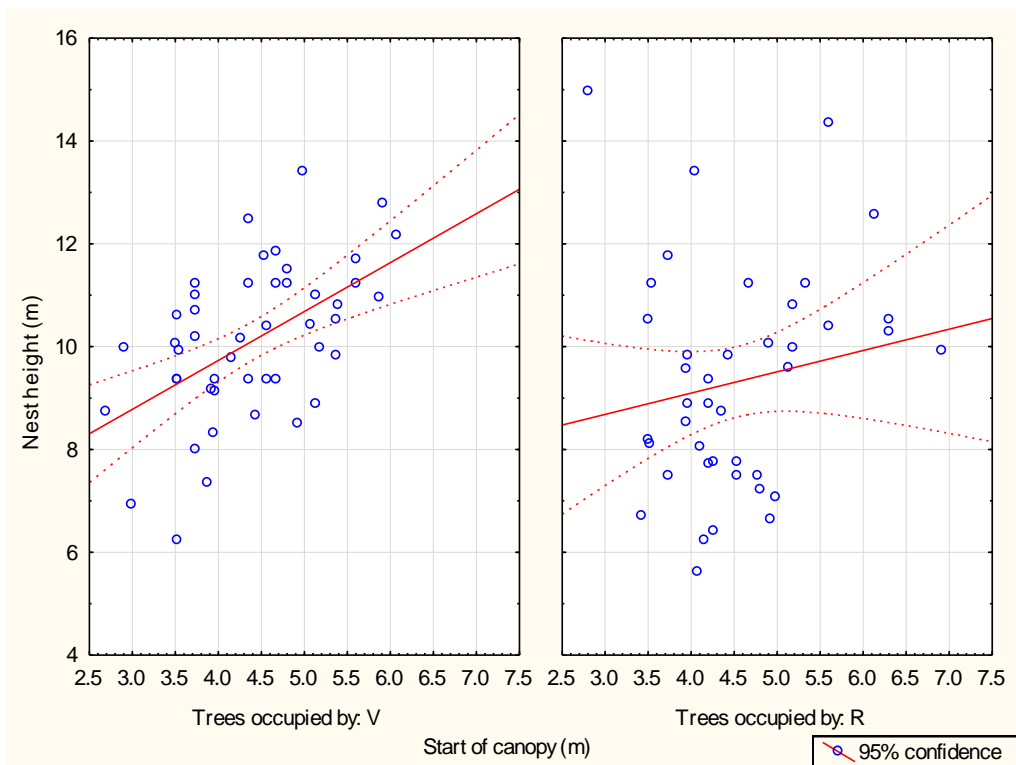
(b)



(c)



(d)



(e)

Fig. 3.6 Correlations of structural measurements for trees occupied by vultures (V) and raptors (R):

- (a) Nest height and tree height: V (N= 47, $r= 0.65$, $p < 0.05$), R (N= 41, $r= 0.64$ $p < 0.05$)
- (b) Nest height and trunk height: V (N= 47, $r= 0.31$, $p < 0.05$) R (N= 41, $r= 0.22$, $p > 0.05$)
- (c) Nest height and canopy width: V (N= 47, $r= 0.48$, $p < 0.05$), R (N= 41, $r= 0.48$ $p < 0.05$)
- (d) Nest height and canopy height: V (N= 47, $r= 0.42$, $p < 0.05$), R (N= 41, $r= 0.56$, $p < 0.05$)
- (e) Nest height and the start of the canopy: V (N= 47, $r= 0.53$, $p < 0.05$), R (N= 41, $r= 0.17$, $p > 0.05$)

Nest location within the tree

The data from the cross tabulation showed that vultures show a definite preference for nests in the fourth branch degree (82%), which is right on top of the canopy (Fig. 3.7). Only 16% of the vulture nests were located in the third branch degree and 2% in the first branch degree (Fig. 3.7). Raptors show a relative preference with 54% of all raptor nests were found in the third branch degree, 24% in the second branch degree and 22% in the fourth (Fig. 3.7). Each tree contained only one nest. The Chi-square test showed that there was a significant difference in proportions between vulture and raptor nests ($\chi^2= 12.59$, $df= 6$, $p < 0.05$).

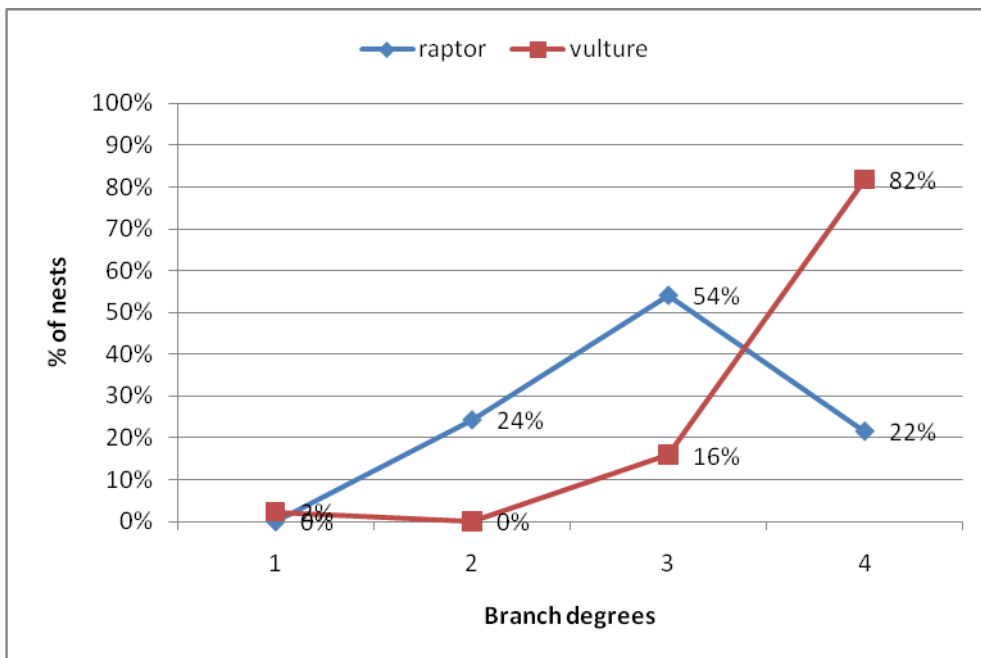


Fig. 3.7 Nest location on different branch degrees within the nesting trees.

3.4 Discussion

Browsers, especially elephants (*Loxodonta africana*), have the ability to noticeably alter system heterogeneity by reducing the number, structure and composition of woody species (Levick & Rogers, 2008). Herremans (1995) mentions that, changes in woody vegetation density and structure could have significant implications for bird species that could lead to a decline in their diversity, due to more uniform shrub like growth. A wide variety of woody vegetation is utilized by elephant and they feed in several ways, by stripping leaves, clipping twigs, breaking branches, removing bark from stems and roots, as well as uprooting and felling trees (Stokke, 1999). Gadd (2002) found that elephants may reduce the survival rate of trees by extensive ring-barking. The breakage of stems and branches by elephants may transform tall trees to short trees (1 – 3 m tall) and create what is called “browsing lawns” (Makhabu *et al.*, 2006). The main impact types found on vulture and raptor nesting trees, in the KPNR, was bark stripping and branch breakage. A study conducted by Greyling (2004) in the APNR, assessed whether family units and bull groups fed on similar woody plant species. An acceptance frequency was calculated by dividing the number of food plots where a woody species was utilised by the number of food plots in which it was present at a feeding site. A mean acceptance index was calculated for each woody species. The results showed that both family units and bull groups both had a medium acceptance frequency for *Acacia nigrescens* and *Sclerocarya birrea*. Furthermore, the study also found that bull groups select for taller trees than family units. Within the same study area, De Villiers (1994) found that elephants preferred *Acacia nigrescens*, *Colophospermum mopane* and *Sclerocarya birrea* trees. Likewise I found that, *Acacia nigrescens* was predominantly used for nesting sites by vultures (98%) and raptors (91%). Therefore the feeding habits of elephants could potentially decrease the availability of existing nesting sites of vultures and raptors. However no significant short-term changes in the survival rate of vulture (96.30%) or raptor (97.87%) nesting trees were found during this study.

Vultures and raptors also nested primarily in trees that were classified as persisting and not at risk of mortality. In, Hlane National Park, vultures avoided nesting in two elephant enclosures. Within these two enclosures almost all the trees had been debarked and killed by elephants (Monadjem & Garcelon, 2005), however more testing is required as

this is only based on two enclosures. It therefore suggests that elephant impact at current levels within the KPNR is not significantly impacting vulture and raptor nesting. During the 2008 survey 51% of the nesting sites recorded was active. In 2009 only 39% of nests were active and in 2010, 32% of the nests were active. These percentages mentioned above reflect breeding attempts (adult birds or chicks found in nests) and not number of nest sites. The decline in nesting activity could not be attributed to elephant impact as 87% of vulture nests and 89% of raptor nests were classified as persisting and not at risk of mortality. In 2009, 17 of the vulture nests recorded in 2008 had fallen out of the trees, the reason for this is unknown but were probably due to strong winds which on occasion can even topple tall trees. Eight new vulture nests were found in 2009 that were not present in 2008. In 2010, the only vulture nest not found was one in a tree that was pushed over by an elephant. Herholdt & Anderson (2006) found that small colonies would be active for a year or two and then they would suddenly be vacated. This phenomenon is possibly related to temporarily available food resources or to disturbance at nesting sites. It is suggested that there is a possibility that raptors/vultures in arid environments may shift their nest sites to avoid predation (Herholdt & Anderson, 2006).

Vultures and raptors nest in tall trees and vultures, mainly White-backed vultures (*Gyps africanus*), nest predominantly on top of the tree canopy and other species in the sub-canopy (Kemp & Kemp, 1975; Mundy *et al.*, 1992; Dean *et al.*, 1999; Monadjem & Garcelon, 2005; Herholdt & Anderson, 2006). In this study 96% of all the vulture nests were occupied by White-backed vultures. Kemp & Kemp (1975) also found that the majority of the nests in the Kruger National Park were White-backed vulture nests. In Swaziland there was a higher density of White-backed vulture than the other species (Monadjem & Garcelon, 2005). I found only one White-headed vulture (*Trigonoceps occipitalis*) nest with two other vulture nest types being unidentified in the study area. Various species of raptors occupied the different nests; Whalberg's eagle (*Aquila wahlbergi*) and African hawk eagle (*Aquila spilogaster*) nests were found more often. On four occasions there was an interchange of nesting sites recorded. In 2009 two nests that were originally classified as a Whalberg's eagle nests were then occupied by a White-backed vulture and the other by a Giant eagle owl (*Bubo lacteus*). Also in 2009, a Tawny eagle (*Aquila rapax*) nest was occupied by a White-backed vulture and a nest recorded as an unknown raptor nest was occupied by a Giant eagle owl. Vultures and

raptors nested in trees of similar dimensions but there was a significant difference between nest heights, this is mostly due to the fact that vultures nest on the canopy of the tree and raptors prefer the sub-canopy. Kemp & Kemp (1975) stated that there was an interchange of nesting sites between raptors but also found that White-backed vultures used the nests of Whalberg's eagle. The interchange of nesting sites may explain the sub-canopy nesting that was recorded for a few of the vultures.

Distance to roads was found to explain most of the variability in nesting site location for raptors. Large trees may also become shaded fertile islands that support distinctive plant assemblages, these 'fertile islands' may also attract a variety of animal species which may be beneficial especially to raptors (Dean *et al.*, 1999), as the food source could be attracted to the trees in which they nest. Raptors typically hunt by two techniques, from the perch or on the wing (Herremans & Herremans-Tonnoeyr, 2000). Roads have shown to be an important landscape feature for raptor nesting sites. Due to runoff of water from the road surface, dust, decomposing animals killed on the road and inputs of carbon dioxide, roads and their verges in arid and semi-arid environments often function as high production systems (O'Farrell, 1997). Small-mammals in these road verges provide food for snakes, raptors and larger mammals (Dean & Milton, 2003). In the study by Dean & Milton (2003) they found that raptors are attracted to roads due to the availability of perches and relatively productive road verges. Raptors also use animals that are killed on roads for food, but they also utilize the fur/hair for nesting material. It is therefore accepted that roads and road verges play an important role in the foraging ecology of raptors (Dean & Milton, 2003). Roads are also 'open' spaces that would make spotting of prey easier for the birds and they might therefore prefer these areas.

In the Kruger National Park, aggregations of vulture nests were found in some areas and could not be explained by there being limited nesting sites (Kemp & Kemp, 1975). Herholdt & Anderson (2006) found one large breeding colony and the rest of the pairs bred in small aggregations in the *Acacia* savanna areas. The most important landscape feature for vulture nesting sites in the KPNR was artificial watering points, followed by nearest nests and rivers/drainage lines, which were consistent with findings by Kemp & Kemp (1975) who found that there was a tendency for nests to be clumped in the vicinity of watering points. Vultures drink and bathe regularly around mid day, in groups of up to

100. Bathing sites have been found to be traditional (Hockey *et al.*, 2005). When comparing the feeding habits of vultures versus raptors, vultures would be in more need of regular bathing to ensure that their carrion feeding habits don't lead to the spread of disease. Kemp & Kemp (1975) found aggregations along rivers and in more open savanna areas. Monadjem & Garcelon (2005) found that White-backed vulture nests were generally spaced closer together than Lappet-faced (*Torgos tracheliotus*) or White-headed vultures. Nesting densities along rivers are described to be more linear (Murn *et al.*, 2002).

The mean nest height for vultures was 10.12 m (SD = ± 1.49) and for raptors 9.32 m (SD = ± 2.17). These heights were correlated to tree height, canopy width and canopy height for raptors. All the tree dimensions measured were correlated to nest height for vulture nesting trees. By looking at trees that have similar tree dimensions one can predict whether the tree would be suitable as nesting trees for vultures or raptors. Similarly, Monadjem & Garcelon (2005) found that nests of White-backed vultures were above 12 m in Swaziland. Kemp & Kemp (1975) estimated that vulture nesting trees ranged in heights between 10 – 25 m and suggested that the nest height depended mainly on the height of the trees in the area (Herholdt & Anderson, 2006) and the height of the tree chosen. In this study nesting tree heights ranged from 8.79 – 16.21 m, this is somewhat different to the results in the adjacent Kruger National Park found by Kemp & Kemp (1975), however all the nesting trees in this study were found in open to mixed woodland areas and in the study by Kemp & Kemp (1975) 28% of the nesting trees were in riparian woodlands, where trees tend to be taller. In accordance with these findings, I found that the distance to the nearest tree with a nest was considerably smaller for vulture nests than raptor nests. These results could therefore be indicative of the clump distribution of vulture nests within suitable habitat types (landscapes with tall trees of suitable height). Vultures and raptors nested predominantly in mixed woodland areas and majority of the nests were found in *Acacia nigrescens* trees. Bird assemblages in woodlands are more variable than those of other habitats (Skowno & Bond, 2003) and Monadjem & Gracelon (2005) found a large proportion of White-backed vultures nesting in open woodlands. Herholdt & Anderson (2006) also found that all the vulture nests were found in the *Acacia* savanna areas of the Kgalagadi Transfrontier Park. It could not be established whether there was a preference for *Acacia nigrescens* trees as no tree density and species

composition count was conducted for the study area. *Acacia nigrescens* could also be used because it is the most common tall tree within the mixed woodland plant communities. The use of thorny *Acacia nigrescens* may also serve as protection against predation (Kemp & Kemp, 1975).

Vultures may also be selecting the top of the canopy for protection against predation as it would be more difficult for predators to get to the nestlings. Raptors could also be selecting to nest within the canopy as it provides some shading and protection from rain during the wet season.

In conclusion, this study found that vultures and raptors nest are found in trees that can potentially be bark-stripped, uprooted or pollarded by elephants as elephants are known to utilize *Acacia nigrescens* in this way, especially during the dry season. Elephant feeding habits however have not shown to affect the nesting trees significantly and elephant impact has not lead to the desertion of nest sites by vultures and raptors in the short term. This study also found distinctions in the landscape features where vultures nest were situated as opposed to raptor nests. Although the morphological structure of the trees used as nesting sites did not differ between vultures and raptors, the location of actual nests within trees was dependent on the species of the birds of prey. The causal reasons for these observations require further investigation.

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Chapter 4

Elephant impact on the nesting trees of Southern ground hornbills

4.1 Introduction

Southern ground hornbills (SGH), *Bucorvus leadbeateri*, occur mainly in large conservation areas and the current population is thought to range over 160 000 km² in South Africa. Population estimates are between 1500 and 2000 birds, with numbers outside large conservation areas declining rapidly (Kemp, 2000). The species has suffered a 50% decline in range and a 10% decline in numbers over the past three decades (Kemp, 1980; Vernon & Herremans, 1997; Spear *et al.*, 2005). The factors contributing to the reduction in range can be attributed to habitat loss, mostly due to agriculture and development, habitat transformation (bush encroachment) and the loss of large trees which could serve as potential nesting sites (Vernon, 1986; Kemp 1987; Kemp & Begg, 1996). SGH require a mosaic of habitat types to satisfy foraging and nesting requirements, including savanna, grassland and woodland areas (Vernon, 1986; Kemp, 1995).

This study builds on a broader and ongoing study of vegetation monitoring across landscapes, focussing on elephant impact on the large tree component of the APNR (irrespective if trees are occupied by avian fauna or not). The monitoring within the broader project, of SGH nesting sites, was started due to the concern that elephants could have an influence on the number of nesting sites available to SGH.

Nest sites are usually large cavities in trees with an internal diameter of at least 40 cm (Kemp & Begg, 1996). It was found in KNP that groups occupy home ranges of up to 100 km² (Kemp & Kemp, 1980) whereas in Zimbabwe and Botswana, the groups are more densely distributed with an average of 20 km² per group (Kemp & Begg, 1996). In the study conducted by Kemp & Begg (1996), they found that 96% of nests were located in 12 species of trees and 4% in rock faces. They further found that the trees *Combretum imberbe*, *Ficus sycomorus*, *Diospyros mespiliformis* and *Sclerocarya birrea*

were frequently used for nesting cavities with these species being common in the KNP. The trees *Adansonia digitata* and *Lannea schweinfurthii* were also frequently used by SGH but are uncommon in the study area. The wide range of species used by SGH suggests that any tree of suitable dimensions would be used as a nest site. In Zimbabwe, similar results were found, with nest sites located in open hollows in a dead or a living tree with the most common tree species used being *Adansonia digitata*, *Acacia* spp., *Colophospermum mopane* and *Diospyros* spp. A number of other tree species were also used but were only reported once (Msimanga, 2004).

Kemp & Begg (1996) found evidence that the principal limiting factors for SGH are a shortage of and competition for suitable nest sites. They suggested that wind and elephants were the two main agents responsible for damage to bark, branches and nest sites in KNP.

In the Associated Private Nature Reserves (APNR) there are 47 known potential nesting sites for SGH. Of these 20 are natural nesting sites and 27 are artificial nest boxes. The first artificial nest boxes were put up in the year 2000. Trees were selected at random, given that they were of suitable height and diameter at breast height so that elephants would not be able to push the tree over. Some of the natural nest sites that were identified have never been used over the ten years as it seems that they are still too small for SGH to utilize them. In total only 17 of the 47 nest sites have been used by SGH and of these only three were in natural cavities.

In this chapter the following questions were addressed:

1. The type of impact prevalent on the trees
2. The survival of the nesting trees over given period
3. The architecture of the nesting trees

4.2 Methods

4.2.1 Study area and field methods

For a detailed description of the study area and methods please refer to Chapter 2.

4.2.2 Data Analyses

Analyses were only conducted for the 17 nesting trees that have been active over the study period. Data was analyzed using Statistica version 9.0 (Statsoft Inc, 2009).

The type of impact that was prevalent on the nesting trees

The type of impact at each nesting trees was recorded, the number of impacted trees were then quantified per impact type and per impact class.

Survival of nesting trees

I used the Kaplan-Meier (Product-limit) survival analysis to plot percent survival (of nesting trees) as a function of time. This analysis calculates the 95% confidence interval (CI) for fractional survival at any particular time. The survival curve was then plotted on a graph. Data used for the survival analysis dated from 2000 until 2010 (the start of the ground hornbill research in the APNR).

Architecture of the tree

Correlations between tree dimensions and nest height

Pearson's correlation coefficient was used to measure the correlation between nest height and tree height, trunk height, canopy width, canopy height and start of the canopy. Pearson's correlation coefficient is the best method of measuring the correlation, because it is based on the covariance. Pearson's correlation coefficient provides information about the degree of correlation as well as the direction of the correlation. The pearson correlation is +1 in the case of a perfect positive (increasing) linear relationship, as it approaches zero there is less of a relationship and therefore the degree of correlation can be described from low (closer to 0) to high (closer to +1). Therefore the following broad categories were defined using the r-value: low (0 – 0.49), moderate (0.5 – 0.79) and high (0.8 – 1.0). The correlations were then plotted on a categorized scatterplot.

4.3 Results

4.3.1 The type of impact that was prevalent on the nesting trees

Data for the impact study included a year (2007) preceding the official study period of 2008 – 2010. Of the 47 nesting trees surveyed, seven of the trees that had natural cavities were already dead at the first survey. Branch breakage was the main impact type, followed by bark stripping. Most of the impact recorded during the 2007 survey was older than one year. By the end of the 2010 survey, persistence to the next season showed that 64% of the trees were fine, 17% showed signs of die-back and 19% of the nesting trees were dead (Tab. 4.1).

Tab. 4.1 Percentage of nesting trees affected by the various types of impact over the study period (2007 – 2010). Percentage of trees impacted, calculated for each year separately. The impact recorded in 2007 reflects accumulated impact prior to the survey (older than one year), data for the years 2008 – 2010 refers to recent impact and not accumulated impact (n = 47).

Impact type	% trees 2007	% trees 2008	% trees 2009	% trees 2010
No impact	55%	89%	96%	100%
Bark stripping	4%	4%	0%	0%
Branch breakage	31%	7%	4%	0%
Bark stripping & branch breakage*	6%	0%	0%	0%
Uprooting/Main stem broken	4%	0%	0%	0%

* Both types of damage found on the same tree

4.3.2 Survival of nesting trees

Data was collated from previous surveys dating back to 2000. Survival curves were calculated from time zero (when the ground hornbill project started) to 3650 days when the last survey was conducted. The survival curves calculated survival proportions and number of subjects at risk (i.e. nesting trees). The survival of ground hornbill nesting trees is fairly high with a survival rate of 84% during the first survey. At the end of the 2010 survey the survival rate was 77% over a ten year period. The survival curve starts at 84% as SGH also used dead trees as nesting sites and seven trees were already dead at the start of the survey (Fig. 4.1).

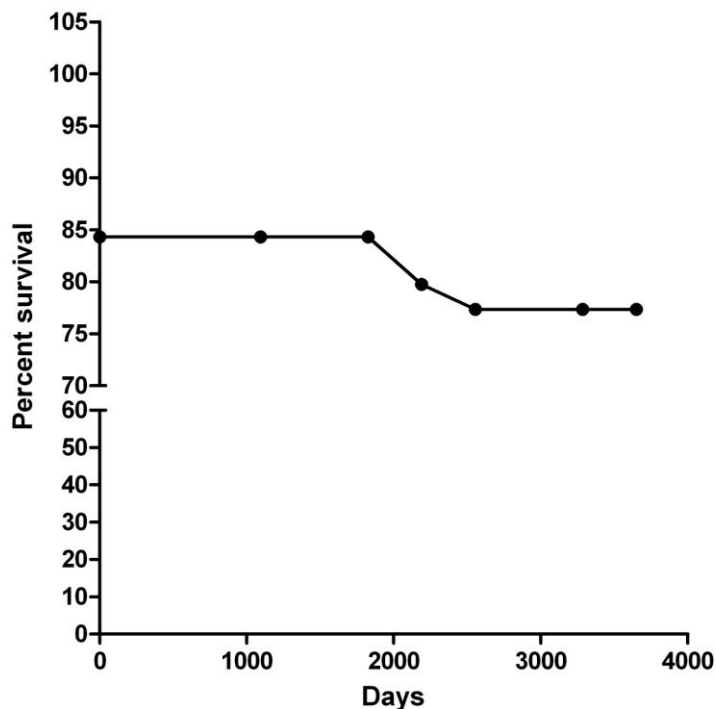


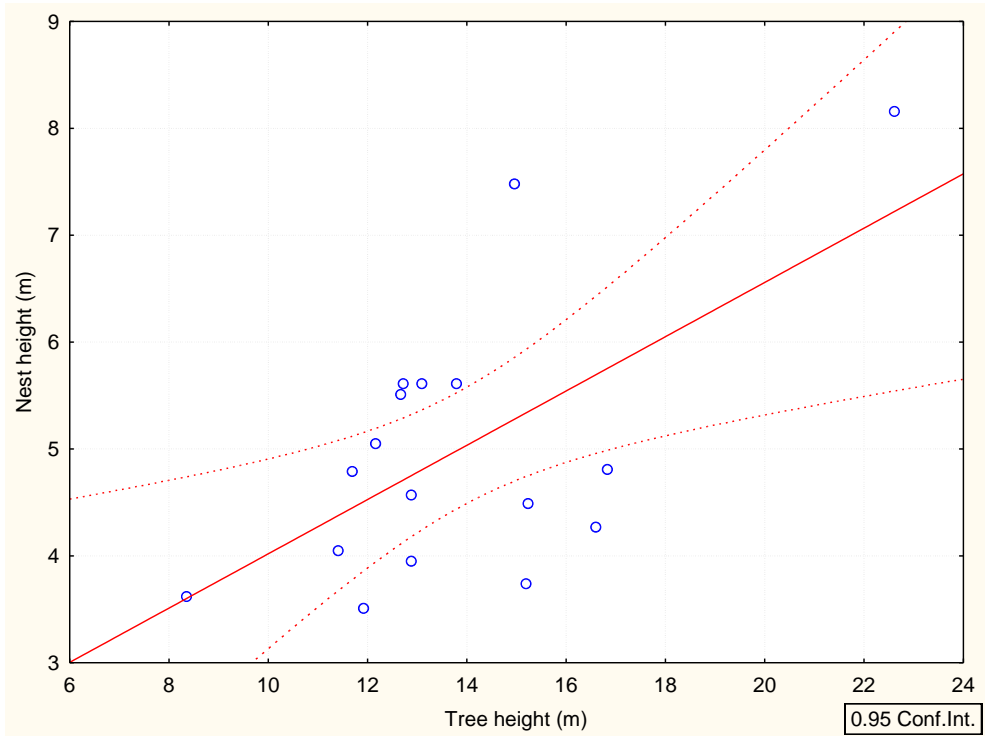
Fig. 4.1 Survival curve showing a slight decrease in survival of nesting trees from 84% during the first survey to 77% at the end of the 2010 survey.

4.3.3 Architecture of the tree

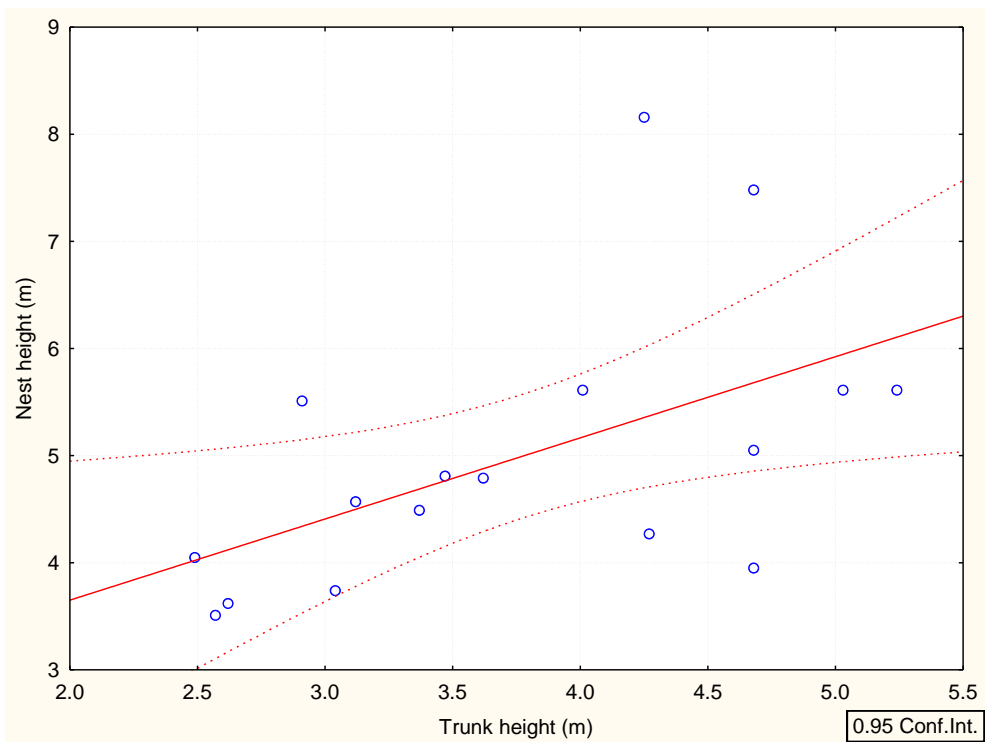
Correlations between tree dimensions and nest height

There was a significant correlation ($p < 0.05$) of moderate degree with positive linear relationships between nest height and tree height ($r = 0.61$), trunk height ($r = 0.54$),

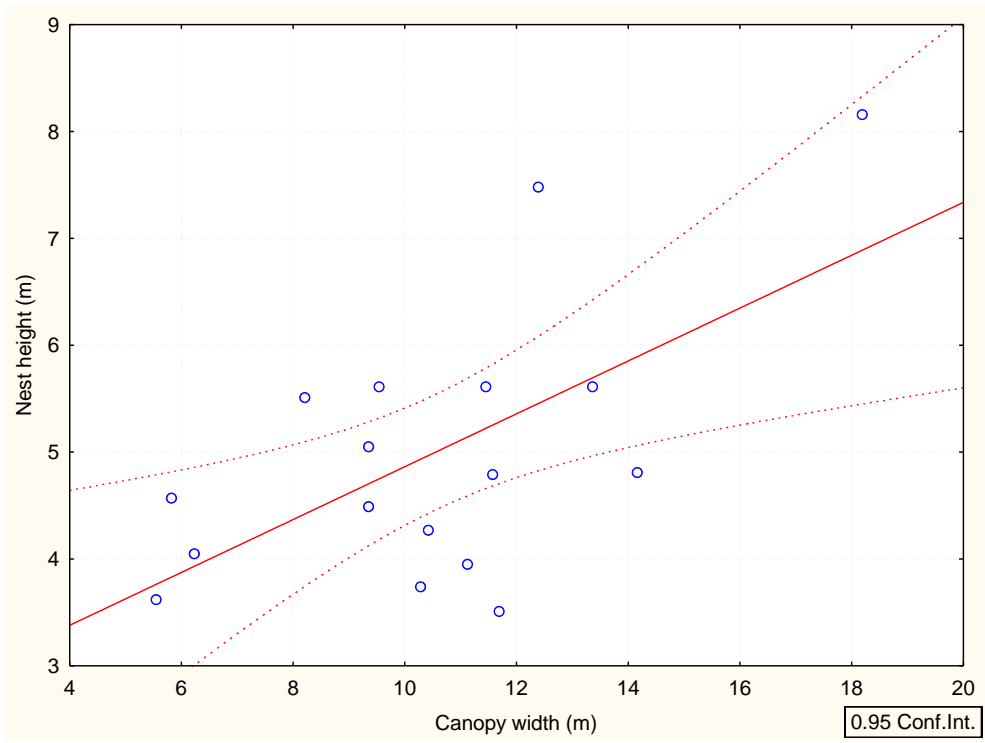
canopy width ($r = 0.61$) and canopy height ($r = 0.60$) (Fig. 4.1). There was also a significant correlation but of low degree between nest height and the start of the canopy ($r = 0.25$).



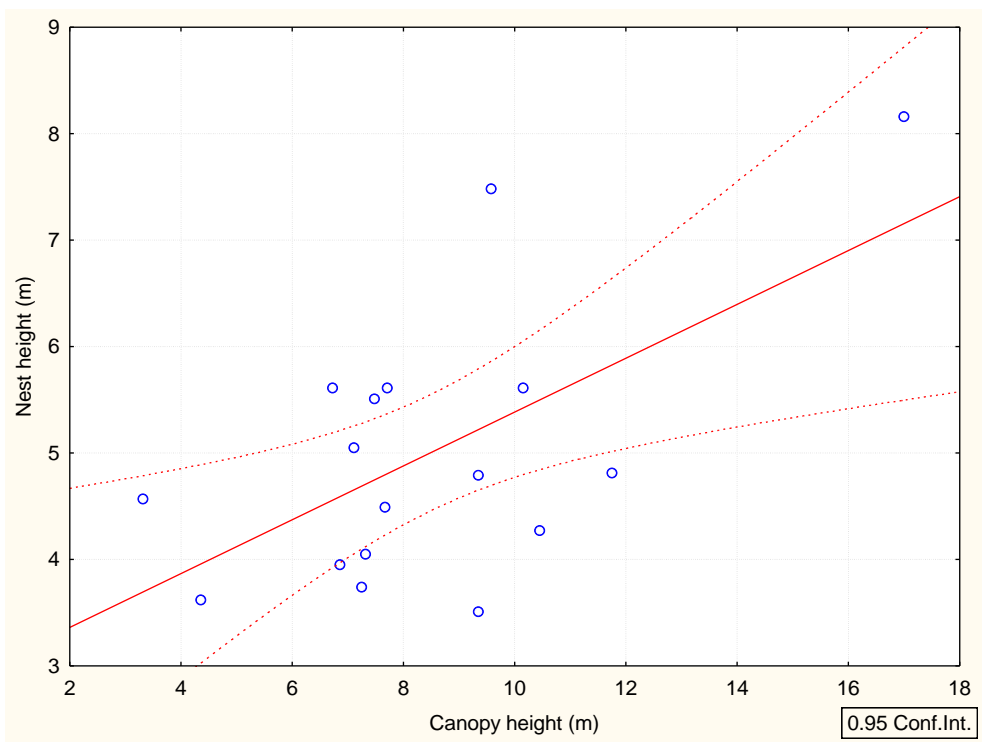
(a)



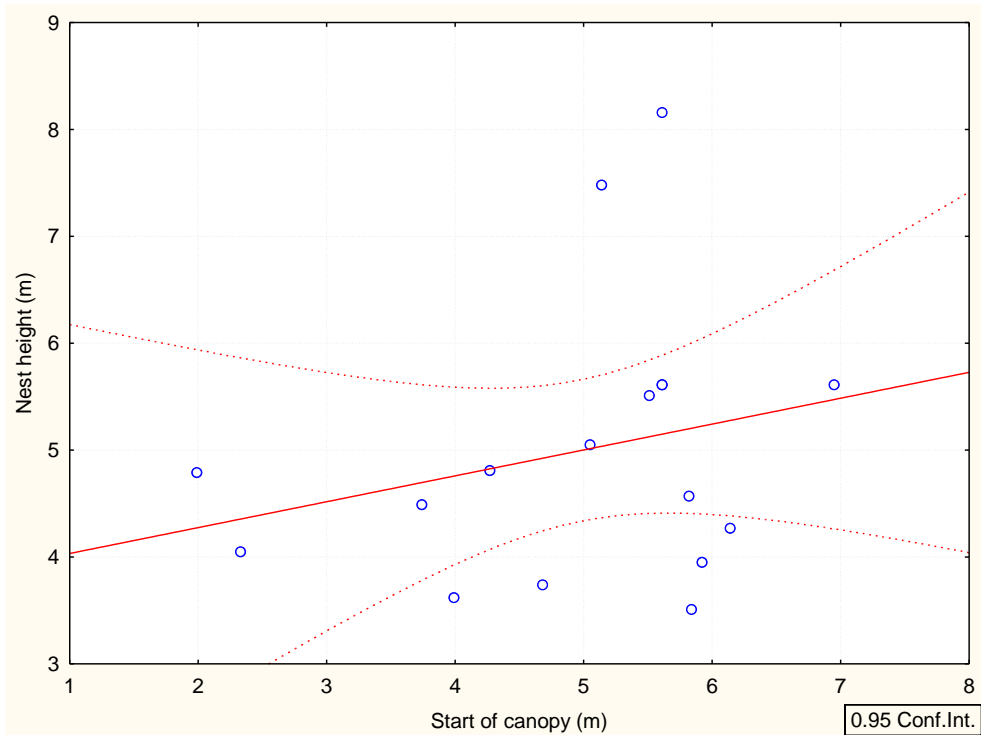
(b)



(c)



(d)



(e)

Fig. 4.2 Correlations of moderate degree between nest height and the following measures: (a) tree height, (b) trunk height, (c) canopy width, (d) canopy height. Correlation of low degree between nest height and (e) the start of the canopy (N= 17, $p < 0.05$).

4.4 Discussion

Southern ground hornbills (SGH) require large areas with tall trees and a mosaic of habitats to satisfy foraging and nesting requirements (Vernon, 1986; Kemp, 1995). SGH are absent from areas that lack tall trees (Morrison & Kemp, [Sa]).

Literature suggests that wind, fire, floods, lightning and elephants probably are the main agents that play a role in the loss and formation of nesting sites and it is estimated that there is a mean annual cavity loss of 7.7 % (Kemp & Begg, 1996; Spear *et al.*, 2005, Morrison & Kemp, [Sa]). Furthermore, it has been suggested that elephants especially impact nesting sites in the drier seasons (Morrison & Kemp, [Sa]). Data from this study shows that elephant impact over a four year period (2007 – 2010) is relatively low and the percentage of impact decreased from 2007 – 2010. Impact recorded in 2007 was older than one year and only three trees had fresh impact (within six months of the

survey). The survival rate for nesting trees in the APNR is high. Over a ten year period (2000 – 2010) survival rate only decreased by 7%, from 84% in 2000 to 77% in 2010. Henley & Henley (2005) suggested that the majority of mature trees felled by elephants in the APNR were not tree species that were predominantly used by SGH. However, in KNP, *Sclerocarya birrea*, is one of the top five trees felled by elephants and these trees are also utilized by SGH (Morrison & Kemp, [Sa]). In the APNR three of the identified natural nests are in *Sclerocarya birrea*, but none of these were actively used by SGH, this is mainly due to the nests not being of suitable dimensions for SGH to breed in. These nests were identified in 2002 at the start of the long term SGH project, at that time, nests were judged on a visual basis and not through measurement and the perception was that over time they might become suitable as the tree grows. SGH need nests with an internal floor diameter of 40 cm, and situated in a tree with a diameter at breast height (DBH) of at least 40 cm (Kemp & Begg, 1996).

The ongoing study in the APNR indicates that the species and sizes (stem diameter) of trees favoured by SGH for nesting sites are at low risk of elephant impact. This is mainly due to the fact that, with the exception of bulls' impact upon *Sclerocarya birrea*, the suite of species preferred and impacted by elephants differed from that favoured by SGH as nesting sites. Furthermore, the stem diameters of trees used as nesting sites made them too large for elephants to compromise the survival of the tree. Natural nest sites are also commonly found in large dead trees (Henley *et al.*, 2008).

The mean tree height for SGH in the APNR was 13.82 m (SD = ± 3.07 m) and the mean nest height was 4.99 m (SD = ± 1.28 m). In Zimbabwe, similar results were found; where natural nests were located 4 – 7 m up the tree trunk (Msimanga, 2004). The average diameter at breast height (DBH) of trees with nesting cavities was 72.3 cm (SD = ± 16.7 cm). Kemp & Begg (1996) found that SGH use trees with a DBH of at least 40 cm and cavities should have a median floor diameter of 40 cm. Kemp & Begg (1996) expected that nest site availability would be correlated to tree size and density.

In this study the nest height was significantly correlated to tree height, trunk height, canopy width and canopy length, which suggests that one could predict which trees could be potential nesting sites for SGH by looking at the correlated characteristics and this

could be important for protecting potential nest trees. The predominant use of artificial nest sites (82%) does seem to suggest that there is a lack of suitable natural nesting sites available to SGH. Kemp & Begg (1996) expected that SGH would consider any tree as a nesting site given it is of suitable dimensions. Furthermore, the most frequently used tree species would be those that are the largest, most common, and most predisposed to forming natural cavities. The loss of large, hollow tree trunks is a major threat for SGH and this is especially true in rural areas, where habitat destruction and transformation takes place (Vernon, 1986; Kemp, 1987; Msimanga, 2004). Kemp, 2000, suggested that foraging requirements may be less of a problem than nesting sites for SGH.

Elephants may facilitate the creation of nesting sites over the long term. When elephant bulls rip large branches from trees to access smaller plant parts, the ripped sections die back over time forming potential nesting cavities for SGH. Elephant bulls, with their larger bite and break diameters (compared to cows) have the potential not only to diminish the potential number of cavity sites in the long run by removing large trees from the system through tree felling and ring barking of particular species but also have the potential to create nesting cavities by breaking primary branches. Elephant impact may eventually make large trees susceptible to insect attack, which weakens the trees. It is however difficult to determine the direct cause of death of large trees unless the causal factor of mortality has recently been surveyed (within a few months for most species). More research is needed to track the accumulated effects of elephant impact on individual trees over time to determine if tree cavities are being lost quicker than what they are being created. Long term research/monitoring is needed, especially in the APNR where baseline data has already been gathered.

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Chapter 5

Facilitatory role of elephant impact

5.1 Introduction

The African elephant (*Loxodonta africana*) has been described as an ecosystem engineer with the capacity to structurally modify the vegetation on which they feed (de Beer *et al.*, 2006). Pringle (2008) defines ecosystem engineers as “organisms that control the availability of resources for other species by modifying the physical environment”. Facilitation occurs when “consumption by a consumer produces a flow of resources into another consumer and secondly, when the latter consumer specializes on consuming the produced resource” (Farnsworth *et al.*, 2002). Body size has been found to be an important aspect for food mediated interactions between small and large herbivore species. Small species often consume highly nutritious plant parts. Large herbivores can increase the production and/or availability of nutritious plant tissue (Makhabu *et al.*, 2006).

The impact of elephants on trees could play a facilitatory role in the production of a food source, i.e. gum, for primates. Gum is a water soluble, complex polysaccharide which potentially represents a calorie-rich food item. In dry weight gum consists of 90% or more carbohydrates. Gum within the *Acacia* genus is composed of the same main sugar residues but vary in proportions of those sugars (Nash, 1986). Because bark is living, photosynthetic tissue it is often utilized by large herbivores (mainly elephants) which results in wounds that produce gum (Altmann, 1985). Primates have been shown to eat gum exudates produced by trees after mechanical or insect damage. On one tree many gum sites can be found. Gum may accumulate on trees as large “globs” or long “streaks” or even just small droplets and as described by Nash (1986) the gum is quickly depleted after a feeding event but is also rapidly renewed. A study of *Acacia tortillis* and *Acacia xanthophloea* has shown that both species produced gum at sites of injury to the bark and vervet monkeys (*Cercopithecus aethiops*) were found to inspect trees daily. Furthermore, competition for especially *A. xanthophloea* gum was observed (Wrangham & Waterman, 1981). Field studies have shown that gum is an important aspect of primate

diets and may be an important source of minerals. According to a study by Altmann (1985), the primary benefit of gum for baboons (*Papio ursinus*) is energy. Certain primates have morphological features that allow them to harvest gum and by scraping or gouging trees they in turn stimulate gum flow. Consuming gum may give primates a competitive advantage (Nash, 1986). Nash (1986), suggested that gum is used extensively by some species year round or only in certain seasons as a dietary supplement. Vervets have been found to use all *Acacia* products for food throughout the year (Wrangham & Waterman, 1981). Bushbabies (*Galago moholi* and *Otolemur crassicaudatus*) are known to utilize gum throughout the year but gum usage was particularly prevalent during the dry season. Bushbabies are known to extensively feed on *Acacia* gum. In summer they focus more on insects than on gum but shift their foraging in winter when invertebrates are almost unavailable (Nash, 1986). Bearder & Martin (1980) found that gum flow increased steadily during summer but maximum gum flow did not coincide with spring or the appearance of new leaves. Indirectly, ecosystem engineers such as elephants may initiate powerful trophic effects which necessitates further investigation (Pringle, 2008).

Elephant feeding habits could either be detrimental to the nesting sites of particular species of birds, have no effect at all or alternatively elephants could, by breaking primary branches, actually play a facilitating role in the creation of nests for ground hornbills (Henley & Henley, 2005) and other species (smaller birds species that require hollows for nests like owls and primates such as bushbabies. Suitable cavities and large trees are often limited resources and therefore play an important role in the ability of groups/birds to become established, reproduce and to survive in a specific territory (Stacey & Ligon, 1987; Restrepo & Mondragon, 1998).

I examined the facilitatory role that elephants play in the production of a food source for primates, by impacting trees, which as a result of the impact produce gum. Further, this chapter will also explain which elephant impact causes gum exudates. Through feeding trial experiments the preference of different gum types by primates is determined. The possibility of elephants creating ground hornbill nesting sites due to primary branch breakage is also investigated.

5.2 Methods

5.2.1 Study area and field methods

For a detailed description of the study area and methods please refer to Chapter 2. Fig. 5.1 shows two photographs of the feeding bowls used in the feeding trial and the presentation to the vervet monkeys.



(a)



(b)

Fig 5.1 (a) Presenting gum samples to a vervet monkey. (b) Feeding bowls used to present gum samples in.

5.2.2 Data analyses

Data was analyzed using STATISTICA version 9.0 (StatSoft Inc., 2009).

Feeding trial

The score that each individual received during the feeding trial was averaged between the duplicates of the same tree species' gum that was tested. The Friedman ANOVA by rank test was then used to determine if there was a significant difference in reaction

between the animals. As there were no significant differences between the reactions of the individuals, the scores were averaged across individuals.

The Wilcoxon matched pairs test was used to compare the reaction of the vervet monkeys to the treatment and control. In order to determine the species preference the difference between the averages of the treatment and control was calculated and ranked from highest difference to lowest difference.

5.3 Results

5.3.1 Feeding trial

The Friedman ANOVA by rank test showed that there was no significant difference in reaction between the individual vervets to the treatment and control ($p > 0.05$). Therefore the scores were averaged across individuals. When pooled across individuals, the trial result showed that vervets in general distinguished between the treatment and control ($p < 0.05$).

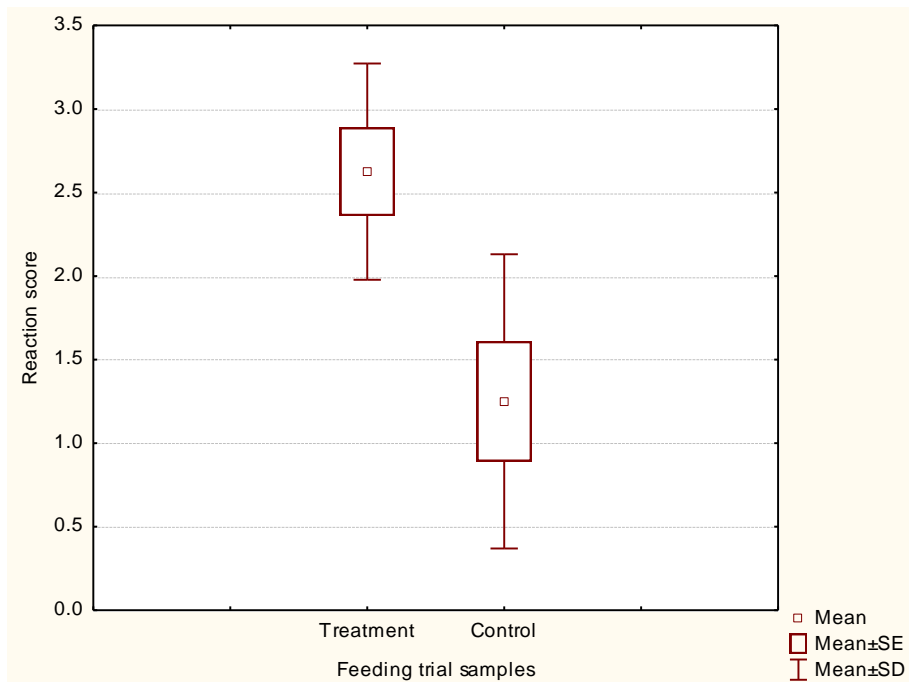


Fig. 5.2 Results from Wilcoxon matched pairs test showing vervet monkeys distinguish between treatment & control.

Tab. 5.1 Difference in reaction score of vervet monkeys between the treatment and control, and the subsequent ranking thereof.

Type	Treatment	Control	Difference	Rank
<i>A. tortillis</i>	3.25	0.75	2.5	1
<i>A. nigrescens</i>	3	0.5	2.5	1
<i>S. birrea</i>	2.75	0.5	2.25	2
<i>A. xantophloea</i>	2.25	1.75	0.5	3
<i>A. karroo</i>	3	2.75	0.25	4
<i>A. nilotica</i>	1.5	1.25	0.25	4

The ranking of the difference in reactions (Tab. 5.1) showed that the animals favoured three species:

- *Acacia nigrescens*
- *Acacia tortillis*
- *Sclerocarya birrea*

There was no significant difference in reaction between the treatment and control for the other three species (Fig. 5.3).

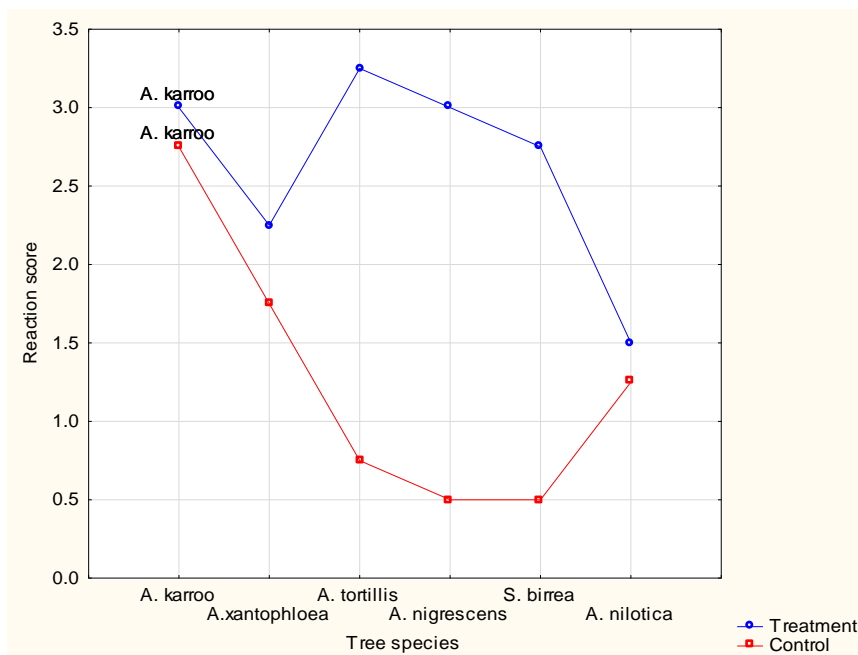


Fig 5.3 Difference in reactions between the treatment & control of five different tree species.

5.3.2 Tree impact survey

During the dry cycle (August 2009 – end of November 2009) 14 trees were impacted and protected. A further 14 trees were impacted and protected from December 2009 till the end of February 2010. A total of 28 trees were surveyed for this period (Fig. 5.4 (a) – (f)).

During the dry cycle all 14 trees were visited on a weekly basis to check for gum. Gum was only produced by six trees directly after impact. These were as follows:

- Two *Acacia nigrescens* trees (bark stripped): gum was found on the first three visits after impact.
- Two *Acacia xanthophloea* trees (bark stripped): gum was found also on the first three visits after impact.
- One *Acacia tortillis* (bark stripped): gum was found on the second visit after impact.
- One *Acacia tortillis* (branch breakage): gum was found on the second visit after impact.

During the wet cycle only two bark stripped *Acacia xanthophloea* trees produced gum directly after impact.



(a)



(b)



(c)



(d)



(e)



(f)

Fig. 5.4 Impacted sites on different tree species:

(a) Approximate size of bark stripped area.

(b) Protected *Acacia nigrescens*.

(c) Protected *Acacia tortillis*.

(d) Protected *Acacia xanthophloea*.

(e) *Acacia xanthophloea* bark stripped area producing gum.

(f) *Acacia tortillis* branch breakage producing

Camera traps

Three 5 Mega pixel digital scouting cameras (ScoutGuard Model: SG550) (Fig. 5.5) were used to gather photographic evidence of animals visiting the impacted sites. The camera traps were motion triggered and infrared enabled, allowing these traps to take photographs at night without disturbing the animals. The impacted sites on the trees were not protected to ensure that the animals could harvest gum. These trees were located in the vicinity of the artificially impacted trees which had been wire-net protected to ensure that all trees were exposed to similar edaphic conditions.



Fig. 5.5 Camera trap on *Acacia nigrescens*.

During July 2009 the camera traps were first tested on various trees that produced gum, to see if they would yield any results. The first trap was placed at an *Elaeodendron transvaalense* tree that regularly produced gum. This tree was at a house and only photographic evidence (Fig. 5.6) of a tree squirrel (*Paraxerus cepapi*) was captured.



Fig. 5.6 Gum site on *Elaeodendron transvaalense*, visited by tree squirrel (*Paraxerus cepapi*).

The second trap was placed in the veld at an *Acacia tortillis* tree for seven days and the gum site was visited once by a vervet monkey (*Cercopithecus aethiops*) (Fig. 5.7).



Fig. 5.7 Gum site on *Acacia tortillis*, inspected by vervet monkey (*Cercopithecus aethiops*).

The third trap was placed at an *Acacia karroo* tree, where gum was harvested for the control of the feeding trial. The trap was also up for seven days and twice during this period the gum site was visited by lesser bush babies (*Galago moholi*) (Fig. 5.8).



Fig. 5.8 Gum site on *Acacia karroo*, visited by lesser bush baby (*Galago moholi*) on two separate nights.

The experiment proved that it was possible to get photographic evidence of animals visiting the gum sites. The camera traps were then placed on three trees away from habitation in August 2009 and were removed in February 2010. The camera traps were each placed on the following artificially impacted trees;

- *Acacia nigrescens*
- *Acacia tortillis*
- *Sclerocarya birrea*

The camera traps were visited once a week when conducting the survey and all available footage was downloaded. The *Acacia nigrescens* and *Sclerocarya birrea* trees at the camera traps did not produce any gum during the survey period and there was no evidence of any primate visiting these trees. Footage of other animals in the vicinity of the tree was gathered.

The *Acacia tortillis* produced a small streak of gum and it was visited on one occasion (Fig. 5.9) during this period by a vervet monkey (*Cercopithecus aethiops*). The vervet monkey possibly ate the gum and the tree produced no further gum for the survey period.



Fig. 5.9 *Acacia tortillis*, inspected by vervet monkey (*Cercopithecus aethiops*).

5.3.3 Creation of nesting sites

All vulture and raptor nesting trees were inspected for possible primary branch breakage incidents that could potentially develop into a nesting site for ground hornbills (SGH) and other birds and mammals. In total 102 nest sites were inspected and of these only two had primary branches broken and the old impact site was hollowed out. These two hollows are however still very small but given time they could potentially develop into bigger nesting sites (Fig. 5.10). Usually the vulture nests were in large *Acacia nigrescens* trees. Most of these trees do not have stem diameters large enough to create suitable nesting sites for ground hornbills but when the branches die back, they could create hollows for various other tree nesting birds and even for bush babies to sleep in. The average diameter at breast height (DBH) for vulture/raptor trees was 60 cm and for SGH it was 72 cm. SGH need hollows with an internal diameter of 40 cm and the tree species focussed on during this survey included only few trees that could be old and big enough to accommodate SGH if they had hollows. If the survey had included other trees as well, one may have found more facilitatory effects by elephant in terms of creation of suitable nesting sites for SGH.



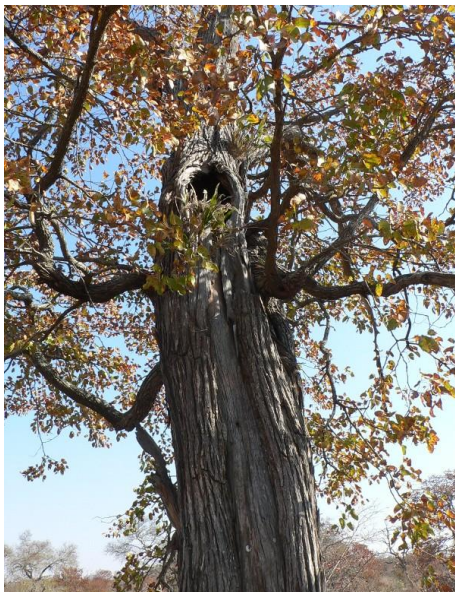
(a)



(b)

Fig. 5.10 (a) Hollow in *Acacia nigrescens* tree. (b) Second site, hollow also in *Acacia nigrescens* tree (smaller than (a)).

In total there were 54 ground hornbill nest sites; 28 were artificial, 11 natural and 15 natural modified. Of the natural nest sites six were established as a result of primary branch breakage. The one nesting site in a *Colophospermum mopane* was confirmed to be due to elephant impact during the survey period, this nest was actively utilized by a group of ground hornbills but they have subsequently moved to an artificial nesting site (Fig. 5.11). The cause for the five other nest sites could not be determined as these were very old, but it could possibly be due to elephant impact or wind. The nesting site in the one *Sclerocarya birrea* is actively used by the ground hornbills and a nesting site in another *Sclerocarya birrea* is used by a barn owl (*Tyto alba*).



(a)



(b)

Fig. 5.11 (a) Hollow in *Colophospermum mopane* tree. (b) Active nest in *Sclerocarya birrea* tree.

5.4 Discussion

Plant exudates or gum feeding has drawn some attention over the years as being an important aspect in the natural diet of small-bodied primates (Bearder & Martin, 1980). Nash (1986) suggested that elephant feeding activity on especially *Acacia* species resulted in copious production of gum at numerous sites and also suggested a need for further studies.

The results from the feeding trial suggest that vervet monkeys (*Cercopithecus aethiops*) do utilize gum and are able to distinguish between gum of different tree species. They showed a preference for *Acacia nigrescens*, *Acacia tortillis* and *Sclerocarya birrea* gum. In the study area *Acacia xanthophloea* trees are very limited and the area is dominated by *Acacia nigrescens*, *Acacia tortillis* and *Sclerocarya birrea* (Acocks, 1988). These species are also heavily utilized by elephants (*Loxodonta africana*) and elephants are the only species that severely impact trees by breaking branches and stems, uprooting or debarking (Guldemon & van Aarde, 2007). Kerley *et al.* (2008) stated that the genera *Acacia* formed a common dietary staple for elephants. *Acacia tortillis* was found by MacGregor & O'Connor (2004) to be highly selected for by elephants. *Sclerocarya birrea* and *Acacia nigrescens* are also favoured species by bull groups in the APNR. Elephant numbers within the APNR have steadily increased over recent years to 0.4 elephant/km². It will therefore be expected that vegetation structure and composition can be altered as the number of elephants increase (Greyling, 2004). As a greater number of trees are impacted this could suggest that this would lead to more gum being available for primates. Selectivity for gum in the field could also relate to its availability (Nash, 1986). Vervets rely on all *Acacia* products throughout the year but the presence of different *Acacia* species within their home range could also influence selectivity and availability (Wrangham & Waterman, 1981).

The three species of gum favoured by vervet monkeys were relatively clear to yellow-brownish in colour. The colours were mostly similar between the treatment and the control, except for *Acacia nilotica*. The gum harvested from the *Acacia nilotica* was produced as a result of insect damage and the gum was deep red in colour (Fig. 5.12).



Fig. 5.12 Deep red *Acacia nilotica* gum seeping from insect hole in tree.

Neither of the vervet monkeys ingested any of the deep red gum. This finding is the same as the study conducted by Wrangham & Waterman (1981), who found that deep red gum was never eaten. Bearder & Martin (1980) found that dark coloured gum was produced when insect larvae bore into the heartwood of the main stem to form chambers 30-50 cm long, they also found an increase in the proportion of orange and red gum from April onward and this was as a result of an increase in insect casts. Wrangham & Waterman (1981) found that vervet monkeys preferred gum from *Acacia xanthophloea* to the gum of *Acacia tortillis* and suggested that it was due to the high tannin content. Further investigation would be required to determine if deeply red gum is infused with a high tannin content and if that would make the gum unpalatable. It would also be important to further investigate the different levels of palatable gum produced by mega herbivore activities as opposed to insects. Other possible agents of gum production include porcupines that bark strip the lower regions of trees and buffalo that frequently rub the back of their ears against tree trunks and young branches because of parasite infestation, thereby removing the bark. Comparing all these different types of gum production by various fauna and their varying levels of palatability could make for interesting future research. Photographic evidence collected prior to the impact survey suggested that gum was produced mainly by bark stripping in *Acacia* species as well as branch breakage to a certain degree, especially in *Acacia tortillis*.



Fig. 5.13 Vervet monkey feeding on gum from bark stripped *Acacia xanthophloea*.



Fig. 5.14 *Sclerocarya birrea* gum seeping from tusk entry point created by an elephant.

Sclerocarya birrea, gum was only found on tusk entry wounds to trees (Fig 5.14). The impact survey however did not yield any significant results. This could be as a result that the induced tusk entry sites might not have been deep enough.

When gum from *Acacia tortillis* is eaten by primates it is usually from young trees as these may contain lower tannin levels compared to gum from mature trees (Nash, 1986). The lack of gum produced from the bark stripping could be as a result of the stripped

area not being deep enough and there was no longitudinal splitting of the wood. Bearder & Martin (1980) found that it was not possible to obtain appreciable amounts of gum simply by drilling holes at random in the *Acacia* trees. To gather useful quantities there needed to be extensive longitudinal splitting of the wood.

Furthermore, Wrangham & Waterman (1981), found trees with permanent access to ground water lose water from the wounds in the bark and crystalline gum is prevented from blocking the wounds by constantly producing more tacky and soft, runny gum. Trees in drier soils and subject to water stress protect themselves from water loss by blocking the wounds with hard crystalline gum. Substantial amounts of gum, for the control sample, in the feeding trial was collected from an *Acacia karroo* which was located within a tourist camp, where it was constantly being watered. Consequently it continually produced soft, runny gum. The other trees that were used for the feeding trial were not watered and water stress could possibly explain why minimal amounts of gum were produced. Wounds were blocked shortly after impact by hard crystalline gum and there was no subsequent production of gum.

The study showed that it is possible for elephant impact on large trees to play a beneficial role in producing nesting sites for ground hornbills, through primary branch breakage. This may also not only benefit ground hornbills but several other smaller birds, vertebrates and invertebrates. This process however is very slow and may take several years before nesting sites may become available. Future studies could investigate whether elephants remove more potential bird and small mammal nesting sites from the system by toppling trees, than they create through primary branch breakage while accessing smaller plant parts. Nasser *et al.* (2010) found that herpetofauna species richness greatly increased in areas of high damage as increased coarse woody debris created refuges, hunting areas and breeding grounds for these species. Further investigation is needed to determine the extent to which elephant damage may benefit other species, by creating microhabitats and increasing nesting sites or breeding holes.

5.5 References

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Chapter 6

Conclusion

In this chapter, I synthesize the important findings of this study. I discuss relevant management implications and recommendations for future research as well as the limitations of this study.

6.1 Elephant impact on vulture and raptor nesting sites

This study found that vulture and raptor nests are present in trees that can potentially be bark-stripped, uprooted or pollarded by elephants as elephants are known to utilize *Acacia nigrescens* in this way, especially during the dry season. De Villiers (1994) found that elephants preferred *Acacia nigrescens*, *Colophospermum mopane* and *Sclerocarya birrea* trees. In this study *Acacia nigrescens* was also used predominantly for nesting sites by vultures (98%) and raptors (91%). Despite the potential vulnerability of these tree species to elephant impact, I found the survival rate of vulture and raptor nesting trees to be 96.30% and 97.87% respectively during the study period. Vultures and raptors also nested primarily in trees that were classified as persisting and not at risk of mortality. Overall elephant feeding habits have not shown to affect the nesting trees significantly and elephant impact has not lead to the desertion of nest sites by vultures and raptors in the short term.

Vultures and raptors nest in tall trees and vultures, mainly White-backed vultures (*Gyps africanus*), nest predominantly on top of the tree canopy and other species in the sub-canopy (Kemp & Kemp, 1975; Mundy *et al.*, 1992; Dean *et al.*, 1999; Monadjem & Garcelon, 2005; Herholdt & Anderson, 2006). In this study 96% of all the vulture nests were occupied by White-backed vultures. Various species of raptors occupied the different nests; Whalberg's eagle (*Aquila wahlbergi*) and African hawk eagle (*Aquila spilogaster*) nests were found more often. On four occasions there was an interchange of nesting sites recorded.

I found that the distance to the nearest tree with a nest was considerably smaller for vulture nests than raptor nests. These results could be indicative of the clump distribution of vulture nests within suitable habitat types (landscapes with tall trees of suitable height). Vultures and raptors nested predominantly in mixed woodland areas with the majority of the nests located in *Acacia nigrescens* trees.

Roads have shown to be an important landscape feature for raptor nesting sites. Roads and their verges in arid and semi-arid environments often function as high production systems (O'Farrell, 1997). Dean & Milton (2003) found that raptors are attracted to roads due to the fairly productive road verges. Raptors use animals that are killed on roads for food while their fur/hair could provide additional nesting material. Furthermore roads represent 'open' spaces that would make spotting of prey easier for the birds and they might therefore prefer these areas.

The most important landscape feature for vulture nesting sites in the KPNR was artificial watering points, followed by nearest nests and rivers/drainage lines, which were consistent with findings by Kemp & Kemp (1975). When comparing the feeding habits of vultures versus raptors, vultures would be in more need of regular bathing to ensure that their carrion feeding habits don't lead to the spread of disease.

Vultures and raptors nested in trees of similar dimensions but there was a significant difference between nest heights, this is mostly due to the fact that vultures nest on the canopy of the tree and raptors prefer the sub-canopy. The mean nest height for vultures was 10.12 m (SD = ± 1.49) and for raptors 9.32 m (SD = ± 2.17). Kemp & Kemp (1975) estimated that vulture nesting trees ranged in heights between 10 – 25 m and suggested that the nest height depended mainly on the height of the trees in the area (Herholdt & Anderson, 2006) and the height of the tree chosen. In this study nesting tree heights ranged from 8.79 – 16.21 m, in accordance with these findings. Vultures might be selecting to nest on top of the canopy as a means of preventing predation of nestlings. In addition their nest structure may not make allowance for sub-conopy nesting. As no vulture nest were found in dead trees, the constructing and maintenance of vulture nests may require the network of fine branchlets found on the upper canopy of predominantly *Acacia nigrescens* trees that are still alive. Raptors nest in the sub-canopy and this could

be to provide shading during the day and more protection from natural elements like wind and rain. Egg laying for raptors found in the study area occurs mainly during the summer, December to April. For vultures egg laying starts from April to June (Hockey *et al.* 2005) and therefore foliage protection is less important for vultures. These observations necessitate further investigation.

6.2 Elephant impact on Southern ground hornbill (SGH) nesting sites

Literature suggests that wind, fire, floods, lightning and elephants probably are the main agents that play a role in the loss and formation of nesting sites and it is estimated that there is a mean annual cavity loss of 7.7 % (Kemp & Begg, 1996; Spear *et al.*, 2005; Morrison & Kemp, [Sa]). Data from this study shows that elephant impact over a four year period (2007 – 2010) was relatively low and that it actually decreased. Impact recorded in 2007 was older than one year with only three trees having had fresh impact (within six months of the survey). The survival rate for nesting trees in the APNR is high. Data gathered in the APNR over a ten year period (2000 – 2010) indicates that survival rate decreased by 7%, from 84% in 2000 to 77% only in 2010. Henley & Henley (2005) suggested that the majority of mature trees felled by elephants in the APNR were not tree species that were predominantly used by SGH for nesting cavities. The results of this study support these suggestions.

Southern ground hornbills (SGH) require large areas with tall trees and a mosaic of habitats to satisfy foraging and nesting requirements (Vernon, 1986; Kemp, 1995). The mean tree height of nesting trees for SGH in the APNR was 13.82 m (SD = ± 3.07 m) and the mean nest height was 4.99 m (SD = ± 1.28 m). The average diameter at breast height (DBH) of trees with nesting cavities was 72.3 cm (SD = ± 16.7 cm). Kemp & Begg (1996), found that SGH use trees with a DBH of at least 40 cm and cavities should have a median floor diameter of 40 cm.

In this study the nest height was significantly correlated to tree height, trunk height, canopy width and canopy height, which suggests that one could predict which trees, would be potential nesting sites for SGH by looking at the correlated characteristics. This could be important for protecting potential nest trees. Although this study could not

attribute the decline in suitable SGH nesting sites to the feeding habits of elephants, the predominant use of artificial nest sites (82%) does seem to suggest that there is a lack of suitable natural nesting sites available to SGH.

6.3 Facilitatory role of elephant impact

Nash (1986) suggested that elephant feeding activity on especially *Acacia* species resulted in copious production of gum at numerous sites and also suggested a need for further studies.

The results from the feeding trial suggest that vervet monkeys (*Cercopithecus aethiops*) do utilize gum and are able to distinguish between gum of different tree species. They also showed a preference for *Acacia nigrescens*, *Acacia tortillis* and *Sclerocarya birrea* gum. These species are heavily utilized by elephants (*Loxodonta africana*) and elephants are the only species that severely impact trees by breaking branches and stems, uprooting or by repeated debarking events (Guldemond & van Aarde, 2007).

Photographic evidence collected prior to the impact survey suggested that gum was produced mainly by bark stripping in *Acacia* species as well as branch breakage to a certain degree, especially in *Acacia tortillis*. Gum from *Sclerocarya birrea* (marula) trees was only found on tusk entry wounds.

When elephant bulls rip large branches from trees to access smaller plant parts, the ripped sections die back over time forming potential nesting cavities for SGH. Elephant bulls in comparison to cows, with their larger bite and break diameters (Greyling, 2004) have the potential not only to diminish the potential number of cavity sites over time by removing large trees from the system through tree felling and ring barking of particular species but also have the potential to create nesting cavities by breaking primary branches.

6.4 Management implications and recommendations

The findings of this study have different management implications for small, fenced reserves, compared to larger reserves where dispersal of elephants, especially bulls, can take place. The implications and recommendations discussed here apply specifically to the Associated Private Nature Reserves (APNR) and reserves of similar size, which are also open to the Kruger National Park (KNP) or in similar habitat.

The following management implications could be implemented to protect trees of particular importance within reserves (Grant *et al.*, 2008):

- Fencing of enclosures to create botanical reserves to protect trees. These botanical reserves can also act as seed banks to populate surrounding areas.
- Protecting individual trees through wire netting, this will prevent trees from being extensively ring barked but does not protect trees from being uprooted or snapped.
- The use of chilli extracts on trees could be implemented for aversion conditioning.
- Manipulating drinking water available to elephants, limited water availability can increase the density of elephants and expand their spatial distribution.

Monitoring of vulture, raptor and ground hornbill nesting sites needs to continue over a longer period to determine the rate and direction of change over time. As all of these species are long lived it is essential to determine what impact elephants have over the long term. Climate data also needs to be recorded over the long term to determine the possible effects of climate change on the nesting and breeding habits of birds, especially vultures.

It would be important to see if elephant numbers and their consequential impact on similar vegetation types differ between the APNR and the KNP.

As previously stated, vulture and raptor nests were found in trees that can potentially be bark-stripped, uprooted or pollarded by elephants. Since elephants are known to utilize *Acacia nigrescens* in this way, it is recommended therefore that the impacts on the trees are continuously monitored so that other actions (see par. 2) could be taken or

considered if the impact increases. It would also be important to determine the preference ratios for nesting trees and this could be done by comparing the proportion of trees utilized, by the birds, with availability of suitable nesting trees. Monitoring of trees that could potentially develop into vulture, raptor and ground hornbill nesting trees should be established by studying the factors influencing the regeneration of trees in the ecosystem.

More research is needed to track the accumulated effects of elephant impact on individual trees over time to determine if tree cavities are being lost due to elephant impact quicker than what they are being created. The indirect consequences of elephant feeding habits should also be researched. Bark-stripping of large trees by elephants often make trees more susceptible to fire damage but the tramping and grazing habits of elephants and other ungulates could likewise result in less biomass closer to tree trunks, thereby preventing fires from scaring the trunk. A cost-benefit analysis of elephant feeding habits to trees and co-existing fauna could deliver some interesting results over time. Furthermore, in depth research into the role of facilitation by elephants in creating micro-habitats, nesting sites and food sources for other species needs to be established in the APNR.

As most publications focus on the negative impact of elephant feeding habits, the positive and often less obvious knock-on effects of elephant feeding habitats should also be made public through popular and scientific articles.

6.5 Significance of this study

This study proved that elephants do not have a significant impact in the APNR, over the short term (2008 – 2010), on the nesting sites of avian fauna and despite the potential vulnerability of these trees to elephant impact, the survival rate of the nesting trees was very high. The impact found on the trees did not lead to the desertion of nesting sites by vultures, raptors and ground hornbills. Observations during the study showed that vultures did vacate some of the nesting sites, but this could not be linked to elephant impact and this necessitates further research to establish why vultures are vacating nesting sites.

Furthermore, this study suggests that elephant feeding habits do influence other species. Through primary branch breakage, elephants have the potential to create nesting cavities for SGH and other smaller bird species over the long term. Feeding habits such as bark stripping and branch breakage potentially also leads to the production of a food source, i.e. gum, for primates.

The objectives of this study were met by showing that vultures and raptors select for tall trees that ranged from 8.79 – 16.21 m with particular morphological characteristics. SGH are less selective and will utilize any tree given the internal diameter of the nesting cavity is 40 cm. The important landscape feature for vultures was artificial waterholes and for raptors roads were important. Most of the SGH nests were artificial and therefore locations were determined by researchers. The nests are spread randomly across the landscape within various plant communities, important landscape features for SGH could therefore not be determined.

6.6 Future research

This study was conducted over a three year period (2008 – 2010) and can therefore only show the impacts of elephants over the short term. The assessment of die-back on large trees needs to be refined over a longer period of at least five to six years. Further research is also needed to determine why vultures vacate nesting sites.

With regards to the production of gum, the potential facilitatory role was only considered for primates but use and dependence of insects (such as butterflies and ants) should also be quantified. A comparative study of impact type (elephant, buffalo, porcupine and insect attack) and quantity, diversity and palatability of gum produced, could represent interesting avenues of research in the future.

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