

POSTMORTEM ANIMAL SCAVENGING OF FORENSIC INTEREST

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0603779M

Original published work submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy

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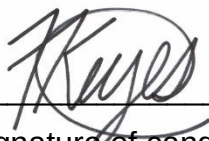
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Johannesburg, 2020

Declaration

I Craig Adam Keyes declare that this Thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

The results of this study include published work(s). The level of contribution by the student to the research and writing of the published work(s) and the input by the co-authors are indicated in [Appendix 8.2: Declaration - Student's contribution to article\(s\) and agreement of co-author\(s\)](#).



(Signature of candidate)

20th day of November 2020 in Edenvale

Dedicated to my parents:
Colleen L. and Trevor T. Keyes

Presentations arising from this study

Oral Presentations:

1. Keyes CA, Myburgh J, Brits D. (2019). Scavenging trauma on bone. 47th Annual Conference of the Anatomical Society of Southern Africa. Pilanesberg, South Africa
2. Keyes CA, Myburgh J, Brits D. (2020). Scavenging taphonomy in the rural Lowveld and Highveld of South Africa. 48th Annual Conference of the Anatomical Society of Southern Africa. Durban, South Africa – accepted for presentation
3. Keyes CA, Myburgh J, Brits D. (2020). Scavenging taphonomy in the rural Lowveld and Highveld of South Africa. World Anatomy Day Symposium - ASSA Highlights

Poster Presentations:

1. Keyes CA, Myburgh J, Brits D. (2020). Urban scavenging of skeletal remains by the slender mongoose (*Galerella sanguinea*) in Johannesburg, South Africa. 72nd American Academy of Forensic Science Annual Scientific Meeting, Humanitarian and Human Rights Resource Center Poster Session. Anaheim, USA
2. Keyes CA, Myburgh J, Brits D. (2020). Urban scavenging of skeletal remains by the slender mongoose (*Galerella sanguinea*) in Johannesburg, South Africa. 48th Annual Conference of the Anatomical Society of Southern Africa. Durban, South Africa – accepted for presentation
3. Keyes CA, Myburgh J, Brits D. (2020). Forensic analysis of scavenging animals' bite marks on bone in South Africa. Wits Faculty of Health Sciences Research Day. Johannesburg, South Africa
4. Keyes CA, Myburgh J, Brits D. (2020). Forensic implications of scavenging guilds in the Lowveld of South Africa Wits Faculty of Health Sciences Research Day. Johannesburg, South Africa

Publications arising from this study

Published/Accepted:

1. Keyes, C.A., Myburgh, J. and Brits, D. (2019). [Taphonomic bone trauma caused by Southern African scavengers](https://doi.org/10.1007/s00414-019-02154-6). International Journal of Legal Medicine, 134(3) pp.1227-38. (<https://doi.org/10.1007/s00414-019-02154-6>)
2. Keyes, C.A., Myburgh, J. and Brits, D. (2020). [Scavenger activity in a peri-urban agricultural setting in the Highveld of South Africa](https://doi.org/10.1007/s00414-020-02413-x). Submitted to International Journal of Legal Medicine (<https://doi.org/10.1007/s00414-020-02413-x>)

Submitted to a journal and under review:

3. Keyes, C.A., Myburgh, J. and Brits, D. (2020). [Vulture scavenging taphonomy in the rural Lowveld of South Africa](#). Submitted to Forensic Science International
4. Keyes, C.A., Myburgh, J. and Brits, D. (2020). [Urban scavenging by the slender mongoose \(*Galerella sanguinea*\) and hageda ibis \(*Bostrychia hagedash*\) in Johannesburg, South Africa](#). Submitted to Forensic Science International

Abstract

Human remains of forensic interest are often scavenged by animals in South Africa. Scavenger modifications of bones could be misinterpreted as tool marks or evidence of trauma caused by a weapon, i.e. sharp, blunt and projectile traumas. Understanding the species-specific and region-specific scattering patterns and behaviours of local scavenger guilds could assist in the holistic collection and forensic analysis of scattered remains. This study aimed to identify scavenging animals of forensic interest in South Africa and describe their scavenging behaviours, scattering patterns, and scavenging induced bone modification patterns.

Sparsely fleshed articulated bovine front and hind limbs, and ribs were fed to wild dog, spotted hyena, lion, leopard, black-backed jackal, caracal, and Cape porcupine at the National Zoological Gardens of South Africa. The surviving skeletal elements were collected after two days and their scavenging induced bone modifications were described. Thirty two pig carcasses (*Sus scrofa domesticus*) (40-80 kg) were also deployed in winter and summer periods in four different environments: a rural wildlife facility (Wits Rural Facility); an abandoned building complex in Braamfontein, Johannesburg; an urban veld (Frankenwald); and a peri-urban agricultural farm (Miertjie Le Roux Experimental Farm). Motion activated cameras recorded the animal scavenging activities. The scavenger species were identified and their behaviours were described. The scattering patterns were mapped and compared and their bone modification patterns on bone were described.

Felids, hyena, porcupine, and mongooses leave potentially distinct identifying bone modification patterns. Vultures (hooded, white-backed, and lappet-faced) dominated the rural scavenging guild, which included marabou stork, slender and banded mongoose, genet, civet, warthog and honey badger. Vultures scavenged after 18-28 hours, skeletonised carcasses between 5 - 98 minutes, and scattered remains up to 7.09m. Slender mongooses were the only scavengers in the urban veld and scattered remains up to 10.5 meters. In the urban city centre, hadeda ibis scavenged on carrion intestines and created multiple, large holes in the skin and removed the lips to access colonising insects. Black-backed jackals dominated the peri-urban scavenger guild, which included

mongooses (slender, yellow, and water mongoose), Cape porcupine, and honey badgers. Jackals scattered remains up to 73.7 m.

The results of this study will assist forensic investigators to discern non-human animal scavenging patterns, effectively locate scattered remains, and assist in reconstructing postmortem scavenging events in various South African environments.

Acknowledgments

I wish to acknowledge financial assistance of the National Institute of Justice and the Forensic Technology Center of Excellence along with the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre.

I am very grateful to GHB Farms and Mr. Dries Du Plessis for providing the pig carcasses for this study. Also acknowledged are the various research sites and their staff: the National Zoological Gardens of South Africa and their staff - Mr Nathaniel Taweni, Dr Ian Espie, and Ms Tracy Rehse; the Wits Rural Facility and their staff: Prof. Wayne Twine and Mr. Cameron Watt; the University of Pretoria and Prof Prashilla Soma for access to the Forensic Anthropology Body Farm on the Mierjie Le Roux Experimental Farm and their staff: Mr. Roelf Cortze and Prof Edward Webb; the Wits Frankenwald research site and their staff: Mr Taffy Adler, Ms Naledi Mathabathe, and the security staff; and the Johannesburg Forensic Pathology Services, Gauteng Health Department, and Forensic Medical Services and their staff - Dr Bridget Ikalafeng and Dr Mosou Paul Morule.

I wish to acknowledge the assistance of Mr. Richard Keyes, Ms. Allison Gilbert, Ms. Deniel Lessing, Mr. Artem Markov, Mr. Ivan Coertze, Ms Tracy Reindorp, and Ms. Rethabile Masiu for their assistance in the search for scattered remains. Ms. Rethabile is also thanked for her assistance with the maceration of the bones and Ms. Tracy Reindorp who took the photographs of the scavenger modifications in bone. Thanks is also extended to Ms Trisha-Jean Mahon for her assistance in the feeding of the animals at the NZG.

I am particularly grateful to my supervisors, Prof Desiré Brits and Dr Jolandie Myburgh, for their invaluable supervision, support and motivation.

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Chapter 1: Introduction

Postmortem human remains under forensic investigation are often scavenged by animals before the remains can be recovered for medico-legal investigation. The damage caused by scavenging animals to the soft tissues and skeletal remains could potentially be misinterpreted by forensic specialists (Rothschild & Schneider, 1997; Young *et al.*, 2014a; Young *et al.*, 2015b). Forensic specialists need to competently discriminate between damage caused by scavenging animals, trauma caused by a human perpetrator, and other taphonomic alterations. Identifying a scavenger by the damage it creates to postmortem remains has the potential to assist forensic specialists in the recovery of scattered remains and the reconstruction of postmortem events (Young *et al.*, 2015b).

1.1 What is scavenging?

The transfer of energy from one trophic level to another is a fundamental ecological process, commonly resulting from one organism consuming another organism. This is generally achieved through the process of predation (Inger *et al.*, 2016). Predation is the act of hunting and killing prey for the purpose of feeding. This same energy transfer can be achieved through scavenging, which is the act of opportunistically consuming the carcasses of animals which have died due to reasons other than predation (Inger *et al.*, 2016).

Scavenging is sometimes favoured over predation by some species (Foltan *et al.*, 2005). Scavenging is favourable because fresh carrion is a rich dietary resource that is equal in value to prey that is acquired through predation (DeVault *et al.*, 2003; Foltan *et al.*, 2005). Additionally, the energy expenditure and the associated risks of scavenging are much lower than in predation (DeVault *et al.*, 2003; Foltan *et al.*, 2005). Scavengers do expend energy in the risky behaviour of scavenging from a carcass that is actively being fed upon by a predator; however, the process of locating a carcass uses less energy than hunting prey and defending the carcass.

Scavenging animals remove carcasses, which have the potential to harbour and spread contagions, from an environment. Carcasses that remain unscavenged have the potential to host dangerous putrefactive bacteria and pathogens that could be fatal to humans, livestock, and wildlife (Reed & Rocke, 1992; Ortiz & Smith, 1994; Monroe *et al.*, 2015; Inger *et al.*, 2016). The role of urban scavengers is an understudied phenomenon compared to wild scavenging, regardless of the benefits they play in the crucial roles of nutrient recycling,

carcass removal, and their benefits to the sanitation of an urban environment (Inger *et al.*, 2016).

Scavengers can be classified as either obligates or facultates. Obligative scavengers rely entirely on carrion for their diet. Vultures (Accipitridae and Cathartidae) are the only obligate terrestrial vertebrate scavengers (Inger *et al.*, 2016). Facultative scavengers do not rely solely on scavenging for food but will opportunistically consume carrion when it is available in addition to their usual predatory hunting. Facultative scavenging is widespread throughout the phylogenetic tree and is geographically dispersed globally (Foltan *et al.*, 2005).

1.2 The effects on carrion on scavenging networks

The unique collective group of scavenger species in an environment (termed a scavenger guild) plays an important role in the environment's food web (Moleón *et al.*, 2015). Carrion has numerous effect on an environment through both direct and indirect interactions with the food web and the transfer of energy within an environment (Moleón *et al.*, 2014).

Scientific knowledge on the direct and indirect influence of a carcass on the behaviours of scavenging animals is limited (Moleón *et al.*, 2015). There are a number of variables that have been suggested to influence carrion-scavenger interactions. Some of these variables depend on the scavenger, which may include the size of the scavenger, their circadian behaviour (nocturnal, diurnal, etc.), and the social behaviour of the species. Certain features of the carcass itself may also have an influence; including the cause of death, stage of decomposition, and the duration of decay. A number of extrinsic variables may also have an influence on carrion-scavenger interactions, such as the level of competition for food, climactic events, and micro-environment influences (DeVault & Rhodes, 2002; DeVault *et al.*, 2003; Kendall *et al.*, 2012; Olson *et al.*, 2012; Moleón *et al.*, 2014).

Carcass size is considered to play a particularly significant role in the interaction between a carcass and a scavenger. The interaction between a predator and prey, or scavenger and carcass, within a food web, is strongly associated with the strength of the feeding animal in relation to the size of the prey. Prey size has been the topic of numerous studies in the field of predation ecology. Unfortunately, carcass size has been severely under-researched in scavenging ecology (Moleón *et al.*, 2015). A study by Sebastián-González *et al.* (2013) suggested that large carcasses promote inter-species competition within a scavenger guild which results in organised or nested scavenging networks. A scavenging network relates to

the species richness attracted to a single carcass (i.e. the scavenger guild). A nested network relates to how competitive scavengers within the same guild will organise themselves so that they can feed on the same carcass (Moleón *et al.*, 2015).

Larger carcasses have been observed to result in a larger scavenger species richness and a resulting increased carcass consumption period (Sebastián-González *et al.*, 2013; Moleón *et al.*, 2015). However, larger carcasses also tend to experience a delay in detection time and the percentage of biomass consumption by scavengers. DeVault *et al.* (2004) suggested that larger carcasses attract a larger scavenger species richness because they are more noticeable.

Dominant scavengers within a guild are often larger in size than other scavengers within a local guild. This allows them to be more competitive when confronted with other smaller species competing for the same carcass. Their size is not the only factor, but hunger and species specific behaviour also impacts their dominance within a guild (Inagaki *et al.*, 2020). The inter-specific nested behaviours of animals within a guild can occur in a predictable manner; however, the removal of a dominant scavenger will impact and change the typical nested network behaviours (Moleón *et al.*, 2015). For example, if a hyena is removed from an environment, the scavenger guild will reorganise their nested scavenging network behaviours, due to competition within the guild. This will impact the overall rate of carrion consumption. This change is variable as it relies on the species richness within each guild.

Another variable that impacts the scavenging network structure within a food web is seasonal changes in climate. Most terrestrial scavengers are facultative (i.e. opportunistic carnivores that also hunt prey). Facultative scavenging behaviour alternates between hunting and scavenging depending on the opportunities availed to them. The availability of live prey or carrion relies heavily on seasonal shifts in the availability of water and food. Dry season may assist scavengers in the detection of carcasses due to lower foliage and vegetation cover (Moleón *et al.*, 2015). These numerous interactions between scavengers and carcasses need to be better understood. The great variety in species richness, globally and locally, in different environments, necessitates further study. It is important to understand how carcasses are used by scavenging animals, as this has wide sweeping wide consequences for biodiversity conservation and human-animal interactions (Moleón *et al.*, 2015).

1.3 How does scavenging impact forensic investigations?

Despite the useful role scavenging animals play in the hygiene of an environment, their behaviour could also be counterproductive to forensic investigations. The scavenging of deceased human remains can negatively impact the postmortem medicolegal investigation into the circumstances around death, the post-mortem interval and the identity of a deceased individual. The postmortem modification of human remains by scavengers can obscure traumatic injuries, create postmortem injuries, and result in the disarticulation and scattering of the remains. Due to the scattering of remains, some elements are not recovered which limits a forensic investigation and the forensic analysis of recovered remains. These can all lead to the misinterpretation of evidence by forensic specialists (Rothschild & Schneider, 1997; Young *et al.*, 2014a; Young *et al.*, 2015b). For the competent analysis of postmortem injuries caused by animals, a forensic specialist should be able to discriminate between damage and trauma inflicted by an animal and that by a human perpetrator.

A critical part of taphonomic studies is the description and analysis of the effects of scavenging on the processes of disarticulation and scattering of skeletonised remains (Cameron & Oxenham, 2012; Spies *et al.*, 2018a). A number of taphonomic variables contribute to the disarticulation and scattering of postmortem remains (such as decomposition, climatic events, and terrain), but research has shown that vertebrate scavengers have the largest impact on the disarticulation and scattering of remains, and they substantially alter the decomposition rate (Spies *et al.*, 2018a). For example, the patterns of scattered remains have been used in the past to assist in the estimation of the postmortem interval (Spies *et al.*, 2018a). An understanding of scattering in a particular environment cannot be used in isolation to estimate PMI but it should be a factor that is considered (Cameron & Oxenham, 2012).

The ability to identify a scavenger by the evidence it leaves at a scene could also assist in the implementation of more reliable search methods and locating scattered remains and evidence (Young *et al.*, 2015b). Additionally, an understanding of the behaviours of different scavenger species and the variables which affect their behaviour can contribute to a more holistic and effective postmortem forensic investigation (Young *et al.*, 2014a; Young *et al.*, 2015b).

There are no international standardised protocols for the search and recovery of scattered human remains due to the scavenging activities of animals. The difficulty of locating scattered remains was highlighted in a study by Young *et al.* (Young *et al.*, 2014b). Their survey indicated that 53% of police specialists (n=90) had been involved in a search for scattered scavenged human remains (Young *et al.*, 2014b). Most investigators (80.83%) were often unable to recover the entire set of human skeletal remains - even when assisted in the search by a cadaver dog (Young *et al.*, 2014b). When investigators were educated on animal scavenging and scattering patterns, there was an increased success rate in the holistic recovery of scattered remains, and investigators were twice more likely to recover skeletal remains (Young *et al.*, 2016). Regional research needs to be performed because forensic investigators need to be aware of the scavenging animals that are active in their own regions, and the behaviours of these animals need to be studied because it is species specific (Reeves, 2009).

Animal scavenging of forensic human remains is of particular interest in South Africa. In South Africa, many bodies are recovered from velds (large open areas of grassland in urbanised locations) which house various animal species. For example, the Johannesburg Forensic Pathology Services (JHB FPS) Medico-legal Laboratory carries out medico-legal postmortem investigations, including autopsies, of all unnatural deaths. This facility receives an annual average of ± 3500 cases. In the year 2010 a total of 4876 medico-legal autopsies were conducted by the JHB FPS – of which 109 were received in various stages of decomposition (Keyes *et al.*, 2016). Scavenging on the soft tissues was evident in many of these cases. The Southern Cluster of the Gauteng Forensic Pathology Services (a collection of eight medico-legal mortuaries) collaborates with the Human Variation and Identification Research Unit (HVIRU) of the School of Anatomical Sciences, University of the Witwatersrand, to perform the forensic anthropological analysis of the skeletonised remains received by the Southern Cluster mortuaries in addition to national cases referred by the Victim Identification Centre of the South African Police Services. Between the years of 2007 – 2017 a total of 187 skeletal cases were received by the mortuaries, of which 103 were referred to the HVIRU for anthropological analysis. These skeletal remains are often incomplete (either due to scattering and/or incomplete retrieval by police officers) and often exhibit taphonomic alterations such bone modifications due to animal scavenging. Despite the large number of decomposed and skeletonised human remains of a forensic nature in

Johannesburg, limited research on decomposition and taphonomic variables have been published (Keyes *et al.*, 2016; Keyes, 2019).

Furthermore, there is limited published research of a forensic nature on species-specific and region-specific scavenging of forensically-important remains (Young *et al.*, 2014a). The few studies of this nature that have been published are mostly anecdotal case studies, such as those presented by (Haglund & Sorg, 1997). The few empirical studies that have been published have mostly been performed in North America and Europe on species such as coyotes, vultures, and wolves (Morton & Lord, 2006; Young *et al.*, 2014a). These studies were performed in isolated, rural areas and there is a paucity of urban studies. The few studies that have been done in South Africa have only been performed in Cape Town on Cape grey mongoose scavenging and their results may not be applicable to other regions and animal species in the country (Spies *et al.*, 2018a; Spies *et al.*, 2018b). There is a necessity for further research on species-specific and region-specific scavenging behaviour, from a forensic perspective, especially in Africa. South African forensic specialists have limited reliable and applicable publications to refer to when faced with a case which exhibits evidence of scavenger activity. More applicable research needs to be performed to identify forensically-important scavengers, their behaviour, the damage they cause, and their scattering patterns, in South Africa.

Chapter 2: Literature review

Scavenging animals are found globally. The distribution of unique scavenger species are often geographically isolated and their scavenging behaviours are species specific. Since they occupy habitats in conjunction with human populations, there are often interactions between them (Fuller *et al.*, 2009; Inger *et al.*, 2016). This results in animals often scavenging upon human remains which impacts forensic investigations (O'Brien *et al.*, 2017; Spies *et al.*, 2018b). It is paramount that forensic specialists understand the species, habitats, and behaviours of scavenging animals. The impact of scavenging on forensic investigations must be understood to allow for a holistic postmortem reconstruction of events.

2.1 Interactions between scavenging animals and humans

Humans and scavengers have been interdependent for millennia (Moleon *et al.*, 2014). It is likely that early humans not only scavenged a significant proportion of their diet but were also competitive with other scavengers (O'Connell *et al.*, 1988). The role scavengers played in relation to humans, developed over time to become more regulatory than competitive, through the removal of carrion, thus, playing a sanitation role in the removal of the pathogens associated with carrion (Markandya *et al.*, 2008; Ogada *et al.*, 2012b).

Despite rapid urbanisation resulting in humans living in highly altered environments, there remains significant wildlife populations in these spaces (Fuller *et al.*, 2009; Inger *et al.*, 2016). The abundance and availability of human organic waste determines the carrying capacity for wildlife populations in anthropogenic environments (Yirga *et al.*, 2012). Rural areas that are inhabited by humans also provide anthropogenic waste which attracts carnivorous species (Yirga *et al.*, 2016). The cultivation of agricultural regions through horticulture has had an effect on the rate of scavenging leading to increased scavenging rates compared to pristine habitats that have not been altered by anthropogenic intervention (Inger *et al.*, 2016). The reason for the greater scavenger densities and scavenging rates in anthropogenic environments is easier access during foraging than in other habitats (Beckmann & Berger, 2003).

The larger density of animals near human habitations is a global phenomenon. In North America black bear (*Ursus americanus*) populations have been reported to be three times larger in human inhabited areas than natural areas. Coyote populations (*Canis latrans*) are similarly larger in human inhabited areas than natural environments (Fedriani *et al.*, 2001;

Beckmann & Berger, 2003; Riley *et al.*, 2003; Bino *et al.*, 2010). Northern Israel hosts larger populations of red foxes (*Vulpes vulpes*) in urban areas that are 15 times higher than in pristine environments (Fedriani *et al.*, 2001; Beckmann & Berger, 2003; Riley *et al.*, 2003; Bino *et al.*, 2010). Urban rubbish dumps in these regions have significantly increased the concentration of animal species including red foxes, raccoons (*Procyon lotor*), bears, cats (*Felis catus*) and Eurasian badgers (*Meles meles*) (Wilkinson & Smith, 2001; Yom-Tov, 2003; Bateman & Fleming, 2012; Yirga *et al.*, 2016). Ethiopia is exemplary of this where spotted hyena (*Crocuta crocuta*) abundance is 15 times higher in regions that are inhabited by humans than other natural locations (Abay *et al.*, 2011; Yirga *et al.*, 2014), as are populations of the African golden wolf (*Canis anthus*) (Yirga *et al.*, 2017).

Although there has been a rapid increase in conservation efforts in Africa by isolating animals within government protected areas, such as national parks, wild animals and humans still live in a relatively close proximity to each other and interact (Abay *et al.*, 2011; Schuette *et al.*, 2013). In Kenya, it is estimated that up to 65% of the lion population is supported in the arid rangelands and these regions continue to be unprotected by the government (i.e. are not fenced off as a national conservation park) (Chardonnet, 2002). Animal attacks on humans are still a common occurrence in South Africa. These often involve individuals who have illegally entered game reserves by climbing over fences, tourists who disregard warning signs and leave the safety of their camping grounds or vehicles, and poachers. The skeletal remains of humans are occasionally recovered in such sites. One such example is that of a victim who was thrown into a lion enclosure by perpetrators at a South African game park and the skeletal remains had to be recovered for forensic investigation (Blau, 2016).

Scavengers play an important role in anthropogenic environments due to their general efficiency of carrion removal in such environments (Kjorlien *et al.*, 2009), yet these animals have received little attention by researchers (Inger *et al.*, 2016). The general public tends to have unfavorable views of scavenger species (Inger *et al.*, 2016). Studies in the UK have indicated that the bird species most disliked and killed by the public actually play an important urban role in the removal carrion (Cox & Gaston, 2015; Inger *et al.*, 2016). There is an ongoing global shift in the perception of scavengers in the public eye as some species are becoming viewed more favorably as charismatic species (animals with symbolic value and general public appeal such as eagles and hawks) resulting in them becoming the focus of targeted conservation projects (Moleón *et al.*, 2014). An increased understanding of the

important role scavengers play in urban ecosystems and their role in promoting the well-being of the public could lead to a greater appreciation and protection of these species (Inger *et al.*, 2016).

The scavenging of carrion is not isolated to the carcasses of animals. The remains of deceased humans are often scavenged too, as is attested to by the rarity of human remains being found intact during forensic investigations (Kjorlien *et al.*, 2009). The scavenging of human remains are not only by wild animals; domesticated pets (particularly dogs) have also been recorded to have scavenged upon the remains of their deceased owners in instances where they were locked indoors with the body of their own. They have even scavenged on their owners even when alternative food sources were available (Tsokos & Schulz, 1999; Chute & Bready, 2017).

Since scavenging species can vary by geographic area, regional studies are important to allow for the accurate postmortem reconstruction of forensic cases (O'Brien *et al.*, 2017; Spies *et al.*, 2018b). South Africa is environmentally diverse with numerous unique habitats – all of which need taphonomic studies. The high homicide rate and the large number of deceased missing and unidentified individuals in South Africa compounds the need for more research (Spies *et al.*, 2018b). South Africa reported 32 622 incidents of murder in the year 2018, of which 6 978 were in the Gauteng province (StatsSA, 2019). The bodies of many of these victims are disposed of in remote locations with their remains often recovered in a state of decomposition and /or scavenged upon by animals.

2.2 Globally identified scavenger animals of forensic interest

As with all taphonomic variables, regional studies are required for the forensic application of scavenging research (O'Brien *et al.*, 2017; Spies *et al.*, 2018a). The scavenging animals present in a region are unique and their behaviours are specific to local environments (O'Brien *et al.*, 2010). Their behaviour is strongly affected by climatological and environmental factors, including the availability of resources, inter-species competition, and the diet of a particular scavenging animal (O'Brien *et al.*, 2010; Cameron & Oxenham, 2012).

A variety of scavenging animals are considered to be of forensic importance in North America including wolves (*Canis lupus*), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), opossums (*Didelphis marsupialis*), rodents, foxes (*Vulpes vulpes*), striped skunks (*Mephitis mephitis*), crows (*Corvus brachyrhynchos*), and a variety of vultures (*Cathartidae*) such as

the turkey vulture (*C. aura*) (Morton & Lord, 2006; Young *et al.*, 2014a). Carrion crows, Eurasian magpies, and European red foxes are common urban scavengers in the UK and Europe (Inger *et al.*, 2016). In Australia facultative avian scavengers consume most carrion (Huijbers *et al.*, 2013), in addition to the Australian raven (*Corvus coronoides*), Chuditch (*Dasyurus geoffroii*), and red fox (O'Brien *et al.*, 2017). In Africa and Asia, large felids such as lions (*Panthera leo*), leopards (*Panthera pardus*), cougars (*Felis concolor*), and tigers (*Panthera tigris*) have been recorded occasionally scavenging on human remains (Pickering & Carlson, 2004). Vultures are the scavengers which are most often discussed in forensic studies (Young *et al.*, 2014a). Vultures are found globally and are widespread expanding over five continents (Ogada *et al.*, 2012a; Ogada *et al.*, 2012b; DeVault *et al.*, 2016). South African research on scavenging in a forensic context is limited. Published research has been performed in Cape Town which highlighted the Cape mongoose and yellow mongoose to be of particular interest in the Western Cape (Spies *et al.*, 2018a; Spies *et al.*, 2018b; Spies *et al.*, 2020).

Carnivores are not the only animals which scavenge on carrion. Taphonomic and zooarcheological literature has well established the consumption and modification of nonhuman animal bones by herbivorous ungulates (large mammals with hooves) in a process termed 'osteophagia' (Sutcliffe, 1973; Brothwell, 1976; Sutcliffe, 1977; Johnson & Haynes, 1985; Keating, 1990; Kierdorf, 1993; Kierdorf, 1994; Cáceres *et al.*, 2011; Cáceres *et al.*, 2013; Hutson *et al.*, 2013). Osteophagia is prompted by a phosphorous deficiency in an herbivorous animal resulting from a nutritional dysfunction and supplements such as calcium, sodium, and other minerals that are low or missing from their diet particularly in periods of low food availability (Meckel *et al.*, 2018). Osteophagia is common in a variety of deer species, caribou/reindeer (*Rangifer tarandus*), elk (*Cervus Canadensis*), bighorn sheep (*Ovis Canadensis*), sheep (*Ovis aries*), camel (*Camelus dromedaries*), giraffe (*Giraffa Camelopardalis*), sable (*Hippotragus niger*), gemsbok (*Oryx gazelle*), kudu (*Tragelaphus strepsiceros*), wildebeest (*Connochaetes spp.*), cattle (*Bos taurus*), and pigs (*Sus scrofa*) (Hutson *et al.*, 2013). Most documented accounts of osteophagia focus on the interpretation of scavenging in archaeological animal bone (Meckel *et al.*, 2018). Despite forensic anthropologist and taphonomists being aware of carnivores consuming human bones, the osteophagia of human bones by herbivores is less widely recognised (Meckel *et al.*, 2018).

2.3 Body region preferences by scavengers

Different species have unique preferences for body regions and decomposition stages, as such the location of trauma on skeletal remains and the state of the bones can be indicative of the species of the offending scavenger. Pickering and Carlson (2004) found that the skeletal elements most likely to be recovered after leopard feeding, as they are not consumed in their entirety, are the C1 and C2 vertebrae, scapulae, os coxae and long bones of the limbs. A number of other skeletal elements may be recovered in the scat including fragments of thoracic and lumbar vertebrae, clavicles, patellae, and the bones of the hands and feet (Pickering & Carlson, 2004). Dogs commonly bite the head and neck of decedents (Chute & Bready, 2017). Scavenging modifications caused by rodents are common on skeletal remains that are dry and weathered (Toledo *et al.*, 2017) – thus, the timing of skeletal trauma can be assessed. A consideration of the feeding habits of different species assists in the correct evaluation of trauma on surviving bones or understanding why some cases may present with the complete absence of skeletal elements after consumption. For example, leopards have been observed to consume the limbs of baboons beginning at the distal ends of the limbs by disarticulating the fingers and toes at the articulation of the proximal phalanges and swallowing the articulated digits whole (Pickering & Carlson, 2004). In contrast, leopard feeding upon the clavicles and ribs is far more destructive due to stronger ligament connections (Pickering & Carlson, 2004). Understanding the feeding habits of scavenging animals could assist in identifying the animal and result in effective search efforts for skeletal remains and highlight where to search for specific skeletal elements and which elements are unlikely to be recovered.

2.4 Scavenging behaviours

Various species of scavenging animals often inhabit the same habitat and are termed a guild – defined as groups of species which exploit the same resources or different resources in similar ways (Simberloff & Dayan, 1991). The behaviour of different species within a guild is variable. Knowledge of how scavengers behave and when they are active can assist in the reconstruction and timing of post-mortem events.

Competition within scavenging guilds is common, particularly between avian species, such as vultures, and mammalian scavengers. Vultures often monopolise carrion over mammals because flying enables them to cover larger areas than mammals and often detecting carrion sooner (Houston, 1979; Ruxton & Houston, 2004). When environmental and weather

conditions are favourable, carcasses can be completely skeletonised by vulture scavenging in less than 12 hours (Reeves, 2009). In other environments, mammals dominate carrion consumption over vultures. In forested habitats Old World vultures (those in Africa, Asia and Europe) have a reduced ability to detect carrion visually, and mammals are often more successful in these regions (Ogada *et al.*, 2012a; Turner *et al.*, 2017). Additionally, nocturnal mammals are more successful at depleting carcasses during the night when avian scavengers are not active (Prior & Weatherhead, 1991; DeVault & Rhodes, 2002; Ogada *et al.*, 2012a). In some habitats, mammalian scavengers are able to deter vultures through their sheer abundance, allowing them to consume most of the carrion (Prior & Weatherhead, 1991; DeVault *et al.*, 2011). Alternatively animals can refer to brute force as has been observed in domestic dogs who have used physical dominance to exclude vultures from carcasses (Butler & Du Toit, 2002). Research in Africa (Ogada *et al.*, 2012a) has demonstrated that when vultures are excluded from carcasses the number of individual mammals scavenging at a carcass increases, including the time spent scavenging at a carcasses. Regional differences are pronounced as research in Spain has described how areas without vultures results in ungulate carcasses remaining unscavenged for longer (Morales-Reyes *et al.*, 2017). In contrast to Africa, American studies have shown that the absence of competition from vultures does not alter the scavenging frequency and non-avian species richness. This difference may be influenced by seasonal differences and the availability of carrion and other resources (Jędrzejewski & Jędrzejewska, 1992; Read & Wilson, 2004). Alterations in the mammalian scavenging guilds also results in changes in competing species' abundancy and activity. When a dominant scavenger is removed from a guild, the abundance and activity levels of competing scavengers increases. Despite this, the rate of carcass removal is slower and less effective, thus, highlighting the role of dominant scavengers in a guild. This has been highlighted in studies on raccoon scavenging (DeVault *et al.*, 2011; Olson *et al.*, 2012).

Due to interspecies competition and a species' preference for body regions and decomposition stages, animals could scavenge in a potentially predictable sequence. This could hypothetically lead to the sequencing of injuries caused by different scavenger species which will contribute to a postmortem interval estimation. Young *et al.* (2014a) observed, in their European study, that there was never more than one scavenging species feeding on a

carcass at one time and never more than two individual animals of the same species scavenging a carcass at one time.

Another scavenging behaviour that reduces the competition between species is the time of day they are active. Scavenging animals tend to restrict their activity to either the daylight hours (diurnal) or night time hours (nocturnal) (18). There are geographical differences in the activity of scavengers. For example, in Australia, 88% of all scavenging by mammals occurs during the night (nocturnal) due to the heat during the day (Huijbers *et al.*, 2013). Canada, by contrast, does not experience heat loading which results in scavengers being active diurnally and nocturnally (O'Brien *et al.*, 2017). Although multiple species restrict their scavenging to nocturnal or diurnal periods, these animals do not intermingle with other species that have the same diurnal/nocturnal predilection. There is still competition and sequencing between the species; therefore, each species is active at different periods during the diurnal/nocturnal periods (18).

The interaction between vertebrate species is not the only influence that determines when each species scavenges. Morton and Lord (2006) observed that arthropod presence on a carcass influences when scavengers will feed on a carcass. They observed that the presence of arthropods on a carcass inhibits vertebrate scavenging (Morton & Lord, 2006). Scavenger activity was observed before arthropod colonisation and after arthropod migration away from a carcass. However, this behaviour may be species specific as Young *et al.* (2014a) observed crow scavenging at all stages of decomposition regardless of the presence or absence of arthropods. Just as arthropod succession is useful in the establishing of a postmortem interval, it is possible that scavenger succession may also be a useful variable to also take into consideration.

The scavenging of carcasses can also be influenced by the nature of the carcass itself. The size of a carcass contributes to the biodiversity of a scavenging guild. Larger carrion often prompts the assembly of a greater richness of scavengers and this seems to facilitate the removal of carcasses more rapidly (Moleón *et al.*, 2015; Turner *et al.*, 2017). The species of the carcass has also shown to influence which scavengers feed and in what order. For example, the species of carcass has shown to influence which animal (mammal, bird, or invertebrate) first opens a carcass by piercing the skin (Olson *et al.*, 2016). For example, rabbit carcasses are more likely to be opened by mammalian scavengers whereas opossum

carcasses are more likely to be opened by birds and invertebrates (Olson *et al.*, 2016). There are also differences in the scavenging of herbivore carcasses and carnivore carcasses. There is no significant differences in the number of scavenger species visiting herbivore and carnivore carcasses and the time to carcass detection is similar (Moleón *et al.*, 2017). However, the mean number of species which feed on herbivore carcasses and the amount of biomass consumed is substantially higher than that of a carnivore carcass (Moleón *et al.*, 2017). The reason for the difference is attributed to an evolutionary adaptation to avoid exposure to parasitism in carnivores (Moleón *et al.*, 2017). That is not to say that carnivore carcasses are not scavenged upon. The consumption of carnivores by other carnivores has also been documented (Moleón *et al.*, 2017) but cannibalism is rare (Moleón *et al.*, 2017).

Abiotic variables also influence the behaviour of scavengers, especially seasonal changes (Olson *et al.*, 2016). In guilds where species do not seasonally migrate, the season does not affect the species that are active but rather the timing of their activity. Colder seasons have shown to have a delayed effect on the onset of scavenging (Olson *et al.*, 2016). The reason for this is that many scavengers rely on their olfactory senses (smell) to detect decomposing carrion. Volatile compounds that are released by decaying tissue, due to putrefactive microbial action, attract invertebrates and vertebrate scavengers and the release of these compounds are dependent on temperature (Tomberlin *et al.*, 2011). Cooler temperatures result in slower rates of decomposition and a delay in the release of volatile compounds, while the opposite applies to warmer temperatures.

2.5 Scattering patterns

It is of forensic importance to understand the scattering patterns of scavengers (Spies *et al.*, 2018a; Spies *et al.*, 2018b). Understanding the scattering pattern by scavengers can assist in the estimation of a PMI and the more thorough collection of remains for analysis (Spies *et al.*, 2018a; Spies *et al.*, 2018b). The scattering of skeletal elements may also cause some damage to these elements. For example, cranial sutures often split when animals move the cranium from a depositional site (Calce & Rogers, 2007). An understanding of damage caused by animals helps forensic investigators to differentiate between scavenging damage and trauma caused by human perpetrators.

As scavengers feed on a carcass the bones are often disarticulated and moved from the original area of deposition. For example, crania are often removed and buried elsewhere as

a form of food storage by raccoons and coyotes (Calce & Rogers, 2007). The disarticulation and scattering of skeletal elements has shown to extend over a large area (Reeves, 2009). The pattern of scattering of elements from their original site of deposition has been shown to be specific to different scavenging animals (Reeves, 2009).

Small scavengers, such as Cape grey mongoose, tend to scatter remains over a relatively small area (Spies *et al.*, 2018a). It has been suggested that the size of a scavenger could account for the distance of scattering. Small mammals, such as mongooses, appear to have a level of predictable directionality in their scattering. For example, the Cape grey mongoose scatters remains in two general directions, typically towards their dens (Spies *et al.*, 2018a). Small or medium sized mammals will also scatter remains towards areas that are protected by high and thick vegetation (Young *et al.*, 2015a). Scavengers will also follow well-established game trails, so scattered remains will likely be scattered along such game trails (Haglund, 1997a; Kjørlien *et al.*, 2009). An understanding of these scattering behaviours in small mammals could assist forensic specialists in the recovery of remains if they can locate the dens of scavengers, areas with foliage or shrubbery, and follow game trails.

Conversely, large avian scavengers, such as vultures, scatter remains over a larger distance than small mammals. One such species that has been studied is the American black vulture, which scatters remains over an area of 83.6m²/899.86ft² (Spradley *et al.*, 2012). Recent studies have indicated that vultures will also revisit skeletonised remains over a long-term period and scatter the remains even further (Miranker *et al.*, 2020).

When forensic specialists search for scattered remains, they tend to use a well-established search method used in anthropology and archeology. This method is called the walk-the-line method, in a grid pattern. This entails a number of individuals, who stand one meter apart from each other, and they walk in a straight line - flagging scattered elements as they are discovered. This method is effective but time-consuming. If the scattering pattern of scavenged remains is known, a more effective and time efficient search method could potentially be devised.

2.6 Animal scavenger modifications to bone

Being able to identify an animal species by the scavenging modifications it leaves on bone is valuable information. A forensic anthropologist's role is to analyse the bone injuries and differentiate between the modifications caused by animals and the perimortem trauma

inflicted by a human perpetrator. Inexperienced individuals can confuse these scavenging modifications with blunt, sharp, or ballistic trauma. A greater understanding of different animal scavenging modifications patterns will result in the easier discerning of evidence of trauma caused by a weapon and other traumas.

Tooth marks on bone can be divided into four categories: pits, furrows, punctures, and scores (Binford, 2014; Young *et al.*, 2015b). Pits are superficial indentations caused by individual tooth cusps that do not penetrate the cortical layer of bone. Punctures are caused by canine and carnassial teeth piercing the cortical bone into the underlying trabecular bone resulting in an irregular puncture. Avian beaks can also form conical punctures on the surfaces of bones, often resulting from their pecking motion when eating soft tissues (Komar & Beattie, 1998). Furrows are longitudinal gouges commonly located in the epiphyses, resulting from the premolars and molars gnawing into trabecular bone in an attempt to gain access to the bone marrow. Scores are scratches along the cortical bone and their length is greater than their breadth (Haynes, 1983). Scores are created when a tooth creates a pit and then slides along the bone surface (Young *et al.*, 2015b). Scores are isolated to the superficial layer of cortical bone whereas furrows penetrate deep into the trabecular bone. Rodent gnaw marks are classic examples of a series of scores on the superficial surfaces of bones, often forming parallel striations with uneven margins (Young *et al.*, 2015b). The general size of pits, punctures, furrows, and scores have been suggested to indicate the relative size of the animal (Young *et al.*, 2015b) but the particular carnivore taxon cannot be accurately identified through tooth mark measurements (Coard, 2007). The extent of the scavenging modifications on bone depends on the relative strength of the bone to the tooth morphology and jaw mechanics of the scavenging animal (Calce & Rogers, 2007).

The claws and talons of animals can also create markings on bone and are often found in conjunction with scavenging modifications when the animal attempts to grasp the bone (Calce & Rogers, 2007). Claw marks appear similar to tooth scores, however, those made by claws have a thinner diameter than tooth scores and are often in parallel rows (Calce & Rogers, 2007).

In cases of ungulate osteophagia, distinct modifications are observed in the epiphyseal ends of bone and are often described as 'forked' in nature. Forking of the bone is often accompanied by superficial striations, or grooves, perpendicular to the shaft, and adjacent

to the forked end (Meckel *et al.*, 2018). Forking usually occurs in the advanced stages of osteophagia after an ungulate has scavenged on the same bone numerous times (Cáceres *et al.*, 2011), however, forking has been observed in human skeletal remains after the first osteophagic event (Meckel *et al.*, 2018). In early stages of osteophagia scavenging the effects of ungulate gnawing can be mistaken for scavenging modifications caused by carnivores or rodents (Sutcliffe, 1973; Brothwell, 1976; Sutcliffe, 1977; Kierdorf, 1993; Kierdorf, 1994; Cáceres *et al.*, 2011). Ungulate scavenging can be differentiated in later stages (Meckel *et al.*, 2018). Ungulates tend to scavenge dry bones that can be manipulated easily such as ribs and long bones that have a rectangular cross section such as the tibia (Meckel *et al.*, 2018). Typical features of ungulate scavenging are superficial stripped marks in weathered cortical bone along the long bone's shaft and the forked pattern of the epiphyseal end of a bone (Meckel *et al.*, 2018). This is in contrast to the pits and punctures that extend into the trabecular bone in the epiphyses of long bones as seen in carnivores (Cáceres *et al.*, 2011; Meckel *et al.*, 2018) and the deeper cortical scores that are perpendicular to the long axis seen in rodent scavenging (Haglund, 1992).

2.7 Multi-disciplinary implications

Understanding the effects of scavenger modification of bone in a forensic setting can be applied to other scientific fields including palaeontology, anthropology, and archaeology. Modern samples have often been the source used to understand paleobiological fossil remains (Weigelt, 2009). There is an interaction between the studies of skeletal remains of ancient origin and modern origin giving rise to a “two-way street” approach (Melbye & Jimenez, 1997). For example the study of poorly preserved ancient skeletal remains has assisted in the recognition, reconstruction, and interpretation of modern fragmented forensic remains. The study of modern forensic skeletal remains has been helpful in the interpretation of trauma, weapon identification, pathology, and recovery of ancient remains (Dirkmaat & Adovasio, 1997). The application of modern forensic studies to ancient remains was summarised best by Henry Lee: “Forensic Science is used to predict not the future but the past” (Thali *et al.*, 2002).

The study of bone damage caused by carnivores is an example of the overlap in the applications of paleobiological research into modern forensic practice. Tooth marks of different African carnivores are a common feature in paleo-archaeological remains. Much effort is ongoing by taphonomists to develop criteria to identify the tooth marks of different

species found in surviving bone and fossils (Haynes, 1983; Selvaggio, 1994; Selvaggio & Wilder, 2001; Domínguez-Rodrigo & Piqueras, 2003). There has been headway in differentiating species such as lions, leopards, cheetahs, spotted hyenas, and jackals by the dimensions of tooth pits they cause in hominid fossils (Domínguez-Rodrigo & Piqueras, 2003). Leopards in particular have been of great interest to taphonomists who are reconstructing Plio-Pleistocene fossils in South Africa (Brain, 1968; Brain, 1969; Brain, 1970; Brain, 1974; Brain, 1983; Brain, 1993; Pickering *et al.*, 2004). Although the focus of this research was on ancient remains, the application to modern forensic cases is of great worth.

Hill (1979) and Rhine *et al.* (1988) have also suggested that studying animal scattering of skeletons may assist in understanding more fully the ecological and environmental conditions under which the disarticulation of remains occurred. Identifying scavengers which are active in urban and peri-urban environments and understanding their behaviours not only have forensic, archaeological, and paleobiological implications, but the potential for conservation outcomes too. Public perceptions of scavengers tend to be unfavourable and this affects the quantity of research into their importance and the need for their conservation (Cox & Gaston, 2015; Inger *et al.*, 2016). This is beginning to change as public perceptions are shifting towards more favourable views towards the importance of scavenger animals. This results in more targeted conservation projects focused on these animals (Moleón *et al.*, 2014). An increased understanding of the important role scavengers play in the sanitation of an environment, particularly in urban ecosystems, could lead to a greater appreciation and protection of these scavenger species (Inger *et al.*, 2016).

2.8 Limitations of past research

The majority of published research on scavenging damage is in the paleoanthropological field (Brain, 1968; Brain, 1969; Brain, 1970; Brain, 1974; Brain, 1983; Haynes, 1983; Brain, 1993; Selvaggio, 1994; Selvaggio & Wilder, 2001; Domínguez-Rodrigo & Piqueras, 2003; Pickering & Carlson, 2004). Forensic research which has been published on scavenging has focused on North American and European environments and species (Young *et al.*, 2014a). This research has concentrated on wolves, coyotes, rodents, and vultures (Young *et al.*, 2014a). Forensic descriptions of scavenging skeletal damage is mostly anecdotal on presumed perpetrating animals and the taphonomic processes have not been recorded or elaborated upon (Pickering & Carlson, 2004). The behaviours of scavenging animals are generally only described in regards to ecological considerations and not the forensic

implications. Descriptions of the skeletal damage caused by South African scavengers of forensic interest is needed. Descriptions of the behaviours and scattering patterns of South African scavenging animals is required, including considerations for their application in forensic contexts. An understanding of these factors will assist forensic investigators in the differentiation between perimortem trauma and animal scavenging modifications. This would also contribute to the development of effective search methods of scattered skeletal remains.

2.9 Aim and objectives of study

The present study aims to address some of the limitations that have been listed and to provide information that is currently lacking in the knowledge of scavenging and its impact on forensic investigations, especially in South Africa. The aim and objectives of this study are as follows:

The aim of this study is to identify the scavenging animals of forensic significance in different environments in South Africa and to describe their bite marks on bone and their scavenging behaviour.

The objectives of the study are as follows:

1. To compare and describe the modifications to skeletal elements caused by different scavenger species.
2. To identify the scavenger species present in an urban city and veld environments and describe their forensically-relevant behaviours and scattering patterns.
3. To identify the scavenger species present in a rural environment and describe their forensically-relevant behaviours and scattering patterns.
4. To identify the scavenger species present in a peri-urban/agricultural environment and describe their forensically-relevant behaviours and scattering patterns.

A general summary of the methods used during this study will be presented in Chapter 3 (Methods and Materials). However, each objective is individually explored in Chapter 4 (Results) in the form of a published or submitted research article; each with its own introduction, results, and discussion, related to the objective. Objective one is addressed by article 1, objective two is addressed by article two, objective three is addressed by article three, and objective four is addressed by article four. Chapter 5 (Discussion) will provide an overall, cohesive discussion of the results presented in the research articles, along with limitations of the study, and an overall conclusion will follow.

Chapter 3: Methods and Materials

3.1 Study design

This study was a prospective, observational, longitudinal study.

3.2 Objective 1: Descriptions of bone modifications by animals

3.2.1 Sample

This sample comprised of three sparsely fleshed and articulated bovine thoracic limbs (consisting of nine bones: humerus, radius, ulna, and carpals), four pelvic limbs (consisting of seven bones: femur, tibia, and tarsals), and seven racks of fleshed ribs (consisting of six ribs per rack and rib shafts as the heads and sternal ends were cut off by the butcher) were purchased from a licenced butchery. The soft tissues were previously removed by a butcher, leaving only a thin layer of soft tissue on the bone. These limbs were used to feed selected animals housed at the National Zoological Gardens of South Africa (NZG). Bovine limbs and ribs were selected as this is the usual meat source fed to the animals at the NZG.

3.2.2 Research site

The National Zoological Gardens of South Africa (NZG) contains ± 9087 animals of ± 705 species and has the mandate to promote and conduct conservation efforts and research to raise awareness in the general public. The NZG provided access to study the scavengers of forensic interest targeted by this study to describe their scavenging modifications on bone.

3.2.3 Data collection

The scavenging animals selected for this objective included wild dog (*Lycaon pictus*), spotted hyena (*Crocuta crocuta*), lion (*Panthera leo*), leopard (*Panthera pardus*), black-backed jackal (*Canis mesomelas*), caracal (*Caracal caracal*), and Cape porcupine (*Hystrix africaeaustralis*).

Lightly fleshed, articulated thoracic and pelvic bovine limbs, and ribs were purchased from a licenced butchery. The leopard, lion, caracal, and hyena had a pelvic limb placed in their enclosure while the thoracic limb was placed in the wild dog, porcupine, and jackals enclosures. A humerus was also placed in the caracal enclosure, in addition to the pelvic limb, to prevent fighting between the two resident caracals. The assignment of limb type was based on the availability of the limb from the butcher; therefore, the type of limb fed to each animal was random. The surviving remains of the limbs and ribs (i.e. bones which were not

consumed or removed by other scavenging animals and were visible in the enclosures) were collected after two days and macerated (removal of any remaining soft tissues by placing the bones in 20L of water in an urn kept at a constant 60°C for 24 hours) at the Johannesburg Forensic Pathology Services. The use of bovine limbs and that of other animal analogues to feed captive animals in a zoological park for similar experimental studies is consistent with previously published literature (Haynes, 1983; Pickering & Carlson, 2004).

3.2.4 Data analysis

The scavenging modifications on the bones was observed using an external light source in the form of a flashlight with controllable light intensity. The described tooth and claw marks observed on each bone were tabulated for each animal. The modifications were described according to the following variables:

1. Number of bones recovered
2. Type of damage: categorised as pits, furrows, punctures, or scores
3. Location of the damage on the bone
4. Number of tooth or claw marks
5. Depth (deep or shallow), breadth (wide or narrow), length (long or short), and the shape (e.g. fan-like, conical, irregular, etc.)
6. The intensity of scavenging recorded as a semiquantative scale (+/++/+++)
 - a. 'none' indicating no damage
 - b. (+) indicating minor or insignificant damage with little-to-no alteration to the morphology or integrity of the bone
 - c. (++) indicating moderate damage with noticeable alterations to the morphology of the bone
 - d. (+++) indicating destruction to the morphology of the bone or the total consumption of the bone

The descriptions of damage were compared between the species and unique species-identifying features were highlighted.

A Canon (SLR) 80D (EOS) camera with an EFS, 15-85mm, I.S. (image stabiliser), U.S. (ultrasonic) lens was used for the photography of the scavenging modifications. The tooth marks were not measured because the size of tooth marks in bone can indicate only the general size of the scavenger but not identify the particular carnivore species (Coard, 2007).

3.3 Objectives 2-4: Identification of scavenging animals in different locations

3.3.1 Sample

This sample comprised of 32 pig (*Sus scrofa domesticus*) carcasses weighing between 40-80kg each. The pigs were donated by a GHB Farms (25°58'03.5"S 28°40'22.6"E). The pigs were not terminated for the primary purposes of this study. They died from natural causes due to hemorrhagic bowel syndrome, frequently called red gut. This is often caused by *Lawsonia intracellularis* or *Clostridium perfringens* and is a common cause of death experienced in large pig farms. This often results in a hemorrhagic bowel syndrome, common in large pig farms, which is caused by the twisting of the intestines. Pigs which potentially died from hemorrhagic bowel syndrome were selected due to ethical reasons, since no pigs had to be terminated for the purposes of the study. Additionally, no external wounds or chemical influences are created by termination, which would have an effect on the decomposition process (Myburgh *et al.*, 2013) and potentially the scavenging of remains. No studies have yet been explicitly performed on the effects of hemorrhagic bowel syndrome on decomposition. Such pigs are often used in forensic decomposition and taphonomy research (Matuszewski *et al.*, 2019).

The chosen weight range is in line with small to medium sized humans and it has also been recommended that taphonomic research use pig carcasses that are larger than 20-30kg (Matuszewski *et al.*, 2019). The disarticulation sequences of pigs have also been observed to be similar to other mammalian quadrupeds and humans and are viable human analogues for scattering studies (Kjorlien *et al.*, 2009).

The 32 pigs were divided among four research sites as follows: Frankenwald research site (n=6), abandoned hospital complex (n=6), Wits Rural Facility (n=10), and Mierjie Le Roux Experimental Farm (n=10). The sample size per site is within the normal sample size of other published research of a similar nature (Pickering & Carlson, 2004; Morton & Lord, 2006; Reeves, 2009; Spradley *et al.*, 2012; Young *et al.*, 2014a; Spies *et al.*, 2020).

3.3.2 Research sites

Human remains are recovered by forensic specialists from a variety of environments. Since each environment has a unique biodiversity, it is important that a variety of environments be investigated. Environments in South Africa have varying levels of urbanisation and animal density and guild makeup. Some environments in South Africa can be broadly divided into

urban city centres, urban veld, peri-urban agricultural farms, and rural bushland. Four research sites were selected to represent these different environments common within South Africa, to identify the scavenging animals present in those environments and to describe their behaviours. The four environments selected were an urban city, an urban veldt, a rural wildlife facility, and a rural farm.

3.3.2.1 Urban city and veld sites

The urban veldt environment was represented by the Frankenwald research site; owned by the University of the Witwatersrand at the time of the study, on which the Department of Forensic Medicine and Pathology had a fenced off research site for forensic decomposition studies (26°04'15.5"S 28°06'12.0"E). The site is located in Kelvin, Sandton and runs along the N3 highway. The suburbs of Sandton and the Alexandra Township border the site. The Frankenwald site is approximately 283 hectares and is representative of a veldt environment with minimal human traffic but with feral and domesticated animals inhabiting the area.

The urban city environment was represented by an abandoned hospital complex adjacent to the Johannesburg Forensic Pathology Services Medicolegal Laboratory (JHB FPS) in Braamfontein, Johannesburg (26°11'27.3"S 28°02'31.7"E). The abandoned hospital complex was the Non-European branch of the Hillbrow Hospital during Apartheid and has been in disuse. These abandoned buildings were selected as a site because these areas are isolated with no human presence allowing for the placement of pig carcasses with no adverse effects to individuals present on the site.

Six pigs were deployed at the Frankenwald site with varying levels of exposure between the months of March to December and left to decompose until they were skeletonised. Two pigs were completely exposed to sunlight (i.e. no foliage coverage), three were partially exposed near a tree (partial sunlight during the day), and one was completely covered by tree foliage (no exposure to direct sunlight). The time permitted at this research site was limited by the site developers due to the site being sold by the University. Therefore, all pigs had to be laid out in the stipulated timeframe, as they became available at the pig farm. The locations that the pigs could be laid out were limited by the available space at the site. Additionally, placing the pigs in areas with different levels of foliage coverage ensured that a variety of microclimates were represented. This allowed for the pig carcasses to attract as great a variety of scavenging animals as possible at the site.

The pigs were deployed at least 20m apart from each other. All pigs were secured by a chain around the torso to a nearby tree or fence to prevent theft. A smaller sample size of six pigs, compared to ten pigs at the other sites, was a result of a limited time frame permitted at the research site due to the site being sold for development.

Six pigs were initially deployed in the abandoned building complex in the months of March and June. The pigs were left to decompose over a period of 4-7 months. This time period was dictated by the Department of Health. The pig carcasses were deployed in locations with varying levels of exposure. Two were deployed in an outdoor garden with full exposure, two were deployed in a courtyard with partial exposure, and two were deployed indoors. The sample size at this site was smaller than the research sites due to a limited time frame which was permitted at the research site due to the site being sold for development.

3.3.2.2 Rural site

The rural wildlife facility environment was represented by the Wits Rural Facility (WRF) (24°32'43.9"S 31°05'48.5"E) which is a wildlife facility and rural campus and of the University of the Witwatersrand situated in Limpopo Province near the border of the Kruger National Park. The WRF is a 315 hectare estate of savannah woodland in the central Lowveld of the Limpopo Province. The WRF is home to a variety of antelope, large cats (serval and caracal), vervet monkeys, baboons, and giraffes. The WRF is neighboured by private game reserves whose elephant, buffalo, lion, leopard, and hyenas occasionally cross the fences into the WRF property. WRF allowed for the observation of the scavenging activities of larger, non-domesticated game animals which are not present in other urban and peri-urban environments. These animals represent scavengers that may not be seen often in forensic cases yet may be of importance in abnormal forensic cases involving African wildlife and provide a holistic overview of central South African environments.

Five pigs were deployed at the Wits Rural Facility for a week in August (winter) and five pigs were deployed at the site for a week in October (summer). Five of the pigs were deployed beneath tree cover (three in summer; two in winter) and five were exposed in the open without being covered by foliage (i.e. avian view not obscured by foliage) (two in summer; three in winter). The locations that the pigs could be laid out were limited by the permitted space at the site. Additionally, placing the pigs in areas with different levels of foliage coverage ensured that a variety of microclimates were represented. This allowed for the pig

carcasses to attract as great a variety of scavenging animals as possible at the site. The one week time frame provided sufficient time for the pigs to become skeletonised and scattered. A distance of at least 50m separated each of the pigs.

The first five pigs initially deployed at the WRF during winter were secured by a chain around the torso to a nearby tree or fence to record the scavenging activity before the remains were disarticulated and scattered beyond the view of the cameras. This proved to be unnecessary because the scavenging of the remains largely fell within the scope of the camera's field of view and the scavenging and scattering of remains were not influenced by the presence or absence of chains. The subsequent summer pig sample were not secured by chains.

3.3.2.3 Peri-urban agricultural site

The peri-urban farm environment was represented by the Mierjie Le Roux Experimental Farm (25°47'21.8"S 28°32'37.5"E) which is owned by the Faculty of Natural and Agricultural Sciences of the University of Pretoria. This farm is used for numerous research projects including decomposition studies of a forensic anthropological nature. The farm represents a typical agricultural environment in South Africa that contains scavenging animals that avoid urban environments. The farm is 570 hectares of dry land subdivided for maize production, pastures, and cow herds. The farm is located in the Highveld plateau of the Gauteng Province and consists of mostly sourveldt grassland.

At the Mierjie Le Roux Experimental Farm, the placement of five pigs was staggered at different times in the winter months - three in July and two in August. Similarly, five pigs were deployed at the site in the summer months – three in October and two in December. Five pigs from the sample were deployed in a 50m by 50m enclosure that was fenced off (three in winter and two in summer). Each of the pigs within the enclosure were deployed at least 30m apart from each other. The other five pigs were deployed in open fields unobstructed by fences (two in winter and three in summer). This allowed for the observation of the possible effect of obstructions, such as fencing, on scattering patterns. The pigs were all secured by a chain around the torso to a nearby tree or fence to facilitate longer viewing and recording times of the scavenging activity.

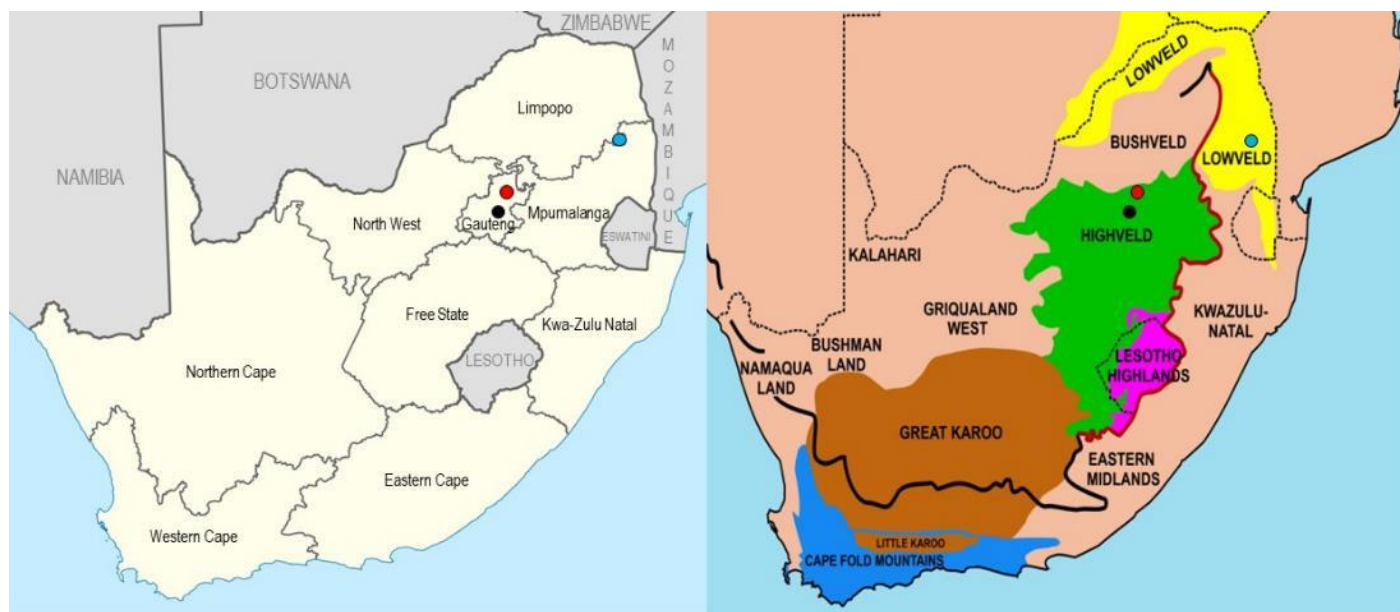


Figure 1: Locations of research sites in South African provincial (map on left) and physiographic (map on right) boundaries (black dot = urban sites; red dot = peri-urban site; blue dot = rural site) (Maps courtesy of Wikimedia Commons)

3.3.3 Data collection

3.3.3.1 Recording of animal scavenging

The scavenging of the carcasses were recorded using remote motion activated, infrared Bushnell Trophy Cam HD Essential E2 12MP Trail cameras. The cameras were set to the highest sensitivity, and took three consecutive photographs when activated by motion, with a five second interval between each motion activation. Camera footage was downloaded in two week intervals. This period was selected to reduce the impact of human interference and replace the batteries in the cameras.

3.3.3.2 Assigning of decomposition stages

The decomposition stages were determined from the photographs and what was viewed in person when on site, using the descriptions provided by Michaud and Moreau (2011) and Galloway *et al.* (1989). The decomposition stages were categorised as follows: the early stage (onset of death up to the onset of bloat), the bloated stage (onset of bloat, distention of the abdomen and/or neck, raising of limbs and/or protrusion of the anus), the active stage (abdominal deflation and moist decomposition), the advanced stage (exposure of skeletal elements in less than half the of body), and the dry stage (skeletonisation of more than half the body) (Galloway *et al.*, 1989; Michaud & Moreau, 2011)

3.3.3.3 Mapping of scattering patterns

At the end of the study, once the pig remains were skeletonised and scattered, each element was located and mapped using a grid pattern method common in archaeological and forensic anthropological practice. This occurred once for each pig. This method entails a group of individuals standing one meter apart from each other in a line and walking together in the same direction at the same pace and flagging the scattered elements (called 'walking the line'). The line walks in a north-to-south direction and then an east-to-west direction – thus, covering the region surrounding the original deposition location of the pig carcass. The search radius was determined by the distance between the pigs and the extent of the scattering. The search started at the original location of each pig placement. The search radius was 30 meters at the Frankenwald site, 20 meters at the Wits Rural Facility, and 200 meters at the Mierjie Le Roux Experimental Farm.

3.3.3.4 Descriptions of scavenger bone modification

The recovered scattered elements were macerated using warm water maceration and washing (placed in 20L of water and 750ml of OMO Auto detergent at a constant 60°C for 24 hours) to remove all remaining soft tissues and to facilitate the recording of bone modification descriptions. A flashlight with controllable light intensity intervals was used to observe the bone modifications.

3.3.4 Data analysis

3.3.4.1 Photograph analysis

The photograph timestamps were used to record the frequency of scavenging events and to separate different scavenging events. Timestamp differences greater than 10 minutes from the previous photograph were recorded as separate scavenging/visiting events. The decomposition stages of the recorded carcasses were determined from the photographs.

3.3.4.2 Scattering analysis

A scatter plot was created for each research site using Microsoft Excel. The recovered remains for all pigs at each site was plotted on the same scatter plot. The location of each recovered scattered element was recorded and mapped, to scale, in relation to the original site of deposition (represented by the origin on the graph).

The number of scatter plots differed for each research site since they were used to highlight any unique variables which were observed to influence the scatter patterns at each site. A

single scatter plot was developed for the Frankenwald site. Two scatter plots were developed for the Wits Rural Facility: one for summer and one for winter. Two scatter plots were developed for the Mierjie Le Roux Experimental Farm: one for the open field scattering and one for scattering within an enclosed fenced area.

3.3.4.3 Bone modification analysis

The scavenging modifications on the bone were described and directly assigned to the perpetrating scavenging animal if they were observed scavenging the skeletal element as captured on camera. Alternatively the modifications were indirectly assigned to an animal by comparing the scavenging modifications patterns to those described in the study at the National Zoological Gardens (Keyes *et al.*, 2019).

3.4 Ethics

Ethical approval for this study was granted by the following agencies (see [Appendix 8.4](#) & [8.5](#)):

- Animal Ethics Research Committee (waiver numbers: AREC-101210-002, AEC H001-19)
- South African National Biodiversity Institute Research Ethics and Scientific Committee (NZG/RES/P18/10)
- Department of Agriculture, Forestry and Fisheries (permit: 12/11/1/1/120 [789])

Permissions to conduct research at the various sites were granted by the following agencies (see [Appendix 8.4](#) & [8.5](#)):

- South African National Biodiversity Institute (National Zoological Gardens of South Africa)
- Dr AMM Grobler: Chief State Veterinarian (Pretoria)
- Gauteng Department of Health: Department of Research and Epidemiology
- Gauteng Department of Health: Forensic Medical Services (Abandoned hospital complex, Johannesburg Forensic Pathology Services)
- Prof Edward C. Webb, Deputy Dean: Research & Postgraduate Education, University of Pretoria (Mierjie Le Roux Experimental Farm)
- Prof Wayne Twine, Associate Professor: School of Animal, Plant & Environmental Sciences, University of the Witwatersrand (Wits Rural Facility)

3.5 Funding

This research was funded by the National Institute of Justice and the Forensic Technology Centre of Excellence along with the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre, and the Wits Faculty Research Committee Individual Grant.

Chapter 4: Results

The results have been formatted according to the divided block format as prescribed by the University of the Witwatersrand Faculty of Health Sciences' "Style Guide for Theses, Dissertations and Research Reports". This format allows for the presentations of the results as published research articles and/or submitted manuscripts that answer the objectives of the thesis. The format of each article follows the formatting prescribed by the journal they have been published in or submitted to, and will differ in terms of spelling, format, and referencing style from the formatting of the other chapters of this thesis.

The results of this thesis were reported in four journal articles. At the time of this thesis being sent for examination, one article has been published and three have been submitted to a journal for review. Subsequent to the examination, two articles have been published and two were still under review.

The document outlining the student's contribution to articles and agreement of co-authors can be found in [Appendix 8.2](#).

The results of each objective were reported in four articles as follows:

[Article 1](#): The descriptions of the scavenging modifications of animals at the National Zoological Gardens (**Published**)

[Article 2](#): The identification of scavenging animals and their behaviour at the Wits Rural Facility (**Submitted to journal and under review**)

[Article 3](#): The identification of scavenging animals and their behaviour at the Frankenwald research site and abandoned building complex in Braamfontein, Johannesburg (**Submitted to journal and under review**)

[Article 4](#): The identification of scavenging animals and their behaviour at the Mierjie Le Roux Experimental Farm (**Published**)

NOTE: The articles have been formatted according to the respective journal's author guidelines in terms of spelling, format, and referencing style and will differ from the formatting of this thesis.

Article 1

TAPHONOMIC BONE TRAUMA CAUSED BY SOUTHERN AFRICAN SCAVENGERS

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Journal: International Journal of Legal Medicine (<https://doi.org/10.1007/s00414-019-02154-6>)

Declaration: The contents of the paper are the original work of the authors submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Acknowledgements: The authors acknowledge the financial assistance of the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre. Also acknowledged is the National Zoological Gardens of South Africa and the invaluable assistance of their staff: Mr Nathaniel Taweni, Dr Ian Espie, and Ms Tracy Rehse. Appreciation is also due to Ms Tracy Reindorp who took the photographs in this article.

Abstract

Forensic anthropologists in Southern Africa are often confronted with post-mortem modifications of human skeletal remains caused by animal scavenging. This is troublesome as the post-mortem pseudo-trauma could be misinterpreted. This study aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest. The scavenging animals selected for this study included wild dog, spotted hyena, lion, leopard, black-backed jackal, caracal, and porcupine housed at the National Zoological Gardens of South Africa. Sparsely fleshed and articulated bovine front and hind limbs as well as ribs were placed in each animal enclosure and collected after two days for cleaning and analysis. Felids (lion, leopard, and caracal) gnawed away the greater trochanter of the humerus leaving deep, parallel furrows. Hyena caused massive trauma to bone with one third of the tibia shaft surviving with jagged fracture edges. Porcupines left distinctive fan-like parallel scores; and large, oval depressions with an eroded, polished appearance. Wild dogs and jackals did not leave any distinctive patterns. Light scavenging trauma is distinct from other bone taphonomy but cannot be used to determine the species. Heavy scavenging trauma patterns can be used to determine the general type of perpetrating animal however the exact taxa or species cannot be determined.

Keywords: Forensic anthropology, taphonomic trauma, scavenging, animals, Southern Africa

Introduction

Animal scavenging often causes post-mortem modifications of human skeletal remains. In a forensic context this is troublesome as the post-mortem pseudo-trauma could be misinterpreted by forensic specialists (1-3). Competent analysis of post-mortem trauma should discriminate between damage and trauma inflicted by an animal, a human perpetrator, and other taphonomic influences. The ability to identify a scavenger by the trauma it causes to bone could also assist in the implementation of more reliable search methods for locating scattered remains and other evidence (2).

Scavenging animals considered to be of forensic importance in North America include wolves (*Canis lupus*), coyotes (*Canis latrans*), rodents, raccoons (*A. arathkone*), foxes (*V. vulpes*), opossums (*D. marsupialis*), striped skunks (*M. mephitis*), crows (*Corvus brachyrhynchos*), and a variety of vultures (*Cathartidae*) such as the turkey vulture (*C. aura*) (1, 4). Vultures are the avian scavengers most often discussed in forensic studies (1) and are commonly found in North America, the Mediterranean, Eastern Europe, Asia, and Africa. Internationally, in more rural regions, large felids such as lions (*Panthera leo*), leopards (*Panthera pardus*), tigers (*Panthera tigris*), and cougars (*Felis concolor*) have been known to occasionally scavenge on human remains (5). In abnormal situations, herbivorous animals, such as deer, have also been observed scavenging on dry bones. This behaviour is termed osteophagia and is caused by a phosphorous deficiency resulting from a nutritional dysfunction (6). In urbanised cities, domesticated pets (particularly dogs) have often resorted to feeding upon the soft tissues and skeletal remains of their deceased owners when locked indoors – even if there are alternative food sources available (7, 8).

Descriptions of bone trauma caused by animal bite marks have been categorised into four categories: pits, furrows, punctures, and scores (2, 9). Pits are described as indentations that do not penetrate the cortical surface of the bone. These pits are caused by individual tooth cusps. Punctures are penetrating marks through the cortical bone with an irregular shape. Punctures can be caused by canine and carnassial teeth. Avian scavengers can also form punctures that are conical in appearance on the surfaces of bones, usually caused by a pecking motion when eating soft tissues (10). Furrows are longitudinal marks commonly found near the epiphyseal ends of bones. These are created by premolars and molars and are the result of scavengers trying to gain access to the bone marrow. A score is a broad term describing any mark in the bone surface where the length is greater than the breadth

(11). This is often caused by a tooth sliding after a pit has been created (2). Rodent gnaw marks appear as scores on the superficial surfaces of bones. These are often exhibited as parallel striations with uneven margins (2). Generally, the size of these respective marks (pits, punctures, furrows, and scores) can indicate the relative size of the animal (2).

Bite marks are not the only marks caused by scavenging animals to bone. Claw marks are often found in conjunction with bite marks when the animal attempts to grasp the bone (12). Claw marks appear similar to tooth-made scores, since the claw marks are also longer than they are wide. However, scores made by claws can be differentiated from tooth marks because the diameter of claw marks are too thin to be confused as tooth marks and the claw marks are often in parallel rows (12).

The extent of the bite marks on bone can vary depending on the animal species and individual animal. The relative amount of damage caused to a bone is dependent on the relation between the strength of the bone and the tooth morphology and jaw mechanics of the scavenging animal (12). Recent studies have determined that the size of tooth marks in bone can assist in determining the general size of the scavenger but the particular carnivore taxon cannot be accurately identified through tooth mark measurements (13). Bones can even be entirely consumed, leaving little to analyse, depending on the size of the scavenging animal (12).

The ability to identify the animal species by its bite marks in bone can be of great worth. In South Africa, there is still a level of proximity and interaction between humans and wild animals despite the rapid increase in global urbanisation and conservation efforts to isolate animals within national parks and government protected areas (14, 15). Animal attacks are common in South Africa and these often involve people who climb over the fences of game reserves, tourists who leave the safety of camping grounds or vehicles, and poachers. As a result, there are often cases where human skeletal remains are recovered in such locations. In these cases, it will be the role of the forensic anthropologist to analyse the bone trauma and differentiate between perimortem trauma inflicted by a human perpetrator and bite marks caused by animals. For example, there was a case where human skeletal remains were recovered from a lion enclosure at a South African game park. The victim was thrown into the enclosure by perpetrators (16). In this instance the forensic anthropologist had to distinguish between bone fractures that resulted from trauma and bite marks from the lions.

Not all animal bite marks look the same. Animal bite marks can be mistaken for blunt, sharp, or ballistic trauma by the inexperienced. The more we can understand the different bite marks caused by different animals, the easier it will be to differentiate them from tool marks and other traumas.

The vast majority of research published on scavenging trauma is of a paleoanthropological nature (11, 17-26) and those in the forensic context are on North American and European environments and species (1). Furthermore, the majority of forensic research on scavenging has been based on wolves, coyotes, rodents, and vultures (1). Much of the published forensic literature describing skeletal trauma caused by scavenging animals is anecdotal and based on actual forensic case studies with the described trauma being inferred upon an assumed animal with no knowledge of the taphonomic processes and previous trauma the bones may have been exposed to (5). This study therefore aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest. The results will provide information that is missing from current forensic literature; a description of African animal bite marks on bone. These descriptions will help provide context to future forensic anthropological analyses of bones in Africa, including discerning or excluding the animal. These results will also assist forensic anthropologists in differentiating between perimortem trauma and animal bite marks.

Methods

The scavenging animals selected for this study included wild dog (*Lycaon pictus*), spotted hyena (*Crocuta crocuta*), lion (*Panthera leo*), leopard (*Panthera pardus*), black-backed jackal (*Canis mesomelas*), caracal (*Caracal caracal*), and porcupine (*Hystrix africaeaustralis*). These animals were selected as they are known to forensic anthropologists as scavengers of forensic cases in South Africa. Some of the animals are common scavengers (wild dog, jackal, caracal, and porcupine) and some are less common scavengers (lion, leopard, and hyena) however all are of forensic interest in South Africa.

Sparsely fleshed and articulated bovine thoracic limbs (consisting of nine bones: humerus, radius, ulna, and carpals), pelvic limbs (consisting of seven bones: femur, tibia, and tarsals), and racks of fleshed ribs (consisting of six ribs per rack and rib shafts only as the heads and sternal ends were cut off by the butcher) were purchased from a licenced butchery. Bovine limbs and ribs were selected as this is the usual meat source fed to the animals at the NZG.

Pelvic limbs were placed in the leopard, lion, caracal, and hyena enclosures and thoracic limbs were placed in the wild dog, porcupine, and jackal enclosures. A humerus was also placed in the caracal enclosure in addition to the pelvic limb to prevent fighting between the two resident caracals. The use of thoracic limbs and pelvic limbs was based on availability and which animals were fed which type of limb was random. A rack of ribs was placed in each animal enclosure. The fleshed limbs and ribs were left in the animal enclosures for two days before collection of the remains. The study of bone trauma on bovine limbs (or other animal analogues) experimentally fed to captive animals in a zoological park is consistent with previously published literature (5, 11). The surviving bones (i.e. bones which were not consumed or removed by other scavenging animals and were visible in the enclosures) were collected and macerated (removal of any remaining soft tissues).

An external light source in the form of a flashlight with controllable light intensity was used to locate and observe the trauma. A table was drafted for each animal that described the tooth and claw marks observed on each bone. The descriptions included: number of bones recovered, type of trauma (pits, furrows, punctures, or scores), location of the trauma on the bone, and a description of the trauma. The descriptions included the number of tooth or claw marks, the depth (deep or shallow), breadth (wide or narrow), length (long or short), and the shape (e.g. fan-like, conical, irregular, etc.). The intensity of scavenging was also recorded as a semiquantitative scale (+/++/+++) with 'none' indicating no trauma, (+) indicating minor or insignificant trauma with little-to-no alteration to the morphology or integrity of the bone, (++) indicating moderate trauma with noticeable alterations to the morphology of the bone, and (+++) indicating destruction to the morphology of the bone or the total consumption of the bone. The descriptions of trauma were compared between the species and unique species-identifying features were highlighted.

Photographs of the trauma were taken with a Canon (SLR) 80D (EOS) camera with an EFS, 15-85mm, I.S. (image stabiliser), U.S. (ultrasonic) lens. Measurements of the tooth marks were not taken. It is suggested that the size of tooth marks in bone can assist in determining the general size of the scavenger but the particular carnivore taxon cannot be accurately identified through tooth mark measurements (13).

Results

The jackals caused the least trauma of all the animals and all bones survived. Observable bite marks were isolated to a few superficial pits and scores on the ribs, humerus, and radius (Table 1 and Figure 1). Nothing was noted on the ulna and carpus bones. Trauma caused by the jackals was very difficult to see on the bones as they were generally short and superficial. A very good light source was employed to see the trauma clearly.

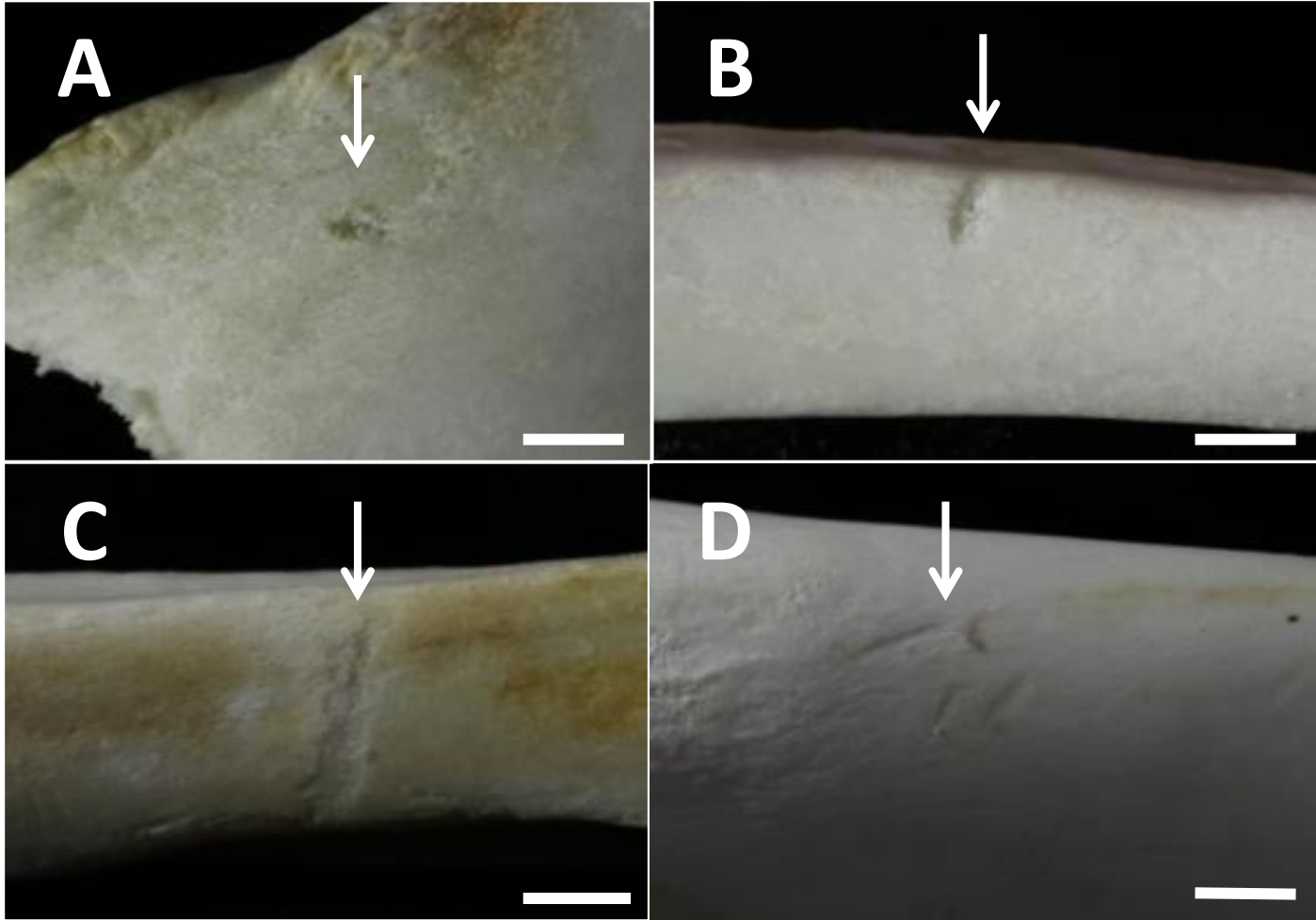


Fig. 1 Jackal trauma (arrows) on bone shafts including: (A) a pit on a rib, (B & C) scores on ribs and (D) the radius (scale line = 5mm)

The wild dogs consumed most of the ribs however a single rib survived along with the humerus, radius, ulna, and carpus bones. Multiple pits and scores of varying depth, size, and shape were present on the ribs, humerus, and ulna (Table 1 and Figure 2). Shallow furrows were present in the trabecular bone of a gnawed region in the margin of the greater

trochanter of the humerus (Figure 2C). Claw marks (thin scores) were also present in the cartilage of humeral head and trochlea (Figure 2D).

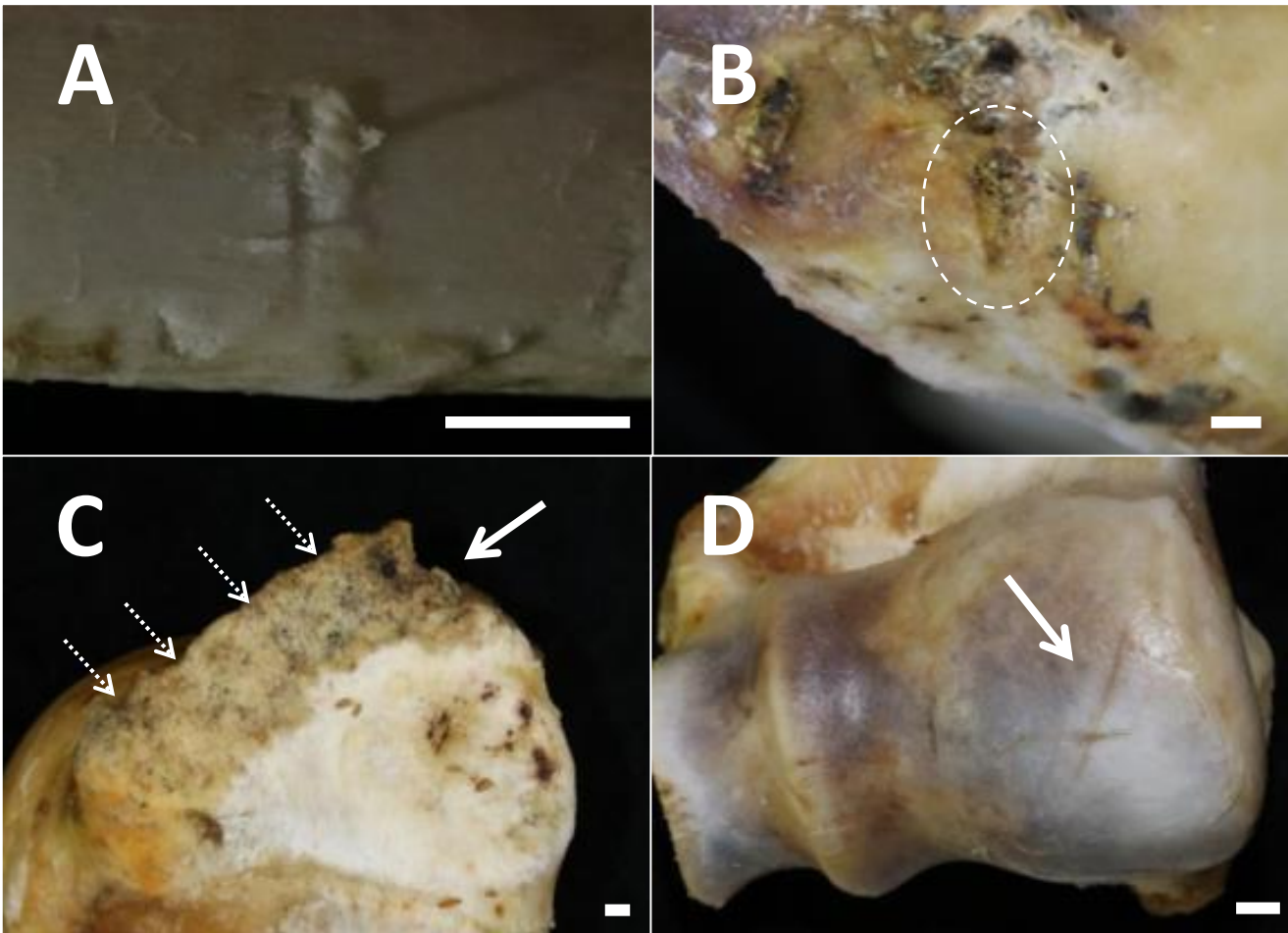


Fig. 2 Wild dog trauma on bone including: (A) a score with frayed edge on a rib shaft, (B) pit on the a head of humerus (dotted circle), (C) gnawing (solid arrow) and shallow furrowing (solid arrow) on a humeral greater trochanter, and (D) claw scores in the cartilage of the humeral trochlea (solid arrow) (scale bar = 10mm)

The hyena caused the most damage with very few remaining skeletal elements (Table 1). Only a fragment of the distal tibia and three tarsus bones remained. The femur and ribs were all consumed entirely. The distal end of the tibia survived with a jagged, uneven fracture margin indicative of a spiral fracture on the shaft (Figure 3A). A tarsus bone exhibited a clear separation of the cortical and trabecular bone with additional gnawing and a shallow furrow (Figure 3B).

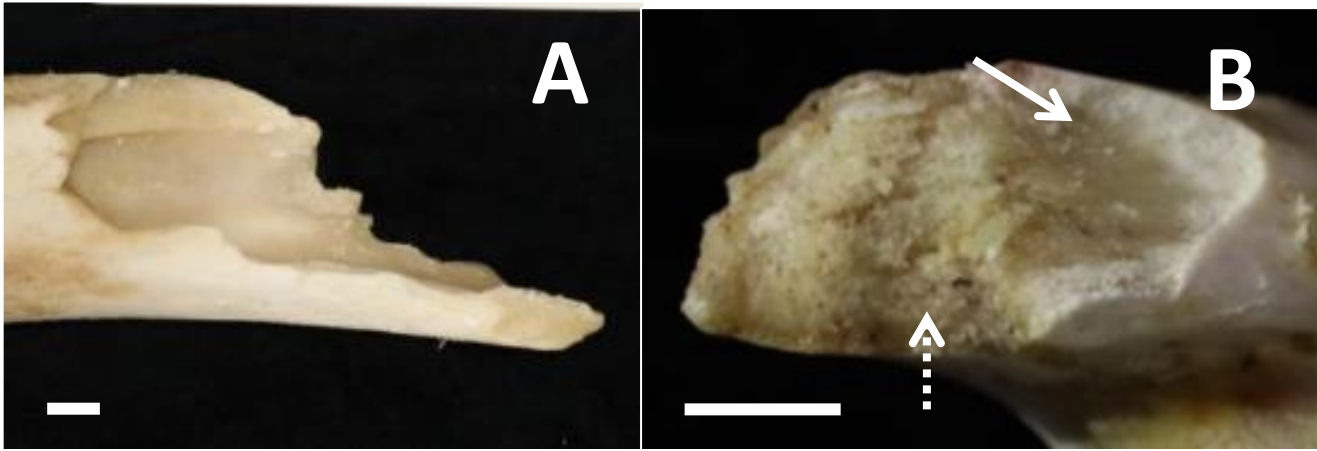


Fig. 3 Hyena trauma on bone including: (A) the jagged margin of the tibia shaft fracture and (B) the separation of cortical and trabecular bone (solid arrow) in addition to gnawing and a shallow furrow (dotted arrow) in a tarsus bone (scale line = 10mm)

The porcupine caused distinct and unique trauma to the recovered humerus, radius, and ulna (Table 1). A common, distinctive, fan-like pattern of clustered scores were observed in six different regions (Table 1 and Figure 4A and B). There was extensive trauma to the greater trochanter as it had been completely gnawed away with an uneven, jagged margin (Figure 4C). Another common pattern was observed in the medial and lateral surfaces of the olecranon tuber and the head of the humerus, where each exhibited a large, oval depression with an eroded, polished appearance (Figure 4D).

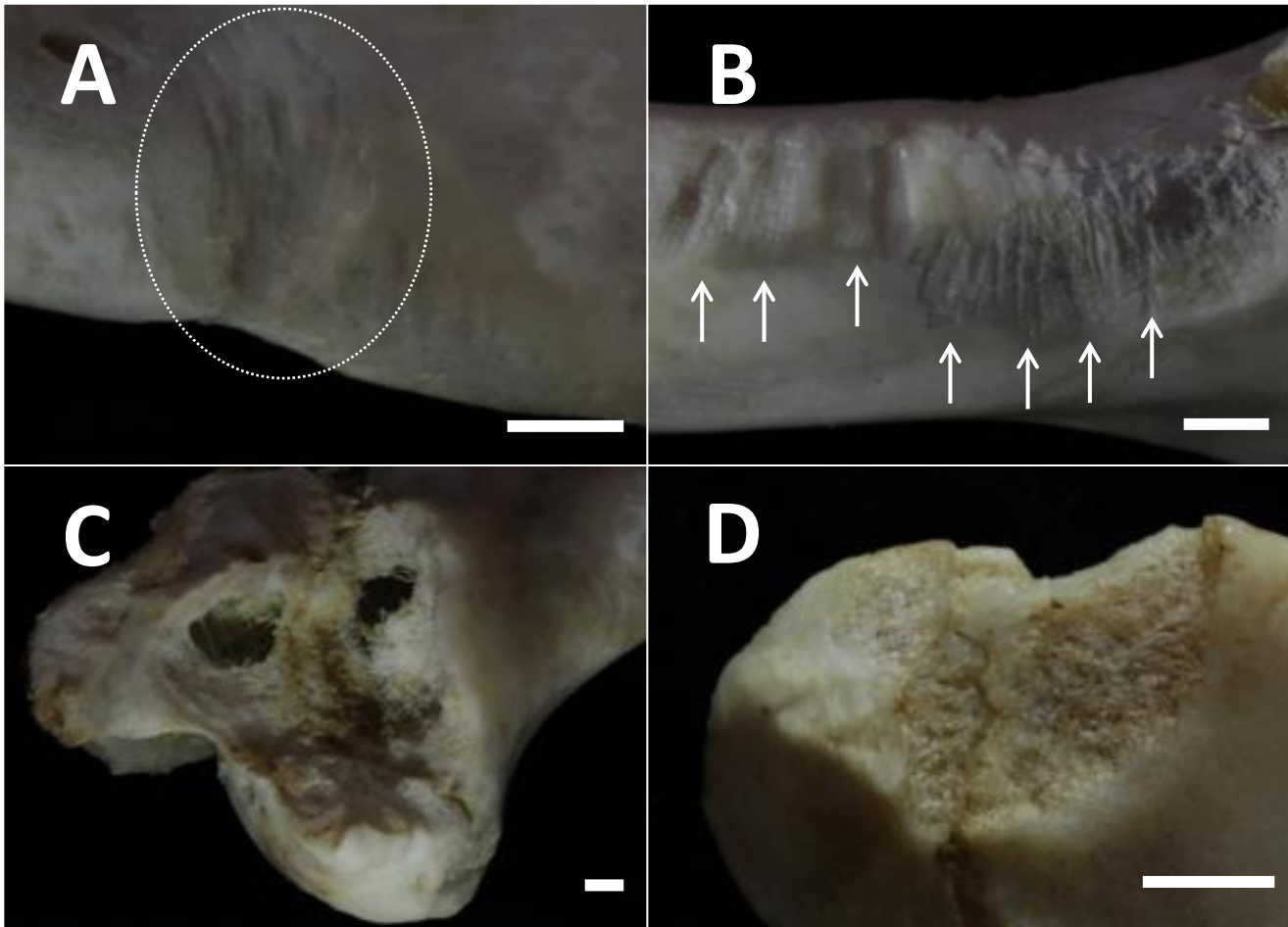


Fig. 4 Porcupine trauma on bone including: (A) fan-like scoring clusters (dotted circle) on the shaft of the humerus and (B) radius (arrows), (C) complete loss of the greater trochanter due to gnawing, and (D) a large, oval depression with an eroded, polished appearance on the olecranon tuber (scale line = 10mm)

The leopard left pits and scores on the ribs, femur, tibia, and the calcaneus (Table 1 and Figure 5). A distinctive gnawing pattern was observed on the greater trochanter of the femur. It had been gnawed with multiple distinctive parallel, deep, wide furrows (Figure 5B).

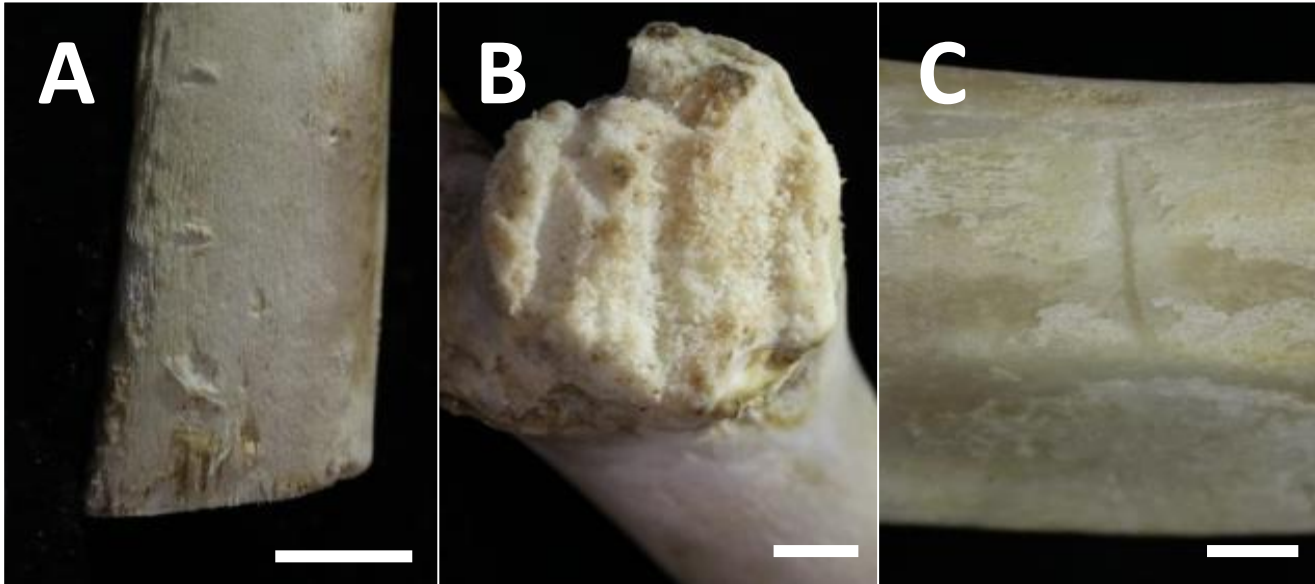


Fig. 5 Leopard trauma on bone including: (A) shallow pits with frayed margins on rib, (B) gnawing with distinct furrows on the femoral greater trochanter, (C) and a wide superficial score on the shaft of a tibia (scale line = 10mm)

The lions also caused a distinctive gnawing pattern on the greater trochanter of the femur (Table 1 and Figure 6). The greater trochanter contained two wide, deep, parallel furrows (Figure 6A). Large pits and punctures were often located adjacent to regions of gnawing and farrowing. It is presumed that these were created as anchor points to stabilise the bone during the scraping motion of gnawing and furrowing. The tibia presented with large, deep punctures on the superior, medial margin of the medial tibial plateau (Figure 6D) and conical punctures in the tibial tuberosity (Figure 6E).

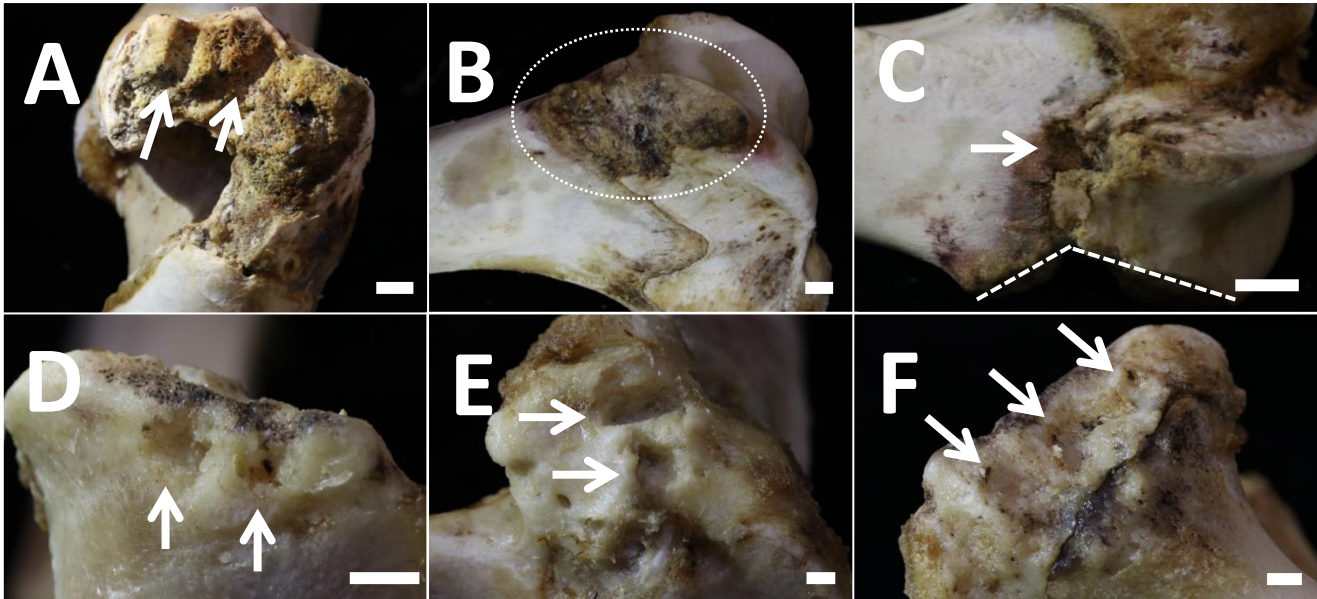


Fig. 6 Lion trauma on bone including: (A) furrows in the greater trochanter (arrows), (B) gnawing of patellar surface (dotted circle), (C) a large conical puncture (arrow) opposite to the gnawed region of the patellar surface (dotted line), (D) punctures in the margin of the medial condyle of the tibia, (E) punctures in the tibial tuberosity, and (F) pits in the margin of the tibial condyle (arrows) (scale line = 10mm)

The caracals exhibited the greatest variety of trauma (Table 1 and Figure 7). The proximal end of the humerus had been extensively gnawed with the head and greater trochanter missing. A distinctive gnawing patterns was observed on proximal epiphysis of the humerus as was caused by the leopard and lions. The gnawed proximal end of the humerus presented with multiple long, deep, parallel furrows (Figure 7B). The margin of the gnawed proximal end of the humerus showed signs of crushing with curved flaked bone fragments still adhering (Figure 7C), and a single deep puncture.

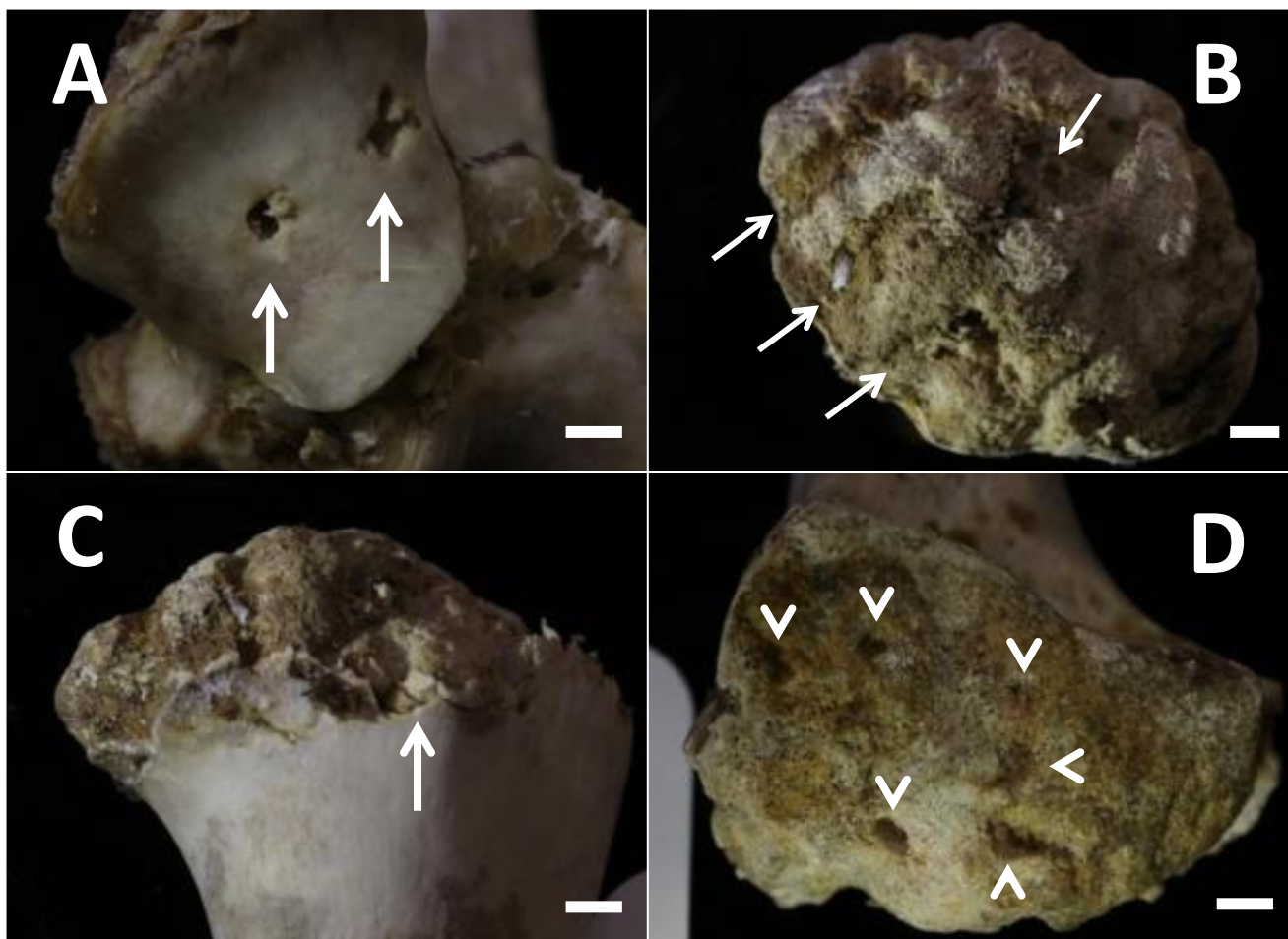


Fig. 7 Caracal trauma on bone including: (A) large irregular punctures (arrows) were present in the condyles of the tibia, (B) furrows (arrows) in the proximal end of the humerus, (C) signs of crushing with curved flaked bone fragments adhering a the gnawed proximal humeral epiphysis (arrow), and (D) multiple large, deep pits (arrows) in the distal end of the humerus (scale line = 10mm)

Table 1: Summary of animal trauma to bovine ribs and limb bones

Animal	Bone	Number of bones placed in enclosure	Number of bones recovered	Intensity of scavenging (+/++/+++)	Type of trauma	Location	Description	Figure
Jackal	Ribs	6	6	+	Pit	Shaft	Single, shallow pit found on one rib	1A
				+	Score	Shaft	Single score found on two ribs each; one shallow & one deep	1B
	Humerus	1	1	+	Score	Mid-shaft	Single, short, shallow, wide score	1C
	Radius	1	1	+	Scores	Shaft	Short, shallow scores clustered in groups of two and three	1D
	Ulna	1	1	None	/	/	No trauma noted	
	Carpus bones	6	6	None	/	/	No trauma noted	
Wild dog	Ribs	6	1	+	Scores	Shaft	The rib exhibited numerous shallow scores; one had frayed borders of bone peeling out.	2A
				+	Pits	Shaft	Numerous shallow pits of varying depth, size, and shape	
	Humerus	1	1	+	Pit	Margin of the humeral head	Large	2B
				+	Gnawing and furrows	Margin of the greater trochanter	Shallow furrows in trabecular bone of gnawed region	2C
				+	Scores	Cartilage of humeral head	Three scores of varying length	
				+	/	Cartilage of trochlear	Numerous claw marks	2D
	Ulna	1	1	+	Scores	Neck of ulna	Numerous claw marks clustered in a V-shape	
	Radius	1	1	None	/	/	No trauma noted	
	Carpus bones	6	6	None	/	/	No trauma noted	
Hyena	Ribs	6	0	+++	/	/	Consumed entirely	
	Tibia	1	1	+++	Fracture	Shaft	Distal end of shaft remaining with a jagged, uneven fracture margin, indicative of a spiral fracture of the shaft.	3A
	Femur	1	0	+++	/	/	Consumed entirely	
	Tarsus bones	4	3	++	Gnawing	Calcaneus	Gnawing with a shallow furrow. A clear separation of cortical and trabecular bone.	3B
Porcupine	Ribs	6	0	/	/	/	No ribs recovered (suspected mongoose theft)	
	Humerus	1	1	++	Gnawing	Greater trochanter	Completely gnawed away with an uneven, jagged margin	4C

				+	Scores	Neck of humerus beneath gnawed away greater trochanter	Thin fan-like pattern of clustered scores	
				+		Shaft	Wide fan-like pattern of clustered scores	4A
				+		Shaft	Wide parallel and overlapping scores	
				++	Gnawing	Head of humerus	Large, circular region with an eroded, polished appearance	
	Radius	1	1	+	Scores	Mid-shaft	Wide parallel and overlapping scores	4B
				+		Superior and distal ends of shaft	Wide fan-like pattern of clustered scores	4B
	Ulna	1	1	++	Gnawing	Medial and lateral olecranon tuber	Large, oval depressions with eroded, polished appearance	4D
	Carpus bones	6	0	/	/	/	No carpals recovered (suspected mongoose theft)	
Leopard	Ribs	6	2	+	Pits	Shaft of ribs	Numerous shallow pits with frayed peeling bone on some pit margins	5A
				+	Score	Shaft	One short, wide score on one rib. One thin, long score on other rib.	
	Femur	1	1	++	Gnawing and furrows	Greater trochanter	Gnawed away cortical bone with three parallel deep, wide, furrows	5B
				+	Scores	Shaft	Two thin claw marks in V-shape vertically along shaft axis	
	Tibia	1	1	+	Gnawing	Medial condyle	Margin gnawed	
				+	Scores	Shaft	Five wide scores of varying lengths, horizontal to the shaft axis	5C
	Tarsus bones	4	4	++	Pits	Calcaneus	Small, deep pits and small shallow pits	
	Ribs	6	0	/	/	/	No ribs recovered (suspected mongoose theft)	
Lion	Femur	1	1	++	Gnawing and furrows	Greater trochanter	Two wide, deep, parallel furrows	6A
				++	Gnawing	Patellar surface	A large, deep defect caused by gnawing	6B
				+	Puncture	Patellar surface	Large deep conical puncture opposite the gnawing region (both on the patellar surface)	6C
				+	Scores	Shaft	Numerous large, parallel scores near region of strongest muscle attachment	
				+	Pits	Greater trochanter, head, condyles, & distal femur	Many pits of varying sized	

	Tibia	1	1	+	Punctures	Superior, medial margin of the medial tibial plateau	Two conical punctures	6D
				+		Tibial tuberosity	Three deep, large punctures, two of which are joined	6E
				+	Scores	Superior shaft	Numerous large, wide, superficial, parallel scores horizontal to the shaft axis	
				+		Condyle cartilage	Numerous clustered claw mark scores	
				+	Pits	Tibial condyles	Multiple deep pits of varying sizes along the lateral boarder	6F
	Tarsus bones	4	3	++	Scores	Calcaneus	Numerous wide, overlapping scores in V-shapes	
Caracal	Ribs	6	5	+	Score	Costal end	One rib exhibits numerous wide, parallel scores along the costal end of the shaft.	
				+		Shaft	One rib exhibits two scores with frayed boarders of cortical bone and one superficial score; all on the shaft. All scores are horizontal to the shaft axis.	
				+	Pit	Costal end	Numerous pits on three of the ribs; all on costal ends or ribs	
	Femur	1	1	+	Scores	Shaft	Seven thin claw mark scores	
	Tibia	1	1	++	Puncture	Condyles	Two large irregular shaped punctures	7A
				+	Scores	Condyles	Numerous clustered scores	
				+	Furrows	Margin of condyle	Six short parallel furrows.	
	Tarsus bones	4	3	None	/	/	No trauma noted	
	Humerus	1	1	+	Scores	Shaft	Numerous long, wide, shallow scores horizontal to shaft axis	
				+++	Gnawing	Proximal epiphysis	Epiphysis gnawed exposing trabecular bone, with a crushed, flaked margin	7C
				++	Furrows	Proximal epiphysis	Numerous long, wide, deep, parallel furrows in the gnawed trabecular bone	7B
				+	Puncture	Proximal epiphysis	Single deep puncture at the gnawing margin	
				++	Pits	Sawn-off trochlea	Six, large, deep pits in trabecular bone in sawn-off trochlea	7D
				++	Gnawing and furrows	Epicondyles	Two short, shallow furrows	

Generally, the animals focus on and caused the most severe trauma to the proximal ends of long bones with scoring on the shafts. Scores tended to always be horizontal across the shafts of on long bones. Furrowing always occurred as multiple, parallel furrows - in gnawed regions where trabecular bone had been exposed. Large and deep pits and punctures in the long bones often occurred opposite or adjacent to gnawed regions. It is presumed that these were created by mandibular canine and carnassial teeth as an anchor point for gnawing and furrowing actions of the maxillary teeth. Trauma to the ribs only ever exhibited as scores and pits. Each of the animals in this study caused a number of different types of trauma (pit, score, puncture, and furrow) in different combinations. One type of trauma on its own was not distinct but rather the pattern and location of the trauma was distinct. This was apparent in the porcupine and the cats (lion, leopard, and caracal). The fan-like clusters of scores caused by porcupines are very distinct and unique. All cats in the study (lion, leopard, and caracal) caused distinctive furrows in gnawed proximal ends of long bones.

Discussion

This study aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest and to determine if the patterns of trauma could be used to identify the animal. The general tooth mark patterns observed on the long bones included scores being isolated to the shafts and the heavier gnawing, and deep pits and punctures being confined to the epiphyses. As is seen in this study and previous research, it is common for heavier bone damage to be produced at the epiphyses (11) by scavengers as they try to gain access to the marrow (18). Scavengers will still gnaw on the epiphyses even after flesh and marrow has been removed because the grease in these regions is enough to attract the attention of animals (18). Gnawing of the epiphyseal margin with the appearance of grooves or furrows is typically caused by the grinding or shearing motions of carnassial or molar teeth where the cusps are pressed into the cancellous bone (11). This was exemplary in the present study in the long bones retrieved from the wild dogs and caracals. The current study observed thin scores caused by animal claws - as seen in the bones recovered from the caracals, lions and wild dogs – which cannot be mistaken for tooth marks as they are too narrow to be caused by tooth cusps (12) but they can easily be mistakenly attributed to other sharp force trauma (such as scalpel marks made during maceration). These marks can all indicate scavenging activity; however they are not indicative of the specific animal. On the

ribs retrieved from the animal enclosures, only shallow pits and scores were observed along the shafts of the ribs. This is likely due to the flesh on the ribs being relatively lighter than on long bones and easily removed by the feeding animals. The pits and scores are likely caused by light tooth cusp pressure as the rib is maneuvered (11). The consequential deformation of the cortical bone is superficial as it does not puncture through to the underlying trabecular bone.

The jackals and wild dogs in this study only caused light bone damage which was isolated to shallow pits and scores with no unique pattern that can be used to isolate them as the perpetrating animal. These were very difficult to observe without a good light source. The wild dog did leave shallow furrows in the gnawed margin of the greater trochanter of the humerus but this alone was not distinctive enough to be diagnostic. Previous literature on jackal and wild dog scavenging has not explicitly described the tooth mark patterns of jackals and wild dogs. This is likely because there is no specific pattern. However, the literature has focused largely on testing if the size of pits caused by jackals can be used to differentiate them from pits caused by other animals (5, 18, 27) with most concluding that tooth dimensions can only be used to determine if a carnivore was large or small (27).

Previous literature has described that heavy gnawing damage to the proximal epiphyseal ends of long bones by large cats, canids, hyenas, and bears is distinctive enough to identify the general type of animal but not the exact taxa or species (11). The deletion of portions of the proximal epiphyses of long bones combined with deep, parallel furrows in the trabecular bone was distinctive in the three felids in this study (leopard, lion, and caracal). This trauma, particularly the removal of the greater trochanter of the humerus leaving relatively deep, parallel furrows has also been observed in tigers and jaguars (11). The furrows in particular are caused by individual tooth cusps (11) as the animal tries to gain access to the marrow (28). This pattern suggests that, although the specific taxon cannot be determined from this trauma, the general identification of felid involvement can be concluded.

The taphonomic alteration of bone by large felids (such as lions, leopards, panthers, and tigers) has been previously studied, however medium-sized felids - such as the caracal - remain underappreciated. The caracals in this study exhibited the greatest variety of trauma. Caracals were the only animal in this study to cause all animal bite mark types: pits, furrows, scores, and punctures in addition to massive gnawing trauma and claw marks. This could

potentially be a discriminatory characteristic for identifying caracals from their trauma; however this needs to be studied in more depth to be stated definitively.

The trauma present on the surviving tibia retrieved from the hyena in this study is also distinct. Total consumption of the proximal end of the tibia, leaving one third of the shaft remaining with jagged fracture edges of the shaft, is a classic sign of hyena scavenging (11). The jagged fracture edges are typically not rounded (11) however in this study the fracture edges were slightly rounded. It has been suggested that the possible cause could be due to repeated licking or rubbing against ground surfaces (11). As the hyena used in this study was captive, the environmental context was different to those in the wild. The removal of competition with other animals for food allows for altered feeding behaviours and as a result different bone modification patterns can be expected (29).

Porcupine scavenging is well documented and has been described as a means of honing the incisor teeth or in cases of osteophagia when the individual animal lacks calcium and/or phosphorus (30). Porcupines will scavenge on fleshed and dry bone without discrimination between the two (31). Porcupine bone damage is well documented in previous literature and is distinguishable from other rodent bone damage (25, 30-33). Porcupine trauma has been described (in this study and other studies previously mentioned) as fan-like parallel scores with undefined contours and regions of heavy gnawing, and the scraping of the epiphyses and adjacent areas resulting in the total destruction of the bony region. The large, oval depression with an eroded, polished appearance observed in this study has not been described explicitly in previous literature. The exact cause is unknown but due to the projecting nature of the olecranon tuber as an easily grasped section of bone, the cause could perhaps be attributed to the repetitive grinding of the mandibular and maxillary incisors on the surface of the olecranon tuber. These characteristic traumas in conjunction with the absence of pits are indicative of porcupine intervention.

In summary, the characteristics of heavy scavenging trauma can be reliable indicators of the perpetrating animal. However, attributing a carnivore to bone modifications should not be based off a single pattern but rather a combination of bone modifications (27). For example the unique fan-like pattern of scores in combination to the absence of pits could suggest a porcupine as the causative taphonomic agent. Very light gnawing damage by all taxa of carnivores could be identical and are not very useful for differentiation between scavengers

(11). For example, the jackals caused very minimal and light trauma isolated to a few single scores and pits.

Limitations

The animals used in this study are of southern African origin, however the most promising bite patterns described by this study are applicable in other regions of the world. Porcupines are not only native to Africa but also in Europe and Asia. A study in Israel described similar porcupine destruction of bones (31). The bite patterns of the large cats in this study have also been described in other large cats such as tigers and jaguars (11). These patterns will therefore be observed in other non-African regions of the world with wild large cats, particularly Asia, North America and South America.

There is a difference in the extent of trauma caused by animals in captivity compared to animals in the wild. Gidna et al. (29, 34) determined that there is a higher number of tooth-marked elements and the number of tooth marks per element caused by lions in captivity and the wild (29), and similarly for leopards (34). Due to the altered animal behaviour caused by captivity, the extent of the bone modifications described are potentially more pronounced than those seen in a natural setting (29, 34). Nevertheless the described patterns of bone modification are still valid. It is suggested that this study be replicated in a natural setting to compare the extent of bone modification differences between the captive and free-roaming animals used in this study. Additionally, the descriptions of bone modifications to ribs are limited as the costal and sternal ends of ribs were sawn off prior to placing them in the animal enclosures. As such it is suggested that a study of scavenging rib trauma be repeated with whole specimens in the future. Additionally, the number of bones can be increased in future studies to ensure that the patterns described are common to each animal. Another issue that can be reviewed is the time animals have to scavenging on bones.

This was a descriptive study of bite marks observed on bone caused by different animals. As such a statistical comparison is very difficult. Most published articles of a similar nature typically only describe the trauma as these descriptions are of value (10, 11, 29, 35, 36). In studies where the sample size of the bones is large enough, the frequency of a particular bite mark pattern is provided (2) and this is something that can be repeated in a subsequent study for the same animals used in the present study. The value of qualitative research should not be underappreciated especially in taphonomic research.

Conclusion

The trauma caused to bone by scavenging animals can be used to isolate the perpetrating animals. Felids (such as lion, leopard, and caracal) gnaw away the greater trochanter of the humerus leaving deep, parallel furrows. Hyenas cause massive trauma to bone with little remaining fragments, however surviving long bones typically remain as one third of the shaft with jagged fracture edges. Porcupines leave distinctive fan-like parallel scores, and large, oval depression with an eroded, polished appearance. Light scavenging trauma can indicate the involvement of scavenging animal behaviour; however the exact taxa or species cannot be determined. These criteria will be helpful in the African forensic anthropological setting to discern scavenging trauma on bone and potentially isolate the animal which caused the trauma, and to distinguish between taphonomic scavenging trauma and perimortem trauma.

Funding: this study was funded by the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre (Federal ID no. 87-0287045)

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical Approval: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in this study involving animals were in accordance with the ethical standards of the institutions at which the study was conducted.

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Article 2

URBAN SCAVENGING BY THE SLENDER MONGOOSE (*GALERELLA SANGUINEA*) AND HADEDA IBIS (*BOSTRYCHIA HAGEDASH*) IN JOHANNESBURG, SOUTH AFRICA

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Journal: Formatted for Forensic Science International (under review)

Declaration: The contents of the paper are the original work of the authors submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Acknowledgements: The authors acknowledge the financial assistance of the National Institute of Justice and the Forensic Technology Center of Excellence along with the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre. Also acknowledged are GHB Farms and Mr. Dries Du Plessis for providing the pig carcasses; Ms. Allison Gilbert, Ms. Tracy Reindorp, and Ms. Rethabile Masiu for their assistance in the search for, and mapping of, the scattered patterns; Ms. Tracy Reindorp who took some of the photographs of scavenging modifications in this article; and Ms. Rethabile Masiu for her assistance with the maceration of the bones.

Abstract

Unidentified human remains are frequently recovered in urban environments in South Africa. These remains often exhibit animal scavenging modifications and are frequently scattered by animals. This study aimed to identify scavenging animals present in two urban environments common in Johannesburg, South Africa, and to describe their scavenging behaviors. Six pig carcasses (*Sus scrofa domesticus*) (40-80 kg) each were placed in a veldt in Frankenwald, Johannesburg and in an abandoned building complex in Braamfontein, Johannesburg. Motion-activated cameras recorded the scavenging. Scavenger species were identified and their behaviours, scattering pattern, and scavenging modifications were described. Slender mongooses (*Galerella sanguinea*) were the most prolific veld scavengers at the Frankenwald research site. They scattered remains to a maximum distance of 10.5 meters in two directions: north and south-east. They scavenged during the advanced and dry stages of decomposition on the skin and subcutaneous fat of the abdomen, on disarticulated limbs, and skeletonized scapulae, ribs, vertebrae and mandible. Gnawing on the angle of the mandible - with multiple parallel scores on the flat surfaces and the angle margin having a stepped appearance - may be a distinguishing bite mark feature of the slender mongoose. Multiple holes in the ground surrounding a carcass is suggestive of previous slender mongoose activity. Hadedda ibis (*Bostrychia hagedash*) were the only scavengers recorded scavenging on the intestines of a pig carcass in the abandoned building complex. They favored colonizing insects and created multiple, large holes in the skin and removed the lips to access the insects. The described scavenging behaviors will assist in the reconstruction of postmortem events in forensic cases and the location and collection of scattered remains.

Key words: taphonomy; scavenging; scattering; slender mongoose; hadeda ibis; South Africa

Literature review

Despite the rapid increase in global urbanization and conservation efforts to isolate animals within national parks and government protected areas, there is still a level of proximity and interaction between humans and wild animals, particularly in Africa (1, 2). For example, in Northern Ethiopia, spotted hyenas (*Crocuta crocuta*) continue to live in close proximity to humans in regions such as the Enderta district (1). In Kenya, it is estimated that up to 65% of the lion population is supported in the arid rangelands and these regions continue to be unprotected by the government (i.e. are not fenced off as a national conservation park) (3). Animal habitations are not isolated to rural and peri-urban areas; urban environments are also very biodiverse, particularly with scavenging animals (4). The increase in the proportion of the human population living in cities and towns does not isolate humans from wildlife (4, 5). The rarity of human remains found intact during forensic investigations highlights this fact (6).

Scavengers play an important role in urban ecosystems due to their general efficiency of carrion removal in such environments (6) yet these animals have received little attention by researchers (4). The general public tends to have unfavorable views of scavenger species (4). Studies in the UK have indicated that the bird species most disliked and killed by the public actually play an important urban role in the removal carrion (4, 7). There is an ongoing global shift in the perception of scavengers in the public eye as some species are becoming viewed more favourably as charismatic species (animals with symbolic value and general public appeal such as eagles and hawks) resulting in them becoming the focus of targeted conservation projects (8). An increased understanding of the important role scavengers play in urban ecosystems and their role in promoting the well-being of the public could lead to a greater appreciation and protection of these species (4).

The presence of scavenging animals in an urban environment results in the scavenging of human remains being a common phenomenon. In cities and suburban areas, domesticated pets (particularly dogs) have often resorted to feeding upon the soft tissues and skeletal remains of their deceased owners when they are locked indoors with the body – even if there are alternative food sources available (9, 10). Wild animals also scavenge on human remains in urban environments. In Cape Town, South Africa, the Cape mongoose and yellow mongoose have been identified as scavenger species which scavenge upon and scatter remains (11). Globally, there is a paucity of research on urban scavenging.

Animal scavenging on human remains can result in the presence of scavenging modifications on soft and hard tissues, and the disarticulation and scattering of remains over a large area. These post-mortem modifications of human remains in a forensic context need to be understood so as to distinguish between trauma that is animal-induced and trauma due to weapons caused by a human perpetrator. Scavenger feeding can also obscure preexisting traumatic injuries on soft tissues and skeletal elements and create post-mortem pseudo-trauma (12). These can all lead to the misinterpretation of evidence by forensic specialists (13, 14). The greater the understanding of the different scavenging modifications caused by different animals, the easier it will be to differentiate them from blunt, sharp, or ballistic trauma. More reliable search methods for locating scattered remains can also be implemented if one can identify a scavenger by the evidence it leaves at a scene (14). A more holistic and effective post-mortem forensic investigation can be achieved if there is an understanding of the interaction between different scavenger species and variables such as a species' dentition and size, environmental factors, the stage of decomposition, the state of skeletal elements, and the period of exposure (14-16).

Animal scavenging of forensic human remains is of particular interest in Johannesburg, South Africa. The Johannesburg Forensic Pathology Services (JHB FPS) Medico-legal Laboratory performs medico-legal postmortem investigations, including autopsies, of all unnatural deaths. On average this facility receives ± 3500 cases per annum. In 2010 a total of 4876 medico-legal autopsies were conducted, 109 of which were received in various stages of decomposition (17). Many of these cases exhibited evidence of scavenging on the soft tissues. The JHB FPS, in collaboration with the Human Variation and Identification Research Unit (HVIRU) (School of Anatomical Sciences, University of the Witwatersrand), perform the forensic anthropological analysis of numerous skeletonized remains received at eight medico-legal mortuaries (Southern Cluster of the Gauteng Forensic Pathology Services) in the Gauteng Province and other regions in South Africa. Between the years of 2007 – 2017 a total of 187 skeletal cases were received, of which 103 were referred to the HVIRU for anthropological analysis. These skeletal remains are often incomplete (either due to scattering and/or incomplete retrieval by police officers) and often exhibit taphonomic alterations such as animal scavenging modifications. Despite the large number of decomposed and skeletonized human remains of a forensic nature in Johannesburg, limited research on decomposition and taphonomic variables have been published (17, 18). The

presence, identification, and effects of scavenging animals in this region has not been previously explored. Studies that have been performed in other countries and regions cannot be applied in Johannesburg. This is because regional studies on scavenging and scattering patterns in different environments are required for forensic purposes as these patterns are specific to local environments and biomes (11).

The aim of this study was to identify the scavenging animals of forensic significance in two different environments in the city of Johannesburg, South Africa and to describe the animals' behavior and scattering patterns as well as the scavenging modifications left on the remains. The results from this study will assist in the thorough collection and analysis of scattered scavenged remains.

Methods

Two research sites were used in this study which are representative of the areas in which skeletal remains are commonly recovered in the Johannesburg area – urban velds and urbanized buildings. An urban veld is a large, open, uncultivated plot of grassland often bordered by industrial and suburban developments, common throughout Johannesburg. The Frankenwald research site (GPS: 26°04'15.7"S 28°06'12.2"E) owned by the University of the Witwatersrand was used to represent the veld environment (Figure 1). An abandoned building complex (GPS: 26°11'27.4"S 28°02'31.7"E) (previously a hospital - adjacent to the Johannesburg Forensic Pathology Services Medico-legal Laboratory) represented an urban city-center environment (Figure 3). Permission to use the abandoned building was granted by the Gauteng Department of Health and Gauteng Forensic Medical Services.

The study sample comprised of 12 domestic pig carcasses (*Sus scrofa domesticus*) weighing between 40-80kg. The pigs were donated by GHB Farms - a licensed pig farm - which died from natural causes due to hemorrhagic bowel syndrome, commonly called red gut. This is commonly caused by *Lawsonia intracellularis* or *Clostridium perfringens* and is a common cause of death experienced in large pig farms. Such pigs are often used in forensic decomposition and taphonomy research (19).

Six pigs were placed at the Frankenwald site between the months of March to December 2019. The pigs were left to decompose until they were skeletonized. The pig carcasses were placed in locations with varying levels of exposure. Two were completely exposed (no tree cover), three were partially exposed near a tree, and one was completely covered by tree

foliage (Figure 3). The pigs were placed at least 20m apart from each other (Figure 1). The pigs were secured in place by a chain around the torso, secured to a nearby tree or fence to facilitate longer viewing and recording times of the scavenging activity before remains were disarticulated and scattered beyond the view of the cameras.



Figure 1: Frankenwald research site outlined in the picture on the left (a square outlines the location the pigs) (Google Earth). The location where each pig was placed is represented by white dots in the picture on the right (Google Earth).



Figure 2: Representatives of how the pig carcasses were placed at Frankenwald in locations with varying levels of exposure. Two which were completely exposed (left), three which were partially exposed near a tree (middle), and one completely covered by tree foliage (right).

Six pigs were initially placed in the abandoned building complex in the months of March and June 2019. The pigs were left to decompose over a period of 4-7 months until they were in an advanced stage of decomposition. The pig carcasses were placed in locations with

varying levels of exposure. Two were placed in an outdoor garden with full exposure, two were placed in a courtyard with partial exposure, and two were placed indoors (Figures 3 and 4).



Figure 3: Abandoned building complex outlined in the picture with a white square (Google Earth).



Figure 4: Representatives of how the pig carcasses were placed at the abandoned building complex in locations with varying levels of exposure. Two were placed in an outdoor garden with full exposure (left), two were placed in a courtyard with partial exposure (middle), and two were placed indoors (right).

Motion activated, infrared Bushnell Trophy Cam HD Essential E2 12MP Trail cameras were used to photograph the scavenging of the carcasses. The cameras were set to the highest sensitivity, took three consecutive photographs when activated by motion, with a five second interval between motion activation. These cameras were activated by fly activity and hence were sensitive enough to capture the scavenger activity of small animals. Data from the cameras were downloaded every two weeks.

The photographs captured by the cameras were used to identify the scavenger species, describe the animal behavior including the time of day it is active, the number of scavengers active at a given time, the season it is active, the decomposition stage it is active, and the body region it prefers to feed upon.

The decomposition stages were assigned and adapted from the descriptions given by Michaud and Moreau (20) and Galloway *et al.* (21): the early stage (begins at the moment of death and ends with the onset of the bloated stage), the bloated stage (abdomen and/or neck distention, limbs are raised and/or protrusion of the anus), the active stage (complete deflation of the abdomen and moist decomposition with the presence of maggot masses on the carcass), the advanced stage (exposure of bone in less than half the of body), and the dry stage (skeletonization of more than half the body). The decomposition stages were assigned from what was viewed in the pictures and when the pigs were viewed in person.

After the remains were skeletonized and scattered, each surviving skeletal element was located using the walk-the-line method in a grid pattern and the located remains were flagged. Each surviving element was mapped using a grid pattern method common in archaeological and forensic anthropological practice.

The bones were macerated to remove all remaining soft tissues for bite mark analysis. An external light source in the form of a flashlight with controllable light intensity was used to locate and observe the trauma. The scavenging modifications on the bone were described.

Results

The slender mongoose (*Galerella sanguinea*) and water mongoose (*Atilax paludinosus*) (Figure 5) scavenged on the pig carcasses placed in the Frankenwald velt. Common large-spotted genet (*Genetta tigrina*) and a number of local domestic dogs were attracted to the carcasses and often marked the pig by rubbing themselves on the carcasses (Figure 6);

however, the genet and dogs were not recorded scavenging on the pig carcasses. A variety of diurnal birds were attracted to the carcasses and fed on colonizing insects, including Swainson's spurfowl (*Pternistis swainsonii*), helmeted guineafowl (*Numida meleagris*), pied crow (*Corvus albus*), hadeda ibis (*Bostrychia hagedash*), and a number of smaller unidentified birds. Nocturnally the spotted thick-knee (*Burhinus capensis*) was the only bird attracted numerous times and remained for long periods, feeding on colonizing and migrating insects. Other smaller nocturnal mammals observed visiting the carcasses were the Africa savannah hare (*Lepus microtus*) and South African pouched mouse (*Saccostomus campestris*). The South African pouched mouse visited the carcasses frequently, feeding on colonizing and migrating insects. There was no interspecies scavenging observed at the same time; however, multiple slender mongooses would scavenge together on rare occasions.

The slender mongoose was the most prolific scavenger at the Frankenwald site and its scavenging behavior and scattering patterns will be highlighted.



Figure 5: Pig carcasses were scavenged by slender mongoose (left) and water mongoose (right)

The slender mongoose mostly scavenged in isolation; however, pairs would occasionally scavenge together – one would scavenge on the pig's carcass while the other ate insects or kept watch. Slender mongooses were attracted to decomposing carcasses from the early and bloat stage of decomposition to feed on colonizing insects. The slender mongoose would often leave distinctive holes in the ground or disturbed soil or fallen foliage around a pig carcass as they exposed burrowed insects (Figure 7). They would also burrow under the carcass to access and remove the ribs if the skin was too hard for them to eat through (Figure

7). Slender mongooses scavenged on the pig carcasses in the active, advanced, and skeletonized stages of decomposition, particularly when the skin was drier. They showed a particular preference for the soft tissues of the abdomen (Figure 8). They would visit the carcasses regularly with an increase in the number of visits in the advanced stage of decomposition. Disarticulated limbs and skeletonized scapula were often selectively scattered away from carcasses. Individual skeletal elements which were favored were the mandible (particularly the angle), ribs, limb bones and vertebrae (Figure 8).



Figure 6: Scent marking by slender mongoose (top left), domestic dogs (top right and bottom left), and genet (bottom right)



Figure 7: Slender mongoose burrowing beneath a pig carcass (left – arrow) and holes in the ground around a pig carcass indicating slender mongoose digging for insects (right – arrow)

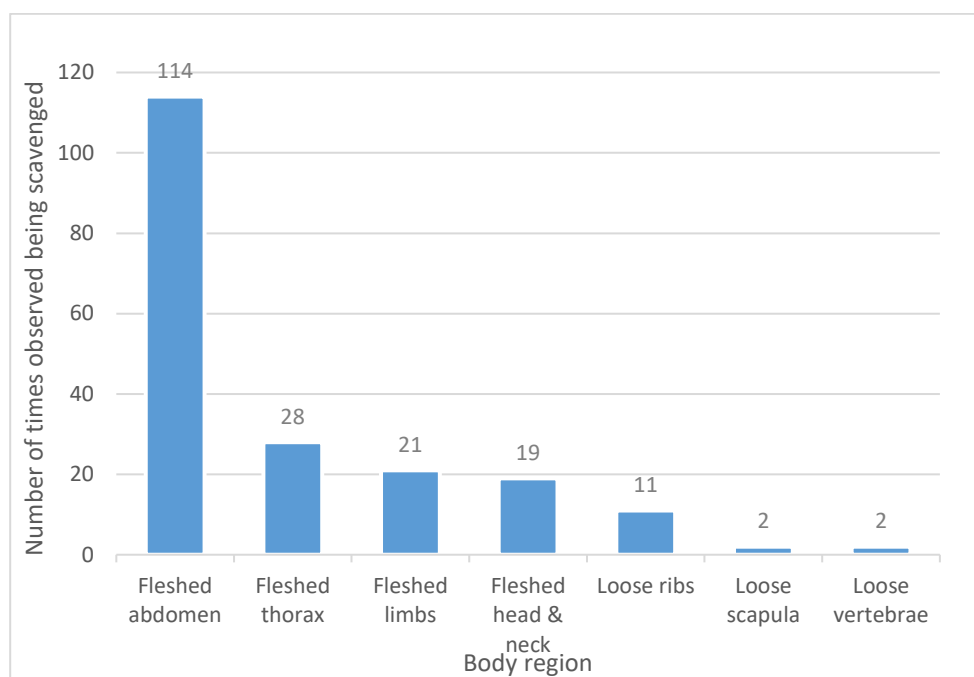


Figure 8: Slender mongoose scavenging preference of fleshed body regions and skeletal elements

The slender mongoose was diurnal and active between 05h00 and 18h00, most commonly observed scavenging between 10h00-10h59 and 14h00-16h59 (Figure 9). No seasonal differences were noted in their activity. A water mongoose; however, was observed only once. The water mongoose was nocturnal, in summer only, and scavenged only on the soft tissues of the abdomen.

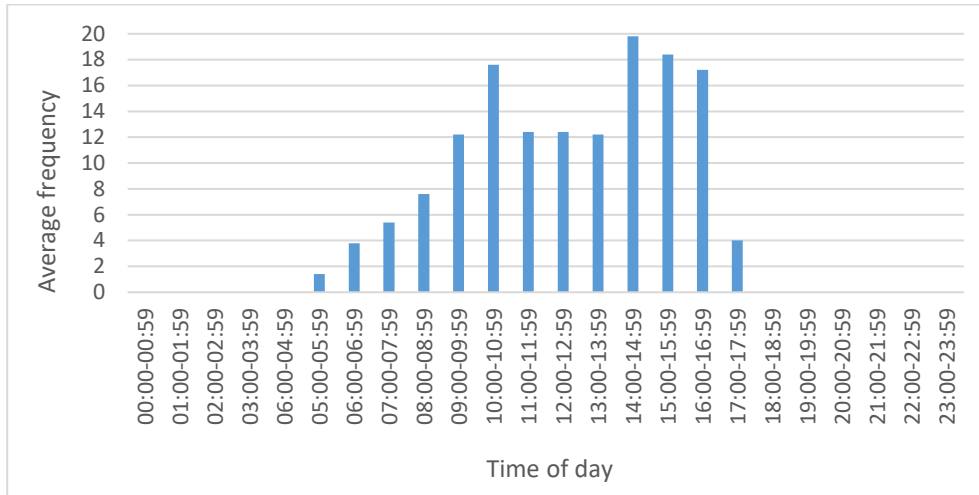


Figure 9: The hourly average frequency of slender mongoose scavenging of six pig carcasses

Skeletal remains were scattered over a small area by slender mongooses, starting with the fore limbs and hind limbs and followed by the scapula and ribs. The direction of each of the scattered remains over time was not unidirectional; however, they would increase in distance away from the original location. The remains were scattered over an area with a maximum radius of 10.5m/34.4ft (Figure 10). The skeletal remains were scattered in two general directions: towards the north and south-east (Figure 10). Disarticulated limbs and scapulae were scattered the furthest and these were often unrecovered at the end of the study. The scattered remains were often located under the cover of trees, fallen foliage, or high grass. There were no significant seasonal differences noted in their behavior.

The slender mongoose did not often leave scavenging modifications on the skeletal elements; however, the few scavenging modifications that were observed were isolated to the ribs, vertebrae, scapula, and mandible (Figure 11). Gnawing on the mandible was concentrated on the angle of the mandible with multiple parallel scores on the flat surfaces and the angle margin having a stepped appearance (Figure 11). The anterior border of one scapula exhibited a series of isolated gnaw marks in the form of furrows (Figure 11). The anterior and posterior ends of the ribs and the transverse processes of the vertebrae were gnawed off with a crushed appearance (Figure 11).

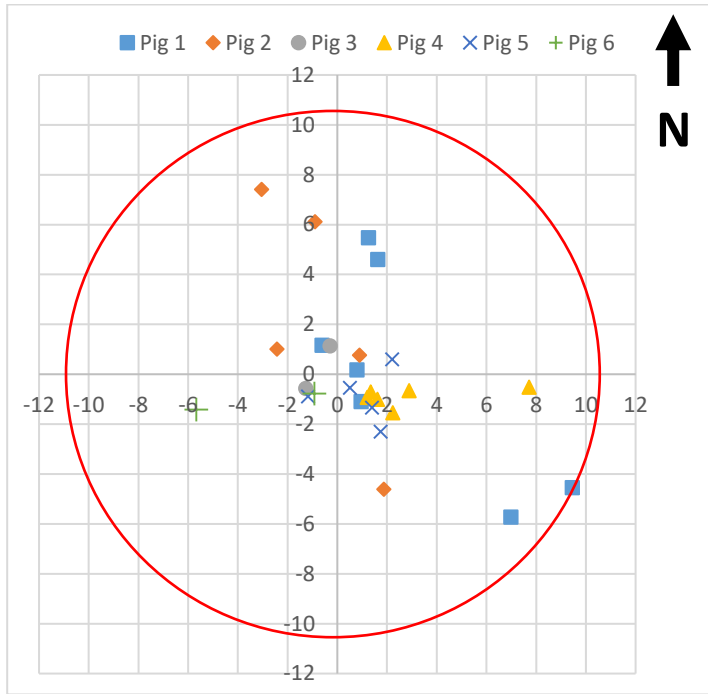


Figure 10: Scatter plot of the skeletal elements of six pigs by slender mongooses, showing distance (in meters) and direction of scattering. The origin (0;0) indicates the original position of each pig. Northern arrow indicates the relative scatter direction. Radius arrow indicate the maximum scatter radius (radius = 10.5m)



Figure 11: Slender mongoose gnaw and scavenging modifications on the mandibular angle (top left – circled), transverse process of a vertebra (top right – circled), superior boarder of a scapula (bottom left - arrows), and rib (bottom right - circled).

At the abandoned building complex in the city center of Johannesburg, very little scavenging occurred on the pig carcasses. A number of feral cats were observed passing by all of the carcasses (indoors and outdoors) but they showed no interest in the carcasses. A large variety of small birds scavenged on the colonizing insects as they migrated away from the courtyard carcasses to pupate. The hadeda ibis (*Bostrychia hagedash*) was the most prolific bird attracted to the decomposing pig carcasses. They were active in all seasons, were diurnal (active between 05:30-17:30) and scavenged together in numbers from one to four at a time. The hadeda ibis' were present in all stages of decomposition; however, their presence increased during the active and advanced stages of decomposition when there was an increase in insect colonization and migration. The hadeda ibis' would alter the soft tissues of the pig in order to gain access to the insects within the carcasses. This included removing the lips (Figure 12) and creating numerous large holes in the skin of the pig carcasses (Figure 12). In one instance, the hadeda ibis was observed scavenging on a portion of the intestines (Figure 13). No scavenging on the pig skeletal elements was noted.



Figure 12: Haded ibis feeding on insects through a hole in the skin (left), multiple holes created in the skin by hadeda ibis (center), and lips removed by hadeda ibis (right)



Figure 13: Haded ibis scavenging on pig intestines

Discussion

This study has described the unique scavenging behaviors of animals in urban areas in Johannesburg, South Africa. The slender mongoose was the most prolific scavenger in a veld environment and understanding its scavenging behavior is of vast importance for forensic investigations for the recreation of postmortem events. The slender mongoose has a widespread distribution throughout sub-Saharan Africa (22) but within South Africa it is restricted to the northern parts of the country (23). The slender mongoose is typically solitary; however, the same home range can support up to four other individuals and they will, on rare occasions, form small groups (24). Slender mongoose dens are often holes, dens, and warrens originally dug by other animals, often in old termite mounds (24). Largely diurnal, the slender mongoose will on occasion hunt at night if it is warm and accompanied by bright

moonlight (22). It is a generalist carnivore with a diet of mainly small vertebrates and insects; however, it will also scavenge on the carcasses of mammals (25). They will scavenge on small carcasses (such as hyrax) and medium carcasses (such as antelope and wildebeest) (26). Larger carcasses are often avoided as they may be perceived to be a high risk for predation (27), but they have been observed scavenging on and around large carcasses (such as giraffe) (28).

The present study is the only study to describe the scavenging behavior of the slender mongoose with a forensic perspective. The only other comparable studies are those by Spies *et al.* (11, 29) performed in Cape Town, South Africa on Cape mongoose (*Galerella purpurulenta*). Despite the environment and climate of their studies in Cape Town, South Africa being very different to Johannesburg, they identified the Cape grey mongoose as a scavenger of forensic interest (11). Despite the environment and climate of Johannesburg and Cape Town being very different and the slender mongoose and Cape mongoose being different species, their scavenging and scattering behaviors are comparable.

The behaviors of both species had a number of similarities. Both mongoose species were observed to be mostly solitary; however, they were social on occasion as multiple mongooses were noted scavenging together - slender mongooses were observed scavenging in pairs and the Cape mongoose sometimes scavenged in groups of up to three individuals at a time (29). Both the slender and Cape mongoose were diurnal – their activity was exclusively during daylight hours (29). Both species visited pig carcasses with a consistent frequency, with the duration decreasing over time as the remains became progressively skeletonized (11).

Both the slender and Cape mongoose began to scatter the remains when the bones were still greasy with desiccated tissue still adhering to them (described as the advanced stage in this study and described as the early skeletonization stage in the study by Spies *et al.* (11)). The limbs were the first elements to be scattered by both the slender mongoose and Cape grey mongoose (11). The slender mongoose also showed a preference for scattering the scapulae. The distance of scattering was also comparable - the Cape grey mongoose scattered remains to a maximum distance of 12.67m (11) and the slender mongoose scattered remains to a maximum distance of 10.5m. The comparable scattering distance could be attributed to the similar size of the slender mongoose and Cape mongoose. The

slender mongoose averages 44-65cm in length and weighs 280-488g compared to the slightly larger Cape grey mongoose which averages 55-76cm in length and weighs 500-1250g (23). The distance and size of a skeletal element scattered by an animal is dependent on the relative size and strength of the scavenger and would account for the similar scattering distance with the slender mongoose's distance being slightly shorter than that of the Cape grey mongoose (30). Both species also scattered the remains of individual carcasses in two main directions: the slender mongoose scattered remains in a north and south-east direction, whereas the Cape grey mongoose scattered remains in either the north and west south-west directions or south and west directions (11). These are assumed to be in the direction of the mongoose dens. This understanding of consistent scattering behavior is important knowledge for those recovering scattered forensic remains to ensure the complete recovery of surviving remains for a holistic skeletal analysis. Understanding the effects of scavenging is also important in the estimation of a postmortem interval. Spies *et al.* (29) noted that mongoose scavenging increased the decomposition rate by at least six-fold (29). This alteration of the decomposition rate would lead to an overestimation of the postmortem interval if the influence of the mongoose activity was unknown (29).

The bite mark patterns on the ribs and vertebrae of the slender mongoose and Cape grey mongoose were both non-specific or cannot be used diagnostically to identify the animals. The Cape grey mongoose often damaged the epiphyseal ends of long bones, ribs were completely consumed and vertebral spines were damaged (11). The extent of bone damage caused by the Cape grey mongoose appears to be greater than that by the slender mongoose and could possibly be attributed to the larger size of the Cape grey mongoose. The slender mongoose left very few scavenging modifications on the skeletal elements. The few ribs that exhibited scavenging modifications were consumed at the anterior and posterior ends leaving a non-specific crushed margin, as were the transverse processes of the vertebrae. The gnawing marks on the anterior border of the scapula are distinctly caused by animal scavenging, but these scavenging modifications in isolation may not be solely indicative of slender mongoose scavenging. The location and pattern of gnawing marks on the angle of the mandible; however, appears to be a distinct bite mark pattern of the slender mongoose. This, in addition to other markers of mongoose activity, could be diagnostic of slender mongoose activity. Additional indications of slender mongoose activity could include the multiple holes dug around the body and the presence of spoor near the body (11). The

behavior of digging holes around a carcass to excavate fly pupae has been previously observed and appears to be a unique feature of slender mongoose behavior (28).

A number of animals other than the slender mongoose were attracted to the pig carcasses. The difference in animal diversity indicates the importance of repeating research in unique environments as the postmortem events are not directly comparable. Numerous bird species and a South African pouched mouse fed on the colonizing insects. An Africa savannah hare also visited the carcasses out of apparent curiosity. The presence of birds and rodents were also noted in a Cape Town scavenging study (29). The common large-spotted genet, slender mongoose, and numerous dogs marked themselves with the pigs' scent by rubbing themselves on the carcasses. This behavior, called interspecific scent marking, is widely recorded in carnivores (31) but the exact reason is unknown and could be different for each species. Slender mongooses and small-spotted genets often visit cheetah scent-marking trees to rub the scent onto themselves (31). Slender mongooses will often mark themselves with a scent after a genet has visited and marked at a site (31). It is unknown why slender mongooses and genets overmark each other's scents (31). It is presumed that smaller mammals mark themselves with the scent of a dominant predator for protection but it is unclear how the overmarking behavior of dogs and small nocturnal genets would enhance the survival of diurnal mongooses (31).

In the abandoned building complex in central Johannesburg, the hadeda ibis was surprisingly the only scavenger that actively scavenged on the pig carcasses. The hadeda ibis is a common, relatively large sized (approximately 1.2 kg), indigenous southern African bird (32). They are typically associated with wetlands where they forage for insects in soft, moist soil (32). In South Africa the hadeda ibis population and its range has increased continuously since 1910, particularly in urban environments, as it has exhibited to be a successful urban exploiter (32, 33).

It is unsurprising that the hadeda ibis scavenged on the colonizing and migrating insects on and around the pig carcasses as these invertebrates are the primary source of their diet. The large holes in the pigs' skin caused by hadedas trying to gain access to the insects is of special interest. These are postmortem taphonomic artifacts which should not be confused with perimortem sharp force or ballistic trauma. Also of note, to the knowledge of the authors, this is the only recorded instance of hadeda ibis actively scavenging on carcasses and

feeding on the intestines. Hadedda ibis were observed to be attracted to carcasses in a Cape Town scavenging study by Spies *et al.* (34); however, the hadeda ibis were not observed scavenging in that study. Given the wide range and large number of hadeda ibis in South Africa, particularly in urbanized centers, it is important that their scavenging behaviors be known for the accurate reconstruction of postmortem events in urbanized South Africa.

A surprising result was the absence of rats and cats scavenging in the abandoned buildings. Rats have been observed at the site as well as a large feral cat population; however, they did not scavenge on the carcasses. It is assumed that the cats preferentially hunted the rats and had no need to feed on the pig carcasses. Spies *et al.* (11) also noted in their study that domestic cats were present but they were not observed scavenging. This suggests that cats will not scavenge when an alternative food source is available and that the cats are keeping the rat population down at the research site.

Conclusion

Slender mongooses (*Galerella sanguinea*) were the most prolific urban veld scavengers at the Frankenwald research site. They scattered remains to a maximum distance of 10.5 meters in two directions: north and south-east. They scavenged during the advanced and dry stages of decomposition on the skin and subcutaneous fat of the abdomen, on disarticulated limbs, and skeletonized scapulae, ribs, vertebrae and mandible. Gnawing on the angle of the mandible - with multiple parallel scores on the flat surfaces and the angle margin having a stepped appearance - may be a distinguishing bite mark feature of the slender mongoose. Multiple holes in the ground surrounding a carcass is suggestive of previous slender mongoose activity. The hadeda ibis (*Bostrychia hagedash*) was the only scavengers recorded scavenging on the intestines of a pig carcass in the abandoned building complex within an urban setting. They favored colonizing insects and created multiple, large holes in the skin and removed the lips to access the insects. The described scavenging behaviors will assist in the reconstruction of postmortem events in forensic cases and the location and collection of scattered remains.

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Article 3

ANIMAL SCAVENGING ON PIG CARCASSES IN THE LOWVELD OF SOUTH AFRICA

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Journal: Formatted for Forensic Science International (under review)

Declaration: The contents of the paper are the original work of the authors submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Acknowledgements: The authors acknowledge the financial assistance of the National Institute of Justice and the Forensic Technology Center of Excellence along with the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre. Also acknowledged are GHB Farms and Mr. Dries Du Plessis for providing the pig carcasses; Mr. Richard Keyes and Ms. Allison Gilbert for assistance in the laying out of the pigs and the mapping of the scattering patterns; Wits Rural Facility, Prof. Wayne Twine and Mr. Cameron Watt for providing the research site; Ms. Tracy Reindorp who took the photographs in this article; and Ms. Rethabile Masiu for her assistance with the maceration of the bones.

Abstract

Scavenging animals often scatter skeletal remains of forensic interest and leave scavenging modifications. This study aimed to identify scavenging animals in the rural Lowveld of South Africa and to describe their scattering pattern and scavenging modifications on bone. Ten pig carcasses (*Sus scrofa domesticus*) (40-80 kg) were placed at the Wits Rural Facility, Limpopo, South Africa during the summer and winter seasons. Motion activated cameras recorded the scavenging. Scavenger species were identified and their behaviors, scattering pattern, and scavenging modifications were described. Scavenging was primarily by vultures (hooded, white-backed, and lappet-faced). Marabou stork, slender and banded mongoose, genet, civet, warthog and honey badger also actively scavenged. Vultures began to scavenge the pig carcasses after 18hrs in summer and between 26-28 hours in winter and skeletonized pig carcasses rapidly between 5 - 98 minutes. Skeletonization occurred more rapidly and diffusely in summer while winter cases were densely scattered. Overall the scattered remains were within an area of 157.9m²/1705.5ft² with a radius of 7.09m/23.3ft. Vultures cleaned bones thoroughly with very minimal markings - primarily nonspecific scores. The described scattering pattern and scavenging modifications will assist in the recovery and analysis of scavenged remains.

Key words: taphonomy, scavenging, vulture, South Africa, scattering

Introduction

An important part of any forensic investigation is the recovery of remains. The quantity of evidence available to forensic investigators for analysis is determined by the quality of a scene's management. Young et al. (1) highlighted that 53% of police specialists (n=90) who participated in a survey on scavenging in a forensic context, in the United Kingdom, indicated that they had been involved in a search for scattered scavenged human remains (1). The scattering of remains by scavenging animals presents an obstacle to the recovery of forensic evidence. Regrettably, there are no international standardized protocols for the search and recovery of scavenged and scattered human remains. A large proportion of the investigators surveyed by Young et al. (1) (80.83%) indicated that they were unable to recover the entire set of human skeletal remains even when assisted by a cadaver dog (1). In a subsequent study, Young et al. (2) found that investigating officers with an understanding of scavenging behaviors were twice as successful in the recovery of skeletal remains than those without the same knowledge (2). It is pertinent to have an understanding of the scavenging animals, which are active in an area of forensic interest, and an understanding of their scavenging behavior and scattering patterns.

Some scavenging animals commonly associated with the post-mortem modification of human remains include dogs, rodents, birds, coyotes, vultures, fish, crabs, turtles, opossum, and raccoons (3, 4). House pets have also been recorded to scavenge on their deceased owner (5). Other less common animals, which have opportunistically scavenged on forensic cases include wolves, leopards, and lions (6, 7). The scavenging animals that are active are often geographically isolated or unique. North American scavenging studies of a forensic nature have included wolves, coyotes, rodents, raccoons, foxes, opossums, striped skunks, crows, and turkey vultures (7, 8). European research has described scavenging by deer, buzzard, carrion crow, wood mouse, and gray squirrel (7). In African and Asian countries, large felids such as lions, leopards and tigers have been known to occasionally scavenge on human remains (6). South African research on animal scavenging and scattering behaviors in a forensic context is lacking with only a few studies having been published in South Africa (9-11).

It is of forensic importance to understand the behaviours of these scavenging animals, such as their scattering patterns. The pattern of scattering of elements from their original site of deposition has been shown to be specific to different scavenging animals (12). Bones in

particular are often disarticulated by scavengers from a body and moved from the original area of deposition. For example, skulls are often removed and buried elsewhere as a form of food storage by raccoons and coyotes (13). The disarticulation and scattering of skeletal elements has shown to extend over a large area (12). Animal scavenging also often cause some trauma or modification to skeletal elements, which is often not related to the feeding of the animal but rather the relocation of the remains. For example, the previously fused sutures of the cranium often split open when a skull is scattered away from its original depositional site by a scavenging animal (13).

The morphology and location of animal scavenging modifications to skeletal remains and the state of the bones can be indicative of the species of the offending scavenger since different species have unique preferences for body regions and decomposition stages (11). Dogs commonly bite the head and neck of decedents (14). Pickering and Carlson (6) found that the skeletal elements most likely to be recovered after leopard feeding, are the C1 and C2 vertebrae, scapulae, os coxae and long bones of the limbs, as they are not consumed in their entirety. A number of other skeletal elements may be recovered in the scat including fragments of thoracic and lumbar vertebrae, clavicles, patellae, and the bones of the hands and feet; including the carpals, tarsals, and phalanges (6). Felids (including lions, leopards, and caracals) prefer to gnaw the greater trochanter of the femur and greater tubercle of the humerus leaving deep, parallel furrows (11). Bite marks caused by the scavenging activities of rodents are common on skeletal remains that are dry and weathered (15) – thus, the timing of skeletal trauma can be assessed.

The behavior of scavenging species is variable. Knowledge of how scavengers behave and when they are active can assist in the reconstruction and timing of post-mortem events. The timing of when scavenging trauma occurred might be broadly estimated if the identity of the scavenger can be inferred from the trauma it has inflicted. For example a rudimentary estimated post-mortem interval could be established in cases of vulture scavenging. When environmental and weather conditions are favourable, carcasses can be completely skeletonized by vulture scavenging in less than 12 hours (12).

The sequencing of trauma caused by different scavenger species may be possible as Young et al. (7) observed, in their European study, that there was never more than one scavenging species feeding on a carcass at one time and never more than two individual animals of the

same species scavenging a carcass at one time. A study of these behaviors has the potential for the development of a time-line in a forensic case where understanding the post-mortem sequence of events is crucial.

Literature of a forensic nature identifying scavenging animals, their behaviors, and scattering patterns in South Africa is severely lacking. In rural South Africa, the proximity of humans to wild animals is high. Animal attacks are common and often involve tourists in game reserves and poachers. Human skeletal remains are often recovered in such rural locations (11). Therefore, the aim of this study is to identify the scavenging animals of forensic significance in a rural region of South Africa and to describe the animals' behavior and scattering patterns as well as the scavenging modification left on the skeletal remains. The results from this study will assist in the more thorough collection and analysis of scattered remains.

Methods

Research was conducted at the Wits Rural Facility (WRF), which is a rural campus of the University of the Witwatersrand situated near the border of the Kruger National Park game reserve (Figure 1). The WRF is a 315 hectare estate of savannah woodland in the central Lowveld of the Limpopo Province. The WRF is home to a variety of antelope, large cats (serval and caracal), vervet monkeys, baboons, and giraffes. The WRF is neighbored by private game reserves containing elephant, buffalo, lion, leopard, and hyenas - which occasionally cross the fences into the WRF.

The study sample comprised of 10 domestic pig carcasses (*Sus scrofa domesticus*) weighing between 40-80kg. The pigs were donated by a licensed pig farm and died from natural causes due to hemorrhagic bowel syndrome, commonly called red gut. This is commonly caused by *Lawsonia intracellularis* or *Clostridium perfringens* and is a common cause of death experienced in large pig farms. Such pigs are often used in forensic decomposition and taphonomy research (16).

Five pigs were deployed at the site in August (winter) and five in October (summer). Five pigs were placed under trees (three in summer; two in winter) and five were exposed in the open (i.e. avian view not obscured by foliage) (two in summer; three in winter). The pigs were placed at least 50m apart from each other (Figure 1).

The first five pigs placed at the WRF (in winter) were secured in place by a chain around the torso, secured to a nearby tree or fence to facilitate longer viewing and recording times of the scavenging activity before remains are disarticulated and scattered beyond the view of the cameras. However this was deemed unnecessary after the first five pigs were studied because the scavenging of the remains largely fell within the scope of the camera and were recorded. As such, subsequent pigs placed in summer were not secured by chains. The scavenging and scattering of remains were not influenced by the chains.

Motion activated, infrared Bushnell Trophy Cam HD Essential E2 12MP Trail cameras were used to photograph the scavenging of the carcasses. The cameras were set to the highest sensitivity, took three consecutive photographs when activated by motion, with a five second interval between motion activation.

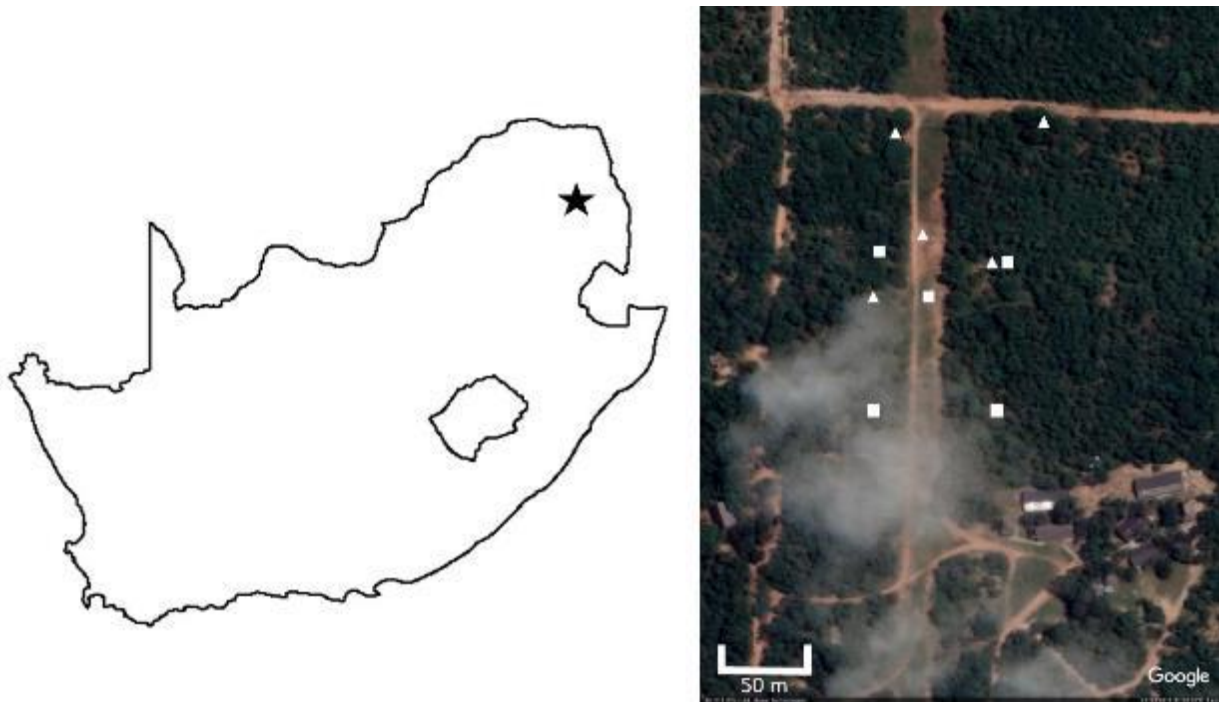


Figure 1: Location of Wits Rural Facility in South Africa (star in the map on left) and the approximate location of where the pigs were placed (winter pigs marked with a triangle and summer pigs marked with a square) on a Google Earth photograph of the Wits Rural Facility

The photographs captured by the cameras were used to identify the scavenger species, describe the animal behavior including the time of day it is active, the number of scavengers

active at a given time, the season it is active, the decomposition stage it is active, and the body region it prefers to feed upon. Due to the rapid rate of scavenging, the decomposition stage was simply recorded as fresh or skeletonized.

After the remains were skeletonized and scattered, the location of each element was located using a spiral search method and remains were flagged. Each surviving element was mapped using a grid pattern method common in archaeological and forensic anthropological practice.

The bones were macerated to remove all remaining soft tissues for analysis of scavenging modifications of the bones. An external light source in the form of a flashlight with controllable light intensity was used to locate and observe the trauma. The remains were visited daily and the visible bone modifications were recorded in situ. If only one species was recorded by the cameras to scavenge on the skeletal element that day, that species recorded as the perpetrating scavenger. The scavenging bone damage, which was observable after maceration, was directly assigned to a scavenger species if the damage event was captured on camera, or indirectly by comparing the patterns described in previous research (11, 17, 18).

Results

A number of animals actively scavenged on the pig carcasses, including the white-backed vulture (*Gyps africanus*), hooded vulture (*Necrosyrtes monachus*), lappet-faced vulture (*Torgos tracheliotos*), marabou stork (*Leptoptilos crumenifer*), common large-spotted genet (*Genetta tigrina*), African civet (*Civettictis civetta*), slender mongoose (*Galerella sanguinea*), banded mongoose (*Mungos mungo*), common warthog (*Phacochoerus africanus*), and honey badger (*Mellivora capensis*) (Figures 2-4; Table 1). Bush pig (*Potamochoerus larvatus*) and giraffe (*Giraffa*) were attracted to the carcasses; however, they were not recorded actively scavenging the remains (Figure 4).

The different vulture species and marabou storks would scavenge together at the same time; however, all other scavenging species would not scavenge at the same time as another species. These other species would also scavenge in isolation (i.e. only one single animal would scavenge at a time) with the exception of the honey badgers and banded mongooses, which both scavenged as a pair (Table 1). Ribs were the most common skeletal element scavenged in this study (Table 1). All of the scavengers were active when the remains were

skeletonized; however, the white-backed vulture, hooded vulture, and common large-spotted genet were also active in the early stage of decomposition.

The white-backed and hooded vultures, marabou stork, common large-spotted genet and slender mongoose were active and scavenged year-round. The lappet-faced vulture, African civet, and banded mongoose were only observed in winter while the honey badgers and warthogs were only observed in summer (Table 1).



Figure 2: Avian scavengers including white-backed vulture (top left), lappet-faced vulture (top right), hooded vulture (bottom left), and marabou stalk (bottom right)



Figure 3: Smaller mammalian scavengers including slender mongoose (top left), banded mongoose (top right), common large-spotted genet (bottom left), and honey badger (bottom right)



Figure 4: Larger mammalian scavengers including giraffe (top left), African civet (top right), warthog (bottom left), and bush pig (bottom right)

Table 1: The scavenging behaviors of Lowveld scavenging animals

Animal	Maximum number of animals of the same species active at the same time at the same carcass	Decomposition stage active	Body region preference	Time active	Season active
White-backed vulture	40	Early, skeletonized	No particular preference noted	Diurnal	Summer & winter
Hooded vulture	4	Early, skeletonized	Abdomen, intestines, anus (head inserted)	Diurnal	Summer & winter
Lappet-faced vulture	1	Skeletonized	No particular preference noted	Diurnal	Winter only
Marabou stork	2	Skeletonized	Ribs, scapula and loose skin	Diurnal	Summer & winter
Common Large-spotted Genet	1	Early, skeletonized	Anus (head inserted) and ribs	Nocturnal (late evening)	Summer & winter
Slender mongoose	1	Skeletonized	Skin and ribs	Diurnal (early morning)	Summer & winter
Warthog	1	Skeletonized	Ribs and vertebrae	Diurnal (early morning, late afternoon)	Summer only
African civet	1	Skeletonized	Ribs and pelvis	Nocturnal	Winter only
Banded mongoose	2	Skeletonized	Ribs	Diurnal (late afternoon)	Winter only
Honey badger	2	Skeletonized	Ribs and limbs bones	Nocturnal (early morning)	Summer only

Diurnal scavengers impacted more significantly on the consumption and scattering of the pig carcasses than nocturnal scavengers. Vultures (white-backed, hooded, and lappet-faced) were responsible for the consumption of the soft tissues and accounted for most of the scattering of the skeletonized remains; however, the marabou stork and warthog consumed whole skeletal elements, which affected the specific skeletal elements recovered after scavenging.

Vultures were the most prolific scavengers in the Lowveld, and as such their scavenging behavior will be highlighted. The pig carcasses were deposited in the late afternoon in both the summer and winter periods. In summer the vultures began to scavenge early the following morning at 09h00 (18 hours after pig deposition). In winter the vultures began to

scavenge after two different periods depending on the location of the pig deposition. Vulture scavenging of pig carcasses lying in the open began in the afternoon (13h00-14h00), 26-28 hours after deposition. Pigs that were laid near fences began to be scavenged by vultures in the morning (09h00-10h00), 90 hours after deposition (Figure 5). The exposure of pigs either in the open or beneath trees did not have an impact on when the pigs were scavenged by vultures in both seasons.

A single hooded vulture was typically attracted to the carcasses first and began to scavenge on the abdomen, thorax, head, and often would insert their head into the anus to gain access to the intestines. White-backed vultures would also be attracted to the carcass during the early decomposition stage and would insert their heads deep into the mouth and throat of the pig carcass. Once the abdomen was perforated and the intestines were exposed, white-backed vultures would push out the hooded vultures and would congregate in numbers ranging from 20 to 30 vultures (up to 40 vultures in one case) in a feeding frenzy. In winter this behavior would start after 2-72 minutes after the first vulture is attracted; however, in summer this would begin after 1-2 minutes.

In winter the pig carcasses were skeletonized by the vultures between 20-98 minutes after first arrival; however, in summer they were skeletonized between 5-26 minutes (Figure 5) after first arrival. The number of vultures drastically decreased ($n < 10$) once skeletonization was achieved. Marabou stork, lappet-faced vultures, and hooded vultures would join the white-backed vultures after the pig carcasses were skeletonization and disarticulated.

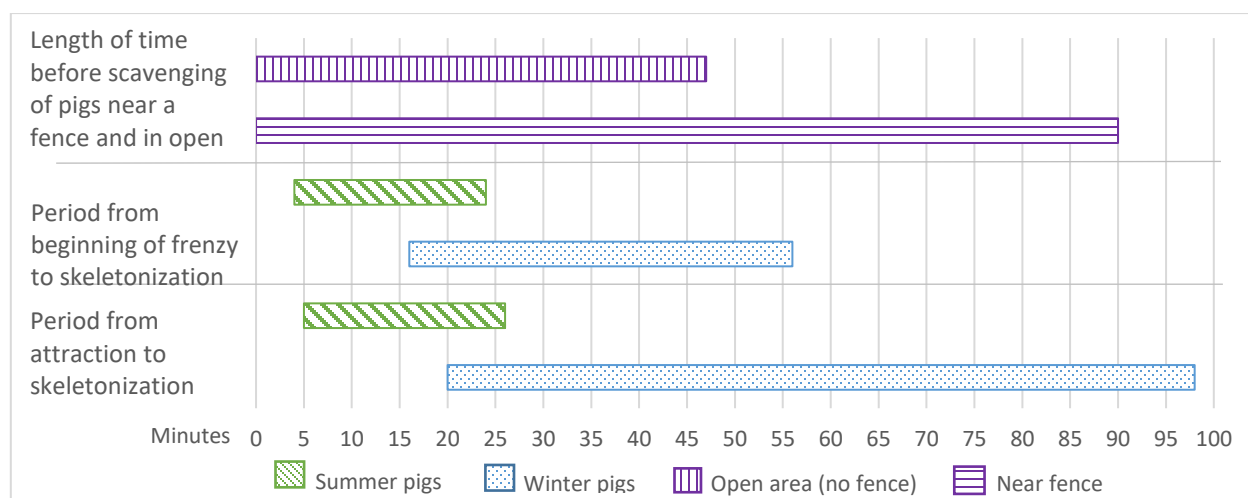


Figure 5: The range of time taken for vultures to begin scavenging and skeletonize pig carcasses in summer and winter

Vultures were very efficient in the skeletonizing of the pig carcasses. The skeletonized vertebral column, rib cage, and pelvis often remained articulated together. The skin was often intact in a single piece with the skull and limbic bones sometimes partially attached. The cranium, mandible, limbs, scapulae, and some ribs were often disarticulated and scattered. The skeletal remains of the winter sample were scattered in a dense pattern within an area of $102.1\text{m}^2/1098.6\text{ft}^2$ with a radius of $5.7\text{m}/18.7\text{ft}$ (one outlying element – pelvis - was scattered beyond this radius at $23.9\text{m}/78.4\text{ft}$) (Figure 6). The summer sample was scattered in a more diffuse pattern within an area of $157.9\text{m}^2/1705.5\text{ft}^2$ with a radius of $7.09\text{m}/23.3\text{ft}$ (Figure 6).

After skeletal remains were scattered by vultures, other animals (mongoose, civet, banded and slender mongoose, genet, warthog, and honey badger) would further scatter the remains; however, within the radius of the vulture scattering.

Vultures left very few marks on the bones. The few markings that were produced were isolated to superficial scores on the flat surfaces of the cranium, mandible, scapulae, and long bones (Figure 7). The distal ends of the transverse processes of the vertebrae were often broken off (Figure 7) while large superficial pits were noted on the humerus in one case (Figure 7).

Of note is the skeletal trauma caused by warthogs. Warthogs caused considerable damage to bone, mostly consuming all ribs and vertebrae, with only splintered and fragmented vertebrae and ribs surviving (Figure 8).

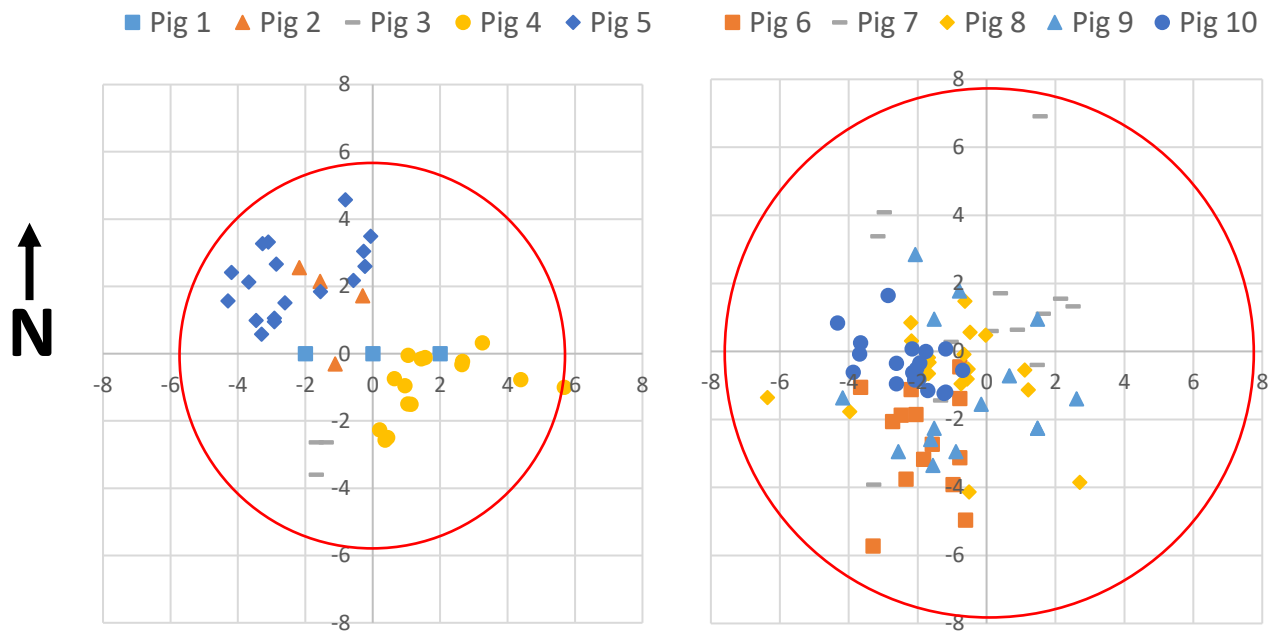


Figure 6: Scatter plot of the skeletal elements of ten pigs, five in winter (left) and five in summer (right), scattered primarily by vultures, showing distance (in meters) and direction of scattering. The origin (0;0) indicates the original position of each pig. The arrow indicates the relative scatter direction. Circles indicate the scatter radius (summer radius = 7.09m; winter radius = 5.7m with one outlying element scattered beyond this radius not included in the figure)

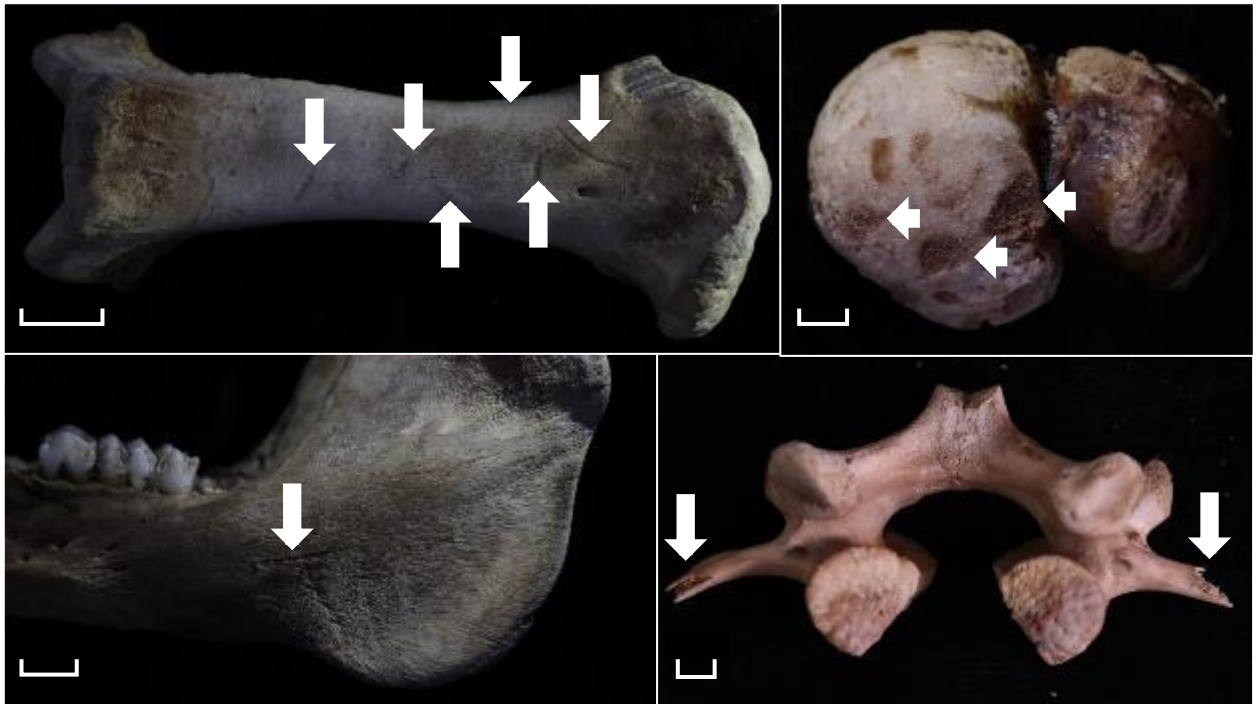


Figure 7: Vulture scavenging modifications pointed out by arrows in the form of scores on the femur (top left) and mandible (bottom left), pits on the head of humerus (top right), and fractured transverse process on vertebrae (bottom right). Scale represents 10mm.



Figure 8: Warthog scavenging resulting in the splintering of the transverse process on vertebrae (left) and fragmentation and splintering of the ribs (right). Scale represents 10mm.

Discussion

The scavenging behaviors of animals is variable and an understanding of their behaviors can assist in the reconstruction and timing of post-mortem events. Vultures were the most prolific scavengers in the South African Lowveld and an understanding of how long it takes for them to be attracted to a body and to skeletonize the body is necessary in the estimation of a postmortem interval.

The white-backed vulture, lappet-faced vulture, and hooded vulture are all common to the Lowveld of South Africa (17). The white-backed vulture is most common and is present year-round (17). Marabou storks also visit the area although they are often observed mostly in the wet season during the warmer months (17). The hooded vulture inhabits a variety of habitats (18). South of the African equator this species is solitary and can be located in deserts, forests, and savanna (19). North of the African equator, the hooded vulture can be found in large groups and can also be located in urban areas near rubbish dumps and slaughterhouses (19).

White-backed vultures, lappet-faced vultures, and hooded vultures rely on their vision to find carcasses to eat (22). Hooded vultures are often the first avian scavengers to locate and feed on a carcass, followed closely by lappet-faced and white-backed vultures (23). Lappet-faced vultures regularly search for carcasses within a restricted area, as a result they often detect a carcass before larger groups of white-backed vultures do (24). The white-backed vultures exhibit herd-following behavior whereby they follow other vertebrate and avian scavengers, on an inter- and intraspecific level, to a food source (24, 25). Although lappet-faced vultures often find carcasses before the white-backed vultures, they only feed on the carcass after the large group of white-backed vultures have already started to feed on a carcass (23). These behaviours were all observed in the present study.

The vultures in the present South African study began to scavenge the pig carcasses after 18hrs in summer and between 26-28 hours in winter. This is in contrast to the Texan studies by Reeves (12) and Spradley et al. (26). Reeves (12) noted that American black vultures (*Coragyps atratus*) and turkey vultures (*Cathartes aura*) waited approximately 24 h before they began to scavenge the pig remains in the warmer months compared to the 37 days observed by Spradley et al. (26) in colder months on human remains. Comparing

the temperatures between the two studies' sites - the South African study site reached a maximum of 40°C (104°F) in summer and a minimum of 16°(60°F) in winter and the Texan studies' site reached a maximum of 32°C (90°F) in summer and a minimum of 4° (39°F) in winter (12, 26). Temperature plays an important role in relation to when New World vultures (those in the Americas) begin to scavenge as they rely on olfaction to locate carcasses (27). Colder temperatures delay decomposition and the release of volatile organic compounds, which will result in the delay of vulture attraction and scavenging. The role of temperature on olfaction would not play a role in the onset of scavenging in Old World vultures (those in Africa, Asia and Europe) as they rely on their vision to locate carcasses (27). The delay in winter scavenging compared to summer scavenging in the present South African study could be attributed to the smaller number of vultures that are active in winter. Vultures are relatively less active in winter because the thermal convections they use to fly long distances are weaker and less frequent than in summer (28). It must be highlighted that it is possible that the vultures could have begun scavenging earlier in both seasons if the pig carcasses were laid out earlier. The pig carcasses were laid out in the late afternoon just prior to sunset in both summer and winter. Since the vultures in this study are diurnal and rely on sight to locate carcasses, it is suggested that the vultures might have scavenged earlier if the pig carcasses were laid out sooner. This needs to be explored further in future research.

The number of vultures observed feeding on a single carcass is a result of two factors: abundance and behavior. The overall number of vultures feeding on a single carcass may indicate the abundance of nesting sites related to the location of their nests (17). The number of individual vultures per species (white-backed, lappet-faced, and hooded vultures) feeding on a single carcass is the result of their species-specific behavior. Lappet-faced vultures roost and forage for food in isolation or in pairs (23) whereas white-backed vultures are social breeding and feeding colonies (17, 27). In Africa, a variety of vulture species often feed on the same carcass with the following approximate percentages: white-backed vultures (85%), hooded vultures (10%), Ruppell's Griffons (2%), lappet-faced vultures (2%), and white-headed vultures (1%) (21). A similar trend, in regards to the number of individuals per vulture species present at a carcass, was observed in the present study between the white-backed (n=40), hooded (n=4), and lappet-faced (n=1) vultures. These numbers of feeding vultures per species are also

consistent with those observed scavenging on carcasses in the nearby Kruger National Park conservation park (17). The diversity and abundance of vulture species is different between Africa and the USA. White-backed, hooded, and lappet-faced vultures and marabou storks all scavenged at the same time in South Africa whereas, in Texas, American black vultures tended to feed in isolation or in conjunction with only turkey vultures (12, 24). This can be attributed to the species-specific behavior of different vulture species in different geographic locations. It is important to note that ecologically diverse areas need to perform their own scavenging research and not solely rely on research that is not applicable to their location.

It is common for multiple vulture species to compete for carcasses, which often results in the species fighting or displacing each other from a carcass – fighting is common between the white-backed and lappet-faced vultures (22, 27-29). To reduce the conflict over food, these different vulture species will often partition the carcass between themselves and consume different types or sizes of carcasses (20). Lappet-faced vultures have larger skulls and beaks and tend to consume harder parts of a carcass such as tendons and skin, and smaller carcasses (27, 28); while the white-backed vultures will prefer softer tissues and larger carcasses (22, 23, 28). This was observed in the one case when a lappet-faced vulture was recorded, which scavenged on disarticulated remains on the periphery of the larger group of white-backed vultures feeding on the pig carcass. Hooded vultures are often pushed aside by the larger white-backed vultures whilst feeding, leaving the hooded vultures to scavenge on remains scattered around the periphery (21). Hooded vultures often are present near a carcass the longest; they are the first vulture species to arrive and they remain long after the carcass is skeletonized, picking at skin and scattered bones (20). This too was observed in the present study.

The skeletonization rate of remains by white-backed, hooded, and lappet-faced vultures in South Africa was drastically faster than that by American black vultures and turkey vultures in Texas. Skeletonization of ten 40-80kg pigs in the present South African study ranged from 5-98 minutes (faster in summer, slower in winter) compared to the 4hrs-12 hours in the study by Reeves (12) (three pigs weighing 27-63kg) and the “5 hours of active feeding over a 24 hour period” observed by Spradley *et al.* (24) (a single adult human cadaver of unknown weight). The number of vultures feeding in a single frame caught by

cameras was comparable between the present study (20-30 vultures on average) and that by Reeves (12) (25-30 vultures).

White-backed, hooded, and lappet-faced vultures scattered the skeletonized remains over an area of $157.9\text{m}^2/1705.5\text{ft}^2$, which was much larger than the $83.6\text{m}^2/900\text{ft}^2$ by American black vultures (24). The scattering pattern in the present South African study showed a more diffuse pattern in summer compared to a denser scatter pattern in winter. This could be due to the summer period exhibiting feeding vulture groups that were much larger than in winter, with skeletonization and scattering occurring much more rapidly in summer. In summer carcasses are less numerous and the thermal convections used by vultures to fly longer distances are stronger and more frequent than in winter (26). This could account for the greater numbers of vultures and increased activity in the summer period compared to the winter period. There is little evidence to suggest that white-backed vultures migrate seasonally (30, 31); therefore, migration is an unlikely reason for the difference in the seasonal behavior of the vultures.

The vultures left very few marks on the bones. These marks were mainly isolated to superficial scores with the distal ends of the transverse processes of the vertebrae often broken off. These were most likely caused by the vultures' beaks and not their claws. Beak marks on bone surfaces can be differentiated from claw and scavenging modifications. Vulture beak marks have been described as shallow, irregular, linear scratches measuring up to 4cm (12), which is consistent with those seen in this study. The irregular nature of the scores prevents their misinterpretation as sharp force trauma caused by claws. The beak scratches are more similar to root etching than sharp force trauma in their appearance (12). Furthermore, the scratches are assumed to be caused by the beaks of the vultures and not their talons, as their feet are relatively weak and used mostly for leverage and not grasping and manipulation of the carcass (12). Previous conflicting literature has reported on the trauma caused by vultures on eye orbits. Anecdotal accounts of vultures pecking out the eyes and damaging the orbits has been reported (12) but this was not observed in this study. Pecking out the eyes was observed but no orbit trauma was present.

Apart from the vultures, marabou storks and warthogs caused considerable loss of surviving skeletal elements as the marabou storks would swallow bones whole (such as

ribs and scapulae) and warthogs would consume ribs and vertebrae. Osteophagia (consumption of bones) has been recorded in warthogs before (32); however, their modification of the bones has not been described previously. The splintered and fractured nature of surviving ribs and vertebral transverse processes described in this needs to be further investigated.

Osteophagia is also common in giraffes and the giraffes observed in the present study were observed to have been attracted to the skeletonized remains; however, they were not recorded scavenging on them. Herbivorous ungulates such as giraffe and deer, in abnormal situations, have been observed scavenging on dry bones. It is suggested that this occurs when the animal has a phosphorous deficiency caused by a nutritional dysfunction (33). Bones will be consumed in any stage from fleshed and fresh to dried and weathered (34). Antlers, horns, and ivory have also been observed to be consumed by herbivores in order to maintain their nutritional requirements (34). Although the giraffes recorded in this study did not consume the scattered remains during the period of this study, it was reported in the week prior to the study that one giraffe was observed consuming an impala femur.

Other animals scavenged the remains after vultures had skeletonized and scattered the remains. The sequencing of trauma caused by different scavenger species may be possible as Young *et al.* (7) observed, in their European study, that there was never more than one scavenging species feeding on a carcass at one time and never more than two individual animals of the same species scavenging a carcass at one time. This was also observed in the present South African study as all other scavengers (slender mongoose, civet, genet and warthog) scavenged in isolation, with the honey badgers and banded mongoose scavenging in pairs. Further studies, such as that by Morton and Lord (8) in the United States, have recorded that scavenging animals are active at different times of the day based on their diurnal or nocturnal behavior. These animals do not intermingle with other species that have the same diurnal/nocturnal predilection. Rather each species is active at different periods during the diurnal/nocturnal periods. This was also observed in the present study.

This study was limited due to the use of motion-activated cameras, as only what was caught on camera could be reported on. On occasion the carcasses were moved beyond

the view of the cameras by scavengers, which limited the observation of scavengers and their behaviors. The study also only occurred over the period of one week in summer and one week in winter. As such this study only reported on the short term scavenging and it is suggested that future studies look into scavenging in the long term. Another limitation that was unforeseen was the delay in vulture scavenging in two pigs during the winter season. The delay is attributed to the two pigs being placed near fences. It is assumed that the vultures were weary of the fences as the barrier fences are electrified, which might have warded off the vultures and other scavenging animals. Pigs laid out in the summer period were not placed near the fences for this reason and may also be the reason for a more rapid onset of scavenging.

Conclusion

Scavenging behavior has proven to be species-specific and region-specific (7). This understanding is critical in the forensic context as it will assist in the identification of scavengers from their scavenging modifications on bone and discerning between animal scavenging modifications and traumas due to weapons, in the search and recovery of scattered remains and evidence, and in the reconstruction of postmortem events and postmortem interval estimation. Vultures proved to be the most prolific scavengers in the Lowveld of South Africa, skeletonizing remains rapidly between 5 - 98 minutes, scattering remains within an area of 157.9m²/1705.5ft² and cleaned bones thoroughly with very minimal markings.

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Article 4

SCAVENGER ACTIVITY IN A PERI-URBAN AGRICULTURAL SETTING IN THE HIGHVELD OF SOUTH AFRICA

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Journal: International Journal of Legal Medicine (<https://doi.org/10.1007/s00414-020-02413-x>)

Declaration: The contents of the paper are the original work of the authors submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Acknowledgements: The authors acknowledge the financial assistance of the National Institute of Justice and the Forensic Technology Center of Excellence along with the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre. Also acknowledged are GHB Farms and Mr. Dries Du Plessis for providing the pig carcasses; Mr. Richard Keyes, Ms. Deniel Lessing, Mr. Artem Markov, Mr. Ivan Coertze, and Ms. Rethabile Masiu for assistance in the search for, and mapping of the scattering patterns; the Mierjie Le Roux Experimental Farm, Prof Edward Webb and Mr. Roelf Coertze for providing the research site; and Ms. Rethabile Masiu for her assistance with the maceration of the bones.

Abstract

Scavenging animals often scatter skeletal remains of forensic interest and cause scavenging damage. This study aimed to identify scavenging animals in the peri-urban agricultural Highveld of South Africa, describe their scattering patterns, and the damage they cause to bone. Ten pig carcasses (*Sus scrofa domesticus*) (40-80 kg) were placed at the University of Pretoria's Mierjie Le Roux Experimental Farm (Highveld) in summer and winter. Motion activated cameras recorded the scavenging. Scavenger species were identified and their behaviors, scattering pattern, and the damage they cause to bone were described. Scavenging was primarily by black-backed jackals, however mongooses (slender, yellow, and water mongoose), Cape porcupine, and honey badger were also active. Remains were commonly scattered in two directions by jackals. The distance of scattering was heavily influenced by fencing. The remains were scattered within a maximum radius of 73.7 m. The remains were scavenged and skeletonized faster in summer. Jackals caused minimal damage to bone, isolated to superficial, nonspecific scores, furrows and punctures. A few mongoose bone alterations were present as jagged gnaw marks on the angle of the mandible and gnawing of the vertebral spinous process. Cape porcupine bone damage included gnaw marks on the condyle of a femur and head of humerus, and destruction of the proximal and distal ends of a tibia. The described scattering pattern and bone modification patterns will assist in the recovery and analysis of scavenged remains found in peri-urban agricultural areas in South Africa.

Key words: taphonomy; scavenging; black-backed jackal; peri-urban; South Africa; scattering

Introduction

One of the purposes of a forensic death investigation is the estimation of a postmortem interval (PMI) [1]. A PMI estimation relies on accurate descriptions of a body's level and rate of decomposition [2,3]. Scavenging animals can alter the rate of decomposition and their scattering of the remains can have an impact on the reconstruction of postmortem events. These events impact heavily on the PMI estimation [1]. It is therefore, critical that taphonomic studies describe the scavenging and scattering of remains by animals and their effects on forensic investigations [1-4].

In South Africa, humans and animals live in close proximity to each other, despite the rapid increase in urbanization and conservation efforts to house and protect wild animals [5,6]. The presence of scavenging animals in urban, peri-urban, and rural environments results in human remains often being scavenged. Since scavenging species can vary by geographic area, regional studies are important to allow for the accurate postmortem reconstruction of forensic cases [1,3]. South Africa is environmentally diverse with numerous unique habitats. Each habitat presents its own unique set of variables that may affect a forensic investigation. South Africa has a high homicide rate which impacts the investigations of the Forensic Pathology Services and their investigations of unnatural deaths [1]. During the year 2018, South Africa reported 32 622 incidents of murder, of which 6 978 were in the Gauteng province [7]. Many of these bodies are disposed of in remote locations. This often leads to their being discovered in the later stages of decomposition. The cases that are in advanced stages of decomposition and referred for forensic anthropological are often discovered in isolated areas such as open land/fields or parks, and farms [8]. They also often exhibit scavenger damage. Despite the regularity of such events experienced by forensic experts in Gauteng, there is a dearth of published research to highlight these issues and their frequency. It is therefore, essential that research on the scavenging of remains in a forensic context be performed, particularly in the Gauteng province of South Africa.

The full recovery of these remains is often difficult if they are disarticulated and scattered by animals. Research has illustrated that most investigators do not recover complete skeletons, even when assisted by a cadaver dog [8]. However, an understanding of animal scavenging and scattering patterns has resulted in an increase in the success rate of

recovering scattered remains [10]. An understanding of local scavenging animals is important, as it will increase the recovery of remains. Scattering patterns are specific to different scavenging animals [11], therefore, research needs to be conducted in different geographic regions.

Apart from scattering human remains, animal scavenging often causes postmortem modifications of remains. The morphology and location of animal damage on skeletal remains can indicate the offending species [12]. Scavenging damage on bone and soft tissues can be troublesome as they can obscure traumatic injuries and create postmortem pseudo-trauma. This can lead to the misinterpretation of evidence by forensic specialists [13-15]. Competent analysis of animal damage to bone can assist a forensic specialist to discriminate between damage inflicted by an animal, taphonomic alterations, and tool marks inflicted by a human perpetrator.

A number of studies have indicated which scavenger species are of forensic interests in their respective regions. North American scavenging animals of forensic importance include a variety of small animals, such as, rodents, racoons, foxes, opossums, and striped skunks. Larger North American scavengers of forensic interest include wolves and coyotes. North American scavenging avians that have been highlighted include crows and a variety of vultures, such as the turkey vulture [13,16]. European scavengers of forensic interest include carrion crows, Eurasian magpies, and European red foxes [17]. In Australia, avian scavengers consume the most carrion [18], in addition to the red fox [3]. In Africa and Asia, large felids such as lions, leopards, and tigers occasionally scavenge on human remains [5].

South African research on scavenging, in a forensic context, is limited. Published research has been performed in Cape Town which highlighted the Cape grey mongoose and yellow mongoose to be of particular interest in the Western Cape [1,4,19]. The damage caused to bone by certain South African animals, suspected to be of forensic interest, have also been briefly described [12]. Research on scavenging animals in South African urban and rural settings is ongoing, however, research pertaining to scavenging within a peri-urban agricultural setting is lacking. Research in these environments is needed because peri-urban agricultural environments comprise a large portion of the Highveld environment in the Gauteng Province of South Africa. Many forensic cases are investigated, and

recovered from, such environments. Six of the eleven Forensic Pathology Services (FPS) Medico-legal Laboratories in Gauteng have catchment areas which are peri-urban agricultural settlements (Springs FPS, Sebokeng FPS, Carltonville FPS, Heidelberg FPS, Ga-Rankuwa FPS, and Bronkhorstspuit FPS). Between the years of 2015-2018, the average annual number of forensic cases received by each of these facilities ranged between 274 – 1408 cases (mean=829) (data supplied by the Gauteng FPS).

The aim of this study was therefore, to identify the scavenging animals of forensic significance in a peri-urban agricultural environment in South Africa. The objectives of the study include providing descriptions of the animals' scavenging behavior, their scattering patterns in open fields and enclosures, and the damage they cause to bone. This information will assist forensic investigators in the thorough collection and analysis of scattered scavenged remains found in peri-urban agricultural regions of Gauteng, South Africa and other regions with similar scavengers. This study will be the first to present data of this nature in the Highveld of South Africa.

Methods

Research was conducted at the Mierjie Le Roux Experimental Farm owned by the Faculty of Natural and Agricultural Sciences of the University of Pretoria (Figure 1). This site represents a typical agricultural environment in the Highveld of South Africa. A section of the site is used for decomposition studies of forensic anthropological nature. The farm is 570 hectares of dry land subdivided for maize production, pastures, and cow herds. The farm is located in the Highveld plateau of the Gauteng Province and consists of mostly sourveldt grassland. This research site represents the peri-urban environment that comprises a large portion of the catchment area of the Gauteng FPS facilities.



Fig 1. Location of original pig deposition sites at Merijie Le Roux Experimental Farm (circle = summer pigs; triangles = winter pigs; square = fenced off site) (Google Earth)

The study sample comprised of 10 domestic pig carcasses (*Sus scrofa domesticus*) weighing between 40-80kg. This weight range is in line with small to medium sized humans, as it has been recommended that taphonomic research use carcasses that are larger than 20-30kg [20]. Carcasses are a commonly accepted analogue of human cadavers in taphonomic research [20]. The pigs used in this study died of natural causes and were donated by a licensed pig farm (GHB Farms). The cause of death was natural and possibly due to an overgrowth of *Clostridium perfringens* or *Escherichia coli*. This often results in a hemorrhagic bowel syndrome, common in large pig farms, which is caused by the twisting of the intestines. Pigs that have died of such causes are often used in taphonomic studies [21,22]. Pigs which potentially died from hemorrhagic bowel syndrome were selected due to ethical reasons, since no pigs had to be terminated for the purposes of the study. Additionally, no external wounds or chemical influences are created by termination, which would have an effect on the decomposition process [21]. No studies have yet been explicitly performed on the effects of hemorrhagic bowel syndrome on PMI, however, it is not expected to have a significant impact on the PMI and the scavengers that are attracted.

Five pigs were deployed at different times during the winter months - three in July and two in August. Another five pigs were deployed at different times during the summer months – three in October and two in December (Figure 1). Seasonality affects the presence and behavior of animals, therefore, the study comprised two different seasonal periods. Five of these pigs were deployed in a 50m by 50m fenced off site (three in winter and two in summer) and five pigs were deployed in open fields unobstructed by fences (two in winter and three in summer) (Figure 1). This allowed for the observation of how obstructions such as fencing affects scattering patterns. In forensic investigations, the environment that a body is recovered from varies on a case-to-case basis. Agricultural environments often present varying levels of accessibility to scavenging animals due to farm fences, enclosures, and paddocks. This would influence the scattering pattern and the recovery of scattered remains. The pigs that were deployed in the fenced off area at the same time, were positioned at least 30m apart from each other (Figure 1). The minimum distance of 30m between the carcasses was dictated by the space available within the fenced-off enclosure. To ensure that the scavenging animals were captured by the cameras in the early stages of scavenging, the pigs were secured with a chain to a permanent fixture, such as a fence or tree. This facilitated longer times to view and record the scavenging activities.

Bushnell Trophy Cam HD Essential E2 12MP Trail cameras were used to photograph the scavengers and scavenging of the carcasses. Each pig was recorded by a single camera secured to a nearby permanent fixture (such as a tree or fence), one to five meters away from the pig, in a padlocked steel camera cage. A single camera was used per pig due to the large number of pigs being recorded for this study and similar, concurrent studies in other environments. The motion activated, infrared cameras were set to the highest sensitivity to ensure that motion over a large area around the pig would trigger the camera. The cameras took three consecutive photographs when activated by motion, with a five second interval between motion activation. Researchers visited the site every two weeks to download data from the cameras. Two week intervals were selected to reduce the impact of human interference and replace the batteries in the cameras. When the camera footage was analyzed, the photograph timestamps were used to separate different scavenging events. Any timestamp difference greater than 10 minutes from the previous photograph was recorded as a separate scavenging/visiting event.

The footage captured by the cameras was used to identify the scavenger species and their scavenging behaviors. The species were identified using field guides for Southern African mammals and birds [23,24]. The behaviors of the scavenging animals were described in terms of the time of day they were active, the season they were active, the number of individual animals per species that scavenged concurrently, the decomposition stage each species was initially attracted to the carcasses and the stages during which they scavenged on the carcass, whether or not there was concurrent inter-species scavenging, and the frequency of each species' scavenging activity. Temporal data was recorded by the camera on the time-stamped photographs. The decomposition stages were assigned using the evidences observed in the photographs, and when the pigs were viewed in person. The stages were assigned using the descriptions provided by Michaud and Moreau [25] and Galloway et al. [26], and grouped as follows: the early stage (onset of death up to the onset of bloat), the bloated stage (onset of bloat, distention of the abdomen and/or neck, raising of limbs and/or protrusion of the anus), the active stage (abdominal deflation and moist decomposition), the advanced stage (exposure of skeletal elements in less than half the of body), and the dry stage (skeletonization of more than half the body). The dominant scavenging species and its behaviors were highlighted.

Once the remains were scattered beyond the view of the cameras and skeletonized, the location of each recovered element was flagged and mapped using a grid pattern method commonly used in archaeological and forensic anthropological recovery practices. This was done using the walk-the-line method, in a grid pattern. This method entails a group of individuals standing one meter apart from each other, walking in a straight line and flagging scattered elements. This is done as they walk in a north-to-south direction and then an east-to-west direction – thus, covering the region surrounding the original location of deployment. Due to each pig being deployed at a different time, there was no overlapping of scattered remains between different carcasses, so this did not confound the mapping of the scattering patterns.

The recovered remains were macerated to remove all remaining soft tissues. This allowed for the analysis of scavenging damage to bone. The bone damage was described in an attempt to highlight unique patterns which can be used to identify a perpetrating animal. The damage was described by their type (pits, furrows, punctures, or scores) [14,27], the

location of the damage on the bone, and a description of the overall alteration of the bone. A flashlight with different light intensities was used to aid in the location of the damage, as they may be superficial and difficult to locate without contrasting light levels. The damage was directly assigned to a scavenger species if the damage event was captured on camera, or indirectly by comparing the patterns described in previous research [12,28-34].

One camera did not capture footage of the scavenging of one summer pig, despite the rapid rate in which that pig was scavenged. For reasons unknown, there was no footage recorded despite the camera appearing to function fine. The scavengers and their behavior, related to this one pig, was not recorded or analyzed, nevertheless, the scattering pattern was recorded. Since this pig was not recorded, it afforded the opportunity to test the applicability of the scattering results, and thus, indicate their applicability to an actual forensic case where the scavenging animal is not definitively known or recorded. The scattering patterns of the other nine pigs were used to devise a more practical search method and applied to, and described for, the unrecorded pig.

Ethical approval for this study was granted by the University of the Witwatersrand's Animal Research Ethics Committee (Waiver 17-04-2018-O) and the University of Pretoria's Animal Ethics Committee (H001-19).

Results

A number of animals actively scavenged on the carcasses, including blacked-backed jackal (*Canis mesomelas*) (Figure 2a), slender mongoose (*Galerella sanguinea*) (Figure 2b), water mongoose (*Atilax paludinosus*) (Figure 2d), Cape porcupine (*Hystrix africaeaustralis*) (Figure 2e), and honey badger (*Mellivora capensis*) (Figure 2g). Yellow mongoose (*Cynictis penicillata*) (Figure 2c) and serval (*Leptailurus serval*) (Figure 2f) were attracted to the carcasses, however, they were not recorded actively scavenging the remains. The serval marked itself in a process called scent marking, by rubbing itself on the carcass. The yellow mongoose visited numerous pigs multiple times but did not scavenge on the pigs (Table 1). Animals attracted to the carcasses to feed on colonizing insects included hadeda ibis (*Galerella sanguinea*), Swainson's spurfowl (*Pternistis swainsonii*), helmeted guineafowl (*Numida meleagris*), pied crow (*Corvus albus*), spotted thick-knee (*Burhinus capensis*) and numerous unidentified species of small birds, mice,

frogs, and hare. Domestic cow herds (*Bos Taurus*) also showed interest in the carcasses, occasionally rolling the carcass over, but they were not recorded to scavenge on the carcass or skeletal elements.

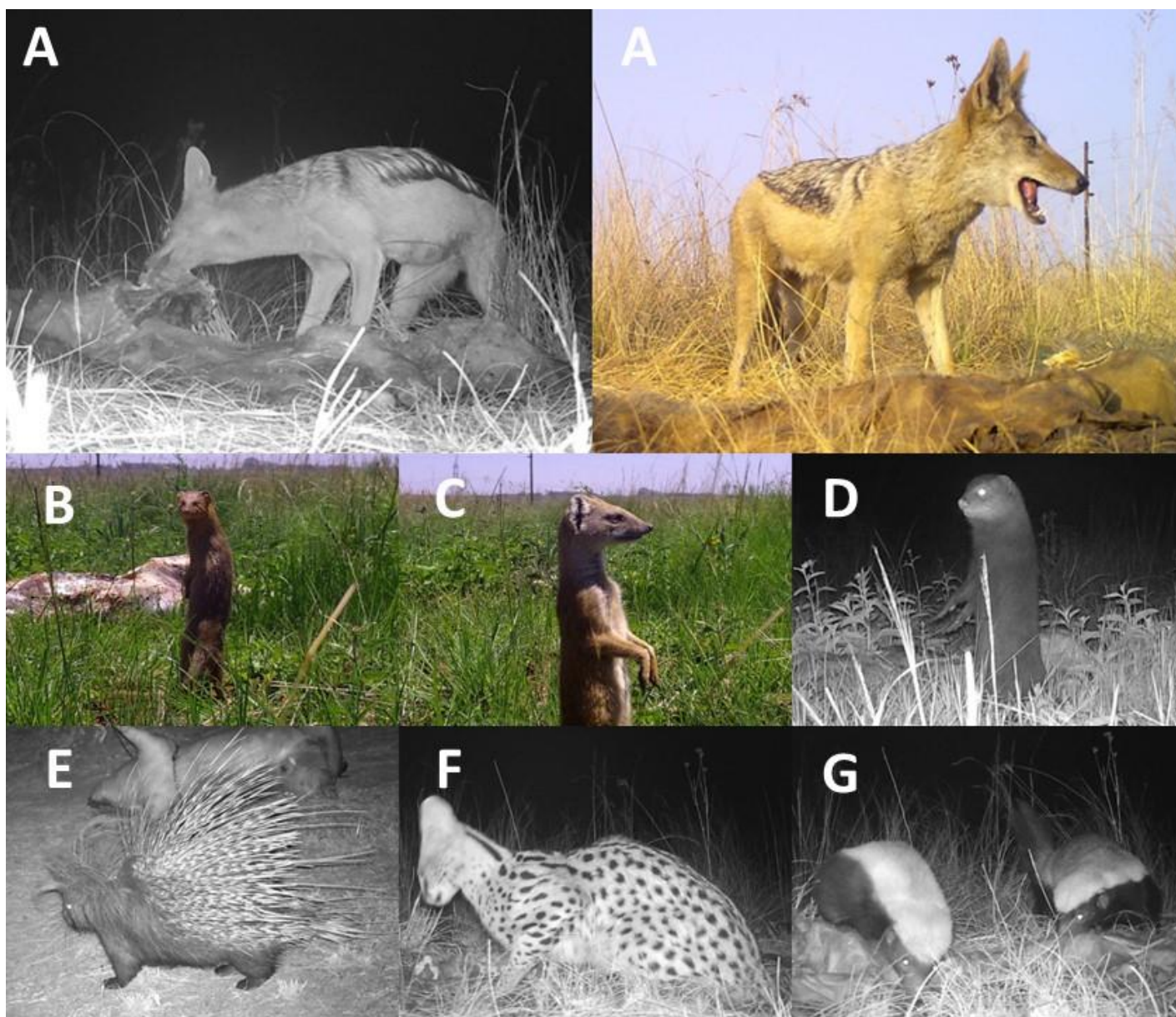


Fig 2. Animals that were attracted to, or scavenged on, pig carcasses, including black-backed jackals (A), slender mongoose (B), yellow mongoose (C), water mongoose (D), Cape porcupine (E), serval (F), and honey badgers (G).

The black-backed jackal, water mongoose, porcupine, serval, and honey badger were nocturnal. The slender mongoose and yellow mongoose were diurnal. The black-backed jackal was the most active scavenger but was rarely active in daylight. On the rare occasion it was observed during daylight, it was active in the early hours of the morning (Table 1). The jackals were mostly active between 18h00-09h59, with peaks in their activity between 21h00-21h59, and 02h00-02h59. Other diurnal animals that were attracted to, but did not directly scavenge on, the carcasses included cows, hadeda ibis, Swainson's spurfowl, pied crow, helmeted guineafowl and other small birds. The nocturnal animals that were attracted to, but did not directly scavenge on, the carcasses included the spotted thick-knee, mice, frogs, and hare.

Most of the scavenging animals were active in both the summer and winter periods. The honey badgers and serval were only active in the winter period while the water mongoose was only active in the summer, after heavy rains (Table 1). The non-scavenging, summer active animals included the frog (after rainfall), Swainson's spurfowl, hare, and helmeted guineafowl. The winter active species included the spotted thick-knee. The species which were active in both seasons included mice, pied crow, and hadeda ibis. In summer there was an increase in the number of individual animals and the diversity of animal species (Table 1). Many of the animals were attracted to the carcasses in the bloat and active stages of decomposition, however, scavenging tended to only start in the later stages of decomposition. The jackals and water mongoose preferred to scavenge when the carcasses were in the active stage of decomposition (Table 1). The slender mongoose, porcupine and honey badgers preferred to scavenge in the more advance stages of decomposition; particularly once most soft tissues were gone and skeletal elements were exposed (Table 1).

There was no interspecies scavenging observed at the same time, although multiple animals of the same species would scavenge together on rare occasions. The black-backed jackals mostly scavenged in solitary but they occasionally scavenged in pairs or a pack of three. The slender mongoose also scavenged in isolation or in occasional pairs. Honey badgers and porcupines often scavenged in pairs (Table 1).

Black-backed jackals were the most active species. Jackals were recorded frequenting the carcasses an average of 40.4 times per pig (Table 1). The slender mongoose was the

second most active scavenger, frequenting the carcasses an average of 19.1 times per pig (Table 1). These were the only two scavengers to visit all of the recorded carcasses. The porcupine, yellow mongoose, and serval frequented the carcasses much less frequently. The water mongoose was the least active of all scavenging animals, as it only scavenged on one carcass on only two separate occasions (Table 1).

Ribs and vertebrae were recovered in all cases but the number of surviving ribs and vertebrae varied per case. The cranium was not recovered in three cases (30%) and the mandible was missing in half of the cases (n=5; 50%). In most cases (n=6; 60%), the limb bones were only partially recovered. All bones of the four limbs, including the long bones and feet, were recovered in only four cases (40%). The bones of the upper limbs were recovered more often than those of the lower limbs: humerus (n=11; 55%), radius (n=9; 45%), ulna (n=11; 55%), femur (n=9; 45%), tibia (n=7; 35%), and fibula (n=7; 35%). The pelvis was not recovered in four cases (40%). In most cases (n=7; 70%), at least one scapula was recovered while both scapulae were only recovered in four cases (40%). In total, 11 scapulae were not recovered (55%).

The black-backed jackals were responsible for the consumption of the soft tissues and accounted for most of the scattering of the skeletonized remains. Since black-backed jackals were the most prolific scavengers in this study, their scattering behavior will be highlighted.

Seasonality affected the jackal scavenging activity. The onset of jackal scavenging was faster in summer (range =4-11 days; mean = 6.5 days) than in winter (range: 15-34 days; mean = 24.6 days) (Figure 3). Jackals consumed most of the soft tissues, leading to rapid skeletonization of the carcasses; which was faster in summer (range: <1-35 days; mean = 14.2 days) than in winter (range: 26-42 days; mean = 34 days) (Figure 3). One carcass (Fig 6 – Figure 3) was scavenged by jackals so rapidly that it reached the skeletonized stage (i.e. skeletonization of more than half the body) on the same day the jackals began to consume it (six days after the pig was deployed at the site).

Table 1: The scavenging behaviors of peri-urban agricultural scavenging animals in the Highveld of South Africa

Animal	Maximum number of animals of the same species active at the same time at the same carcass	The number of pigs each animal visited/ scavenged (N=9)*	Average number of scavenging or visiting events per species between the nine* pig carcasses	Decomposition stage active	Body region preference when scavenging	Time active	Season active
Black-backed jackal	3	9	40.4	Attracted: bloat stage Scavenging: active, advanced and skeletonized stages	Abdomen, pelvis, limbs, ribs, scapula, cranium	Nocturnal (mostly)	Summer and winter
Slender mongoose	2	9	19.1	Attracted: active stage Scavenging: advanced and skeletonized stages	Abdomen, vertebral column, and limbs	Diurnal	Summer and winter
Yellow mongoose	1	4	0.8	Attracted: active, advanced, and skeletonized stages		Diurnal	Summer and winter
Water mongoose	1	1	0.2	Scavenging: active stage	Abdomen	Nocturnal	Summer only
Cape porcupine	2	6	1.7	Attracted: Bloat and advanced stages Scavenging: skeletonized stage	Unknown	Nocturnal	Summer and winter
Serval	1	2	0.2	Attracted: bloat and advanced stages		Nocturnal	Winter only
Honey Badger	2	1	0.1	Scavenging: advanced stage	Abdomen and ribcage	Nocturnal	Winter only
* Camera did not capture scavenging of one summer pig despite the rapid rate that pig was scavenged							

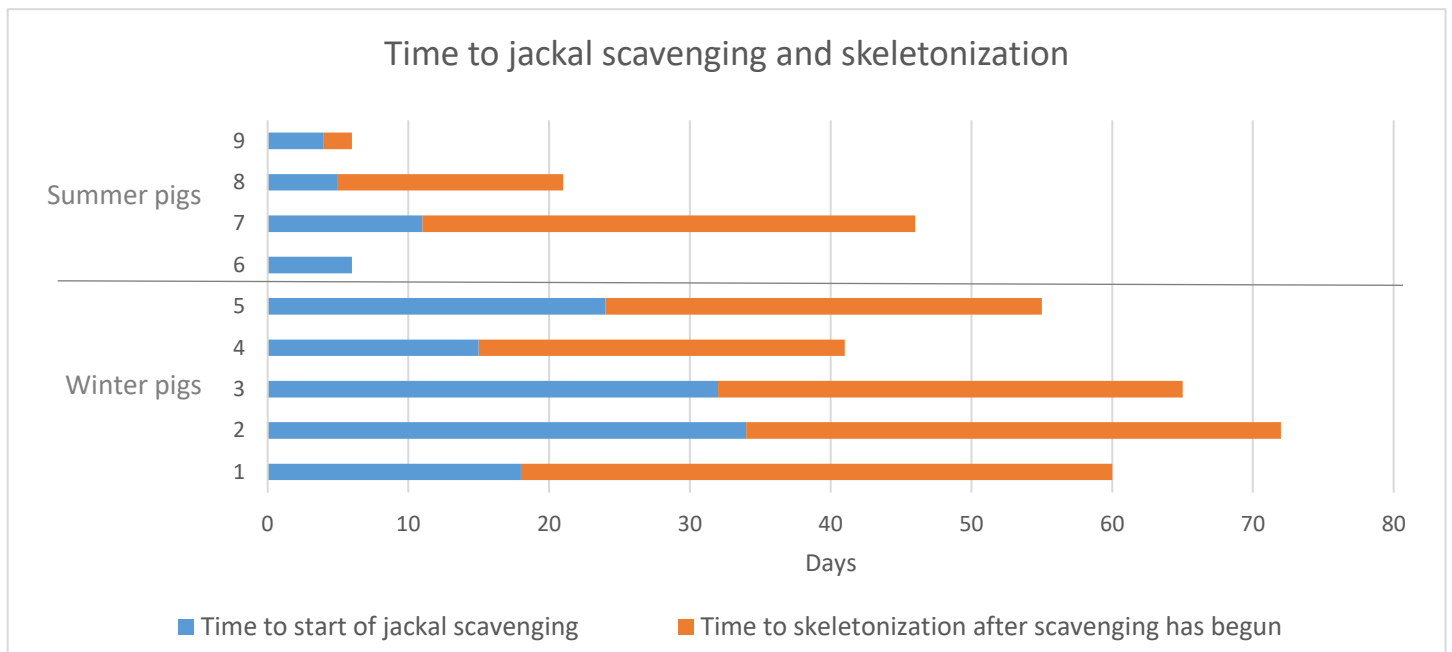


Fig 3. Comparison of time of jackal scavenging onset to skeletonization of pig carcasses

Skeletal remains were scattered over a large area by jackals. The pattern and range of scattering was influenced largely by physical barriers (such as fences) and, to a lesser extent, the season. Scattered remains within the fenced enclosure were confined within the enclosure, with a maximum radius of 42.8m/137.8ft (Figure 4). Scattered remains that were unobstructed in open fields were scattered over a very large area, with a maximum radius of 73.7m/241.8ft (Figure 4). The remains within the enclosure were scattered towards a hole in the fence where, presumably, the scavenging animals gained entrance/exit. The remains in the open fields were often scattered towards animal burrows. Individual pig remains were often scattered in two diverging directions, within a 90° arc, from the original location of deployment (highlighted by the two examples in Figure 4).

Knowledge of these scattering patterns were helpful in the recovery of the unrecorded pig remains (due to malfunctioning of the camera). Understanding that remains are often scattered in two diverging directions within a 90° arc with a radius of proximally 73.7m/241.8ft was particularly beneficial. Cues such as game trails and burrows were initially used to determine where the remains were most likely scattered. Once the two directions of scattering were identified, a grid search was implemented in those two directions. The search distance was determined by the general search radius of the other

nine pigs (approximately 73.7m/241.8ft). This assisted in the implementation of a more efficient search method for the scattered remains of this particular pig.

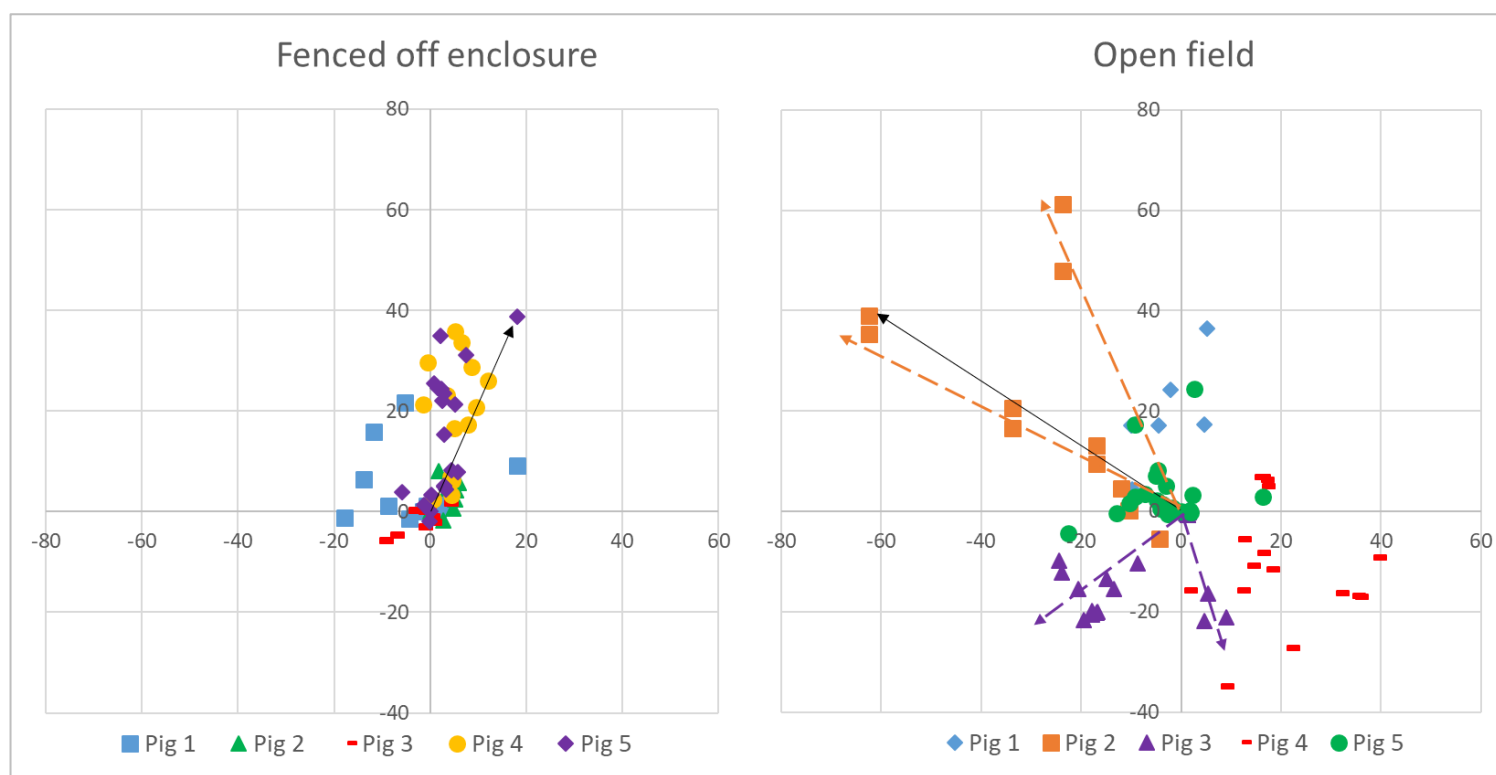


Fig 4. Scatter plot of the skeletal elements of ten pigs, five in a fenced off enclosure (left) and five in open fields (right), scattered primarily by black-backed jackals, showing distance (in meters) and direction of scattering. The origin (0;0) indicates the original position of each pig. Northern arrow indicates the relative scatter direction. Radius arrow (dark solid arrow) indicate the maximum scatter radius (fenced off area radius = 42.8m; open field radius = 73.7m). Directional arrows (dotted arrows) indicate directional trends of the scattered remains.

Black-backed jackals caused very little damage to the skeletal elements. Most pig skeletons did not exhibit any apparent signs of damage. A few sternal ends of ribs were consumed and the transverse processes of a number of vertebrae were fractured but complete. Distinct punctures were present in one head of a humerus (Figure 5), and a puncture was also present in the medial boarder of one scapula (Figure 5). Furrows were present in the cranioventral spine of one ilium (Figure 5).

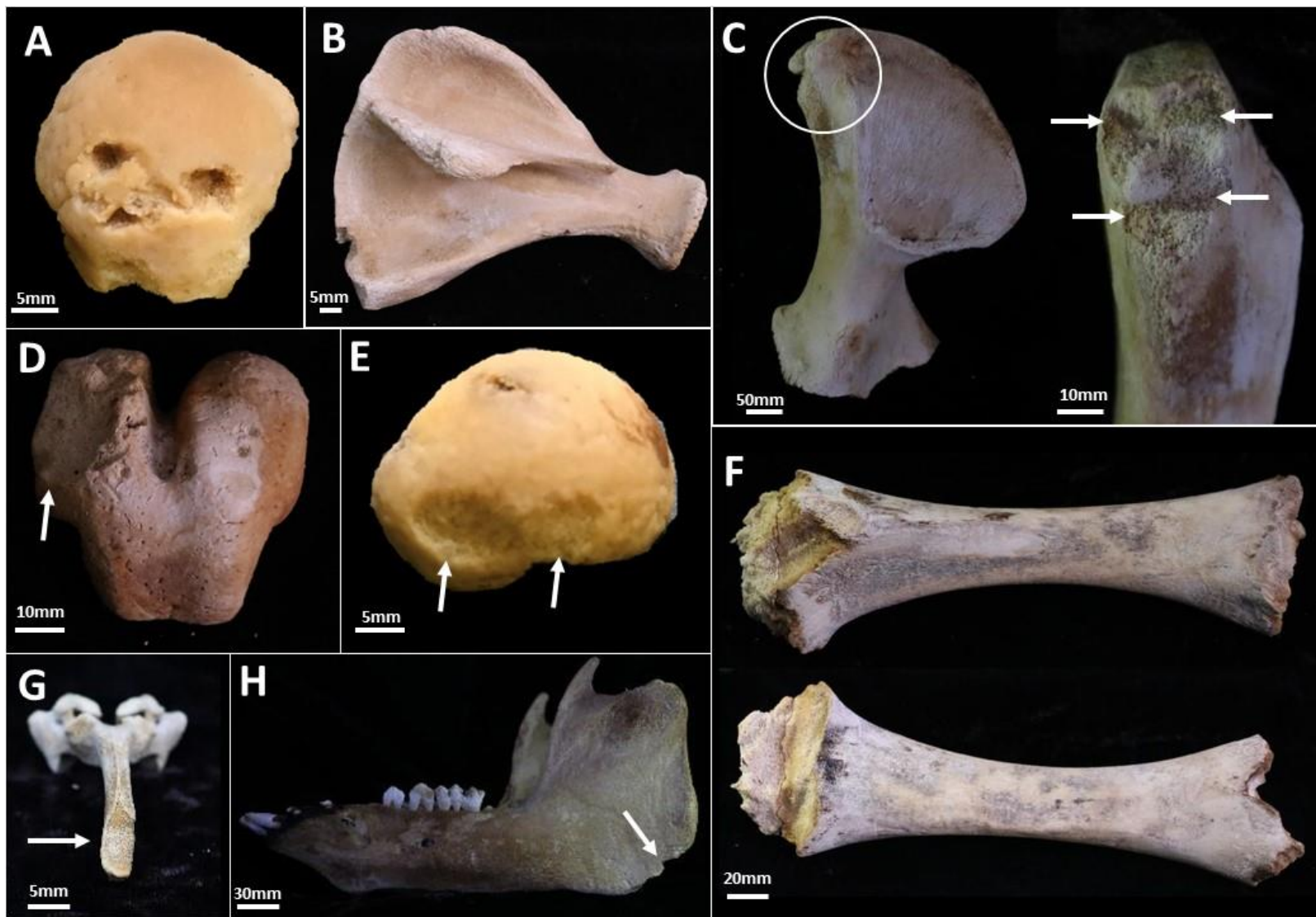


Fig 5. Damage caused by scavenging animals: A) black-backed jackal punctures in the head of humerus, B) black-backed jackal puncture in the medial boarder of the scapula, C) black-backed jackal furrows in the cranioventral spine of the ilium (left picture is the ventral view of the ilium with circle highlighting the cranioventral spine, right picture is of the ventral view of the cranioventral spine with arrows highlighting the furrows), D) Suspected porcupine gnawing of the condyle of a femur, E) Suspected porcupine gnawing of the head of humerus, F) suspected porcupine damage on the proximal and distal ends of a tibia (top picture is the anterior view and the bottom picture is the posterior view of the same tibia), G) suspected mongoose damage on the vertebral spinous process, and H) suspected mongoose damage on the angle of the mandible is of the ventral view of the cranioventral spine with arrows highlighting the furrows.

It is suspected that porcupines caused round, gnawed areas, with a polished appearance, to the condyle of a femur and to the head of a humerus (Figure 5). Massive destruction to the distal and proximal ends of a tibia are also assumed to be caused by porcupines, as described by Keyes et al. [12] (Figure 5).

Bone damage caused by suspected slender or yellow mongoose was observed as gnawing of the tip of a spinous process of a vertebra. This gnawing removed the cortical bone and exposed the trabecular bone (Figure 5). Jagged gnaw marks, suspected to be caused by mongooses, were also observed on the angle of two mandibles (Figure 5). These patterns of slender mongoose damage have been observed by the authors in other research sites (not yet published). The gnawing of the mandible, in particular, is highly suggestive of mongoose scavenging. It is unlikely to be caused by jackals because they tend to cause superficial scores or pits. It is also unlikely to be caused by porcupines because they leave distinctive fan-like scores and focus on the long bones [12].

Discussion

Black-backed jackals were identified as the dominant species in this study's scavenger guild. Their distribution, scavenging behavior, scattering pattern, and patterns of damage to bone will first be highlighted, including the respective impact it could have on forensic investigations. The lesser species of the study's scavenger guild will then be briefly discussed in terms of their distribution and patterns of damage to bone, and their potential influences on forensic investigations.

Black-backed jackals (referred to jackals from here onwards) are abundant and widespread throughout Eastern and Southern Africa, in a variety of environments [35]. Jackals are primarily scavengers, although they do occasionally hunt [36,37,38,39]. Since jackals are primarily scavengers, the presence of Diptera larvae in their scat is a common occurrence. This can be used as evidence to determine if their food source was fresh or decomposing [38,40]. The jackals in the present study were originally attracted to the carcasses in the bloat stage of decomposition but only started to scavenge from the active stage onwards. It appears that conventional methods of postmortem estimation could be used in the early and bloat stages. These methods cannot be used in cases from the active stage onwards if they have been scavenged by jackals because the typical

decomposition rates and patterns would have been altered. The season should also be taken into consideration when estimating a PMI because there are seasonal differences in the jackal-instigated skeletonization and scattering rates. Jackals were primarily nocturnal and the level of their activity increased during twilight and the early morning before dawn [40]. They were rarely active during the day with no activity from the late morning to mid-day [40]. This should be considered when reconstructing postmortem events in cases of jackal scavenging.

The feeding behaviors of jackals are different to other canines. The jackals kill and feed more neatly than dogs [41]. They also prefer to consume the soft tissues rather than the skeletal elements. They show a preference for the flesh and skin of the flank and haunch of a leg [41]. They will also eat the organs such as the heart, liver, lungs and the stomach and its contents [41]. The preference for soft tissues over skeletal elements, including the neater manner in which they scavenge [41], would account for the limited and superficial damage noted on the scattered skeletal elements. One study on jackal predation noted that ribs are partially consumed by jackals [41]. A minimal number of ribs were partially consumed in the present study - with only the costal ends being fractured. It is likely that this is a result of the jackals feeding on the organs within the chest cavity, which are protected by the costal ends of the ribs. The minimal alteration to bone by jackals has previously been described by the present authors regarding jackals in captivity [12] and these alterations were also observed in the present study on jackal behavior in the wild.

The scattering patterns of the jackals became apparent to the authors early on in the data collection period. This assisted in the location and collection of scattered remains. In the enclosed area, no remains were scattered beyond the fences. The directionality of the scatter was apparent and led to the holes in the fence where the animals were presumed to gain entrance. This knowledge allowed for more thorough and rapid recovery times of the scattered remains with each progressive pig that was laid out. In a forensic context, understanding the physical boundaries at a death scene and the effects it would have on animal movement will greatly enhance the search and recovery of scattered remains. The scatter pattern of remains in the open fields was much more diffuse and over a much larger area. The scattered remains of each pig (in both the fenced off enclosure site and the open field sites) were generally in two directions and confined within a 90° arc. This

pattern also became apparent to the authors early in the data collection period and increased the efficiency and rate of the search and recovery of scattered remains. Once the two general directions were noted, it was easier to predict where the remains would be. This knowledge can assist in improving the recovery of remains by forensic specialists. Investigating officers with an understanding of scavenging behaviors have been proven to be twice as successful in the recovery of skeletal remains as those without the same knowledge [10]. This highlights the necessity for continuing research on scavenging and scattering patterns in unique areas with unique scavenging species.

The need to implement a search method unique to the black-backed jackal scavenging was most apparent in the search for the scattered remains of the pig whose camera malfunctioned. The method of 'walking the line' in a grid formation was used to locate the scattered remains of the other nine pigs which ultimately highlighted the pattern of remains being scattered in two directions within a 90 degree arc. Although the grid method is very affective it is also very time consuming, particularly in the recovery of remains scattered over a very large area. Once the scattering pattern of the other nine pigs became apparent, a 'link search method' [14] was implemented for the pig that was not recorded. The link search method is more flexible than the grid method since it allows the searcher to adjust their direction based on the identification of cues. Cues include drag marks in the soil, clumps of fur, animal scat, game trails, or disturbed soil [14]. In the present study, the cues included the branching of scattered remains into two directions within a 90 degree arc, often along game trails and towards burrows. A combination of the 'walking the line method in a grid fashion' and the 'link search method' was intuitively implemented in the search for remains of the unrecorded pig. The principles of the 'link search method' determined in which directions the grid search should be focused. The experience of locating and mapping the scatter patterns described in the present study, lead to the suggestion that search methods should be flexible and chosen based on the suspected scavenging animal and the size of the scatter area. In a forensic case it is suggested that a combination of the grid method and link the search method be combined particularly when a case is time-sensitive.

The effectiveness of any forensic skeletal analysis relies on the number of skeletal elements recovered. Fewer recovered remains will limit the trauma analysis and the

estimation of a biological profile, which is invaluable to the identification of skeletal remains. Only 40% of limb bones were recovered in this study. This will have a bearing on the estimation of the sex [42-46] and stature [47,48] of an individual in a forensic context because the limb bones are valuable in assessing these individual features [49]. The mandible is also an important element used to estimate the sex and age of an individual [40-52] and the mandible was only retrieved in 50% of scattered cases. Although the scavenging of human remains and carcasses may potentially be dissimilar, the skeletal elements are similar and the scavenging of these individual elements are expected to be comparable.

The black-backed jackal was not the only animal to scavenge on the remains. A variety of mongooses were attracted to, and scavenged on, the carcasses. This included the slender mongoose, yellow mongoose, and water mongoose. The behaviors of the different mongoose species varied. Small, social species - such as the slender and yellow mongoose - tend to be diurnal with a mostly insectivorous diet. Larger, solitary mongoose species - such as the water mongoose - are mostly nocturnal with a diet largely on small vertebrates [53]. The slender mongoose has a widespread distribution throughout sub-Saharan Africa [54] but within South Africa it is restricted to the northern parts of the country [21]. It is a generalist carnivore with a diet of mainly small vertebrates and insects but it will also scavenge on the carcasses of mammals [55]. In Cape Town, South Africa, the Cape mongoose and yellow mongoose have been identified as scavenger species which scavenge upon and scatter human remains [4]. The water mongoose (*Atilax paludinosus*) is widely distributed across southern Africa and can be found further north in Africa. They inhabit a variety of habitats that provide plant cover and fresh water sources. Due to their size (which is larger than most other mongoose species) their diet constitutes larger prey. Their diet usually includes small mammals such as rodents, birds, amphibians, mollusks, fish and insects [56]. Water mongooses are nocturnal and tend to hunt along the banks of bodies of water but they may submerge themselves when hunting for food [57]. Water mongooses are solitary. The yellow mongoose (*Cynictis penicillata*) is widely distributed in South Africa most commonly occurring in the western and central Orange Free State and Western Gauteng provinces [58]. They forage for food whether in isolation or in pairs. Despite being primarily insectivorous, they have been observed scavenging on carcasses [4,59]. These three mongoose species, in addition to the

banded mongoose, have been observed as scavengers on forensic interest by the authors in other vastly different environments such as the rural Lowveld and urban Johannesburg (currently under review for publication) and also in coastal Cape Town as observed by Spies et al. [4]. They are prolific scavengers in a variety of environments in South Africa. Their prevalence highlights the need to better understand their scavenging behaviors as they are likely actively scavenging on human remains of forensic interest in South Africa [4].

The Cape porcupine (*Hystrix africaeaustralis*) also scavenged on the carcasses once they were skeletonized. Porcupine scavenging has been well documented. Porcupines will scavenge on bones either to sharpen their incisor teeth or to consume the bones, in a process called osteophagia, when the individual lacks calcium and/or phosphorus in their system [32]. Porcupines will scavenge on fleshed and dry bone without preference [33]. Bone damage caused by porcupines is distinguishable from other rodent bone damage [30,32-34,60]. Fan-like parallel scores with undefined contours are common along shafts of long bones with regions of heavy gnawing resulting in the total destruction of epiphyseal ends of long bones being common [12]. Large, oval depressions with an eroded, polished appearance is also a sign of porcupine gnawing [12]. The destruction of epiphyseal ends of long bones and the large, oval depressions with a polished appearance in the present study are also consistent with porcupine damage [12]. The destruction of skeletal elements by porcupine scavenging is of forensic concern as they have the potential to alter or destroy evidence such as tool marks and traumatic fracture patterns.

Honey badgers (*Mellivora capensis*) are solitary, predatory carnivores [61,62], although the territorial home ranges of adult male honey badgers often overlap extensively with other adult males and encompass smaller home ranges of younger males [61]. This often results in the formation of groups of two to five adult males which travel together [61]. This behavior is not observed in female honey badgers who tend to avoid each other [61]. They can be found spread across most of sub-Saharan Africa, Arabia, Iran and western Asia spreading to the Indian peninsula [62]. A pair of honey badgers were observed scavenging on the carcass of one pig in the present study. They showed preference for the abdomen and rib cage. Their scavenging was most likely the result of opportunistic foraging. Since numerous animal species scavenged on a single carcass, it should be expected that,

during skeletal analysis, multiple and differing patterns of damage could be present on a single case. They did not scatter the remains beyond the radius of jackal scavenging.

Two tangential observations made in this study, unrelated to the scattering of the remains, but related to the decomposition of the remains, must be noted. There was an increase in the number and diversity of animal species which continued to be attracted to the location where the pigs decomposed, long after the remains were removed. It is assumed that they were attracted to volatile compounds soaked into the soil and/or insects that had pupated in the soil. This is a topic that could be studied in the future as it could potentially contribute to further taphonomic understanding of postmortem events. Also noted in one case was the significant movement of a carcass without any visible external source. The carcasses was in an advanced stage of decomposition and moved erratically over short distances - particularly the limbs. It is assumed that the cause of the movement could be attributed to maggot activity beneath the carcass. This has also been observed by time-lapse cameras at the Australian Facility for Taphonomic Experimental Research in a long term decomposition study [63] but this phenomenon has not yet been studied, explained, or published. This phenomenon would have an impact on our understanding on the postmortem movement of remains not attributed to a perpetrator or human influence.

Limitations

The identification and descriptions of scavenging animals their behavior relied on the motion-activated cameras. The camera footage was only retrieved every two weeks. In one case a camera did not record footage for unknown reasons. No footage was recorded for that one case reducing the quantity of data collected in this study. It is unlikely that this negatively affected the results because the same animal species scavenged the remaining nine carcasses with consistently. It is therefore, likely that the same animal species scavenged this pig similarly to the other nine pigs.

The carcasses were chained to a permanent fixture to increase the cameras' viewing times of scavenging activities in the event of scavenging in the early stages of decomposition. These chains were also used to prevent theft of the carcasses. These chains did not appear to have any significant effect on the scavenging and scattering of the remains. The chains did not deter the attraction of animals in the early stages of decomposition. The animals scavenged on the remains in the advanced stages of

decomposition when the remains could be easily disarticulated without hindrance by the chains. Therefore, the chaining of the carcasses did not appear to have any significant impact on the scattering of the remains, however further research is needed to confirm this.

Conclusion

Scavenging at this peri-urban agricultural site was primarily by black-backed jackals, and a variety of mongoose species (slender, yellow, and water mongoose), Cape porcupine, and honey badger also scavenged on the carcasses. The scattering of each pig's remains was generally in two directions confined within a 90 degree arc. The distance of scattering of five pigs was heavily restricted by the fencing. Overall, the remains were scattered within a maximum radius of 73.7 m and the resulting skeletonization of the remains assisted by jackals scavenging was faster in the summer months than the winter months. Jackals caused minimal damage isolated to superficial, nonspecific scores, furrows and punctures. Slender mongoose and Cape porcupine damage to bone was also described. The described scattering pattern and scavenging damage to bone will assist in the recovery and analysis of scavenged remains in South Africa, especially in a peri-urban environment.

Funding: this study was funded by the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Center

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical Approval: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in this study involving animals were in accordance with the ethical standards of the institutions at which the study was conducted.

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Chapter 5: Discussion

A number of scavenging animals which are unique to sub-Saharan Africa and of forensic interest in South Africa have been identified through this study and other studies. These scavengers exhibited scavenging behaviours, scattering patterns and scavenging modifications arks which are unique and species-specific. Understanding the impact of these variables within a forensic context could be invaluable in the reconstruction of postmortem events and the recovery of scattered scavenged remains.

5.1 Identified scavenging animals, their environments, and scavenging behaviours

Three groups of animals were identified as the dominant scavengers in their respective guilds: mongooses (particularly the slender mongoose) in an urban environment, vultures (particularly the white-backed vulture) in a rural environment, and black-backed jackals in a peri-urban/agricultural environment. Each of these dominant scavenger groups will be discussed in detail. A general discussion will also be provided on the lesser scavengers that were identified (largely medium-sized mammals) and their behaviours and interactions within their guild.

The species which make up the scavenging guilds in different environments vary greatly. The two urban sites presented scavenger guilds with the lowest biodiversity. Only one specie actively scavenged at each of the urban sites: slender mongoose at the Frankenwald site and hadeda ibis at the abandoned building complex in Braamfontein, Johannesburg. A greater variety of animals were attracted to the colonising insects on the carcasses, although, these had no bearing on the scavenging and scattering of the pig remains.

The peri-urban agricultural site, the Mierjie Le Roux Experimental Farm in the Highveld of Gauteng, had a much more biodiverse scavenging guild than the urban sites. Blacked-backed jackals had the most substantial impact on the scavenging of remains, in addition to the slender mongoose, water mongoose, Cape porcupine, and honey badger. All of these species displayed potentially unique scavenging preferences and sequencing. A great variety of additional species were also attracted to the colonising insects on the carcasses, yet, these had no bearing on the scavenging and scattering of the pig remains.

The rural site, represented by Wits Rural Facility, had the greatest biodiverse scavenging guild out of the four research sites. Avian scavengers – notably the white-backed vulture, hooded vulture, lappet-faced vulture, and marabou stork – dominated other guild species and had the greatest impact on the scavenging of remains contributing to the most dramatic and rapid skeletonisation of the pig carcasses. Medium sized mammals also impacted on the scavenging of remains at this site, including the common large-spotted genet, African civet, slender mongoose, banded mongoose, common warthog, and honey badger.

The slender mongoose was the most prolific scavenger species in this study as it was observed scavenging in three of the four research sites, indicating its vast distribution across many environments in South Africa. Mongooses as a whole (including the slender, yellow, banded, and water mongoose) were prolific in this study and their impact on forensic investigations has clearly been under-researched and underappreciated. These scavengers need to be highlighted in further research.

The taphonomic reconstruction of postmortem scavenging events that occur at each of these sites will differ greatly. Knowledge of the scavenging behaviours of the respective guilds at each site will assist greatly in the estimation of a PMI. Additionally, the succession of numerous animal species within each scavenging guild has been outlined, and it should be expected that, during skeletal analysis, multiple and differing bite mark patterns could be present on the skeletal elements of a single case.

5.1.1 Mongooses

Mongooses were the most prevalent scavengers identified in this study as they were observed in three of the four research sites. The only site they were not observed in was the abandoned hospital building complex in Braamfontein, Johannesburg. The other three sites, despite varying in levels of urbanisation, all contained large open velds/fields. A variety of different mongoose species were attracted to and/or scavenged on the pig carcasses. This included the slender mongoose (*Galerella sanguinea*), yellow mongoose (*Cynictis penicillata*), banded mongoose (*Mungos mungo*) and water mongoose (*Atilax paludinosus*). The behaviours of the different mongoose species were variable. Small, relatively-social species such as the slender, yellow, and banded mongoose are diurnal with a mostly insectivorous diet; while larger, solitary species such as the water mongoose

are mostly nocturnal with a diet largely of small vertebrates (Nel & Avenant, 1992). The Cape grey mongoose and yellow mongoose are the only mongoose species to have been previously described as forensically significant in previous publications (Spies *et al.*, 2018a). The present study is the first to highlight the significance of the slender, banded, and water mongooses in forensic investigations. Each of the identified mongoose species will be discussed here in relation to their behaviours, habitats, and their potential impact on forensic investigations in South Africa.

5.1.1.1 Slender mongoose

The slender mongoose has a widespread distribution throughout sub-Saharan Africa (Taylor, 1975) but within South Africa it is restricted to the northern parts of the country (Stuart & Stuart, 2017). They are common in various habitats such as semi-desert, thick woodland, rocky hill, Acacia bush and dense shrub cover and they are particularly common in cultivated lands (Ramesh & Downs, 2014). Slender mongoose dens are often holes, dens, and warrens originally dug by other animals, often in old termite mounds (Cronk, 2019). The slender mongoose is typically solitary, but the same home range can support up to four other individuals and they will, on rare occasions, form small groups (Cronk, 2019). Largely diurnal, the slender mongoose will occasionally hunt at night if it is warm and accompanied by bright moonlight (Taylor, 1975). It is a generalist carnivore with a diet made up of mainly small vertebrates and insects, however, it will also scavenge on the carcasses of mammals (Skinner & Chimimba, 2005). They will scavenge on small carcasses (such as hyrax) and medium carcasses (such as antelope and wildebeest) (Cronk & Pillay, 2018). Larger carcasses are often avoided as they may be perceived to be a high risk for predation (Moleón *et al.*, 2015), but they have been observed scavenging on and around large carcasses (such as giraffe) (Vaughan, 1976).

The slender mongoose was the most common mongoose and the most common scavenger overall in this study. It scavenged pig carcasses in a variety of habitats represented in the study, including the rural Wits Rural Facility in the Lowveld of Limpopo province, the peri-urban Mierjie Le Roux Experimental Farm in the Highveld of Gauteng province, and the urban Frankenwald research site in Johannesburg, Gauteng. This indicates the widespread dispersal of this species throughout the northern regions of South Africa, highlighting the particular interest of this species forensic contexts. The impact of the slender mongoose scavenging was minimal in the rural and peri-urban sites

due to competition with a more biologically rich scavenging guild than that in the urban veld. At the Frankenwald research site the slender mongoose had no competition with other scavenging species. As the slender mongoose only scavenged directly on the carcasses in the advanced stages of decomposition, the skeletonisation rate was much slower in the urban environment compared to that in the rural and peri-urban habitats. The slender mongoose was attracted early to the carcasses by the colonising insects which it preyed upon. They would dig multiple holes around and beneath the body (Spies *et al.*, 2018a). The behaviour of digging holes around a carcass to excavate fly pupae has been previously observed and appears to be a potentially unique feature of slender mongoose behaviour (Vaughan, 1976). This would be a potentially unique indicator of slender mongoose scavenging which forensic investigations should consider as it would discount the possibility of human alteration of the soil around a body. The slender mongoose showed a preference for the dried skin and subcutaneous fat of the abdomen and the following skeletal elements: the mandible, ribs, whole disarticulated limbs and their skeletal elements, vertebrae, and scapulae. This general behaviour has also been observed in the Indian mongoose (*Herpestes javanicus*) in Ohau, Hawaii. This species of mongoose would also first be attracted by carcasses to feed on the larvae. Scavenging directly on the carcass would also only occur in the advanced stage of decomposition, where the Indian mongoose would feed on the remaining dried skin and tissues (Dibner *et al.*, 2019). When forensic anthropological analysis is performed on a skeletonised case that is suspected to have been scavenged by slender mongooses, these elements can be expected to be absent or possess scavenging modifications. Understanding that their preference for carrion in the advanced stages of decomposition should also be considered when estimating a postmortem interval as they could affect the state of decomposition. This would not be problematic in the earlier stages of decomposition (early, bloat, and active stages) as they only prey on invertebrates at that stage. Spies *et al.* (2018b) observed that mongoose scavenging increased the skeletonisation rate of remains. Scavenged remains reached early skeletonisation in only 14 days compared to unscavenged remains which remained in advanced decay until the conclusion of the study at 93 days. The authors also noted how this difference in skeletonisation rate could lead to the overestimation of the PMI. All of these potentially unique behaviours and evidences of slender mongoose scavenging should be noted when reconstructing postmortem

events, including the location of scattered remains, and the analysis of scavenging modifications on bone.

5.1.1.2 Yellow mongoose

The yellow mongoose is widely distributed in South Africa most commonly occurring in the western and central Orange Free State and Western Gauteng provinces (Zumpt, 1976). They inhabit a variety of environments but are particularly preferential to habitats with a wide range and low vegetation (Blaum *et al.*, 2007; Cronk, 2019). They are social and occur in family groups ranging from two to 13 individuals (Balmforth, 2004; Mbatyoti, 2012; Cronk, 2019). They are diurnal and are solitary foragers, searching for food in isolation or in pairs. Despite being primarily insectivorous, they have been observed to prey on small mammals and scavenge on carcasses (Ryan & Shaw, 2015; Spies *et al.*, 2018a).

Yellow mongoose have been shown to be of forensic significance in South Africa, as indicated in a 2017 case in Cape Town (Spies *et al.*, 2018a). A body was discovered on Table Mountain with missing hands and evidence of scavenging. The spoor present at the scene was identified as that from yellow mongoose. Closer inspection revealed clothing fibers within the spoor that matched the clothing of the deceased. A small tunnel was discovered near the body and after the removal of surrounding shrubbery, most of the hand bones were recovered at the entrance of the tunnel (Spies *et al.*, 2018a).

In the present study, Yellow mongoose were only observed at the Mierjie Le Roux Experimental Farm. They were not caught on camera scavenging, however, this does not rule out the possibility of them scavenging the remains after they were scattered out of the field of view of the cameras. Similar to the slender mongoose, they were attracted to the pig carcasses in the advanced stages of decomposition. They were not observed in the early stages when insect colonisation was highest. This behaviour was not expected as the yellow mongoose's primary source of diet is invertebrates. It is possible that the black-backed jackals at this site consumed and scattered the remains before the yellow mongoose were aware of their presence. Additionally, the biodiversity of the scavenging guild at this site was very high (including black-backed jackal, slender mongoose, water mongoose, Cape porcupine, and honey badger), thus, competition might have been too high for the yellow mongoose to make any significant scavenging contribution. It is

possible that in a different site where competition is lower, the yellow mongoose might have a greater impact. The Cape Town case discussed earlier (Spies *et al.*, 2018a) indicates that the influence of the yellow mongoose should not be discounted and a greater understanding of the local scavenging guild at a forensic site will highlight the probability of yellow mongoose scavenging.

5.1.1.3 Banded mongoose

The banded mongoose is common and widespread throughout sub-Saharan Africa. Unlike most small mammals, the banded mongoose is diurnal – similar to the slender and yellow mongoose (Rood, 1975). The banded mongoose is a social animal, and unlike the slender and yellow mongoose, it lives in large social groups (called a mob, gang or pack) that are larger than just a single family unit. These mobs can be as large as 36 individuals which are equally divided in numbers between males and females (Rood, 1975). Their diet is primarily on invertebrates with a preference for millipedes and beetles in particular, which they often locate in thickets, near dung piles of larger animals, and through digging in the soil. They occasionally prey on small vertebrates such as frogs, toads, snakes and murid rodents (small rodents such as mice, rats, and gerbils) (Rood, 1975). Banded mongooses will occasionally steal fresh prey away from predators in a process termed ‘mobbing’. One study observed banded mongooses mobbing a freshly killed hare from a pair of fish eagles and successfully fending off the fish eagles’ attacks (Rood, 1975). The same study recorded a different mob driving away a wake (group of feeding vultures) of white-backed vultures from an antelope carcass, however they only investigated the carcass and then abandoned it (Rood, 1975), indicating that they do not preferentially scavenge on carrion. A mob will forage for food as a unit, although each individual will feed independently. Banded mongoose mobs are nomadic and do not inhabit permanent dens. Their dens include preexisting features such as termite mounds, erosion gullies, and aardvark holes. These structures are usually inhabited for only a few days and then abandoned, but they may be reused by the same mob at a later stage (Rood, 1975).

Banded mongoose have been recorded scavenging on fresh carrion (Rood, 1975), yet, publications discussing the scavenging behaviour of the banded mongoose on decomposed carrion is rare with only one publication, to the knowledge of the author, making a cursory mention of the potential for banded mongoose to scavenge carcasses (Brüns *et al.*, 2017). Banded mongoose have been recorded scavenging on human waste

(Medley *et al.*, 2020) but there appears to be no published record of banded mongooses scavenging on decomposed carcasses. This highlights that banded mongooses appear to not preferentially scavenge on carrion however, in the present study, there was one instance of a single banded mongoose scavenging on the skeletonised ribs and scapula of a winter pig for a brief period. Given that a very large mob of >30 banded mongoose frequented the area, it is likely that this was a rare event. This indicates that banded mongooses do scavenge on carcasses on very rare occasions but their impact is minimal. Other species in the scavenging guild that scavenged on this pig carcass made much more obvious and significant alterations to the carcasses. This makes the banded mongoose, in a forensic context, to be of negligible interest, unlike the slender, yellow, water, and Cape mongoose.

5.1.1.4 Water Mongoose

The water mongoose (alternatively known as the marsh mongoose) is widely distributed across southern Africa and can be found further north in Africa. They are semiaquatic and populate a variety of habitats that provide plant cover and fresh water sources. Due to their size (which is much larger than most other mongoose species) their diet constitutes larger prey. Their diet usually includes small mammals such as rodents, birds, amphibians, mollusks, fish and insects (Louw, 1986). Water mongooses are nocturnal (contrary to the slender, yellow, and banded mongoose) and tend to hunt along the banks of bodies of water but they may submerge themselves when hunting for food (Somers & Purves, 1996). Water mongooses are solitary and do not form packs as smaller mongoose species do. Anecdotal accounts have mentioned that water mongoose do scavenge on carcasses (Power, 2014), however, this behaviour has not been previously discussed explicitly in published literature.

Water mongooses were recorded in two research sites, the Mierjie Le Roux Experimental Farm and the Frankenwald research site. Both these sites are bordered by rivers. The water mongoose was a rare visitor as it only scavenged one time on one carcass at the Mierjie Le Roux Experimental Farm, and on two separate occasions on a single carcass at the Frankenwald site. These pig carcasses were in the active and advanced stages of decomposition. The water mongooses were only observed during the summer months after rainfall and they scavenged only on the abdominal regions of the carcasses. Similar to the banded mongoose, the water mongoose appears to be of negligible forensic interest

as it rarely scavenged remains and made less of an impact on the scavenging and scattering alterations to the carcasses than the other species in the respective urban and peri-urban guilds.

5.1.2 Avians

Avian scavengers are widespread globally and are a vital part of any larger regional scavenging guild. Avian scavenger guilds are made up of various species and sub-species indigenous to the region. Their scavenging behaviour depends largely on the interspecific dominance hierarchy within a guild which is primarily based on body size. Larger species tend to be more dominant over smaller species and will steal and defend a carcass from smaller species (Wallace & Temple, 1987). Because avian scavenging guilds interact so closely together, studies should be inclusive of the whole group and not study single species in isolation (Mills *et al.*, 1993; Soulé *et al.*, 2005; Oro *et al.*, 2009; Cortés-Avizanda *et al.*, 2010).

The makeup of an avian scavenger guild varies regionally. European avian scavenger guilds include, in part, the griffon vulture (*G. fulvus*), the Egyptian vulture (*Neophron percnopterus*), the bearded vulture (*Gypaetus barbatus*), the red kite (*Milvus milvus*), Eurasian magpies (*Pica pica*) (Inger *et al.*, 2016), the black kite (*Milvus migrans*), and the common raven (*Corvus corax*) (Cortés-Avizanda *et al.*, 2010). Some Asian avian scavengers include the mountain hawk-eagle (*Nisaetus nipalensis*), black kite (*Milvus migrans*), and jungle crow (*Corvus macrorhynchos*) (Cortés-Avizanda *et al.*, 2015; Inagaki *et al.*, 2020), white-rumped vulture (*Gyps bengalensis*), and a variety of *Gyps* vultures (DeVault *et al.*, 2016). South American avian guilds include turkey vultures (*Cathartes aura*), black vultures (*Coragyps atratus*), Andean condors (*Vultur gryphus*), king vultures (*Sarcoramphus papa*), and crested caracaras (*Polyborus plancus*) (Wallace & Temple, 1987). In North America, American black vultures (*Coragyps atratus*) and turkey vultures (*Cathartes aura*) are common scavengers (Spradley *et al.*, 2012). African avian scavengers include marabou storks (*Leptoptilos crumeniferus*), black kites (*Milvus migrans*), pied crows (*Corvus albus*), white-backed vultures (*Gyps africanus*), hooded vultures (*Necrosyrtes monachus*), and lappet-faced vultures (*Torgos tracheliotos*) (Ssemmanda & Pomeroy, 2010). From this list it is clear that vultures are the most prolific avian scavengers globally.

5.1.2.1 Vultures

Vultures are highly specialised scavengers which only eat carrion and do not supplement their diets with other sources (Buechley & Şekercioğlu, 2016). They can be divided into two geographical groups: New World and Old World vultures. New world vultures are found in North and South America and they rely on their olfactory senses (smell) to detect decomposing carrion (Grigg *et al.*, 2017). Old World vultures are found in Africa, Europe and Asia and they rely on sight to detect carrion (Grigg *et al.*, 2017). Despite the indispensable carrion removal service they provide to environments, global vulture populations are declining rapidly, a decline of more than 90% in some populations (Prakash *et al.*, 2003) – the most rapid decline compared to any other group of birds over the last decade (Buechley & Şekercioğlu, 2016). This makes them the most threatened avian guild in the world (Buechley & Şekercioğlu, 2016). There are 22 vulture species, of which nine are ‘critically endangered’, three are classified as ‘endangered’ and four as ‘near threatened’ by the International Union for Conservation of Nature (Buechley & Şekercioğlu, 2016). The reasons for their decline are farm poisonings, poaching, and electrocution by power lines (Oaks *et al.*, 2004; Ogada *et al.*, 2012b; Ogada *et al.*, 2016).

Vultures are such successful scavengers because they are voracious scavengers that can consume more carcass biomass than all mammalian carnivores combined (Houston, 1994). Vultures in the Serengeti National Park, Tanzania, are estimated to consume 14 million kilograms of meat alone (Houston, 1979). Similarly, turkey vultures in North, Central and South America are estimated to consume 219 million kilograms of carrion annually (Singh & Chakravarthy, 2006; Chhangani, 2010; Inzunza *et al.*, 2010). The reason they consume more carrion than mammals is that their flying enables them to cover larger areas than mammals which results in their detection of carrion sooner (Houston, 1979; Ruxton & Houston, 2004). Vultures are able to consume up to 90% of a carcass before any other scavenging species arrive (Houston, 1986). Vultures are not the only avians that exhibit dominating behaviour over other scavengers feeding on carcasses. For example, Andean condors (*Vultur gryphus*) have been observed to chase away pumas from a carcass (Elbroch & Wittmer, 2013) and ravens (*Corvus corax*) have done the same to carcasses being scavenged by wolves (Vucetich *et al.*, 2004).

In the present study, at the Wits Rural Facility in Limpopo, the white-backed vulture, lappet-faced vulture and hooded vulture represented the vulture species in that region’s

scavenging guild. These three vulture species are common to the general Lowveld of South Africa (Kemp & Kemp, 1975). The white-backed vulture is the most common vulture species in the Lowveld and is perennially present year-round (Kemp & Kemp, 1975). The hooded vulture inhabits a variety of habitats, such as deserts, forests, and savanna and is solitary in nature south of the African equator (Anderson, 1990; Ogada & Buij, 2011). Their behaviour is different north of the African equator, where the hooded vulture is more social and forms large groups, particularly in urban areas near rubbish dumps and slaughterhouses (Anderson, 1990).

Since white-backed, lappet-faced, and hooded vultures are Old World vultures, they rely on their vision to locate carcasses (Spiegel *et al.*, 2013). The first vultures to arrive at, and feed on carrion, are the hooded vultures, closely followed by the lappet-faced and white-backed vultures (Petrides, 1959). Lappet-faced vultures tend to arrive before large groups of white-backed vultures because they regularly search for carcasses within a restricted area (Kruuk, 1967). The white-backed vultures rely on other vertebrate and avian scavengers to indicate the presence of a food source, thus, exhibiting herd-following behaviour (Kruuk, 1967; Pennycuik, 1971). Despite lappet-faced vultures finding carrion before white-backed vultures, they will only feed after the white-backed vultures open the carcass and begin to feed (Petrides, 1959). Each of these described behaviours were observed in the present study at the Wits Rural Facility.

The succession and competition observed in the South African guild of avian scavengers at the Wits Rural Facility behaved in a manner similar to a South American avian guild studied in Peru (Wallace & Temple, 1987). The Peruvian study (Wallace & Temple, 1987) highlighted how different avian species interact and compete with each other in the consuming of carrion. Turkey vultures would locate the carrion first via their well-developed olfactory senses. They would often open small-to-medium sized carrion, but their beaks are not strong enough to open large carrion (Wallace & Temple, 1987). When they scavenge larger carrion with thicker skin, these vultures would often gain access only through the oral and anal cavities or regions of skin that have pre-existing lesions. They are able to consume smaller carrion on their own before more dominant guild members arrive (Wallace & Temple, 1987). The second member of the guild to arrive would be the black vultures. Individual turkey vultures will dominate individual black vultures, however, black vultures will dominate a carcass as a large group. The study observed that black

vultures often form wakes of greater than 50 individuals, although, they recorded one case where a wake of 230-240 black vultures arrive at a carcasses in less than one hour (Wallace & Temple, 1987). Next to arrive at a carcass are king vultures and Andean condors with their heavier, stronger beaks which can open carrion with thicker hides (Wallace & Temple, 1987). This leads to a feeding frenzy where the usually subordinate black vultures will again dominate higher ranking guild members. Once the more easily accessible tissues are consumed, leaving less accessible elements of a carcass to remain, the dominant guild members will again take dominance over the carcass (Wallace & Temple, 1987). Once vultures have abandoned a carcass, crested caracaras (small birds of prey native to Central America and northern South America) arrive and feed on the remaining scraps of meat. If vultures are still present, they will remain on the periphery and feed on insects or scattered small scraps of meat (Wallace & Temple, 1987).

In comparison, at the Wits Rural Facility, the smaller hooded vultures were often the first to arrive at a carcass in small numbers (one to four individuals at a time). They would gain access to the carcass through the anus, occasionally inserting their head into the rectum to gain access to the soft tissues. It appears that they were unable to lacerate the hide of the pigs. The white-backed vultures would arrive next in large numbers (up to more than 40 at a time) and dominate the carcass, pushing away the hooded vultures. Their stronger beaks would open the skin which would initiate a feeding frenzy. Early in the process before the skin is pierced, the white-backed vultures were observed inserting their heads in the oral cavity deep down the throat of the pig carcasses to access the soft internal tissues. Once the carcasses were opened and scattering began, a single lappet-faced vulture and the hooded vultures were observed to scavenge on scattered meat and skeletal elements on the periphery of the feeding frenzy huddle.

Multiple vulture species within the same guild will often compete for a carcass and this frequently results in either inter-specific fighting or distancing from each other around a carcass. Fighting is particularly common between the white-backed and lappet-faced vultures (Kruuk, 1967; Houston, 1974; Mundy *et al.*, 2001; Kendall *et al.*, 2012), but this was not observed in the current study. In an effort to reduce the conflict over food, different vulture species often consume different sized carrion (lappet-faced vultures prefer smaller carcasses (Houston, 1974; Mundy *et al.*, 2001) and white-backed vultures prefer larger carcasses (Kruuk, 1967; Pennycuik, 1971; Houston, 1974)) or if they feed on the same

carcass they will often partition the carcass between themselves (Spiegel *et al.*, 2013). When dividing a carcass between the species of a guild, the lappet-faced vultures tend to consume the harder parts of a carcass such as tendons and skin (due to having larger skulls and beaks) while the white-backed vultures will consume the softer tissues (Kruuk, 1967; Pennycuick, 1971; Houston, 1974). This was observed in the present study when the lappet-faced vulture scavenged on the scattered remains on the periphery of the white-backed vultures' feeding frenzy. Hooded vultures were also dominated by the larger white-backed vultures, leaving the hooded vultures to also scavenge on scattered remains on the periphery (Petrides, 1959). Hooded vultures would persist near a carcass the longest as they were the first vulture species to arrive and they would remain long after the carcass is skeletonised, picking at skin and scattered bones (Spiegel *et al.*, 2013). These behaviours were observed in the present study and other studies (Petrides, 1959; Kruuk, 1967; Pennycuick, 1971; Houston, 1974; Mundy *et al.*, 2001; Spiegel *et al.*, 2013; Kendall *et al.*, 2014).

The rate at which vultures find and begin to scavenge remains varies between regions. In the present South African study, vulture scavenging began after 18 hours in summer (with a maximum temperature of 40°C/104°F) and after 26-28 hours in winter (with a minimum temperature of 16°C/60°F). This was much faster than that observed in Texas, USA (Reeves, 2009; Spradley *et al.*, 2012). In Texas, American black vultures (*Coragyps atratus*) and turkey vultures (*Cathartes aura*) began to scavenge pig carcasses after approximately 24 hours in summer (with a maximum temperature of 32°C/90°F) (Reeves, 2009) and they began to scavenge human remains after 37 days in winter (with a minimum temperature of 4°C/39°F) (Spradley *et al.*, 2012). The temperature will play an important role in the location of carrion by the New World vultures in Texas since they rely on olfaction to locate carrion (Grigg *et al.*, 2017). Cooler temperatures result in slower rates of decomposition which delays the release of volatile organic compounds resulting in the slower detection of carrion by New World vultures. This explains the seasonal difference in carrion detection at the Texas site. The impact of temperature on olfaction does not influence the scavenging by Old World vultures in the present South African study as they rely on vision to locate carrion (Grigg *et al.*, 2017). The seasonal difference in the onset of vulture scavenging in the present South African study could be attributed to the seasonal variation in vulture volt size which is larger in the wet/summer season when

chicks have hatched and matured (Kemp & Kemp, 1975). Seasonal climactic differences could also have an influence as cooler winter temperatures result in weaker and less frequent thermal convections which vultures rely upon to fly long distances and this would result in delayed detection of a carcass compared to summer (Monsarrat *et al.*, 2013).

The total number of vultures in a scavenger guild and the number of individuals per species in a scavenger guild is the result of abundance and behaviour. The total number of vultures feeding on a single carcass is an indication of the nesting site abundance in a region (Kemp & Kemp, 1975) and would be region specific. The inter-species ratio of individual vultures per species in a guild (i.e. white-backed: lappet-faced: hooded vultures) is the result of their species-specific behaviour. Lappet-faced vultures are solitary and roost and scavenge in isolation or in pairs (Pennycuik, 1971). White-backed vultures are social and they breed and scavenge as colonies (Kemp & Kemp, 1975; Mundy *et al.*, 2001). A general proportion of vulture species in an African guild would reflect the following approximate percentages: white-backed vultures (85%), hooded vultures (10%), Ruppell's Griffons (2%), lappet-faced vultures (2%), and white-headed vultures (1%) (Petrides, 1959). This general trend was observed in the present study between the white-backed (n=40), hooded (n=4), and lappet-faced (n=1) vultures. These proportions are also consistent with those observed in the nearby Kruger National Park conservation park (Kemp & Kemp, 1975).

The rate of carcass skeletonisation by white-backed, hooded, and lappet-faced vultures in South Africa was far more rapid than that reported in Texas by American black vultures and turkey vultures (Reeves, 2009; Spradley *et al.*, 2012). The ten 40-80kg pigs in the present South African study were skeletonised by vulture scavenging in 5-26 minutes in summer and 20-98 minutes in winter. In contrast, three pigs weighing 27-63kg were skeletonised in 4-12 hours during summer (Reeves, 2009) and a single adult human cadaver of unknown weight was skeletonised in "5 hours of active feeding over a 24 hour period" in winter (Spradley *et al.*, 2012). The number of vultures in the Texan study (25-30 vultures) (Reeves, 2009) is comparable to the present South African study (20-30 vultures on average) but their behaviours and rate of scavenging differed greatly. This highlights the differences in regional influence and species behaviour and indicates the need for region specific studies of this nature.

5.1.2.2 Marabou stork

Marabou storks (*Leptoptilos crumeniferus*) are common in tropical African regions, widely distributed from the southern border of the Sahara to the east, northern, and central regions of South Africa (Kahl, 1966a; Monadjem *et al.*, 2012). They are particularly numerous in Eastern Africa where they commonly inhabit cities such as Nairobi, Kenya and Kampala, Uganda (Ssemmanda & Pomeroy, 2010). Marabous frequent regions where there is game or domestic animals in abundance (Kahl, 1966b). Breeding colonies are often found in close proximity to vultures and hyenas, and the carrion they consume, as well as areas with fresh water sources (Kahl, 1966b; Pomeroy, 1975). Marabou storks are active year-round, however, they are often observed mostly in the wet season during the warmer months (Kemp & Kemp, 1975).

Young nestling marabous require a high calcium diet to maintain their rapid growth and their diet consists of small vertebrates such as fish and frogs (Kahl, 1966b). Adult marabou storks can subsist purely on a diet of carrion for long periods. Adults feed mainly on pieces of soft tissue that have been scattered by vultures and fish (Kahl, 1966b), although, modern marabou musters have adapted to anthropogenic settlements and consume a variety of human waste scavenged from abattoirs, rubbish dumps, and fish camps. They have been observed to swallow a variety of items such as paper, bones, and objects such as knives, later regurgitating objects that are indigestible (Kahl, 1966b). They are also opportunistic feeders and have been observed preying on fish, frogs, mice, insects, greater flamingo eggs and juveniles, new-born domestic pigs, crocodile hatchlings, and flying sparrows (Kahl, 1966a).

Marabous often arrive at a carcass after vultures have arrived and begun to scavenge on a carcass. The bill of a marabou stork is not adapted for tearing flesh or the manipulation of large pieces of meat. As such, they will wait for the vultures to tear off pieces of a carcasses and scatter the remains which the marabou will attempt to steal from the vultures and swallow scattered and disarticulated remains whole (Kahl, 1966a).

In the present South African study, the scavenging behaviours of Marabou storks were consistent with that described in published literature. They were active in both the summer and winter periods. Marabous were observed scavenging in conjunction with vultures; arriving after the vultures had begun scavenging and scattering remains. No more than

two adult storks were observed scavenging a carcass at a single time and they distanced themselves to the periphery of a vulture feeding frenzy, opportunistically consuming scattered remains. They do not contribute to the scattering of remains, but rather to the loss of skeletal elements as they were observed consuming skeletal elements whole. They were observed consuming whole ribs and scapulae as well as a large sheet of loose skin.

Marabou storks make up an integral part of the scavenging guild in the Lowveld region in Limpopo, South Africa. In the forensic recovery of scavenged and scattered skeletal remains, the impact of Marabou storks must not be underestimated. In the recovery of incomplete skeletal remains, the potential for Marabou stork interference must be considered.

5.1.2.3 *Hadeda ibis*

The hadeda ibis (*Bostrychia hagedash*) is an indigenous southern African bird. It is relatively large (approximately 1.2 kg) and is wide spread throughout South Africa (Singh & Downs, 2016). Their natural habitat is wetlands where they can forage for insects in moist soil (Singh & Downs, 2016), although, like the Marabou stork, they have adapted very successfully to anthropogenic environments. In South Africa, the population and its range of hadeda ibis has dramatically increased since 1910, particularly in urban environments (Macdonald *et al.*, 1986; Singh & Downs, 2016). This was demonstrated well in the present study as the hadeda ibis was observed in all anthropogenic research sites – the abandoned building complex in Johannesburg, the urban veld in Frankenwald, and the peri-agricultural Mierjie Le Roux Experimental Farm. It was not observed at the Wits Rural Facility, which was not unexpected because the site is rural with a very low human population and a very dry habitat.

Invertebrates are the primary food source of the hadeda ibis diet. This was observed in the current study as they scavenged on the colonising and migrating insects on and around the pig carcasses. Of particular forensic interest were the large holes that the ibis created in the pigs' skin as they tried to gain access to the insects. It is important to discern between these postmortem taphonomic artifacts and perimortem sharp force or ballistic trauma. Forensic pathologists are experienced with the classic signs of sharp force or ballistic trauma in skin and are unlikely to misdiagnose the postmortem holes, however, less experienced or specialised forensic investigators may not know the difference.

The single case recorded in this study of hadeda ibis actively scavenging on carcasses and feeding on the intestines (at the abandoned hospital building complex in central Johannesburg) is a behaviour that has not been previously published. In the only comparable study in Cape Town by Spies *et al.* (Spies *et al.*, 2020), hadeda ibis were attracted to carcasses but they did not scavenge the carcasses. This behaviour is most likely an example of the opportunistic feeding habits of hadeda ibis in urbanised locations. Given the wide range and large number of hadeda ibis in South Africa, it is likely that they may have an impact on the decomposition and scavenging process of human remains in South Africa, particularly in urbanised centers. It is imperative that there is a better understanding of their scavenging behaviours as this could potentially impact the accuracy of the reconstruction of postmortem events in urbanised South Africa. Further research is needed to determine if this is a repetitive behaviour of the hadeda ibis or if this single recorded case is an anomaly.

5.1.3 Black-backed jackals

Black-backed jackals are widespread throughout Eastern and Southern Africa with abundant populations. They inhabit a variety of environments from coastal to mountainous regions, but they are most commonly found in arid habitats (Kaunda, 2010) and were recorded in the present study at the Mierjie Le Roux Experimental Farm. Black-backed jackals are primarily nocturnal and the level of their activity increases between 18h00-19h00 and 24h00-05h00 (Rowe-Rowe, 1983). They are rarely active during daylight hours and they are inactive from the late morning to mid-day (09h00 and 14h59) (Rowe-Rowe, 1983) as was observed in the present study.

The black-backed jackal's omnivorous diet is highly variable as is exhibited in their opportunistic feeding behaviours. The content of their diet varies regionally as it is influenced by the seasonal availability of different food sources (Jenner *et al.*, 2011; Van de Ven *et al.*, 2013). They are predominantly scavengers however they do hunt prey as well, such as seals and their pups, birds, mussels, rodents, reptiles, ungulates, and primates. They even occasionally consume vegetation (Avery *et al.*, 1987; Hiscocks, 1987; Van de Ven *et al.*, 2013).

The feeding behaviours of black-backed jackals differ from other canines. Other canines kill and feed in a more chaotic fashion unlike black-backed jackals, which kill and feed

more neatly. Other canines show a preference for the skeletal elements contrarily to the black-backed jackal, which prefers to consume the soft tissues (Rowe-Rowe, 1975). The black-backed jackal feeds preferentially on the flesh and skin of the flank and the haunch of a leg, and the organs such as the heart, liver, lungs and stomach (Rowe-Rowe, 1975). This feeding behaviour was exhibited in the present study. The black-backed jackals showed preference for soft tissues resulting in the rapid skeletonisation of the remains in an average of 14.2 days in summer and 34 days in winter. This skeletonisation rate was substantially faster than what was recorded in a previous decomposition study at the same site, which prevented scavenging (Myburgh, 2011).

Although the black-backed jackals in the present study were aware of the carcasses from the earlier stages of decomposition, they only started to scavenge in the later stages from the active stage onwards, thus, indicating a preference for putrefied soft tissues. Previous studies on the diet of black-backed jackals have studied their spoor to identify the sources of their diet. The presence of Diptera larvae in jackal scat was a common occurrence and this is evidence that their original food source was actively decomposing (Rowe-Rowe, 1983; Hiscocks, 1987). These findings support the notion that black-back jackals preferentially consume putrefied soft tissues. This would have an impact on forensic investigations that involve human remains that have been scavenged in regions where black-backed jackals are active. In such a case, it is possible that conventional methods of postmortem interval (PMI) estimation could be considered only if the individual is in the early and bloat stages of decomposition. These methods cannot be accurately used in scavenged cases from the active stage onwards. The level of skeletonisation of the remains could have been altered by jackal scavenging, which would result in an inaccurate PMI that is too high. For example, remains whose soft tissues have been consumed by scavenging animals will be skeletonised faster than remains that decompose typically without animal interference. Forensic investigators might incorrectly overestimate the PMI of remains that have been skeletonised by scavenging activity, if the PMI is assessed on the stages of decomposition. Another variable that should be considered is the effect of the season on jackal scavenging rates as the jackals were active much sooner in the summer than in winter, and the skeletonisation and scattering of the remains were very rapid in summer compared to winter. An additional seasonal effect on the jackal scavenging, which had a bearing on the skeletonisation rate was the number of jackals

scavenging at a time on the same carcass. The jackals scavenged in larger packs more frequently in the summer period, which increased the rate of skeletonisation. Since jackals are social animals, they often pair up in mating pairs and may be accompanied by subordinates. The size of a pack depends largely on the resources available in their territory (Jenner *et al.*, 2011). As resources increase in the summer period, pack numbers increase. This was observed in the present study as the pack numbers increased during the summer months. This phenomenon should also be considered in forensic investigations where black-backed jackal scavenging is suspected when estimating a PMI.

5.1.4 Other mammals that make up the scavenging guilds

5.1.4.1 Cape porcupine

The Cape porcupine (*Hystrix africaeaustralis*) is a large (10-24kg) nocturnal rodent of the sub order: hystricomorpha. Their distribution extends widely throughout southern Africa (Corbet & Aarde, 1996). Their dens constitute extensive burrow systems, caves and crevices in rocks (Corbet & Aarde, 1996). The diet of porcupines includes geophyte plants, roots, and tree bark (van Aarde, 1987; Yeaton, 1988; De Villiers & Van Aarde, 1994). Porcupines often sharpen their incisor teeth by gnawing on bones. They also consume bones, fleshed and dry bone without any notable preference (Kerbis-Peterhans, 1990; Rabinovitch & Horwitz, 1994). Porcupines are social and live in monogamous breeding pairs or in small groups that include their mature and immature offspring and/or siblings (Morris & Van Aarde, 1985; van Aarde, 1987).

The Cape porcupines were attracted to six of the ten pig carcasses at the Highveld agricultural farm site (Mierjie Le Roux Experimental Farm) and they scavenged on the remains in a predictable manner. They were observed in both the summer and winter periods, however, they were only observed in isolation in winter and as a pair in summer. This is possibly due to their seasonal breeding period being isolated to the rainy season in summer (Morris & Van Aarde, 1985). They are nocturnal (Corbet & Aarde, 1996) animals so it is unsurprising that they scavenged at night (van Aarde, 1987). The porcupines only actively scavenged the carcasses after they were skeletonised and scattered by black-backed jackals. This is because they prefer bone that is lightly fleshed or dry (Kerbis-Peterhans, 1990; Rabinovitch & Horwitz, 1994). The Cape porcupine

showed a preference for scavenging the long bones of the limbs, particularly the epiphyses. These scavenged remains were recovered, although, the porcupine scavenging damage varied. Given that the Cape porcupine is wide spread throughout most habitats in southern Africa (van Aarde, 1987), they are of forensic interest and should be considered in forensic cases that exhibit scavenging and scattering.

5.1.4.2 Honey badger

Honey badgers (*Mellivora capensis*) are solitary, predatory carnivores (Begg *et al.*, 2003a; Begg *et al.*, 2003b), although the territorial home ranges of adult male honey badgers often overlap extensively with other adult males and encompass smaller home ranges of younger males (Begg *et al.*, 2003a). This often results in the formation of groups of two to five adult males, which travel together (Begg *et al.*, 2003a). This behaviour is not observed in female honey badgers, which tend to avoid each other (Begg *et al.*, 2003a). They can be found spread across most of sub-Saharan Africa, Arabia, Iran and western Asia spreading to the Indian peninsula (Begg *et al.*, 2003b).

Honey badgers were not prolific scavengers in this study. Honey badgers were observed scavenging on a single pig carcass in two different sites: the Wits Rural Facility (Limpopo) and the Mierjie Le Roux Experimental Farm (Gauteng). There was only a single recorded episode of honey badger scavenging at each site, which likely indicates that the scavenging was most likely the result of opportunistic foraging. At both sites the badgers scavenged in pairs – thus, they were likely a pair of males (Begg *et al.*, 2003a). The badgers exhibited a preference for scavenging on the ribs, whole disarticulated limbs, and the soft tissues of the abdomen in the advanced (Mierjie Le Roux Experimental Farm) and skeletonised (Wits Rural Facility) stages of decomposition. They were also active in the summer (Wits Rural Facility) and winter (Mierjie Le Roux Experimental Farm) periods.

Despite honey badgers being widespread in South Africa, their scavenging behaviours suggest that they are more opportunistic scavengers and are, thus, of lower forensic importance than other animals within the scavenging guild.

5.1.4.3 Common warthog

The common warthog (*Phacochoerus africanus*) is a medium sized, non-migratory ungulate with a wide distribution across African savannah ecosystems (Treydte *et al.*, 2006). Although its diet is omnivorous, it is largely herbivorous consisting of roots, tubers,

and other subterranean vegetation (Field, 1970). Osteophagia (consumption of bone) and geophagia (consumption of soil) are also common (Field, 1970). Common warthogs live in fairly flexible social structures, the size of, which depends of the age and sex of the individuals within the sounder (group). Young warthogs form larger sounders than adults. Sounders primarily comprised of males that are typically similar in size to sounders primarily comprised of females, although males are likely to be more solitary (White, 2010). The variable nature of warthog sounders often result in the formation of clans – several sounders with overlapping home ranges (Cumming, 1975).

The common warthog was an active scavenger at the Wits Rural Facility in Limpopo. They were only active in the summer period and they scavenged on all five summer pig carcasses. Only one warthog scavenged at a time, during the early morning and late afternoon, when the carcasses were in the skeletonised stage (after vulture scavenging) and they showed a preference for ribs and vertebrae. The warthog consumed whole skeletal elements, which affected the specific skeletal elements recovered after scavenging.

The common warthog has proven to play a role in the scavenging guild of the Lowveld in Limpopo. Although the dominating vultures skeletonised and scattered the remains, they did not consume the skeletal remains. The subsequent scavenging by the common warthog has proven to be the contributing cause to the loss of skeletal elements. Forensic investigators need to be cognisant of the potential influence common warthogs have on the number and type of surviving skeletal elements, which survive in African savannah ecosystems. This could assist forensic investigators in the reconstruction of postmortem events and account for missing skeletal elements.

5.1.4.4 African civet

The African civet (*Civettictis civetta*) is the largest species in the civet family (*Viverridae*). It is widely distributed through tropical rainforests and dry savanna ecosystems of sub-Saharan Africa to northern South Africa and Botswana (Ewer & Wemmer, 1974) and it selects thickets or burrows as resting sites (Abebe, 2003). Due to the African civet's solitary, timid, and nocturnal behaviour, little is known of its behaviour in the wild (Ewer & Wemmer, 1974). African civets are primarily carnivorous although they are omnivorous generalists that rely on their acute sense of smell and hearing to locate the sources of

their diet of fruit, carrion, eggs, small vertebrates, and invertebrates (Ewer & Wemmer, 1974; Mullu & Balakrishnan, 2015).

The African civet was recorded scavenging on the pig carcasses at the Wits Rural Facility (Lowveld of Limpopo) only in winter. They scavenged nocturnally, in isolation when the carcasses were skeletonised and they preferentially scavenged on the ribs and pelvis for short durations. It appears that the scavenging was opportunistic and did not appear to cause any significant loss of skeletal elements. The minimal and opportunistic scavenging behaviour of the African civet suggests that it is more opportunistic and is, thus, of lower forensic importance than other animals within the scavenging guild.

5.1.4.5 Common large-spotted genet

The common large-spotted genet (*Genetta tigrina*) is distributed over Southern Africa from northeastern Namibia, north and eastern Botswana, and eastern South Africa (Skinner & Chimimba, 2005). Their habitat includes well-watered savannah woodlands, fynbos biomes, and anthropogenic regions that have been cultivated and human settlements (Kingdon, 2015). Their resting sites are made up of dense trees, shrubs, or cacti (Fuller *et al.*, 1990). Genets are mostly solitary and they are nocturnal or crepuscular (active during twilight) (Skinner & Chimimba, 2005). Their diet comprises invertebrates, small mammals, birds, fish, reptiles, fruits, and seeds (Roberts *et al.*, 2007; Widdows & Downs, 2015). The common large-spotted genet is also known to scavenge on carcasses (Butler & Du Toit, 2002; Moleón *et al.*, 2015).

The common large-spotted genet was attracted to pig carcasses in the present study at two sites: the Wits Rural Facility and the Frankenwald research site, in the winter and summer periods. Genets were surprisingly not recorded at the Mierjie Le Roux Experimental Farm, although their absence is likely due to the presence of black-backed jackals at this site. The relative abundance of jackals have been noted to negatively influence the detection probability of large spotted genet (Ramesh & Downs, 2014). The genets did not scavenge on the pigs at the Frankenwald site, but they did at the Wits Rural Facility. At this site in the Lowveld of Limpopo, the common large-spotted genet scavenged in isolation when the pig carcasses were in the early and skeletonisation stages of decomposition. In the early stage (not more than six hours after the pig carcass was deployed) a genet was recorded, on two occasions, inserting its head into the anus

of a single pig, presumably feeding on the internal soft tissues. The genet also scavenged on pig remains when they were skeletonised, with a preference for the ribs.

The common large-spotted genet had a minimal impact on the scavenging and scattering of the remains suggesting that it is of lower forensic importance than other animals within the scavenging guild.

5.1.4.6 Domestic and feral dogs and cats

Domesticated animals such as dogs and cats have often scavenged upon human remains, particularly in cities and suburban areas (Tsokos & Schulz, 1999; Chute & Bready, 2017). It is surprising that no scavenging was recorded by domestic and feral dogs and cats in the present study, particularly at the Frankenwald site and abandoned building complex in Braamfontein, Johannesburg. At the Frankenwald site, a number of domestic dogs were attracted to the carcasses. They scent-marked themselves on the carcasses but they were not recorded scavenging on the pig carcasses. At the abandoned building complex, a number of feral cats were observed passing by all of the carcasses but they showed no interest in the carcasses. Equally surprising was the absence of rat scavenging in the abandoned buildings despite rats having been previously observed at the site. It is assumed that the cats hunt the rats and have no need to scavenge on the pig carcasses. A similar study in Cape Town (Spies *et al.*, 2018a) also noted that domestic cats were present in their research site but also did not scavenge the pig remains. This suggests that cats will not scavenge when an alternative food source is available and that the cats are keeping the rat population down at the research site. Mice were observed at the Frankenwald site but they only foraged for migrating insects.

These findings suggest that domestic and feral dogs and cats potentially are unlikely to scavenge on remains if there is alternative food sources (Tsokos & Schulz, 1999; Chute & Bready, 2017) and they aren't confined in a dwelling with the remains.

5.1.5 Scent marking

Numerous animals at various research sites were attracted to the pig carcasses not only to scavenge on the carcasses or feed on the colonising insects, but to also utilise the carcasses for a behaviour termed 'interspecific scent marking'. The common large-spotted genet, slender mongoose, and domestic dogs were observed rubbing themselves on the carcasses, thus, marking themselves with the pig carcass' scent. Interspecific scent

marking has been widely recorded in numerous carnivores (Apps *et al.*, 2017), however, the exact reason for this behaviour is unknown and the reasons may be different for each species. Slender mongooses and small-spotted genets often visit trees that have been marked by cheetahs to rub the cheetah's scent onto themselves (Apps *et al.*, 2017). Slender mongooses will often follow after a genet has visited and marked a site and the mongoose will mark themselves with the scent in a process termed 'overmarking' (Apps *et al.*, 2017). The reason for why slender mongooses and genets overmark each other's scents is unknown (Apps *et al.*, 2017). The hypothesis that is currently maintained is that smaller mammals mark themselves with the scent of a dominant predator for protection. This explanation does not explain how the overmarking behaviour of dogs, genets, and mongooses on pig carcasses would enhance their survival (Apps *et al.*, 2017).

5.2 Scattering patterns of scavenging animals

The dominant scavenger species in each environment (slender mongoose, vultures (particularly the white-backed vulture), and black-backed jackals) had the greatest influence on the scavenging-assisted skeletonisation rate and the scattering of remains in their respective environment. Each of these dominant scavenger species presented a unique scattering pattern. It is important for forensic specialists to know, which animal species is dominant in the area they are recovering scattered remains from. This will assist them in the holistic recovery of scattered remains for analysis. The scattering patterns of the slender mongoose, vultures, and black-backed jackals will be presented and compared.

5.2.1 Scattering patterns of dominant scavenger species

5.2.1.1 Slender mongooses

The scavenging behaviours and patterns of the slender mongoose, at Frankenwald, in the present study and the Cape grey mongoose in Cape Town, observed by Spies *et al.* (Spies *et al.*, 2018a), are very similar. As such, the scattering patterns of the slender mongoose will be discussed in comparison to the scattering pattern of the Cape grey mongooses. Both mongoose species scatter the remains when the skeletal elements are exposed, and the bones are still greasy with desiccated tissue still adhering to it. The first elements to be scattered are disarticulated limbs (all bones of the limbs are still articulated

together with desiccated tissues) (Spies *et al.*, 2018a). In addition to the limbs, the slender mongoose also scattered the scapulae early in this process.

Both mongoose species scattered carrion remains over a relatively small area. The slender mongoose scattered remains to a maximum distance of 10.5m /34.45ft compared to the 12.67m /41.57ft of the Cape grey mongoose (Spies *et al.*, 2018a). The small distance could be accounted for, in part by their relatively small body sizes. The average size of a slender mongoose is 44-65cm in length and 280-488g in weight compared to the slightly larger Cape mongoose, which has an average length of 55-76cm and weighs 500-1250g (Stuart & Stuart, 2017). The scattering distance could also be accounted for by the size and strength of the scavenger to the size and weight of skeletal elements (Haglund, 1997b).

The scattering pattern of both mongoose species indicated clear directionality in two general directions. The slender mongoose scattered remains in both north and south-east directions, whereas the Cape grey mongoose scattered remains in sets of bilateral directions: one case was scattered in north and west south-west directions, and a second case was scattered in south and west directions (Spies *et al.*, 2018a). The assumed reason for the general directionality of the scattering in both studies was not related to any geographic influence other than the directions of the mongoose dens. Small or medium sized mammals often scatter remains towards areas of high and thick vegetation or dense assemblages of fallen trees by (Young *et al.*, 2015a). Forensic specialists should search for nearby dens and areas of thick vegetation near a scavenged body as remains will likely be scattered in their direction.

Understanding the consistent scattering behaviour of mongooses is important knowledge because mongooses have been shown to be prolific scavengers in South Africa with a high probability that they will scavenge and scatter forensic cases. Understanding that mongooses scatter remains in two general directions will assist in the search and recovery of scattered skeletal remains, which will contribute to holistic skeletal analysis. It has been demonstrated that skeletal elements are scattered towards dens and burrows (Spies *et al.*, 2018a) and in directions away from human activity (Kjorlien *et al.*, 2009).

5.2.1.2 Vultures

Various vulture species scavenged together (white-backed, hooded, and lappet-faced) but the white-backed vultures were most numerous and dominated the carcasses and they were the main species accountable for the scattering of carrion remains at the Wits Rural Facility. The scattering of skeletal elements was limited because the vultures efficiently consumed all soft tissues of a pig carcass leaving most of the skeleton intact and articulated as a whole. The axial skeleton would be completely exposed and articulated, with the skin surviving as a single sheet still attached to the neck and head and attached to the disarticulated limbs.

The feeding pattern of the vultures – leaving the skeleton largely articulated – would account for the relatively small area the remains are scattered over. The few individual skeletal elements, which were disarticulated and scattered by vultures at the Wits Rural Facility (mostly ribs, scapulae, and disarticulated limbs) by a maximum distance of 7.09m/23.3ft or an approximate circular area of 157.9m²/1699.62ft². This scattering distance by the white-backed vulture is larger than that by the American black vulture, which scatters remains over a distance of 5.16m/16.93ft or a circular area of 83.6m²/899.86ft² (Spradley *et al.*, 2012). The articulated skeleton would only slightly be moved from its original deposition site.

Seasonal variables affected the scavenging behaviour of the vultures, which resulted in seasonal differences on the dispersal of scattered remains. The scattering pattern at the Wits Rural Facility was more diffuse in summer and denser in winter. The size of summer vulture wakes was much larger, which resulted in more rapid vulture skeletonisation and scattering. Vultures are able to fly longer distances in summer in search of food (Monsarrat *et al.*, 2013) and this could be one reason that accounts for the larger numbers of vultures in the summer period resulting in a wider scatter pattern. An increase in vulture numbers scavenging on a single carcass increases the competition for food and results in more active feeding frenzies and greater scattering of remains.

The seasonal differences in the vulture scattering distance and dispersal of remains does not have a large impact on the recovery of forensic remains as they are still within a small and manageable area and are easy to locate. The surviving, articulated skeleton also assists in the recovery and survivability of remains.

No special search methods need to be employed in forensic cases of vulture scattering. The remains remain closely scattered around the original site of deposition and their location and recovery is simple.

5.2.1.3 *Black-backed jackals*

In the search for scattered remains, it is likely that they will be scattered along game trails (Haglund, 1997a; Kjørlien *et al.*, 2009). Animals are habitual and they follow well established game trails that they frequent. These game trails are easy to locate as they are clearly trampled into the long grass. It has been suggested that in a search for scattered remains, well established game trails, newer or fresh paths and drag marks should be followed, which will assist in the discovery of scattered remains (Haglund, 1997a; Kjørlien *et al.*, 2009). This became very apparent as a successful method to locating scattered remains by black-backed jackals at the Mierjie Le Roux Experimental Farm within the fenced-off enclosure. During the summer period, after frequent rainfalls, long grass was abundant within the enclosure and game trails were plenty and distinct. These game trails could be followed from the original deposition site of the pig carcasses to the holes in the fences where the animals gained entrance to the enclosure. Most of the scattered remains within this enclosure were within or alongside the game trails. Game trails were more difficult to locate outside of the enclosure as the grass was short and fresh; sprouting after recent veld fires.

The scattering patterns exhibited by the black-backed jackals also highlighted the effects of physical boundaries on scattering. Carcasses scavenged within the enclosed fenced off area did not have their remains scattered beyond the boundaries of the fences resulting in a maximum scatter radius of 42.8m/137.8ft. The carcasses that were not inhibited by fencing and were deployed in open fields had a much larger maximum scattering distance of 73.7m/241.8ft.

It is advised in forensic cases where jackal scavenging is suspected that game trails be identified and followed when recovering scattered remains. The search radius should appropriately be determined by the physical boundaries that are present at a site.

5.2.2 The influence of multiple scavengers on scattering patterns

Although the vultures and the black-backed jackals were the dominant species in their respective scavenger guilds, and they were the primary cause of the scattering of carcass

remains, other scavengers within their guild also scattered the remains further. It must be noted though that none of these other scavengers scattered the remains beyond the radius of the dominant scavengers and they did not drastically alter the scattering patterns. Most of these secondary scavengers only moved the remains slightly or they consumed the skeletal elements thereby removing them from the site completely. It is important for forensic investigators to be aware of which species is the dominant scavenger within a local guild as their scattering pattern should direct the search patterns for scattered remains.

5.2.3 Search patterns for scattered remains

Identifying the direction of scattering can assist greatly in the holistic recovery of remains. The method of 'walking the line' in a grid formation was used to locate the scattered remains in the present study. This method was very effective in the sites where the remains were scattered diffusely in no particular directions, such as that by the vultures. This method was very time consuming, although effective, in the recovery of remains scattered over a very large area, such as in the case of the black-backed jackals. It has been suggested a 'link search method' should be used instead in the location of scattered scavenged remains (Young *et al.*, 2015a). This search method is far more flexible and relies on the searcher to adjust their direction based on the identification of cues, such as drag marks in the soil, clumps of fur, animal scat, game trails, or disturbed soil (Young *et al.*, 2015a). A combination of the 'walking the line method in a grid fashion' and the 'link search method' was intuitively implemented in the search for remains scattered by the black-backed jackals. Searching in a grid pattern allowed for the initial discovery of scattered remains and once it was clear that the remains were scattered in two general directions by mongooses and black-backed jackals within a 90 degree arc, the principles of the 'link search method' directed in which directions the grid search should be focused. The experience of locating and mapping the scatter patterns observed in the present study, lead to the suggestion that search methods should be flexible and chosen based on the size of the scatter area. Remains which have been scattered over short distances should use the grid pattern and remains scattered over large areas should initially use the grid pattern to discern any directionality that may exist followed by the 'link the search method' to save time if a case is time-sensitive.

Ribs and vertebrae appear to be scattered in a consistent pattern. Haglund (Haglund, 1997a) observed that ribs and vertebrae often remain close to the original site of a carcass' deposition. This is supported by the present study in all four research sites. Most ribs and vertebrae remained *in situ* when scavenged upon by slender mongooses at the Frankenwald site. At the Mierjie Le Roux Experimental Farm most ribs and vertebrae were clustered together very near the original deposition site after being scavenged by black-backed jackals; and at the Wits Rural Facility the disarticulated ribs were scattered in close proximity to the articulated ribs and vertebrae of carcasses scavenged by vultures. The ribs and vertebrae are difficult to disarticulate, compared to the limbs, and they are less likely to be transported and scattered away from the original disposition site. This would depend on the stage of decomposition when scavenging occurs (Kjorlien *et al.*, 2009). When scavenging is initiated in the later stages of decomposition, the skeletal elements are more likely to be located close to the original deposition site. Contrarily, carcasses that are scavenged in the early stages of decomposition are most likely to have fewer skeletal elements located close to the original deposition site. The reason for this can be attributed to the disarticulation sequence of remains. Earlier stages of decomposition force scavengers to disarticulate whole limbs or skeletal groups, thus, leading to skeletal elements being scattered further. Later stages of decomposition allow scavengers to selectively choose individual skeletal elements which are not still held together by intact muscles, tendons, and ligaments, thus, leaving more elements to remain closer to the original deposition site (Kjorlien *et al.*, 2009). This principle was highlighted in the present study.

5.3 Animal scavenging modifications on bone

There were bite mark patterns that were left on bone by scavenging animals, which could be useful evidence in the identification of the perpetrating animals. Felids (lion, leopard, and caracal), spotted hyena, Cape porcupine, and slender mongooses all caused potentially unique and identifying bite mark patterns to skeletal elements in the present study. Heavy gnawing damage has been reported by previous literature to be distinctive enough to identify the general type of animal, such as large cats, canids, hyenas, and bears, but the exact taxonomic species cannot be accurately concluded (Haynes, 1983). Canids (wild dogs and black-backed jackals), vultures (white-backed, hooded, and lappet-faced), and common warthogs caused damage that was identifiable as animal scavenging

modifications, however, they were not distinctive enough to identify the perpetrating animal.

The characteristics of heavy damage caused to bone by scavenging can be reliable indicators of which type of animal was the perpetrator, however, a combination of bone modification patterns should be used rather than a single pattern (Andrés *et al.*, 2012). Very light gnawing damage is identifiable as animal scavenging but the patterns are indecipherable between various taxa of scavengers and are not very useful for differentiation between scavengers (Haynes, 1983). A discussion of the species-specific scavenging alterations to bone is provided below and will assist forensic investigators in Africa to discern between scavenging damage on bone and perimortem trauma, such as evidence of trauma caused by a weapon, i.e, sharp, blunt and projectile traumas.

5.3.1 Large felids (lion, leopard, caracal)

Lions, tigers, and jaguars have been recorded to all follow the same scavenging process when consuming long bones (Haynes, 1983). They do not sustain long periods of gnawing on bones, however, captive cubs and adults do occasionally mouth bones and briefly gnaw on them (Haynes, 1983). The primary damage caused by large cats is the biting off of the greater trochanter, biting the neck beneath the femoral head, and scraping of the trochlea leaving furrows in the distal femur (Haynes, 1983). Adult lions occasionally leave scores on the diaphysis, perpendicular to the long axis. The greater trochanter may contain deep pits. The most identifying characteristic of large cat gnawing are the furrows in the cancellous bone of the epiphyses, which are caused by the large cheek teeth (Haynes, 1983). The tibia exhibit deeper scores isolated to the proximal articular edges on both the medial and lateral aspects (Haynes, 1983). The tibial crest is occasionally furrowed perpendicular to the long axis. This is attributed to the consumption of muscles and soft tissue surrounding the patella. The crest may also be completely removed (Haynes, 1983).

All felids in the present study - lion (*Panthera leo*), leopard (*Panthera pardus*), and caracal (*Caracal caracal*) - caused strikingly similar bite mark patterns in long bones (Keyes *et al.*, 2019). Common to all three species were the gnawing away of the greater trochanter or greater tubercle, or the entirety of the proximal epiphyses of long bones, with deep, parallel furrows remaining within the trabecular bone (Keyes *et al.*, 2019). This bite mark

pattern has also been described in tiger and jaguar scavenging (Haynes, 1983). The furrows are created by individual tooth cusps scraping away at the trabecular bone (Haynes, 1983) as the animal tries to access the marrow (Haglund *et al.*, 1988). This pattern is specific to felid scavenging and can, thus, be used to concluded felid involvement although the specific species cannot be determined (Haynes, 1983).

The scavenging modifications caused to bone by large felids such as lions, leopards, panthers, and tigers, has been previously studied, however medium-sized felids - such as the caracal – has not been previously published. The caracals in this study caused the most variety of scavenging modifications to long bones than any other animal. Caracals were the only animal to cause all bite mark types: pits, furrows, scores, and punctures (Keyes *et al.*, 2019). They additionally caused massive gnawing damage by removing the entire distal epiphyseal ends of long bones (not just the greater trochanter or tubercle) and they also left claw marks (Keyes *et al.*, 2019). This variety of scavenging modifications could potentially be used to differentiate caracal damage from other felid damage; however, this needs to be studied more thoroughly to support this suggestion.

5.3.2 Spotted hyena

The extent and pattern of hyena damage to bovine femora and tibia have previously been recorded and the bite mark pattern evolves over time (Haynes, 1983). Hyena scavenging of the femur begins with simple scoring and pitting in the cortical bone in the early stage of feeding. This is followed by partial consumption of the greater trochanter, the shaft is ground up and crushed, and the trochlea is furrowed (Haynes, 1983). If a femur is not abandoned at this point and carried to a hyena's den, or in cases of captive hyenas, the hyena feeding will continue as follows: the proximal epiphysis is consumed entirely, and the diaphysis fragmented gradually. Fragments of the diaphysis may be ignored, or swallowed whole, or chewed over time. It is common for a single distal condyle (often the medial condyle) to remain uneaten (Haynes, 1983). This level of femoral consumption can occur within one hour. Surviving femoral fragments may exhibit scores and pits in the cortical bone. The fractured edges of shaft fragments may, in part or in whole, be rounded due to chewing abrasion, repetitive licking, or friction against the ground. Surviving areas with exposed trabecular bone may have numerous furrows (Haynes, 1983).

Hyena scavenging of the tibia begins with the proximal anterior crest being gouged out leaving furrows in the exposed trabecular bone. This is followed by the complete consumption of the proximal end leaving the shaft with a sharp, fractured edge (Haynes, 1983). Scores and pits are left in the cortical bone of the shaft as the periosteum is peeled off and the bone is carried horizontally in the jaws of the hyena. Tarsals are often disarticulated at this point (Haynes, 1983). The hyena will then fragment the shaft. The fragmented edges are then rounded by continuous gnawing with an increase in the number of pits and scores in the cortical bone, which may lead to patchy delamination of the external bone layers (Haynes, 1983). What remains of the fragmented tibia is often less than one-third of the shaft, with well-rounded fracture edges. The distal end of the tibia often survives with no tooth marks (Haynes, 1983). This is exactly what remained of the limb bones fed to the captive spotted hyena (*Crocuta crocuta*) in the present study (Keyes *et al.*, 2019).

All that remained of the long bones of the limbs which were fed to the spotted hyena in the present study was a tibia with total consumption of the proximal end, leaving one third of the shaft remaining with jagged fracture edges. This is a classic sign of hyena scavenging (Haynes, 1983). The jagged fracture edges are typically sharper (Haynes, 1983), however, in this study the fracture edges were slightly rounded due to repeated licking or rubbing against ground surfaces (Haynes, 1983). This continuous licking is a common behaviour of hyenas in captivity. The same would not be commonly seen in the wild due to limited time with remains due to competition with other animals for food (Gidna *et al.*, 2013).

5.3.3 Canids (wild dog and black-backed jackal)

The tooth marks of wild dogs (*Lycaon pictus*) have been documented on equine bones (Yravedra *et al.*, 2014). Wild dog modification of bone is very minimal with no deletion of long bone sections and no fragmentation (Yravedra *et al.*, 2014). This often leads to the recovery of all long bones (Yravedra *et al.*, 2014). The femur, humerus, tibia, and radius often present with few superficial pits and scores located mostly on the diaphysis (Yravedra *et al.*, 2014). They did cause furrowing in the proximal epiphysis of the ulna. These bite mark patterns were supported by the present study using bovine bones (Keyes *et al.*, 2019). Previous literature on black-backed jackal scavenging has not explicitly

described the tooth mark patterns of jackals. This is likely because there is no specific pattern observed.

In the present study, the captive wild dogs and black-backed jackals (housed at the National Zoological Gardens) caused very light bone damage isolated to shallow pits and scores. These bite mark patterns are not unique enough to be diagnostic of which animal caused the tooth marks. The tooth marks were so superficial that they were very difficult to observe without a good light source that could alternate between varying intensities. The captive wild dog left shallow furrows in the gnawed margin of the greater tubercle of the humerus (as was seen in the equine ulna in a previous study (Yravedra *et al.*, 2014)), nevertheless, this alone was not distinctive enough to identify the perpetrating animal. Previous literature has investigated if the size of pits caused by wild dogs and jackals can be used to differentiate them from pits caused by other animals (Selvaggio & Wilder, 2001; Pickering & Carlson, 2004; Andrés *et al.*, 2012), however, it has been concluded that tooth dimensions can only be used to determine the general size (large or small) of the carnivore (Andrés *et al.*, 2012). The repeatability of such measurements has not yet been explicitly studied.

The wild black-backed jackals at the Mierjie Le Roux Experimental Farm exhibited a number of additional non-specific scavenging modifications (Rowe-Rowe, 1975). A few sternal ends of ribs were consumed and the transverse processes of a number of vertebrae were fractured but complete. Jackals prefer to consume soft tissues, such as the organs within the chest cavity, over skeletal elements (Rowe-Rowe, 1975). This could account for the partial consumption of the ribs and fracturing of the transverse process of the vertebrae. Since some organs are protected by the rib cage, the jackals have to bite through the sternum and ends of the ribs to gain access to the organs. Punctures were also present in one head of a humerus and the medial boarder of one scapula, and furrows were present in the cranioventral spine of one ilium. These scavenging modifications did not create a pattern that is distinct or unique enough to identify jackals as the perpetrating species if observed in a forensic case.

5.3.4 Cape porcupine

Cape porcupine (*Hystrix africaeaustralis*) scavenging of bone has been well documented as a common occurrence, used to sharpen the incisors or supplement the calcium and/or

phosphorus content of their diet (Duthie & Skinner, 1986). Porcupine scavenging modifications patterns are distinct and distinguishable from other rodent tooth marks (Brain *et al.*, 1980; Brain, 1983; Duthie & Skinner, 1986; Kerbis-Peterhans, 1990; Rabinovitch & Horwitz, 1994). Flat bony regions that have been gnawed by porcupines present fan-like parallel scores with undefined contours (Keyes *et al.*, 2019). Heavy gnawing of the epiphyses results in the total destruction of the bony region, with the appearance of the bone being scooped out as was observed in a femur fed to the captive porcupines housed at the NZG (Keyes *et al.*, 2019) and the distal and proximal ends of a tibia scavenged by wild porcupines at the Mierjie Le Roux Experimental Farm. Large, oval depressions with an eroded, polished appearance were also observed in an olecranon tuber scavenged by the captive NZG porcupines (Keyes *et al.*, 2019) and in the condyle of a femur and the head of a humerus scavenged by wild porcupines at the Mierjie Le Roux Experimental Farm. This bite mark pattern has not been described before in previous literature. These characteristic damages, in conjunction with the absence of pits, are indicative of porcupine intervention.

5.3.5 Vultures

Avian scavengers leave few marks on bone. They can form conical punctures when making a pecking motion whilst eating soft tissues (Komar & Beattie, 1998). Their beak marks are described as shallow, irregular linear scores measuring up to 4cm (Reeves, 2009). Previous conflicting literature has reported on the damage caused by vultures on eye orbits. Anecdotal accounts of vultures pecking out the eyes and damaging the orbits has been reported (Reeves, 2009) but this was not observed in this study. Pecking out the eyes was observed but no orbit damage was present.

Vulture marks in the present study were characterised by shallow, irregular linear scores, similar to root etching, which were caused by their beaks. Distinguishing between beak marks and claw marks was easily achieved. Beak marks are wider and blunter than the sharp scores caused by claws. Claw marks are also less common than beak marks since their talons are relatively weak and are only used for leverage and not for grasping and manipulating the carcass (Reeves, 2009). The transverse processes of some vertebrae were also often partially fractured in a hinge-like manner. This could potentially be attributed to the rough manner in which the carcasses is scavenged by vultures during a

feeding frenzy where multiple vultures pile on top of the carcass and fight over access to the soft tissues and internal organs.

The beak marks alone are not sufficient to identify vulture scavenging of a carcass, however, their presence in addition to the full skeletonisation and persisting articulation of the skeletal remains, and the presence of a full sheet of skin would altogether suggest vulture scavenging.

5.3.6 Slender mongoose

The slender mongoose left very few scavenging modifications on a limited number of skeletal elements. The ribs, vertebrae, a scapula, and mandibles were the elements which did contain mongoose scavenging modifications. The few ribs that did exhibit scavenging modifications were consumed at the anterior and posterior ends leaving a non-specific crushed margin. The transverse processes and spinous processes of the vertebrae also occasionally had been gnawed away at their extremities. The anterior border of a scapula was also gnawed forming furrows. The bite mark patterns on the ribs and vertebrae were also described in the scavenging by the Cape grey mongoose in Cape Town, South Africa (Spies *et al.*, 2018a). The Cape grey mongoose also damaged the epiphyseal ends of long bones, in addition to the complete consumption of ribs, and vertebral spines were damaged (Spies *et al.*, 2018a). The extent of bone damage caused by the Cape grey mongoose appears to be more extensive than that by caused by the slender mongoose. This is likely attributable to the larger size of the Cape grey mongoose. These scavenging modifications are all distinctly caused by animal scavenging, however, in isolation, they are not specific enough to confirm mongoose scavenging.

The location and pattern of gnaw marks on the angle of the mandible does appear to be a distinct bite mark pattern of the slender mongoose. The gnawing was concentrated on the angle of the mandible with multiple parallel scores on the flat surfaces giving the angle margin a stepped appearance. This bite mark pattern was observed in mongoose scavenging at the Frankenwald research site and the Mierjie Le Roux Experimental Farm. The combination of bite mark patterns, in addition to other markers of mongoose activity such as the multiple holes dug around the body and the presence of spoor near the body (Spies *et al.*, 2018a), could be diagnostic of slender mongoose scavenging.

5.3.7 Common warthog

Scavenging by the common warthog resulted in the considerable loss of many skeletal elements, which survived the initial scavenging by vultures and marabou storks. Warthogs consumed many ribs and vertebrae whole. The consumption of bones by warthogs has been reported before (Field, 1970), yet, their modification of the bones has not been described previously. The fragmentary ribs that were partially consumed by warthogs were splintered and fractured with no distinct manner other than having the appearance of being crushed. The vertebrae that survived warthog scavenging had transverse processes which were split and frayed. However, the described bone modification pattern by warthog scavenging are not distinct enough to confirm warthog scavenging on their own.

5.4 Limitations

There are a number of limitations to this study that need to be addressed so as to define the context, relevance, and applicability of the results of this study.

5.4.1 Bite mark analysis

The first objective of this study was to describe animal bite mark patterns of pre-selected animals housed at the National Zoological Gardens (NZG) of South Africa. Only two of the seven animals that were selected at the NZG were observed scavenging in the wild at the other three sites – the black-backed jackal and Cape porcupine. In retrospect, it would have been beneficial to have performed the research at the NZG after the scavenging animals had been identified at the different research sites. This could have guided the selection of more common and relevant scavengers housed at the NZG, such as various mongoose species, honey badgers, warthogs, and vultures. This approach would have provided more focused and controlled bite mark analysis and could have allowed for a wider comparison of bite mark patterns between captive and wild animals.

The scavenging modifications patterns of animals in captivity were only described on the long bones of limbs. This is a common limitation in studies that have been published using captive animals. There is a necessity for more research on the bite mark patterns of scavenging animals on the axial skeleton.

5.4.2 Motion-activated cameras

The identification of scavenging animals and the descriptions of their behaviour relied heavily on the motion-activated cameras placed at the research sites. The camera footage was only retrieved every two weeks at the Frankenwald site, abandoned building complex, and Mierjie Le Roux Experimental Farm. There were rare instances when a camera did not record footage for unknown reasons. This occurred in a few instances at the Frankenwald research site where a camera malfunctioned and did not record for a day or two but this did not have any significant implications on the recording of the mongoose scavenging. However, in one case highlighted in the study at the Mierjie Le Roux Experimental Farm, the same malfunction occurred but the implications were more significant in that case. No footage was recorded for that case and this affected the quantity of data. Fortunately, the same animal species scavenged the remaining nine pig carcasses with consistent behaviours. It is unlikely that any significant scavenging species and their behaviours were not recorded in the cases where camera footage was not recorded.

Another limitation to the use of remote motion-activated cameras was the variable demand on battery-life. The battery life of the cameras relied heavily on the level of animal activity and wind-grass motion, which would activate the cameras. In some instances, the activation rate was much higher than anticipated, which drained the batteries at a faster rate than anticipated. This resulted in the cameras being deactivated a few days before the end of the standardised two week recording period, thus, a couple of days of recording was occasionally lost. This issue was identified early on at each research site and was amended by better anticipation of when batteries needed to be changed.

In the earliest instances when the camera batteries did run dry, the time and date stamps were automatically reset to factory settings, which made the analysis of the footage difficult. Fortunately the date and time stamps could be retrospectively amended manually and this did not drastically effect the results in such instances.

Reliance on remote cameras to record animal scavenging limited the visual range that could be recorded. When carcasses were moved beyond the view of the cameras by scavengers, the observation of scavengers and their behaviours was limited.

5.4.3 Wits Rural Facility

The study at the Wits Rural Facility only occurred over a period of one week in summer and one week in winter. This limited the results to the short term scavenging behaviours of animals and it is suggested that future studies look into scavenging in the long term. The vulture scavenging was also affected by the proximity of fences to the pig carcasses. There was a noticeable delay in the vulture scavenging of two pigs that were deployed near fences. It was observed that the vultures were weary of fences in general and it is assumed that this is a learned behaviour as the barrier fences are electrified to prevent the crossing of animals between the neighboring game reserves. All other pigs were laid out away from the fences and were observed to have relatively increased onsets of scavenging.

The time of day that the pig carcasses were laid out could have also influenced the rate of vulture scavenging. At the Wits Rural Facility, all pig carcasses were laid out in the late afternoon just prior to sunset due to the traveling distance to the sites. Due to the diurnal activity of vultures, it is possible that the vultures might have scavenged earlier if the pig carcasses were laid out in the early morning. This needs to be explored further in future research.

5.4.4 Chaining of carcasses

The carcasses were chained to a permanent fixture to increase the cameras' viewing times of scavenging activities in the event of scavenging in the early stages of decomposition. These chains were also used to prevent theft of the carcasses. These chains did not appear to have any significant effect on the scavenging and scattering of the remains. The chains did not deter the attraction of animals in the early stages of decomposition. The animals scavenged on the remains in the advanced stages of decomposition when the remains could be easily disarticulated without hindrance by the chains. It is possible that chaining the carcasses may have impacted scavenging and scattering in the early stages of decomposing and further research is needed to confirm this.

5.4.5 Cause of the death in pig sample

The pig sample for this study likely died as a result of natural death precipitated by hemorrhagic bowel syndrome, which is caused by the twisting of the intestines. This

initiated by an overgrowth of *Clostridium perfringens* or *Escherichia coli* in the intestines and is a common cause of death in large pig farms. Such pigs were selected as the sample for this study due to ethical reasons, since no pigs had to be terminated for the purposes of the study. Such pigs have also been used in published taphonomy studies (Keyes, 2019; Keyes *et al.*, 2020).

5.5 Recommendations for future research

1. The present study provided descriptions of bite mark patterns mostly isolated to the long bones. Future research should consider the bite mark patterns on the axial skeleton.
2. The bite mark patterns of various mongoose species need to be compared particularly between the Cape grey mongoose, yellow mongoose, slender mongoose, and yellow mongoose.
3. The bite mark patterns of the common warthog and honey badger needs to be further investigated and described.
4. There was an increased biodiversity of animal species attracted to the original deposition site of pig carcasses after carcasses had been removed from the site by scavengers. It is assumed that volatile compounds soaked into the soil and/or insects that had pupated in the soil were attracting the animals. This phenomenon and its potential implications for the reconstruction of postmortem events needs to be explored.
5. The time of the day that carcasses are deposited and its influence on the rate of vulture carrion detection and the resulting skeletonisation should be considered.
6. Significant movement was noted in one carcass that was in the advanced stage of decomposition at the Mierjie Le Roux Experimental Farm. The cause of the movement was not visible. The carcass moved erratically over short distances - particularly the limbs. Maggot activity beneath the body could be the potential cause. This phenomenon has also been observed at the Australian Facility for Taphonomic Experimental Research in a long term decomposition study (Stünzner, 2019). This should be investigated further as it would have an impact on our understanding on the taphonomic influence of postmortem movement.

7. The potentially unique bone modifications that have been described by this study need to be investigated further to determine if the features can be differentiated in a blind setting.
8. Future studies need to further investigate and quantify the effects of scavenging of different species on PMI estimations.
9. Most scavenging studies have focused on the short term (until skeletonisation). One recent study (Miranker *et al.*, 2020) did note that vultures will continue to visit skeletonised remains and scatter them further; however, there is a need for further research into the effects of scavenging in the long-term after skeletonisation.
10. The effects of hemorrhagic bowel syndrome on pig carcass decomposition and scavenging needs to be explored further.

Chapter 6: Conclusion

The scavenging behaviours presented by different guilds in this study have proven to be species-specific and region-specific. A greater understanding of their potential impact within a forensic context will greatly assist in the location of scattered remains, the analysis of their taphonomic evidences, and the reconstruction of postmortem events.

A number of animals did exhibit potentially unique, identifying bite mark patterns – particularly in the animals which cause heavy damage to bone. The felids (lion, leopard, and caracal) all exhibited the same gnawing pattern of removing the greater trochanter and leaving deep, parallel furrows. The hyena caused the most damage to bone, reducing the few surviving long bones to fragments, namely, one third of the tibial shaft with a jagged fracture edge. Cape porcupines also caused massive destruction to long bones, scooping out large portions of the distal epiphysis and leaving potentially distinctive fan-like parallel scores, and large, oval depression with an eroded, polished appearance. The slender mongoose characteristically gnawed on the angle of the mandible leaving the angle margin with a stepped appearance. Other animals caused lighter, non-identifiable scavenging modifications like nondescript pits and scores. These scavenging modifications can still be useful to suggest the involvement of scavenging animals, however, the exact species cannot be determined. These descriptions of bite mark patterns will assist African forensic anthropologists in the identification of scavenging damage on bone. This will be most beneficial in distinguishing between taphonomic scavenging damage and perimortem trauma, such as traumas due to weapons.

The species-specific behaviour was apparent in the scavenging animals observed in this study. The biodiversity of scavenger guilds varied greatly between the different environments. This indicated how important it is that regional studies are performed. Vultures were the most prolific scavengers in the Lowveld of South Africa. Although studies on vulture scavenging has been well documented in the past, the present study recorded skeletonisation rates that far exceed that in other studies in the Americas and Europe. This again highlights the need for region-specific research as the vulture species differed from previous research and their behaviours also differed substantially. The white-backed, hooded, and lappet-faced vultures skeletonised remains far more rapidly than has been recorded by vultures in previous forensic literature, at a rate between 5 - 98

minutes. This has serious implications for the accurate estimation of a postmortem interval where there has been vulture involvement.

Mongoose were the most prolific scavengers in this study. They also presented as the most diverse taxonomic family, with the species of slender, yellow, banded, and water mongooses comprising the guilds in a variety of combinations. Mongooses were members of scavenging guilds in three unique environments: the rural wildlife facility, the peri-urban agricultural farm, and the urban veld. The slender mongoose was the most common scavenger species and they were the sole urban veld scavenger at the Frankenwald research site – a surprising urban inhabitant. Their preference for scattering scapulae, ribs and vertebrae should be considered when these elements are not recovered in forensic cases.

The hadeda ibis (*Bostrychia hagedash*) is a common avian in urban environments and their presence at decomposing carcasses was not surprising. They did, however, exhibit opportunistic scavenging behaviours that were surprising and have bearing in a forensic context. Hadedda ibis were recorded scavenging on the intestines of a pig carcass in the abandoned building complex within an urban setting. This is a behaviour that has not been described or published prior. Their preference for feeding on colonising insects resulted in their creating multiple, large holes in the skin and the removal of the lips. These postmortem taphonomic alterations of decomposing remains are important to understand so that they are not confused for sharp force or ballistic trauma by the inexperienced.

The peri-urban agricultural environment had the greatest biodiverse scavenging guild of all the research sites. The black-backed jackals dominated the guild and was responsible for the scattering of the remains, although a variety of mongoose species (slender, yellow, and water mongoose), Cape porcupine, and honey badger also scavenged on the pig carcasses. The scattering of remains by the black-backed jackal highlighted the most useful patterns. Similar to the slender mongoose, the black-backed jackal scattered remains with clear directionality in two directions confined within a 90 degree arc. Since this pattern was observed in two different species it is possible that it could be common in other scavengers too and will assist in the search for scattered remains. The effect of terrain and barriers substantially altered the range of scattering (42.8m when confined by fences and 73.7 m when there are no barriers). This behaviour highlighted the need for

flexibility in the techniques used to search for scattered remains. Since the animals react to the environment around them, their scattering of remains is affected. As such it is suggested that a combination of methods be used, such as the 'link search method' and the grid search method. Due to the numerous environmental factors that affect scavenging and their taphonomic alteration of remains, it will be difficult to develop a single standardised protocol; however, suggestions for best practice should be explored in future studies.

In conclusion, it is imperative that forensic research continue to study taphonomic variables such as the species-specific and region-specific scavenging of remains. This will result in the improvement of thorough evidence collection and this will improve the accuracy of postmortem event reconstruction.

7. References

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I, **Craig Adam Keyes**, student number **0603779M**, declare that this Thesis is my own work and that I contributed adequately towards research findings published in the article(s) stated below which are included in my Thesis.

Signature of Student  Date...11 June 2020.....

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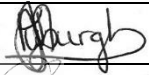
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Authors	Name	Signature	Date
1 st author	Craig Adam Keyes		11 June 2020
2 nd author	Jolandie Myburgh		11 June 2020
3 rd author	Desiré Brits		11 June 2020

Comments by primary supervisor:

Mr Keyes was instrumental in conceptualizing the research topic. He was also responsible for the data collection, analyses and interpretation as well as preparing the manuscript.

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8.4 Ethics certificates

8.4.1 Wits Animal Ethics Committee Ethics Waiver



ANIMAL RESEARCH ETHICS COMMITTEE

Registration number: AREC-101210-002

17 April 2018

To whom it may concern,

Re: Waiver from the Animal Ethics Research Committee of the University of the Witwatersrand

This letter is to confirm that Craig Keyes, PhD student (# 0603779M) under the supervision of Dr Desiré Brits, University of the Witwatersrand and Dr Jolandie Myburgh, University of Pretoria, does not require full Animal Ethics Research Committee clearance to undertake the work titled '**Postmortem animal scavenging of forensic interest**'.

Reason for waiver

This study will be a prospective, observational, longitudinal study. The animals will not be terminated for the primary purposes of this study.

Details of the study

This study aims to identify the scavenging animals of forensic significance in South Africa, to describe their behavior, and to describe the skeletal trauma they cause. The sample will comprise of 40 pig (*Sus scrofa domesticus*) carcasses weighing between 50-100kg. These pigs will have died from either natural causes and donated by a licenced pig farm (such as Topig SA), and/or purchased from a licenced abattoir.

Research will also be performed at the National Zoological Gardens of South Africa (NZG). Lightly fleshed hind limbs (including os coxa, femur and foot) and ribs of pigs and/or cows (depending on the feeding animal's preference), sourced from a licenced abattoir, will be fed to different carnivores and the animal faeces will be collected from the enclosure for the recovery of any undigested bone fragments.

The individuals covered by the waiver are:

Craig Keyes

Dr Desiré Brits

Dr Jolandie Myburgh.

Conditions

Permission has been tentatively been granted by the NZG pending an application to their NZG Research Ethics and Scientific Committee. An ethics waiver from WITS is given to this study on condition that the NZG approves the study.

8.4.2 University of Pretoria Animal Ethics Committee



Faculty of Veterinary Science Animal Ethics Committee

Approval Certificate New Application

AEC Reference No.: H001-19

Title: Post mortem animal scavenging of forensic interest

Student name: CA Keyes

Supervisor: Dr. D Brits

Dear Dr. Brits

The **New Application** as supported by documents received on 13 November 2018 for your research, was approved by the Animal Ethics Committee on its quorate meeting of 29 January 2019.

Please note the following about your ethics approval:

1. The use of the following species Wild dog, spotted and striped hyena, lion, leopard, jackal, caracal, porcupine, as well as bovine bones sourced from a local butchery and pig carcasses is approved. The number of samples has to be reported by completing the annual progress report
2. Ethics Approval is valid for 1 year and needs to be renewed annually by December 2019.
3. Please remember to use your protocol number (H001-19) on any documents or correspondence with the AEC regarding your research.
4. Please note that the AEC may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

Please note the DAFF conditions (reference 12/11/1/1/20-789)

We wish you the best with your research.

Yours sincerely

Prof V Naidoo
CHAIRMAN: UP-Animal Ethics Committee

Room 6-13, Arnold Theiler Building, Onderstepoort
Private Bag X04, Onderstepoort 0110, South Africa
Tel +27 12 529 8483
Fax +27 12 529 8321
Email aec@up.ac.za
www.up.ac.za

Fakulteit Veeartsenykunde
Lefapha la Diseanse tša Bongakadiriwa

8.4.3 South African National Biodiversity Institute Research Ethics and Scientific Committee



NZG/RES/P18/10

25 April 2018

Craig Adam Keyes

University of the Witwatersrand (WITS)

OUTCOME OF SUBMITTED RESEARCH PROPOSAL

This letter serves to inform you that your submitted research proposal titled "Postmortem animal scavenging of forensic interest" was **approved** by the SANBI Research Ethics and Scientific Committee (RESC).

The following provisos should be taken into consideration:

1. Inform the RESC of completion or termination (with reason) of your research at the NZG.
2. Submission of an annual progress report in November of each year. Failure to submit a progress report may result in approval to be withdrawn.
3. Submission of a written request for an extension or for any changes within the research project.
4. The following must be used and/or stated in the acknowledgement of the NZG after the completion of the research project:
 - All scientific publications and abstracts (please include PDF documents of all publications) presented at conferences must be submitted with progress reports annually.
 - The NZG Biobank for providing the samples.
 - The NZG for contributing as a research platform.
5. Submission of a final report in December of each year.

IMPORTANT: It is your responsibility to ensure compliance to Section 20 of the Animal Diseases Act 1984 (Act 35 of 84) that applies to "investigation, experiment or research". A copy of your section 20 permit must be sent to this office before research can commence.

The research proposal has been registered on the database as P18/10. Please use this project number in all future correspondence.

Thank you for making use of the NZG as a research platform.
Yours sincerely

National Zoological Garden, 232 Boom Street, Pretoria
T: +27 (0)12 339 2700 F: +27 (0) 12 323 4540 W: www.nzg.ac.za

25 April 2018



environmental affairs

Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA



8.5 Governmental letters of approval

8.5.1 Section 20 Permit



agriculture, forestry & fisheries

Department:
Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Directorate Animal Health, Department of Agriculture, Forestry and Fisheries
Private Bag X138, Pretoria 0001

Enquiries: Mr Herry Gololo • Tel: +27 12 319 7532 • Fax: +27 12 319 7470 • E-mail: HerryG@daff.gov.za
Reference: 12/11/1/1/20 - 789

Mr Craig Keyes

Lecturer/Research Coordinator/Course Coordinator

Department of Forensic Medicine and Pathology

Faculty of Health Sciences

University of the Witwatersrand

e-mail: craig.keyes@wits.ac.za

RE: PERMISSION TO DO RESEARCH IN TERMS OF SECTION 20 OF THE ANIMAL DISEASES ACT, 1984 (ACT NO 35 OF 1984)

Dear Mr Keys,

Your application dated 27 March 2018 (received on the 18th May 2018) requesting permission under Section 20 of the Animal Disease Act, 1984 (Act No. 35 of 1984) to perform a research project or study, refers. I am pleased to inform you that permission is hereby granted to perform the following study, with the following conditions:

Conditions:

1. This permission does not relieve the researcher of any responsibility which may be placed on him by any other Act of the Republic of South Africa;
2. The study is approved as per the application form dated 27 March 2018 and the correspondence thereafter. Written permission from the Director: Animal Health must be obtained prior to any deviation from the conditions approved for this study under this Section 20 permit. Please apply in writing to HerryG@daff.gov.za ;
3. If required, an application for an extension must be made by the responsible researcher at least one month prior to the expiry of this Section 20 permit. Please apply in writing to HerryG@daff.gov.za ;
4. No part of this study may begin until the valid ethical approval has been obtained in writing from the relevant South African authority;
5. Only animal bones derived from a butcher may be used for this study;

8.5.2 Permission from Chief State Veterinarian



agriculture and
rural development
Department: Agriculture and Rural Development
GAUTENG PROVINCE

Diamond Corner Building, 68 Eloff & Market
Street, Johannesburg
P O Box 8769, Johannesburg, 2000

Telephone: (011) 355-1900
Fax: (011) 337-2292
Email: dace@gpg.gov.za

Reference: CA Keyes-Postmortem animal
scavenging of forensic interest
Date: 4 June 2018
Enquiries: Dr AMM Grobler
Telephone: (012) 316 1702

Dear Mr. CA Keyes

Subject: APPROVAL LETTER FOR THE FORENSIC POST MORTEM STUDY ON THE TRAUMA
CAUSED BY ANIMAL SCAVENGING ON BONE

The above matter has reference in the application for the following research study titled:
"Postmortem animal scavenging of forensic interest".

I have no objection to this study to be conducted at the National Zoological gardens.

Yours sincerely

Dr AMM Grobler
Chief State Veterinarian
Pretoria

Dr. A. Grobler
BVSc Reg No: D94/3497
Chief State Veterinarian
Themba Animal Clinic
FC15/13424



8.5.3 Permission from Gauteng Forensic Medical Services



FORENSIC MEDICAL SERVICES

Enquiries: Dr MP Morule
Tel: +27 (0)11 241 5750

18 June 2018

Mr Craig Keyes
Lecturer / Research Coordinator
Department of Forensic Medicine & Pathology
Faculty of Health Sciences
University of the Witwatersrand

SUBJECT: REQUEST FOR PERMISSION TO PERFORM RESEARCH: POSTMORTEM ANIMAL SCAVENGING OF FORENSIC INTEREST

Your correspondence of 28 March 2018 has reference.

I hereby grant you provisional permission to conduct research on: "**Post-mortem Animal Scavenging of Forensic Interest**"

However, final permission to conduct your research will be granted by the Gauteng Department of Health, Epidemiology and Research Unit: Attention Dr B Ikalafeng. Her contact details are **011 355 3503 or 082 461 9354 / 079 713 8170** on submission of inter – alia:

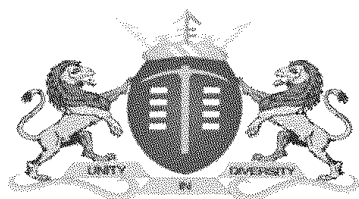
- a) Relevant proposal /protocol
- b) Ethics committee approval
- c) Statements to indemnify Gauteng Department of Health and FPS of any liability arising out of the research activity

Kind regards

DR MP MORULE
ACTING CEO: FORENSIC MEDICAL SERVICES

19/06/2018

8.5.4 Permission from Gauteng Department of Health



GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

PERMISSION TO CONDUCT RESEARCH IN PUBLIC HEALTH FACILITIES

Researcher's Name (PI)	Mr Craig Keyes
Organization / Institution	Wits
Research Title	Postmortem Animal Scavenging Of Forensic Interest
Contact details	<u>craig.keyes@wits.ac.za</u> <u>Tel:0114891656</u> Cell: 0832965196

Your request to conduct the abovementioned study has been reviewed by the relevant provincial structures and is granted support.



Permission granted



Permission denied

You are kindly requested to submit a report after completion of your study and present your findings to the Gauteng Health Department.

Dr. Bridget Ikalafeng
Deputy Director: Research Unit

Date:

19/09/18

8.6 Published article 1

International Journal of Legal Medicine (2020) 134:1227–1238
<https://doi.org/10.1007/s00414-019-02154-6>

ORIGINAL ARTICLE



Taphonomic bone trauma caused by Southern African scavengers

Craig A. Keyes¹ · J. Myburgh² · D. Brits³

Received: 30 May 2019 / Accepted: 26 August 2019 / Published online: 30 August 2019
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Abstract

Forensic anthropologists in Southern Africa are often confronted with post-mortem modifications of human skeletal remains caused by animal scavenging. This is troublesome as the post-mortem pseudo-trauma could be misinterpreted. This study aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest. The scavenging animals selected for this study included wild dog, spotted hyena, lion, leopard, black-backed jackal, caracal, and porcupine housed at the National Zoological Gardens of South Africa. Sparsely fleshed and articulated bovine front and hind limbs as well as ribs were placed in each animal enclosure and collected after 2 days for cleaning and analysis. Felids (lion, leopard, and caracal) gnawed away the greater trochanter of the humerus leaving deep, parallel furrows. Hyena caused massive trauma to bone with one-third of the tibia shaft surviving with jagged fracture edges. Porcupines left distinctive fan-like parallel scores and large, oval depressions with an eroded, polished appearance. Wild dogs and jackals did not leave any distinctive patterns. Light scavenging trauma is distinct from other bone taphonomy but cannot be used to determine the species. Heavy scavenging trauma patterns can be used to determine the general type of perpetrating animal; however, the exact taxa or species cannot be determined.

Keywords Forensic anthropology · Taphonomic trauma · Scavenging · Animals · Southern Africa

Introduction

Animal scavenging often causes post-mortem modifications of human skeletal remains. In a forensic context, this is troublesome as the post-mortem pseudo-trauma could be misinterpreted by forensic specialists [1–3]. Competent analysis of post-mortem trauma should discriminate between damage and trauma inflicted by an animal, a human perpetrator, and other taphonomic influences. The ability to identify a

scavenger by the trauma it causes to bone could also assist in the implementation of more reliable search methods for locating scattered remains and other evidence [2].

Scavenging animals considered to be of forensic importance in North America include wolves (*Canis lupus*), coyotes (*Canis latrans*), rodents, raccoons (*A. arathkone*), foxes (*V. vulpes*), opossums (*D. marsupialis*), striped skunks (*M. mephitis*), crows (*Corvus brachyrhynchos*), and a variety of vultures (Cathartidae) such as the turkey vulture (*C. aura*) [1, 4]. Vultures are the avian scavengers most often discussed in forensic studies [1] and are commonly found in North America, the Mediterranean, Eastern Europe, Asia, and Africa. Internationally, in more rural regions, large felids such as lions (*Panthera leo*), leopards (*Panthera pardus*), tigers (*Panthera tigris*), and cougars (*Felis concolor*) have been known to occasionally scavenge on human remains [5]. In abnormal situations, herbivorous animals, such as deer, have also been observed scavenging on dry bones. This behaviour is termed osteophagia and is caused by a phosphorous deficiency resulting from a nutritional dysfunction [6]. In urbanised cities, domesticated pets (particularly dogs) have often resorted to feeding upon the soft tissues and skeletal remains of their deceased owners when locked indoors—even if there are alternative food sources available [7, 8].

Presented at the 47th Annual Conference of the Anatomical Society of Southern Africa, 07–10 April 2019, in Pilanesberg, South Africa.

✉ Craig A. Keyes
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¹ Department of Forensic Medicine and Pathology, School of Clinical Medicine, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa

² Department of Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa

³ Human Variation and Identification Research Unit, School of Anatomical Sciences, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa

Descriptions of bone trauma caused by animal bite marks have been categorised into four categories: pits, furrows, punctures, and scores [2, 9]. Pits are described as indentations that do not penetrate the cortical surface of the bone. These pits are caused by individual tooth cusps. Punctures are penetrating marks through the cortical bone with an irregular shape. Punctures can be caused by canine and carnassial teeth. Avian scavengers can also form punctures that are conical in appearance on the surfaces of bones, usually caused by a pecking motion when eating soft tissues [10]. Furrows are longitudinal marks commonly found near the epiphyseal ends of bones. These are created by premolars and molars and are the result of scavengers trying to gain access to the bone marrow. A score is a broad term describing any mark in the bone surface where the length is greater than the breadth [11]. This is often caused by a tooth sliding after a pit has been created [2]. Rodent gnaw marks appear as scores on the superficial surfaces of bones. These are often exhibited as parallel striations with uneven margins [2]. Generally, the size of these respective marks (pits, punctures, furrows, and scores) can indicate the relative size of the animal [2].

Bite marks are not the only marks caused by scavenging animals to bone. Claw marks are often found in conjunction with bite marks when the animal attempts to grasp the bone [12]. Claw marks appear similar to tooth-made scores, since the claw marks are also longer than they are wide. However, scores made by claws can be differentiated from tooth marks because the diameter of claw marks is too thin to be confused as tooth marks and the claw marks are often in parallel rows [12].

The extent of the bite marks on bone can vary depending on the animal species and individual animal. The relative amount of damage caused to a bone is dependent on the relation between the strength of the bone and the tooth morphology and jaw mechanics of the scavenging animal [12]. Recent studies have determined that the size of tooth marks in bone can assist in determining the general size of the scavenger but the particular carnivore taxon cannot be accurately identified through tooth mark measurements [13]. Bones can even be entirely consumed, leaving little to analyse, depending on the size of the scavenging animal [12].

The ability to identify the animal species by its bite marks in bone can be of great worth. In South Africa, there is still a level of proximity and interaction between humans and wild animals despite the rapid increase in global urbanisation and conservation efforts to isolate animals within national parks and government protected areas [14, 15]. Animal attacks are common in South Africa and these often involve people who climb over the fences of game reserves, tourists who leave the safety of camping grounds or vehicles, and poachers. As a result, there are often cases where human skeletal remains are recovered in such locations. In these cases, it will be the role of the forensic anthropologist to analyse the bone trauma

and differentiate between perimortem trauma inflicted by a human perpetrator and bite marks caused by animals. For example, there was a case where human skeletal remains were recovered from a lion enclosure at a South African game park. The victim was thrown into the enclosure by perpetrators [16]. In this instance, the forensic anthropologist had to distinguish between bone fractures that resulted from trauma and bite marks from the lions. Not all animal bite marks look the same. Animal bite marks can be mistaken for blunt, sharp, or ballistic trauma by the inexperienced. The more we can understand the different bite marks caused by different animals, the easier it will be to differentiate them from tool marks and other traumas.

The vast majority of research published on scavenging trauma is of a paleoanthropological nature [11, 17–26], and those in the forensic context are on North American and European environments and species [1]. Furthermore, the majority of forensic research on scavenging has been based on wolves, coyotes, rodents, and vultures [1]. Much of the published forensic literature describing skeletal trauma caused by scavenging animals is anecdotal and based on actual forensic case studies with the described trauma being inferred upon an assumed animal with no knowledge of the taphonomic processes and previous trauma the bones may have been exposed to [5]. This study therefore aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest. The results will provide information that is missing from current forensic literature, a description of African animal bite marks on bone. These descriptions will help provide context to future forensic anthropological analyses of bones in Africa, including discerning or excluding the animal. These results will also assist forensic anthropologists in differentiating between perimortem trauma and animal bite marks.

Methods

The scavenging animals selected for this study included wild dog (*Lycaon pictus*), spotted hyena (*Crocuta crocuta*), lion (*Panthera leo*), leopard (*Panthera pardus*), black-backed jackal (*Canis mesomelas*), caracal (*Caracal caracal*), and porcupine (*Hystrix africae australis*). These animals were selected as they are known to forensic anthropologists as scavengers of forensic cases in South Africa. Some of the animals are common scavengers (wild dog, jackal, caracal, and porcupine) and some are less common scavengers (lion, leopard, and hyena); however, all are of forensic interest in South Africa.

Sparsely fleshed and articulated bovine thoracic limbs (consisting of nine bones: humerus, radius, ulna, and carpals), pelvic limbs (consisting of seven bones: femur, tibia, and tarsals), and racks of fleshed ribs (consisting of six ribs per rack and rib shafts only as the heads and sternal ends were cut off

by the butcher) were purchased from a licenced butchery. Bovine limbs and ribs were selected as these are the usual meat source fed to the animals at the NZG. Pelvic limbs were placed in the leopard, lion, caracal, and hyena enclosures, and thoracic limbs were placed in the wild dog, porcupine, and jackal enclosures. A humerus was also placed in the caracal enclosure in addition to the pelvic limb to prevent fighting between the two resident caracals. The use of thoracic limbs and pelvic limbs was based on availability and which animals were fed which type of limb was random. A rack of ribs was placed in each animal enclosure. The fleshed limbs and ribs were left in the animal enclosures for 2 days before collection of the remains. The study of bone trauma on bovine limbs (or other animal analogues) experimentally fed to captive animals in a zoological park is consistent with previously published literature [5, 11]. The surviving bones (i.e. bones which were not consumed or removed by other scavenging animals and were visible in the enclosures) were collected and macerated (removal of any remaining soft tissues).

An external light source in the form of a flashlight with controllable light intensity was used to locate and observe the trauma. A table was drafted for each animal that described the tooth and claw marks observed on each bone. The descriptions included the following: number of bones recovered, type of trauma (pits, furrows, punctures, or scores), location of the trauma on the bone, and a description of the trauma. The descriptions included the number of tooth or claw marks, depth (deep or shallow), breadth (wide or narrow), length (long or short), and shape (e.g. fan-like, conical, and irregular). The intensity of scavenging was also recorded as a semiquantitative scale (+/++/+++) with 'none' indicating no trauma, (+) indicating minor or insignificant trauma with little-to-no alteration to the morphology or integrity of the bone, (++) indicating moderate trauma with noticeable alterations to the morphology of the bone, and (+++) indicating destruction to the morphology of the bone or the total consumption of the bone. The descriptions of trauma were compared between the species and unique species-identifying features were highlighted.

Photographs of the trauma were taken with a Canon (SLR) 80D (EOS) camera with an EFS, 15–85 mm, I.S. (image stabiliser), U.S. (ultrasonic) lens. Measurements of the tooth marks were not taken. It is suggested that the size of tooth marks in bone can assist in determining the general size of the scavenger but the particular carnivore taxon cannot be accurately identified through tooth mark measurements [13].

Results

The jackals caused the least trauma of all the animals and all bones survived. Observable bite marks were isolated to a few superficial pits and scores on the ribs, humerus, and radius

(Table 1 and Fig. 1). Nothing was noted on the ulna and carpus bones. Trauma caused by the jackals was very difficult to see on the bones as they were generally short and superficial. A very good light source was employed to see the trauma clearly.

The wild dogs consumed most of the ribs; however, a single rib survived along with the humerus, radius, ulna, and carpus bones. Multiple pits and scores of varying depth, size, and shape were present on the ribs, humerus, and ulna (Table 1 and Fig. 2). Shallow furrows were present in the trabecular bone of a gnawed region in the margin of the greater trochanter of the humerus (Fig. 2c). Claw marks (thin scores) were also present in the cartilage of the humeral head and trochlea (Fig. 2d).

The hyena caused the most damage with very few remaining skeletal elements (Table 1). Only a fragment of the distal tibia and three tarsus bones remained. The femur and ribs were all consumed entirely. The distal end of the tibia survived with a jagged, uneven fracture margin indicative of a spiral fracture on the shaft (Fig. 3a). A tarsus bone exhibited a clear separation of the cortical and trabecular bone with additional gnawing and a shallow furrow (Fig. 3b).

The porcupine caused distinct and unique trauma to the recovered humerus, radius, and ulna (Table 1). A common, distinctive, fan-like pattern of clustered scores was observed in six different regions (Table 1 and Fig. 4a, b). There was extensive trauma to the greater trochanter as it had been completely gnawed away with an uneven, jagged margin (Fig. 4c). Another common pattern was observed in the medial and lateral surfaces of the olecranon tuber and the head of the humerus, where each exhibited a large, oval depression with an eroded, polished appearance (Fig. 4d).

The leopard left pits and scores on the ribs, femur, tibia, and calcaneus (Table 1 and Fig. 5). A distinctive gnawing pattern was observed on the greater trochanter of the femur. It had been gnawed with multiple distinctive parallel, deep, wide furrows (Fig. 5b).

The lions also caused a distinctive gnawing pattern on the greater trochanter of the femur (Table 1 and Fig. 6). The greater trochanter contained two wide, deep, parallel furrows (Fig. 6a). Large pits and punctures were often located adjacent to regions of gnawing and furrowing. It is presumed that these were created as anchor points to stabilise the bone during the scraping motion of gnawing and furrowing. The tibia presented with large, deep punctures on the superior, medial margin of the medial tibial plateau (Fig. 6d) and conical punctures in the tibial tuberosity (Fig. 6e).

The caracals exhibited the greatest variety of trauma (Table 1 and Fig. 7). The proximal end of the humerus had been extensively gnawed with the head and greater trochanter missing. A distinctive gnawing pattern was observed on the proximal epiphysis of the humerus as was caused by the leopard and lions. The gnawed proximal end of the humerus presented with multiple long, deep, parallel furrows (Fig. 7b).

Table 1 Summary of animal trauma to bovine ribs and limb bones

Animal	Bone	Number of bones placed in enclosure	Number of bones recovered	Intensity of scavenging (+/++/+++)	Type of trauma	Location	Description	Figure
Jackal	Ribs	6	6	+	Pit	Shaft	Single, shallow pit found on one rib	1a
				+	Score	Shaft	Single score found on two ribs each; one shallow & one deep	1b
	Humerus	1	1	+	Score	Mid-shaft	Single, short, shallow, wide score	1c
	Radius	1	1	+	Scores	Shaft	Short, shallow scores clustered in groups of two and three	1d
Wild dog	Ulna	1	1	None	/	/	No trauma noted	
	Carpus bones	6	6	None	/	/	No trauma noted	
	Ribs	6	1	+	Scores	Shaft	The rib exhibited numerous shallow scores; one had frayed borders of bone peeling out	2a
				+	Pits	Shaft	Numerous shallow pits of varying depth, size, and shape	2b
	Humerus	1	1	+	Pit	Margin of the humeral head	Large	2b
				+	Gnawing and furrows	Margin of the greater trochanter	Shallow furrows in trabecular bone of gnawed region	2c
				+	Scores	Carilage of the humeral head	Three scores or varying length	2d
				+	/	Carilage of trochlear	Numerous claw marks	
Hyena	Ulna	1	1	+	Scores	Neck of ulna	Numerous claw marks clustered in a V-shape	
	Radius	1	1	None	/	/	No trauma noted	
	Carpus bones	6	6	None	/	/	No trauma noted	
	Ribs	6	0	+++	/	/	Consumed entirely	
	Tibia	1	1	+++	Fracture	Shaft	Distal end of shaft remaining with a jagged, uneven fracture margin, indicative of a spiral fracture of the shaft	3a
	Femur	1	0	+++	/	/	Consumed entirely	
	Tarsus bones	4	3	++	Gnawing	Calcaneus	Gnawing with a shallow furrow	3b
							A clear separation of cortical and trabecular bone	
Porcupine	Ribs	6	0	/	/	/	No ribs recovered (suspected mongoose theft)	
				++	Gnawing	Greater trochanter	Completely gnawed away with an uneven, jagged margin	4c
				+	Scores	Neck of the humerus beneath gnawed away greater trochanter	Thin fan-like pattern of clustered scores	
				+		Shaft	Wide fan-like pattern of clustered scores	4a

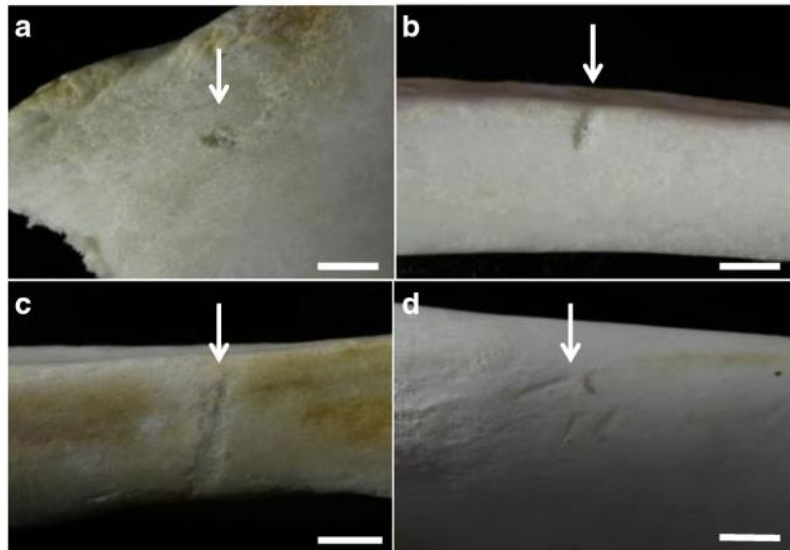
Table 1 (continued)

Animal	Bone	Number of bones placed in enclosure	Number of bones recovered	Intensity of scavenging (+/+ / +++ / ++++)	Type of trauma	Location	Description	Figure
Leopard	Radius	1	1	+	Gnawing	Shaft	Wide parallel and overlapping scores	
				++		Head of the humerus	Large, circular region with an eroded, polished appearance	
				+	Scores	Mid-shaft	Wide parallel and overlapping scores	4b
				+		Superior and distal ends of shaft	Wide fan-like pattern of clustered scores	4b
Leopard	Ulna	1	1	++	Gnawing	Medial and lateral olecranon tuber	Large, oval depressions with eroded, polished appearance	4d
	Carpus bones	6	0	/	/	/	No carpals recovered (suspected mongoose theft)	
	Ribs	6	2	+	Pits	Shaft of ribs	Numerous shallow pits with frayed peeling bone on some pit margins	5a
				+	Score	Shaft	One short, wide score on one rib	
Femur		1	1	++	Gnawing and furrows	Greater trochanter	One thin, long score on other rib	
				+	Scores	Shaft	Gnawed away cortical bone with three parallel deep, wide, furrows	5b
				+	Gnawing	Medial condyle	Two thin claw marks in V-shape vertically along shaft axis	
				+	Scores	Shaft	Margin gnawed	
Lion	Tarsus bones	4	4	++	Pits	Calcaneus	Five wide scores of varying lengths, horizontal to the shaft axis	5c
	Ribs	6	0	/	/	/	Small, deep pits and small shallow pits	
				+	Gnawing and furrows	Greater trochanter	No ribs recovered (suspected mongoose theft)	
				++	Gnawing	Patellar surface	Two wide, deep, parallel furrows	6a
Femur		1	1	++	Puncture	Patellar surface	A large, deep defect caused by gnawing	6b
				+	Scores	Shaft	Large deep conical puncture opposite the gnawing region (both on the patellar surface)	6c
				+	Pits	Greater trochanter, head, condyles, & distal femur	Numerous large, parallel scores near region of strongest muscle attachment	
				+	Punctures	Superior, medial margin of the medial tibial plateau	Many pits of varying sized	
Tibia		1	1	+	Scores	Superior shaft	Two conical punctures	6d
				+	Scores	Superior shaft	Three deep, large punctures, two of which are joined	6e

Table 1 (continued)

Animal	Bone	Number of bones placed in enclosure	Number of bones recovered	Intensity of scavenging (+/+/+/++)	Type of trauma	Location	Description	Figure
Caracal	Tarsus bones	4	3	+	Pits	Condyle cartilage	Numerous large, wide, superficial, parallel scores horizontal to the shaft axis	6f
						Tibial condyles	Numerous clustered claw mark scores	
						Calcaneus	Multiple deep pits of varying sizes along the lateral boarder	
						Calcaneus	Numerous wide, overlapping scores in V-shapes	
	Ribs	6	5	+	Score	Costal end	Numerous pits in the distal end	7a
Femur	Tibia	1	1	+	Pit	Shaft	One rib exhibits numerous wide, parallel scores along the costal end of the shaft	
						Costal end	One rib exhibits two scores with frayed boarders of cortical bone and one superficial score; all on the shaft.	
						Costal end	All scores are horizontal to the shaft axis	
						Costal end	Numerous pits on three of the ribs; all on costal ends or ribs	
	Shaft					Shaft	Seven thin claw mark scores	
Tarsus bones	Humerus	1	3	None	Puncture	Condyles	Two large irregular shaped punctures	7b
						Condyles	Numerous clustered scores	
						Margin of condyle	Six short parallel furrows	
						/	No trauma noted	
	Shaft					Shaft	Numerous long, wide, shallow scores horizontal to shaft axis	
Humerus	Proximal epiphysis	1	1	+++	Gnawing	Proximal epiphysis	Epiphysis gnawed exposing trabecular bone, with a crushed, flaked margin	7c
						Proximal epiphysis	Numerous long, wide, deep, parallel furrows in the gnawed trabecular bone	
						Proximal epiphysis	Single deep puncture at the gnawing margin	
						Proximal epiphysis	Six, large, deep pits in trabecular bone in sawn-off trochlea	
	Epicondyles					Epicondyles	Two short, shallow furrows	

Fig. 1 Jackal trauma (arrows) on bone shafts including the following: **a** a pit on a rib, **b, c** scores on ribs, and **d** the radius (scale line = 5 mm)



The margin of the gnawed proximal end of the humerus showed signs of crushing with curved flaked bone fragments still adhering (Fig. 7c) and a single deep puncture.

Generally, the animals focus on and caused the most severe trauma to the proximal ends of long bones with scoring on the shafts. Scores tended to always be horizontal across the shafts of long bones. Furrowing always occurred as multiple, parallel furrows—in gnawed regions where trabecular bone had been exposed. Large and deep pits and punctures in the long bones often occurred opposite or adjacent to gnawed regions. It is presumed that these were created by mandibular canine and carnassial teeth as an anchor point for gnawing and furrowing actions of the maxillary teeth. Trauma to the ribs only ever exhibited as scores and pits. Each of the animals in this study

caused a number of different types of trauma (pit, score, puncture, and furrow) in different combinations. One type of trauma on its own was not distinct but rather the pattern and location of the trauma was distinct. This was apparent in the porcupine and the cats (lion, leopard, and caracal). The fan-like clusters of scores caused by porcupines are very distinct and unique. All cats in the study (lion, leopard, and caracal) caused distinctive furrows in gnawed proximal ends of long bones.

Discussion

This study aimed to describe the skeletal trauma caused by Southern African scavengers which are of forensic interest

Fig. 2 Wild dog trauma on bone including the following: **a** a score with frayed edge on a rib shaft, **b** pit on the head of the humerus (dotted circle), **c** gnawing (solid arrow) and shallow furrowing (solid arrow) on a humeral greater trochanter, and **d** claw scores in the cartilage of the humeral trochlea (solid arrow) (scale bar = 10 mm)

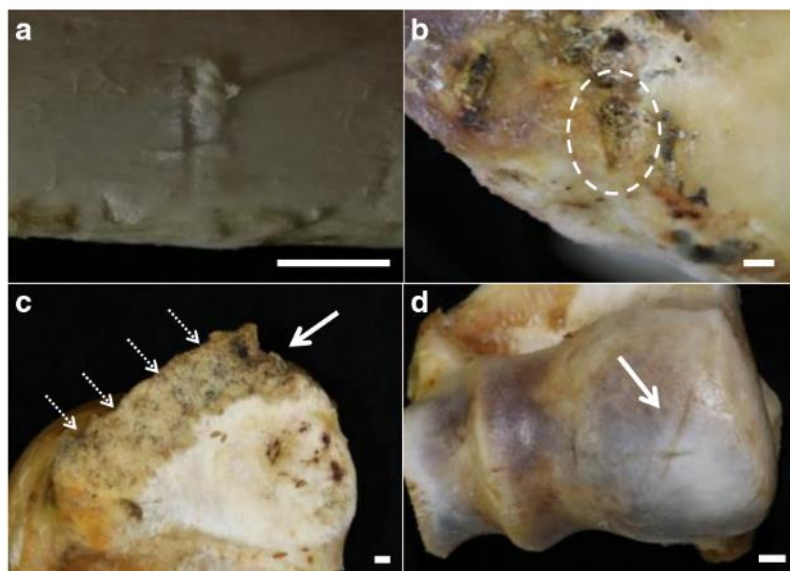
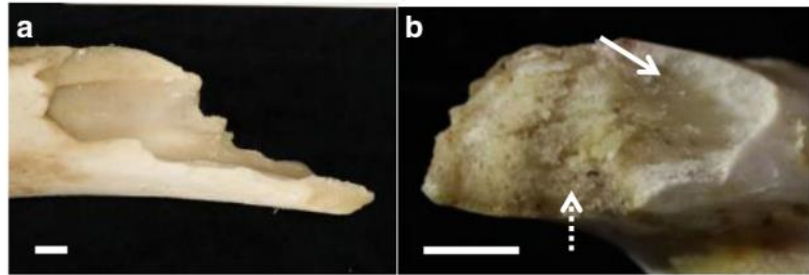


Fig. 3 Hyena trauma on bone including the following: **a** the jagged margin of the tibia shaft fracture and **b** the separation of cortical and trabecular bone (solid arrow) in addition to gnawing and a shallow furrow (dotted arrow) in a tarsus bone (scale line = 10 mm)



and to determine if the patterns of trauma could be used to identify the animal. The general tooth mark patterns observed on the long bones included scores being isolated to the shafts and the heavier gnawing and deep pits and punctures being confined to the epiphyses. As is seen in this study and previous research, it is common for heavier bone damage to be produced at the epiphyses [11] by scavengers as they try to gain access to the marrow [18]. Scavengers will still gnaw on the epiphyses even after flesh and marrow has been removed because the grease in these regions is enough to attract the attention of animals [18]. Gnawing of the epiphyseal margin with the appearance of grooves or furrows is typically caused by the grinding or shearing motions of carnassial or molar teeth where the cusps are pressed into the cancellous bone [11]. This was exemplary in the present study in the long bones retrieved from the wild dogs and caracals. The current study observed thin scores caused by animal claws—as seen in the bones recovered from the caracals, lions, and wild dogs—which cannot be mistaken for tooth marks as they are too narrow to be caused by tooth cusps [12], but they can easily be mistakenly attributed to other sharp force trauma (such as scalpel marks made during maceration). These marks can all indicate scavenging activity; however, they are not indicative of the specific animal. On the

ribs retrieved from the animal enclosures, only shallow pits and scores were observed along the shafts of the ribs. This is likely due to the flesh on the ribs being relatively lighter than on long bones and easily removed by the feeding animals. The pits and scores are likely caused by light tooth cusp pressure as the rib is manoeuvred [11]. The consequential deformation of the cortical bone is superficial as it does not puncture through to the underlying trabecular bone.

The jackals and wild dogs in this study only caused light bone damage which was isolated to shallow pits and scores with no unique pattern that can be used to isolate them as the perpetrating animal. These were very difficult to observe without a good light source. The wild dog did leave shallow furrows in the gnawed margin of the greater trochanter of the humerus, but this alone was not distinctive enough to be diagnostic. Previous literature on jackal and wild dog scavenging has not explicitly described the tooth mark patterns of jackals and wild dogs. This is likely because there is no specific pattern. However, the literature has focused largely on testing if the size of pits caused by jackals can be used to differentiate them from pits caused by other animals [5, 18, 27] with most concluding that tooth dimensions can only be used to determine if a carnivore was large or small [27].

Fig. 4 Porcupine trauma on bone including the following: **a** fan-like scoring clusters (dotted circle) on the shaft of the humerus and **b** radius (arrows), **c** complete loss of the greater trochanter due to gnawing, and **d** a large, oval depression with an eroded, polished appearance on the olecranon tuber (scale line = 10 mm)

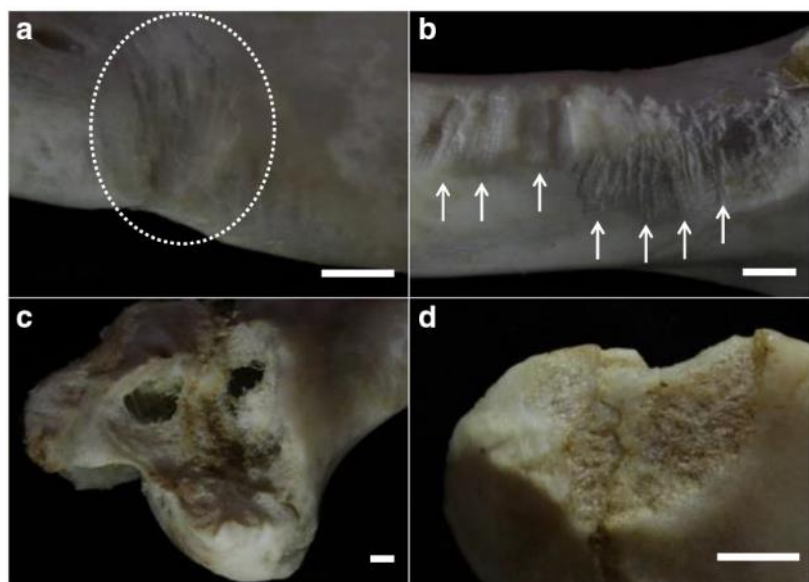
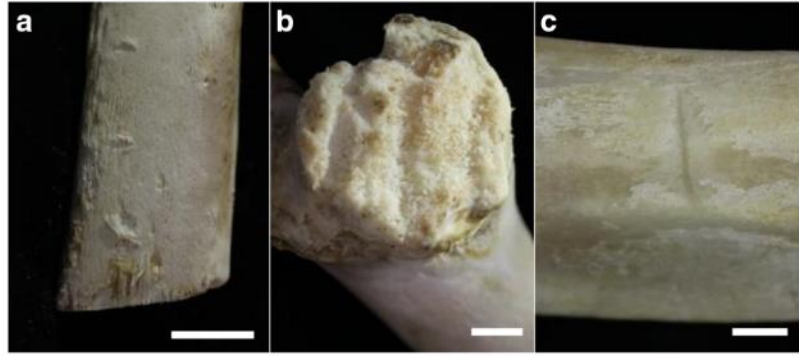


Fig. 5 Leopard trauma on bone including the following: **a** shallow pits with frayed margins on the rib, **b** gnawing with distinct furrows on the femoral greater trochanter, and **c** a wide superficial score on the shaft of a tibia (scale line = 10 mm)



Previous literature has described that heavy gnawing damage to the proximal epiphyseal ends of long bones by large cats, canids, hyenas, and bears is distinctive enough to identify the general type of animals but not the exact taxa or species [11]. The deletion of portions of the proximal epiphyses of long bones combined with deep, parallel furrows in the trabecular bone was distinctive in the three felids in this study (leopard, lion, and caracal). This trauma, particularly the removal of the greater trochanter of the humerus leaving relatively deep, parallel furrows, has also been observed in tigers and jaguars [11]. The furrows in particular are caused by individual tooth cusps [11] as the animal tries to gain access to the marrow [28]. This pattern suggests that, although the specific taxon cannot be determined from this trauma, the general identification of felid involvement can be concluded.

The taphonomic alteration of bone by large felids (such as lions, leopards, panthers, and tigers) has been previously studied; however, medium-sized felids—such as the caracal—remain underappreciated. The caracals in this study exhibited the greatest variety of trauma. Caracals were the only animal in this study to cause all animal bite mark types: pits,

furrows, scores, and punctures in addition to massive gnawing trauma and claw marks. This could potentially be a discriminatory characteristic for identifying caracals from their trauma; however, this needs to be studied in more depth to be stated definitively.

The trauma present on the surviving tibia retrieved from the hyena in this study is also distinct. Total consumption of the proximal end of the tibia, leaving one-third of the shaft remaining with jagged fracture edges of the shaft, is a classic sign of hyena scavenging [11]. The jagged fracture edges are typically not rounded [11]; however, in this study, the fracture edges were slightly rounded. It has been suggested that the possible cause could be due to repeated licking or rubbing against ground surfaces [11]. As the hyena used in this study was captive, the environmental context was different to those in the wild. The removal of competition with other animals for food allows for altered feeding behaviours, and as a result, different bone modification patterns can be expected [29].

Porcupine scavenging is well documented and has been described as a means of honing the incisor teeth or in cases

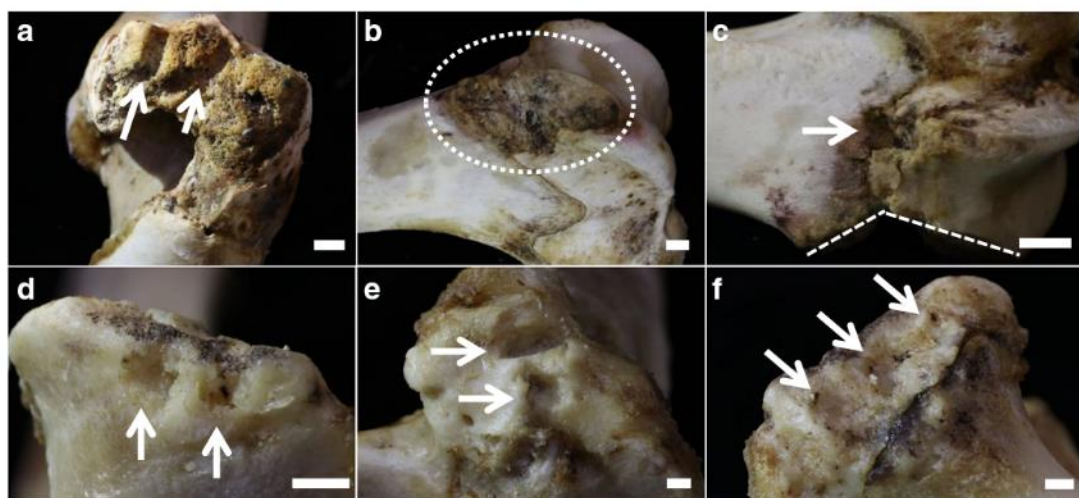
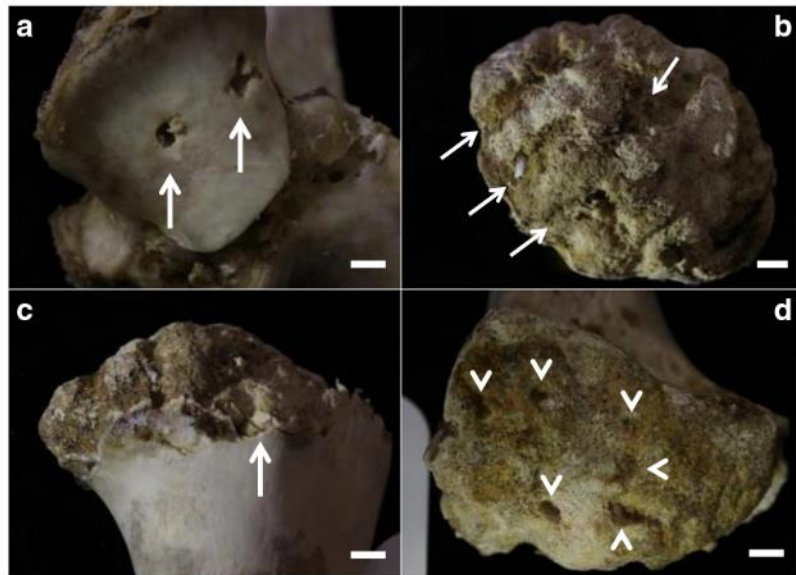


Fig. 6 Lion trauma on bone including the following: **a** furrows in the greater trochanter (arrows), **b** gnawing of patellar surface (dotted circle), **c** a large conical puncture (arrow) opposite to the gnawed region of the

patellar surface (dotted line), **d** punctures in the margin of the medial condyle of the tibia, **e** punctures in the tibial tuberosity, and **f** pits in the margin of the tibial condyle (arrows) (scale line = 10 mm)

Fig. 7 Caracal trauma on bone including the following: **a** large irregular punctures (arrows) were present in the condyles of the tibia, **b** furrows (arrows) in the proximal end of the humerus, **c** signs of crushing with curved flaked bone fragments adhering the gnawed proximal humeral epiphysis (arrow), and **d** multiple large, deep pits (arrows) in the distal end of the humerus (scale line = 10 mm)



of osteophagia when the individual animal lacks calcium and/or phosphorus [30]. Porcupines will scavenge on fleshed and dry bone without discrimination between the two [31]. Porcupine bone damage is well documented in previous literature and is distinguishable from other rodent bone damage [25, 30–33]. Porcupine trauma has been described (in this study and other studies previously mentioned) as fan-like parallel scores with undefined contours and regions of heavy gnawing and the scraping of the epiphyses and adjacent areas resulting in the total destruction of the bony region. The large, oval depression with an eroded, polished appearance observed in this study has not been described explicitly in previous literature. The exact cause is unknown but due to the projecting nature of the olecranon tuber as an easily grasped section of bone, the cause could perhaps be attributed to the repetitive grinding of the mandibular and maxillary incisors on the surface of the olecranon tuber. These characteristic traumas in conjunction with the absence of pits are indicative of porcupine intervention.

In summary, the characteristics of heavy scavenging trauma can be reliable indicators of the perpetrating animal. However, attributing a carnivore to bone modifications should not be based off a single pattern but rather a combination of bone modifications [27]. For example, the unique fan-like pattern of scores in combination to the absence of pits could suggest a porcupine as the causative taphonomic agent. Very light gnawing damage by all taxa of carnivores could be identical and is not very useful for differentiation between scavengers [11]. For example, the jackals caused very minimal and light trauma isolated to a few single scores and pits.

Limitations

The animals used in this study are of southern African origin; however, the most promising bite patterns described by this study are applicable in other regions of the world. Porcupines are native not only in Africa but also in Europe and Asia. A study in Israel described similar porcupine destruction of bones [31]. The bite patterns of the large cats in this study have also been described in other large cats such as tigers and jaguars [11]. These patterns will therefore be observed in other non-African regions of the world with wild large cats, particularly Asia, North America, and South America.

There is a difference in the extent of trauma caused by animals in captivity compared with animals in the wild. Gidna et al. [29, 34] determined that there is a higher number of tooth-marked elements and the number of tooth marks per element caused by lions in captivity and the wild [29], and similarly for leopards [34]. Due to the altered animal behaviour caused by captivity, the extent of the bone modifications described is potentially more pronounced than that seen in a natural setting [29, 34]. Nevertheless, the described patterns of bone modification are still valid. It is suggested that this study be replicated in a natural setting to compare the extent of bone modification differences between the captive and free-roaming animals used in this study. Additionally, the descriptions of bone modifications to ribs are limited as the costal and sternal ends of ribs were sawn off prior to placing them in the animal enclosures. As such, it is suggested that a study of scavenging rib trauma be repeated with whole specimens in the future. Additionally, the number of bones can be increased in future studies to ensure that the patterns described are common to each animal.

Another issue that can be reviewed is the time animals have to scavenging on bones.

This was a descriptive study of bite marks observed on bone caused by different animals. As such a statistical comparison is very difficult. Most published articles of a similar nature typically only describe the trauma as these descriptions are of value [10, 11, 29, 35, 36]. In studies where the sample size of the bones is large enough, the frequency of a particular bite mark pattern is provided [2] and this is something that can be repeated in a subsequent study for the same animals used in the present study. The value of qualitative research should not be underappreciated especially in taphonomic research.

Conclusion

The trauma caused to bone by scavenging animals can be used to isolate the perpetrating animals. Felids (such as lion, leopard, and caracal) gnaw away the greater trochanter of the humerus leaving deep, parallel furrows. Hyenas cause massive trauma to bone with little remaining fragments; however, surviving long bones typically remain as one-third of the shaft with jagged fracture edges. Porcupines leave distinctive fan-like parallel scores and large, oval depression with an eroded, polished appearance. Light scavenging trauma can indicate the involvement of scavenging animal behaviour; however, the exact taxa or species cannot be determined. These criteria will be helpful in the African forensic anthropological setting to discern scavenging trauma on bone and potentially isolate the animal which caused the trauma, and to distinguish between taphonomic scavenging trauma and perimortem trauma.

Acknowledgements The authors acknowledge the National Zoological Gardens of South Africa and the invaluable assistance of their staff: Mr. Nathaniel Taweni, Dr. Ian Espie, and Ms. Tracy Rehse. Appreciation is also due to Ms. Tracy Reindorp who took the photographs in this article.

Funding information This study was funded by the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Centre (Federal ID no. 87-0287045).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in this study involving animals were in accordance with the ethical standards of the institutions at which the study was conducted.

Disclaimer The main author conceived this study and performed the data collection, analysis and interpretation, and the writing of this article. The manuscript, data, figures, and tables have not been previously published and are not under consideration elsewhere.

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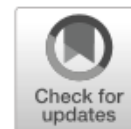
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8.7 Published article 2

International Journal of Legal Medicine
<https://doi.org/10.1007/s00414-020-02413-x>

ORIGINAL ARTICLE



Scavenger activity in a peri-urban agricultural setting in the Highveld of South Africa

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Received: 29 April 2020 / Accepted: 27 August 2020
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Abstract

Scavenging animals often scatter skeletal remains of forensic interest and cause scavenging damage. This study aimed to identify scavenging animals in the peri-urban agricultural Highveld of South Africa, describe their scattering patterns, and the damage they cause to bone. Ten pig carcasses (*Sus scrofa domesticus*) (40–80 kg) were placed at the University of Pretoria's Mierjie Le Roux Experimental Farm (Highveld) in summer and winter. Motion-activated cameras recorded the scavenging. Scavenger species were identified and their behaviors, scattering pattern, and the damage they cause to bone were described. Scavenging was primarily by black-backed jackals; however, mongooses (slender, yellow, and water mongoose), Cape porcupine, and honey badger were also active. Remains were commonly scattered in two directions by jackals. The distance of scattering was heavily influenced by fencing. The remains were scattered within a maximum radius of 73.7 m. The remains were scavenged and skeletonized faster in summer. Jackals caused minimal damage to bone, isolated to superficial, nonspecific scores, furrows, and punctures. A few mongoose bone alterations were present as jagged gnaw marks on the angle of the mandible and gnawing of the vertebral spinous process. Cape porcupine bone damage included gnaw marks on the condyle of a femur and head of humerus, and destruction of the proximal and distal ends of a tibia. The described scattering pattern and bone modification patterns will assist in the recovery and analysis of scavenged remains found in peri-urban agricultural areas in South Africa.

Keywords Taphonomy · Scavenging · Black-backed jackal · Peri-urban · South Africa · Scattering

Introduction

One of the purposes of a forensic death investigation is the estimation of a postmortem interval (PMI) [1]. A PMI estimation relies on accurate descriptions of a body's level and rate of decomposition [2, 3]. Scavenging animals can alter the rate of decomposition, and their scattering of the remains can have an impact on the reconstruction of postmortem events. These

events impact heavily on the PMI estimation [1]. It is therefore, critical that taphonomic studies describe the scavenging and scattering of remains by animals and their effects on forensic investigations [1–4].

In South Africa, humans and animals live in close proximity to each other, despite the rapid increase in urbanization and conservation efforts to house and protect wild animals [5, 6]. The presence of scavenging animals in urban, peri-urban, and rural environments results in human remains often being scavenged. Since scavenging species can vary by geographic area, regional studies are important to allow for the accurate post-mortem reconstruction of forensic cases [1, 3]. South Africa is environmentally diverse with numerous unique habitats. Each habitat presents its own unique set of variables that may affect a forensic investigation. South Africa has a high homicide rate which impacts the investigations of the Forensic Pathology Services and their investigations of unnatural deaths [1]. During the year 2018, South Africa reported 32,622 incidents of murder, of which 6978 were in the Gauteng province [7]. Many of these bodies are disposed of in remote locations. This often leads to their being discovered in the later stages of

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decomposition. The cases that are in advanced stages of decomposition and referred for forensic anthropological are often discovered in isolated areas such as open land/fields or parks, and farms [8]. They also often exhibit scavenger damage. Despite the regularity of such events experienced by forensic experts in Gauteng, there is a dearth of published research to highlight these issues and their frequency. It is therefore, essential that research on the scavenging of remains in a forensic context be performed, particularly in the Gauteng province of South Africa.

The full recovery of these remains is often difficult if they are disarticulated and scattered by animals. Research has illustrated that most investigators do not recover complete skeletons, even when assisted by a cadaver dog [9]. However, an understanding of animal scavenging and scattering patterns has resulted in an increase in the success rate of recovering scattered remains [10]. An understanding of local scavenging animals is important, as it will increase the recovery of remains. Scattering patterns are specific to different scavenging animals [11]; therefore, research needs to be conducted in different geographic regions.

Apart from scattering human remains, animal scavenging often causes postmortem modifications of remains. The morphology and location of animal damage on skeletal remains can indicate the offending species [12]. Scavenging damage on bone and soft tissues can be troublesome as they can obscure traumatic injuries and create postmortem pseudo-trauma. This can lead to the misinterpretation of evidence by forensic specialists [13–15]. Competent analysis of animal damage to bone can assist a forensic specialist to discriminate between damage inflicted by an animal, taphonomic alterations, and tool marks inflicted by a human perpetrator.

A number of studies have indicated which scavenger species are of forensic interests in their respective regions. North American scavenging animals of forensic importance include a variety of small animals, such as, rodents, racoons, foxes, opossums, and striped skunks. Larger North American scavengers of forensic interest include wolves and coyotes. North American scavenging avians that have been highlighted include crows and a variety of vultures, such as the turkey vulture [13, 16]. European scavengers of forensic interest include carrion crows, Eurasian magpies, and European red foxes [17]. In Australia, avian scavengers consume the most carrion [18], in addition to the red fox [3]. In Africa and Asia, large felids such as lions, leopards, and tigers occasionally scavenge on human remains [5].

South African research on scavenging, in a forensic context, is limited. Published research has been performed in Cape Town which highlighted the Cape gray mongoose and yellow mongoose to be of particular interest in the Western Cape [1, 4, 19]. The damage caused to bone by certain South African animals, suspected to be of forensic interest, has also been briefly described [12]. Research on scavenging animals

in South African urban and rural settings is ongoing; however, research pertaining to scavenging within a peri-urban agricultural setting is lacking. Research in these environments is needed because peri-urban agricultural environments comprise a large portion of the Highveld environment in the Gauteng Province of South Africa. Many forensic cases are investigated, and recovered from such environments. Six of the eleven Forensic Pathology Services (FPS) medico-legal laboratories in Gauteng have catchment areas which are peri-urban agricultural settlements (Springs FPS, Sebokeng FPS, Carltonville FPS, Heidelberg FPS, Ga-Rankuwa FPS, and Bronkhorstspuit FPS). Between the years of 2015–2018, the average annual number of forensic cases received by each of these facilities ranged between 274 and 1408 cases (mean = 829) (data supplied by the Gauteng FPS).

The aim of this study was therefore, to identify the scavenging animals of forensic significance in a peri-urban agricultural environment in South Africa. The objectives of the study include providing descriptions of the animals' scavenging behavior, their scattering patterns in open fields and enclosures, and the damage they cause to bone. This information will assist forensic investigators in the thorough collection and analysis of scattered scavenged remains found in peri-urban agricultural regions of Gauteng, South Africa and other regions with similar scavengers. This study will be the first to present data of this nature in the Highveld of South Africa.

Methods

Research was conducted at the Mierjie Le Roux Experimental Farm owned by the Faculty of Natural and Agricultural Sciences of the University of Pretoria (Fig. 1). This site represents a typical agricultural environment in the Highveld of South Africa. A section of the site is used for decomposition studies of forensic anthropological nature. The farm is 570 ha



Fig. 1 Location of original pig deposition sites at Mierjie Le Roux Experimental Farm (circle = summer pigs; triangles = winter pigs; square = fenced off site) (Google Earth)

of dry land subdivided for maize production, pastures, and cow herds. The farm is located in the Highveld plateau of the Gauteng Province and consists of mostly sourveldt grassland. This research site represents the peri-urban environment that comprises a large portion of the catchment area of the Gauteng FPS facilities.

The study sample comprised of 10 domestic pig carcasses (*Sus scrofa domesticus*) weighing between 40 and 80 kg. This weight range is in line with small- to medium-sized humans, as it has been recommended that taphonomic research use carcasses that are larger than 20–30 kg [20]. Carcasses are a commonly accepted analogue of human cadavers in taphonomic research [20]. The pigs used in this study died of natural causes and were donated by a licensed pig farm (GHB Farms). The cause of death was natural and possibly due to an overgrowth of *Clostridium perfringens* or *Escherichia coli*. This often results in a hemorrhagic bowel syndrome, common in large pig farms, which is caused by the twisting of the intestines. Pigs that have died of such causes are often used in taphonomic studies [21, 22]. Pigs which potentially died from hemorrhagic bowel syndrome were selected due to ethical reasons, since no pigs had to be terminated for the purposes of the study. Additionally, no external wounds or chemical influences are created by termination, which would have an effect on the decomposition process [21]. No studies have yet been explicitly performed on the effects of hemorrhagic bowel syndrome on PMI; however, it is not expected to have a significant impact on the PMI and the scavengers that are attracted.

Five pigs were deployed at different times during the winter months—three in July and two in August. Another five pigs were deployed at different times during the summer months—three in October and two in December (Fig. 1). Seasonality affects the presence and behavior of animals; therefore, the study comprised two different seasonal periods. Five of these pigs were deployed in a 50 m by 50 m fenced off site (three in winter and two in summer) and five pigs were deployed in open fields unobstructed by fences (two in winter and three in summer) (Fig. 1). This allowed for the observation of how obstructions such as fencing affects scattering patterns. In forensic investigations, the environment that a body is recovered from varies on a case-to-case basis. Agricultural environments often present varying levels of accessibility to scavenging animals due to farm fences, enclosures, and paddocks. This would influence the scattering pattern and the recovery of scattered remains. The pigs that were deployed in the fenced-off area at the same time, were positioned at least 30 m apart from each other (Fig. 1). The minimum distance of 30 m between the carcasses was dictated by the space available within the fenced-off enclosure. To ensure that the scavenging animals were captured by the cameras in the early stages of scavenging, the pigs were secured with a chain to a permanent fixture, such as a fence or tree. This

facilitated longer times to view and record the scavenging activities.

Bushnell Trophy Cam HD Essential E2 12MP Trail cameras were used to photograph the scavengers and scavenging of the carcasses. Each pig was recorded by a single camera secured to a nearby permanent fixture (such as a tree or fence), one to five meters away from the pig, in a padlocked steel camera cage. A single camera was used per pig due to the large number of pigs being recorded for this study and similar, concurrent studies in other environments. The motion activated; infrared cameras were set to the highest sensitivity to ensure that motion over a large area around the pig would trigger the camera. The cameras took three consecutive photographs when activated by motion, with a 5-s interval between motion activation. Researchers visited the site every 2 weeks to download data from the cameras. Two-week intervals were selected to reduce the impact of human interference and replace the batteries in the cameras. When the camera footage was analyzed, the photograph timestamps were used to separate different scavenging events. Any timestamp difference greater than 10 min from the previous photograph was recorded as a separate scavenging/visiting event.

The footage captured by the cameras was used to identify the scavenger species and their scavenging behaviors. The species were identified using field guides for Southern African mammals and birds [23, 24]. The behaviors of the scavenging animals were described in terms of the time of day they were active, the season they were active, the number of individual animals per species that scavenged concurrently, the decomposition stage each species was initially attracted to the carcasses and the stages during which they scavenged on the carcass, whether or not there was concurrent inter-species scavenging, and the frequency of each species' scavenging activity. Temporal data was recorded by the camera on the time-stamped photographs. The decomposition stages were assigned using the evidences observed in the photographs, and when the pigs were viewed in person. The stages were assigned using the descriptions provided by Michaud and Moreau [25] and Galloway et al. [26], and grouped as follows: the early stage (onset of death up to the onset of bloat), the bloated stage (onset of bloat, distention of the abdomen and/or neck, raising of limbs and/or protrusion of the anus), the active stage (abdominal deflation and moist decomposition), the advanced stage (exposure of skeletal elements in less than half the of body), and the dry stage (skeletonization of more than half the body). The dominant scavenging species and its behaviors were highlighted.

Once the remains were scattered beyond the view of the cameras and skeletonized, the location of each recovered element was flagged and mapped using a grid pattern method commonly used in archeological and forensic anthropological recovery practices. This was done using the walk-the-line method, in a grid pattern. This method entails a group of

individuals standing 1 m apart from each other, walking in a straight line and flagging scattered elements. This is done as they walk in a north-to-south direction and then an east-to-west direction—thus covering the region surrounding the original location of deployment. Due to each pig being deployed at a different time, there was no overlapping of scattered remains between different carcasses, so this did not confound the mapping of the scattering patterns.

The recovered remains were macerated to remove all remaining soft tissues. This allowed for the analysis of scavenging damage to bone. The bone damage was described in an attempt to highlight unique patterns which can be used to identify a perpetrating animal. The damage was described by their type (pits, furrows, punctures, or scores) [14, 27], the location of the damage on the bone, and a description of the overall alteration of the bone. A flashlight with different light intensities was used to aid in the location of the damage, as they may be superficial and difficult to locate without contrasting light levels. The damage was directly assigned to a scavenger species if the damage event was captured on camera, or indirectly by comparing the patterns described in previous research [12, 28–34].

One camera did not capture footage of the scavenging of one summer pig, despite the rapid rate in which that pig was scavenged. For reasons unknown, there was no footage recorded despite the camera appearing to function fine. The scavengers and their behavior, related to this one pig, was not recorded or analyzed, nevertheless, the scattering pattern was recorded. Since this pig was not recorded, it afforded the opportunity to test the applicability of the scattering results, and thus, indicate their applicability to an actual forensic case where the scavenging animal is not definitively known or recorded. The scattering patterns of the other nine pigs were used to devise a more practical search method and applied to, and described for, the unrecorded pig.

Ethical approval for this study was granted by the University of the Witwatersrand's Animal Research Ethics Committee (Waiver 17-04-2018-O) and the University of Pretoria's Animal Ethics Committee (H001–19).

Results

A number of animals actively scavenged on the carcasses, including blacked-backed jackal (*Canis mesomelas*) (Fig. 2a), slender mongoose (*Galerella sanguinea*) (Fig. 2b), water mongoose (*Atilax paludinosus*) (Fig. 2d), Cape porcupine (*Hystrix africaeaustralis*) (Fig. 2e), and honey badger (*Mellivora capensis*) (Fig. 2g). Yellow mongoose (*Cynictis penicillata*) (Fig. 2c) and serval (*Leptailurus serval*) (Fig. 2f) were attracted to the carcasses; however, they were not recorded actively scavenging the remains. The serval marked itself in a process called scent marking, by rubbing itself on the

carcass. The yellow mongoose visited numerous pigs multiple times but did not scavenge on the pigs (Table 1). Animals attracted to the carcasses to feed on colonizing insects included hadeda ibis (*Galerella sanguinea*), Swainson's spurfowl (*Pternistis swainsonii*), helmeted guineafowl (*Numida meleagris*), pied crow (*Corvus albus*), spotted thick-knee (*Burhinus capensis*), and numerous unidentified species of small birds, mice, frogs, and hare. Domestic cow herds (*Bos Taurus*) also showed interest in the carcasses, occasionally rolling the carcass over, but they were not recorded to scavenge on the carcass or skeletal elements.

The black-backed jackal, water mongoose, porcupine, serval, and honey badger were nocturnal. The slender mongoose and yellow mongoose were diurnal. The black-backed jackal was the most active scavenger but was rarely active in daylight. On the rare occasion, it was observed during daylight, it was active in the early hours of the morning (Table 1). The jackals were mostly active between 18 h00–09 h59, with peaks in their activity between 21 h00–21 h59, and 02 h00–02 h59. Other diurnal animals that were attracted to, but did not directly scavenge on, the carcasses included cows, hadeda ibis, Swainson's spurfowl, pied crow, helmeted guineafowl, and other small birds. The nocturnal animals that were attracted to, but did not directly scavenge on, the carcasses included the spotted thick-knee, mice, frogs, and hare.

Most of the scavenging animals were active in both the summer and winter periods. The honey badgers and serval were only active in the winter period while the water mongoose was only active in the summer, after heavy rains (Table 1). The non-scavenging, summer active animals included the frog (after rainfall), Swainson's spurfowl, hare, and helmeted guineafowl. The winter active species included the spotted thick-knee. The species which were active in both seasons included mice, pied crow, and hadeda ibis. In summer, there was an increase in the number of individual animals and the diversity of animal species (Table 1). Many of the animals were attracted to the carcasses in the bloat and active stages of decomposition; however, scavenging tended to only start in the later stages of decomposition. The jackals and water mongoose preferred to scavenge when the carcasses were in the active stage of decomposition (Table 1). The slender mongoose, porcupine, and honey badgers preferred to scavenge in the more advance stages of decomposition; particularly once most soft tissues were gone and skeletal elements were exposed (Table 1).

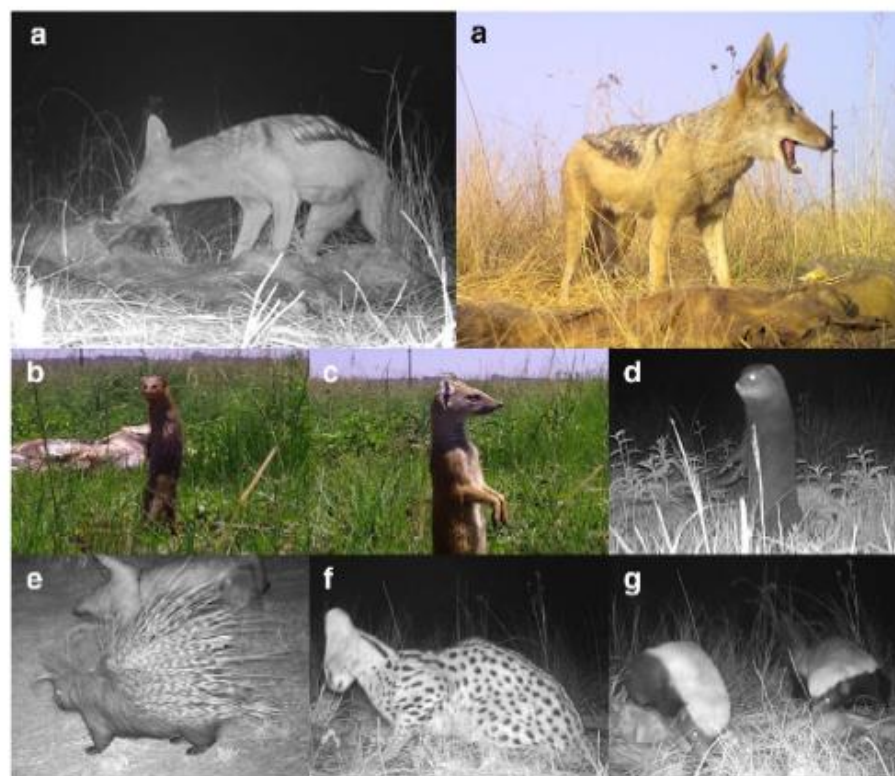
There was no interspecies scavenging observed at the same time, although multiple animals of the same species would scavenge together on rare occasions. The black-backed jackals mostly scavenged in solitary but they occasionally scavenged in pairs or a pack of three. The slender mongoose also scavenged in isolation or in occasional pairs. Honey badgers and porcupines often scavenged in pairs (Table 1).

Table 1 The scavenging behaviors of peri-urban agricultural scavenging animals in the Highveld of South Africa

Animal	Maximum number of animals of the same species active at the same time at the same carcass	The number of pigs each animal visited/ scavenged ($N=9$)*	Average number of scavenging or visiting events per species between the nine ^a pig carcasses	Decomposition stage active	Body region preference when scavenging	Time active	Season active
Black-backed jackal	3	9	40.4	Attracted: bloat stage Scavenging: active, advanced and skeletonized stages	Abdomen, pelvis, limbs, ribs, scapula, cranium	Nocturnal (mostly)	Summer and winter
Slender mongoose	2	9	19.1	Attracted: active stage Scavenging: advanced and skeletonized stages	Abdomen, vertebral column, and limbs	Diurnal	Summer and winter
Yellow mongoose	1	4	0.8	Attracted: active, advanced, and skeletonized stages Scavenging: active stage		Diurnal	Summer and winter
Water mongoose	1	1	0.2	Scavenging: active stage	Abdomen	Nocturnal	Summer only
Cape porcupine	2	6	1.7	Attracted: bloat and advanced stages Scavenging: skeletonized stage	Unknown	Nocturnal	Summer and winter
Serval	1	2	0.2	Attracted: bloat and advanced stages Scavenging: skeletonized stage		Nocturnal	Winter only
Honey badger	2	1	0.1	Scavenging: advanced stage	Abdomen and ribcage	Nocturnal	Winter only

*Camera did not capture scavenging of one summer pig despite the rapid rate that pig was scavenged

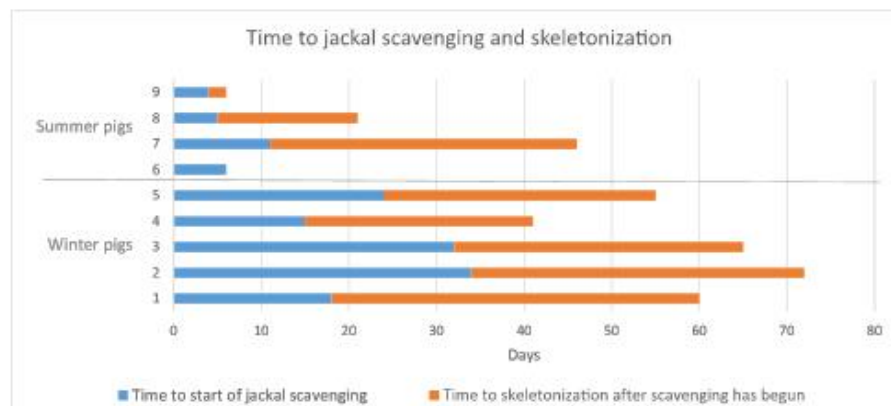
Fig. 2 Animals that were attracted to, or scavenged on, pig carcasses, including black-backed jackals (a), slender mongoose (b), yellow mongoose (c), water mongoose (d), Cape porcupine (e), serval (f), and honey badgers (g)



Black-backed jackals were the most active species. Jackals were recorded frequenting the carcasses an average of 40.4 times per pig (Table 1). The slender mongoose was the second most active scavenger, frequenting the carcasses an average of 19.1 times per pig (Table 1). These were the only two scavengers to visit all of the recorded carcasses. The porcupine, yellow mongoose, and serval frequented the carcasses much less frequently. The water mongoose was the least active of all scavenging animals, as it only scavenged on one carcass on only two separate occasions (Table 1).

Ribs and vertebrae were recovered in all cases but the number of surviving ribs and vertebrae varied per case. The cranium was not recovered in three cases (30%) and the mandible was missing in half of the cases ($n = 5$; 50%). In most cases ($n = 6$; 60%), the limb bones were only partially recovered. All bones of the four limbs, including the long bones and feet, were recovered in only four cases (40%). The bones of the upper limbs were recovered more often than those of the lower limbs: humerus ($n = 11$; 55%), radius ($n = 9$; 45%), ulna ($n = 11$; 55%), femur ($n = 9$; 45%), tibia ($n = 7$; 35%), and fibula ($n = 7$; 35%). The pelvis was not recovered in four cases

Fig. 3 Comparison of time of jackal scavenging onset to skeletonization of pig carcasses



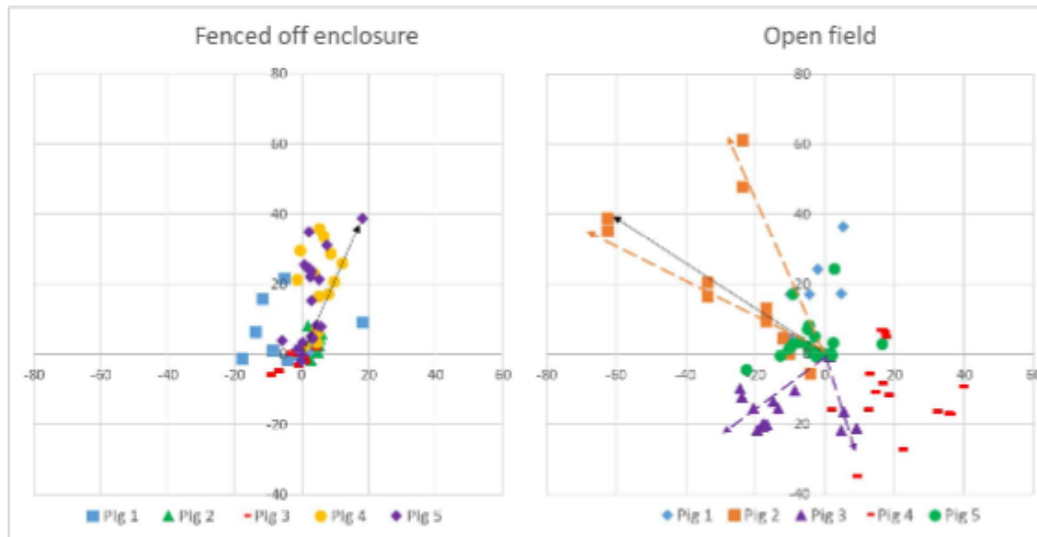


Fig. 4 Scatter plot of the skeletal elements of ten pigs, five in a fenced off enclosure (left) and five in open fields (right), scattered primarily by black-backed jackals, showing distance (in meters) and direction of scattering. The origin (0;0) indicates the original position of each pig.

(40%). In most cases ($n = 7$; 70%), at least one scapula was recovered while both scapulae were only recovered in four cases (40%). In total, 11 scapulae were not recovered (55%).

The black-backed jackals were responsible for the consumption of the soft tissues and accounted for most of the scattering of the skeletonized remains. Since black-backed jackals were the most prolific scavengers in this study, their scattering behavior will be highlighted.

Seasonality affected the jackal scavenging activity. The onset of jackal scavenging was faster in summer (range = 4–11 days; mean = 6.5 days) than in winter (range: 15–34 days; mean = 24.6 days) (Fig. 3). Jackals consumed most of the soft tissues, leading to rapid skeletonization of the carcasses; which was faster in summer (range: <1–35 days; mean = 14.2 days) than in winter (range: 26–42 days; mean = 34 days) (Fig. 3). One carcass (Pig 6 – Fig. 3) was scavenged by jackals so rapidly that it reached the skeletonized stage (i.e., skeletonization of more than half the body) on the same day the jackals began to consume it (6 days after the pig was deployed at the site).

Skeletal remains were scattered over a large area by jackals. The pattern and range of scattering were influenced largely by physical barriers (such as fences) and, to a lesser extent, the season. Scattered remains within the fenced enclosure were confined within the enclosure, with a maximum radius of 42.8 m/137.8 ft. (Fig. 4). Scattered remains that were unobstructed in open fields were scattered over a very large area, with a maximum radius of 73.7 m/241.8 ft. (Fig. 4). The remains within the enclosure were scattered towards a hole in the fence where, presumably, the scavenging animals gained entrance/exit. The remains in the open fields were

Northern arrow indicates the relative scatter direction. Radius arrow (dark solid arrow) indicate the maximum scatter radius (fenced off area radius = 42.8 m; open field radius = 73.7 m). Directional arrows (dotted arrows) indicate directional trends of the scattered remains

often scattered towards animal burrows. Individual pig remains were often scattered in two diverging directions, within a 90° arc, from the original location of deployment (highlighted by the two examples in Fig. 4).

Knowledge of these scattering patterns was helpful in the recovery of the unrecorded pig remains (due to malfunctioning of the camera). Understanding that remains are often scattered in two diverging directions within a 90° arc with a radius of proximally 73.7 m/241.8 ft was particularly beneficial. Cues such as game trails and burrows were initially used to determine where the remains were most likely scattered. Once the two directions of scattering were identified, a grid search was implemented in those two directions. The search distance was determined by the general search radius of the other nine pigs (approximately 73.7 m/241.8 ft). This assisted in the implementation of a more efficient search method for the scattered remains of this particular pig.

Black-backed jackals caused very little damage to the skeletal elements. Most pig skeletons did not exhibit any apparent signs of damage. A few sternal ends of ribs were consumed and the transverse processes of a number of vertebrae were fractured but complete. Distinct punctures were present in one head of a humerus (Fig. 5), and a puncture was also present in the medial border of one scapula (Fig. 5). Furrows were present in the cranioventral spine of one ilium (Fig. 5).

It is suspected that porcupines caused round, gnawed areas, with a polished appearance, to the condyle of a femur and to the head of a humerus (Fig. 5). Massive destruction to the distal and proximal ends of a tibia are also assumed to be caused by porcupines, as described by Keyes et al. [12] (Fig. 5).



Fig. 5 Damage caused by scavenging animals. **a** Black-backed jackal punctures in the head of humerus. **b** Black-backed jackal puncture in the medial border of the scapula. **c** Black-backed jackal furrows in the cranioventral spine of the ilium (left picture is the ventral view of the ilium with circle highlighting the cranioventral spine, right picture is of the ventral view of the cranioventral spine with arrows highlighting the

furrows). **d** Suspected porcupine gnawing of the condyle of a femur. **e** Suspected porcupine gnawing of the head of humerus. **f** Suspected porcupine damage on the proximal and distal ends of a tibia (top picture is the anterior view and the bottom picture is the posterior view of the same tibia). **g** suspected mongoose damage on the vertebral spinous process. **h** Suspected mongoose damage on the angle of the mandible

Bone damage caused by suspected slender or yellow mongoose was observed as gnawing of the tip of a spinous process of a vertebra. This gnawing removed the cortical bone and exposed the trabecular bone (Fig. 5). Jagged gnaw marks, suspected to be caused by mongooses, were also observed on the angle of two mandibles (Fig. 5). These patterns of slender mongoose damage have been observed by the authors in other research sites (not yet published). The gnawing of the mandible, in particular, is highly suggestive of mongoose scavenging. It is unlikely to be caused by jackals because they tend to cause superficial scores or pits. It is also unlikely to be caused by porcupines because they leave distinctive fan-like scores and focus on the long bones [12].

Discussion

Black-backed jackals were identified as the dominant species in this study's scavenger guild. Their distribution, scavenging

behavior, scattering pattern, and patterns of damage to bone will first be highlighted, including the respective impact it could have on forensic investigations. The lesser species of the study's scavenger guild will then be briefly discussed in terms of their distribution and patterns of damage to bone, and their potential influences on forensic investigations.

Black-backed jackals (referred to jackals from here onwards) are abundant and widespread throughout Eastern and Southern Africa, in a variety of environments [35]. Jackals are primarily scavengers, although they do occasionally hunt [36–39]. Since jackals are primarily scavengers, the presence of Diptera larvae in their scat is a common occurrence. This can be used as evidence to determine if their food source was fresh or decomposing [38, 40]. The jackals in the present study were originally attracted to the carcasses in the bloat stage of decomposition but only started to scavenge from the active stage onwards. It appears that conventional methods of postmortem estimation could be used in the early and bloat stages. These methods cannot be used in cases from the active

stage onwards if they have been scavenged by jackals because the typical decomposition rates and patterns would have been altered. The season should also be taken into consideration when estimating a PMI because there are seasonal differences in the jackal-instigated skeletonization and scattering rates. Jackals were primarily nocturnal, and the level of their activity increased during twilight and the early morning before dawn [40]. They were rarely active during the day with no activity from the late morning to mid-day [40]. This should be considered when reconstructing postmortem events in cases of jackal scavenging.

The feeding behaviors of jackals are different to other canines. The jackals kill and feed more neatly than dogs [41]. They also prefer to consume the soft tissues rather than the skeletal elements. They show a preference for the flesh and skin of the flank and haunch of a leg [41]. They will also eat the organs such as the heart, liver, lungs, and the stomach and its contents [41]. The preference for soft tissues over skeletal elements, including the neater manner in which they scavenge [41], would account for the limited and superficial damage noted on the scattered skeletal elements. One study on jackal predation noted that ribs are partially consumed by jackals [41]. A minimal number of ribs were partially consumed in the present study—with only the costal ends being fractured. It is likely that this is a result of the jackals feeding on the organs within the chest cavity, which are protected by the costal ends of the ribs. The minimal alteration to bone by jackals has previously been described by the present authors regarding jackals in captivity [12], and these alterations were also observed in the present study on jackal behavior in the wild.

The scattering patterns of the jackals became apparent to the authors early on in the data collection period. This assisted in the location and collection of scattered remains. In the enclosed area, no remains were scattered beyond the fences. The directionality of the scatter was apparent and led to the holes in the fence where the animals were presumed to gain entrance. This knowledge allowed for more thorough and rapid recovery times of the scattered remains with each progressive pig that was laid out. In a forensic context, understanding the physical boundaries at a death scene and the effects it would have on animal movement will greatly enhance the search and recovery of scattered remains. The scatter pattern of remains in the open fields was much more diffuse and over a much larger area. The scattered remains of each pig (in both the fenced off enclosure site and the open field sites) were generally in two directions and confined within a 90° arc. This pattern also became apparent to the authors early in the data collection period and increased the efficiency and rate of the search and recovery of scattered remains. Once the two general directions were noted, it was easier to predict where the remains would be. This knowledge can assist in improving the recovery of remains by forensic specialists. Investigating

officers with an understanding of scavenging behaviors have been proven to be twice as successful in the recovery of skeletal remains as those without the same knowledge [10]. This highlights the necessity for continuing research on scavenging and scattering patterns in unique areas with unique scavenging species.

The need to implement a search method unique to the black-backed jackal scavenging was most apparent in the search for the scattered remains of the pig whose camera malfunctioned. The method of “walking the line” in a grid formation was used to locate the scattered remains of the other nine pigs which ultimately highlighted the pattern of remains being scattered in two directions within a 90° arc. Although the grid method is very effective, it is also very time consuming, particularly in the recovery of remains scattered over a very large area. Once the scattering pattern of the other nine pigs became apparent, a “link search method” [14] was implemented for the pig that was not recorded. The link search method is more flexible than the grid method since it allows the searcher to adjust their direction based on the identification of cues. Cues include drag marks in the soil, clumps of fur, animal scat, game trails, or disturbed soil [14]. In the present study, the cues included the branching of scattered remains into two directions within a 90° arc, often along game trails and towards burrows. A combination of the “walking the line method in a grid fashion” and the “link search method” was intuitively implemented in the search for remains of the unrecorded pig. The principles of the “link search method” determined in which directions the grid search should be focused. The experience of locating and mapping the scatter patterns described in the present study, lead to the suggestion that search methods should be flexible and chosen based on the suspected scavenging animal and the size of the scatter area. In a forensic case, it is suggested that a combination of the grid method and link of the search method be combined particularly when a case is time-sensitive.

The effectiveness of any forensic skeletal analysis relies on the number of skeletal elements recovered. Fewer recovered remains will limit the trauma analysis and the estimation of a biological profile, which is invaluable to the identification of skeletal remains. Only 40% of limb bones were recovered in this study. This will have a bearing on the estimation of the sex [42–46] and stature [47, 48] of an individual in a forensic context because the limb bones are valuable in assessing these individual features [49]. The mandible is also an important element used to estimate the sex and age of an individual [40–52] and the mandible was only retrieved in 50% of scattered cases. Although the scavenging of human remains and carcasses may potentially be dissimilar, the skeletal elements are similar and the scavenging of these individual elements are expected to be comparable.

The black-backed jackal was not the only animal to scavenge on the remains. A variety of mongooses were attracted

to, and scavenged on, the carcasses. This included the slender mongoose, yellow mongoose, and water mongoose. The behaviors of the different mongoose species varied. Small, social species—such as the slender and yellow mongoose—tend to be diurnal with a mostly insectivorous diet. Larger, solitary mongoose species—such as the water mongoose—are mostly nocturnal with a diet largely on small vertebrates [53]. The slender mongoose has a widespread distribution throughout sub-Saharan Africa [54] but within South Africa it is restricted to the northern parts of the country [21]. It is a generalist carnivore with a diet of mainly small vertebrates and insects but it will also scavenge on the carcasses of mammals [55]. In Cape Town, South Africa, the Cape mongoose and yellow mongoose have been identified as scavenger species which scavenge upon and scatter human remains [4]. The water mongoose (*Atilax paludinosus*) is widely distributed across southern Africa and can be found further north in Africa. They inhabit a variety of habitats that provide plant cover and fresh water sources. Due to their size (which is larger than most other mongoose species) their diet constitutes larger prey. Their diet usually includes small mammals such as rodents, birds, amphibians, mollusks, fish, and insects [56]. Water mongooses are nocturnal and tend to hunt along the banks of bodies of water but they may submerge themselves when hunting for food [57]. Water mongooses are solitary. The yellow mongoose (*Cynictis penicillata*) is widely distributed in South Africa most commonly occurring in the western and central Orange Free State and Western Gauteng provinces [58]. They forage for food whether in isolation or in pairs. Despite being primarily insectivorous, they have been observed scavenging on carcasses [4, 59]. These three mongoose species, in addition to the banded mongoose, have been observed as scavengers on forensic interest by the authors in other vastly different environments such as the rural Lowveld and urban Johannesburg (currently under review for publication) and also in coastal Cape Town as observed by Spies et al. [4]. They are prolific scavengers in a variety of environments in South Africa. Their prevalence highlights the need to better understand their scavenging behaviors as they are likely actively scavenging on human remains of forensic interest in South Africa [4].

The Cape porcupine (*Hystrix africaeaustralis*) also scavenged on the carcasses once they were skeletonized. Porcupine scavenging has been well documented. Porcupines will scavenge on bones either to sharpen their incisor teeth or to consume the bones, in a process called osteophagia, when the individual lacks calcium and/or phosphorus in their system [32]. Porcupines will scavenge on fleshed and dry bone without preference [33]. Bone damage caused by porcupines is distinguishable from other rodent bone damage [30, 32–34, 60]. Fan-like parallel scores with undefined contours are common along shafts of long bones with regions of heavy gnawing resulting in

the total destruction of epiphyseal ends of long bones being common [12]. Large, oval depressions with an eroded, polished appearance is also a sign of porcupine gnawing [12]. The destruction of epiphyseal ends of long bones and the large, oval depressions with a polished appearance in the present study are also consistent with porcupine damage [12]. The destruction of skeletal elements by porcupine scavenging is of forensic concern as they have the potential to alter or destroy evidence such as tool marks and traumatic fracture patterns.

Honey badgers (*Mellivora capensis*) are solitary, predatory carnivores [61, 62], although the territorial home ranges of adult male honey badgers often overlap extensively with other adult males and encompass smaller home ranges of younger males [61]. This often results in the formation of groups of two to five adult males which travel together [61]. This behavior is not observed in female honey badgers who tend to avoid each other [61]. They can be found spread across most of sub-Saharan Africa, Arabia, Iran, and western Asia spreading to the Indian peninsula [62]. A pair of honey badgers were observed scavenging on the carcass of one pig in the present study. They showed preference for the abdomen and rib cage. Their scavenging was most likely the result of opportunistic foraging. Since numerous animal species scavenged on a single carcass, it should be expected that, during skeletal analysis, multiple and differing patterns of damage could be present on a single case. They did not scatter the remains beyond the radius of jackal scavenging.

Two tangential observations made in this study, unrelated to the scattering of the remains, but related to the decomposition of the remains, must be noted. There was an increase in the number and diversity of animal species which continued to be attracted to the location where the pigs decomposed, long after the remains were removed. It is assumed that they were attracted to volatile compounds soaked into the soil and/or insects that had pupated in the soil. This is a topic that could be studied in the future as it could potentially contribute to further taphonomic understanding of postmortem events. Also noted in one case was the significant movement of a carcass without any visible external source. The carcasses was in an advanced stage of decomposition and moved erratically over short distances, particularly the limbs. It is assumed that the cause of the movement could be attributed to maggot activity beneath the carcass. This has also been observed by time-lapse cameras at the Australian Facility for Taphonomic Experimental Research in a long-term decomposition study [63] but this phenomenon has not yet been studied, explained, or published. This phenomenon would have an impact on our understanding on the postmortem movement of remains not attributed to a perpetrator or human influence.

Limitations

The identification and descriptions of scavenging animals, their behavior relied on the motion-activated cameras. The camera footage was only retrieved every 2 weeks. In one case, a camera did not record footage for unknown reasons. No footage was recorded for that one case reducing the quantity of data collected in this study. It is unlikely that this negatively affected the results because the same animal species scavenged the remaining nine carcasses with consistently. It is therefore, likely that the same animal species scavenged this pig similarly to the other nine pigs.

The carcasses were chained to a permanent fixture to increase the cameras' viewing times of scavenging activities in the event of scavenging in the early stages of decomposition. These chains were also used to prevent theft of the carcasses. These chains did not appear to have any significant effect on the scavenging and scattering of the remains. The chains did not deter the attraction of animals in the early stages of decomposition. The animals scavenged on the remains in the advanced stages of decomposition when the remains could be easily disarticulated without hindrance by the chains. Therefore, the chaining of the carcasses did not appear to have any significant impact on the scattering of the remains; however, further research is needed to confirm this.

Conclusion

Scavenging at this peri-urban agricultural site was primarily by black-backed jackals, and a variety of mongoose species (slender, yellow, and water mongoose), Cape porcupine, and honey badger also scavenged on the carcasses. The scattering of each pig's remains was generally in two directions confined within a 90° arc. The distance of scattering of five pigs was heavily restricted by the fencing. Overall, the remains were scattered within a maximum radius of 73.7 m and the resulting skeletonization of the remains assisted by jackals scavenging was faster in the summer months than the winter months. Jackals caused minimal damage isolated to superficial, non-specific scores, furrows, and punctures. Slender mongoose and Cape porcupine damage to bone was also described. The described scattering pattern and scavenging damage to bone will assist in the recovery and analysis of scavenged remains in South Africa, especially in a peri-urban environment.

Acknowledgements The authors would like to thank Mr. Dries Du Plessis from GHB Farms for providing the pig carcasses for this research as well as Mr. Roelf Cortze and Prof Edward Webb for providing access the Mierjie Le Roux Experimental Farm as the research site. Mr. Richard Keyes, Ms. Daniel Lessing, Mr. Artem Markov, Mr. Ivan Coertze, and Ms. Rethabile Masiu are also recognized for their assistance in the search

for, and mapping of the scattering patterns. Ms. Rethabile is also thanked for her assistance with the maceration of the bones.

Funding This study is funded by the National Institute of Justice and the Forensic Technology Center of Excellence along with the American Academy of Forensic Sciences Humanitarian and Human Rights Resource Center.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in this study involving animals were in accordance with the ethical standards of the institutions at which the study was conducted.

Presentations Accepted for oral presentation at the 48th Annual Conference of the Anatomical Society of Southern Africa in Durban, South Africa.

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