Title: Identifying forensically relevant urban scavengers in Johannesburg, South Africa

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Scavenging of forensic remains by vertebrates is commonplace in South Africa. This interferes with the recovery and forensic analysis of remains. This study identified which scavenging vertebrates are of forensic interest in urban Johannesburg, South Africa, and describes their scavenging and scattering behaviours. Slender mongooses (*Galerella sanguinea*) were the most prolific veldt (urban grassland) scavengers of forensic interest. Their scattering patterns, scavenging behaviours and bone modifications are highlighted. Hadeda ibis (*Bostrychia hagedash*) were the only scavengers in the urban city centre. They scavenged on colonizing insects and created multiple, large holes in the skin and removed the lips of pig carcasses to access the insects. The described scavenging behaviours will assist in the reconstruction of postmortem events in forensic cases and the location and collection of scattered remains in South Africa.

Abstract

Unidentified human remains are frequently recovered in urban environments in South Africa, which undergo forensic (medico-legal) investigations. These remains often exhibit animal scavenging modifications and are frequently scattered by animals. This impacts the collection and forensic analysis of the remains. This study aimed to identify scavenging animals present in two urban environments in Johannesburg, South Africa, and describe their scavenging and scattering behaviours. Six pig carcasses (*Sus scrofa domesticus*) (30-80 kg) were placed in a veldt in Johannesburg and in an abandoned building complex. Motion-activated cameras recorded the scavenging activities. Scavenger species were identified and their behaviours, scattering pattern, and scavenging bone modifications were described. Slender mongooses (*Galerella sanguinea)* were the most prolific veldt scavengers. They scattered remains to a maximum distance of 10.5 meters in two directions: north and southeast. These mongooses scavenged during the advanced and dry decomposition stages. 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 scavenging modification feature of the slender mongoose. Hadeda ibis (*Bostrychia hagedash*) were the only scavengers recorded scavenging on the intestines of a pig carcass in the abandoned building complex. They favoured colonizing insects and created multiple, large holes in the skin and removed the lips to access the insects. The described scavenging behaviours will assist in the reconstruction of postmortem events in forensic cases and the location and collection of scattered remains in Southern Africa.

Key words: Taphonomy; Scavenging; Scattering; Slender mongoose; Hadeda ibis; South Africa

Introduction

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; 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]. Although urbanisation continues to increase, humans are not becoming isolated 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 [6]; however, these animals have received little attention by researchers on their roles in urban environments [4]. Generally, the public tends to have unfavourable 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 of carrion [4,7]. There is a global shift in the public perception with some animals, previously viewed negatively, 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]. Understanding the important role that 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]. This will not only increase our knowledge of animal involvement in carrion removal in urban environments, but also their impact on human remains in this environment.

Scavenging animals in an urban environment commonly results in the scavenging of human remains. In cities and suburban areas, domesticated pets (particularly dogs, *Canis familiaris*) 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 grey mongoose (*Galerella pulverulenta*) and yellow mongoose (*Cynictis penicillata)* have been identified as specie that scavenge upon and scatter remains [11]. Globally, there is a paucity of research on urban scavenging.

Animal scavenging on human remains modifies soft and hard tissues and can scatter remains over a large area. These post-mortem modifications of human remains in a forensic context need to be understood to distinguish between trauma that is nonhuman-induced and tool marks caused by a human perpetrator. Additionally, scavenger feeding can obscure pre-existing traumatic injuries on soft tissues [12]. These can all lead to the misinterpretation of evidence by forensic specialists [13,14]. A greater understanding of scavenging modifications improves the ability of experts to differentiate them from blunt, sharp, or ballistic trauma. A more holistic and effective post-mortem forensic investigation can be achieved if there is an understanding of the interaction between different scavenger species. Variables that need to be understood include a species' dentition and size, environmental factors (i.e. geographic boundaries, foliage, climate, etc.), the stage of decomposition, the state of skeletal elements, and the period of exposure [14-16].

Animal scavenging of human remains of a forensic nature 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. 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. 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 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 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 thus to identify the scavenging animals of forensic relevance in two different environments in the city of Johannesburg, South Africa and to describe the animals' behaviour and scattering patterns as well as the scavenging modifications left on the remains.

Methods

Two research sites were used in this study that are representative of the areas in which skeletal remains are commonly recovered in the Johannesburg, South Africa vicinity – urban veldts and buildings in the densely populated city centre. An urban veldt is a large, open, uncultivated plot of grassland often bordered by industrial and suburban developments. The Frankenwald research site (GPS: 26°04'15.7"S 28°06'12.2"E) was used to represent the veldt environment. 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-centre environment. 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 30-80kg. The pigs were donated by a licensed pig farm. The pigs had died from natural causes, most likely due to haemorrhagic bowel syndrome, usually 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. The pigs were placed at least 20m apart from each other. Their placement was staggered between the months of March to December 2019 (Table 1). The pigs were left to decompose until they were skeletonized. The conclusion of data collection at this site was determined either by the complete exposure of all skeletal elements, including the ceasing of notable scattering of remains; or the end of the authorised data collection period. The authorized data collection period was limited by the owners of the site, resulting in the study at this site concluding on 11 December 2019. 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 obscured beneath a thicket of trees (Figure 1). The pigs were secured in place by a chain around the torso, secured to a nearby tree or fence. These chains were used to prevent theft of the carcasses in the early stages of the study. These chains did not have any impact on the scavenging and scattering of the remains and did not deter the attraction of animals in the early stages of decomposition. The animals only scavenged on the remains in the advanced stages of decomposition when the remains were naturally disarticulated through decomposition processes or could be easily dismembered by small animals without hindrance by the chains. The area is the habitat of small animal species, and they cannot drag entire carcasses away; therefore, chaining the carcasses was not a matter of concern in the present study. Apart from this potential hindrance, there were no other barriers to limit the scattering of the disarticulated remains.

Six pigs were placed at an abandoned complex between the months of March to October 2019 (Table 1). The conclusion of data collection at this site was determined by the owners of the site, resulting in the study concluding on 24 October 2019. The abandoned building complex was the Non-European branch of the Hillbrow Hospital during Apartheid and has been in disuse since 1983. This complex was selected because it is isolated with no human presence, allowing for the placement of pig carcasses with no adverse health effects to the public. Two pig carcasses were placed in an outdoor garden with full exposure, two were placed in a courtyard with partial aerial exposure, and two were placed indoors (Figure 1). All locations had no physical restrictions in place that would limit scavenger access; these carcasses were not chained to any permanent features, as theft was unlikely.

At both sites, the staggering of the pig placements resulted in multiple pig carcasses being present at each research site concurrently (Table 1). This does present a possible limitation of scavenger swamping, which is when the number of carcasses simultaneously present in an environment exceeds the capacity of scavengers to manage them [20,21]. This could potentially influence the regularity of scavenger visitations; however, scavenger swamping is a hypothesis that has not yet been studied robustly and could not be controlled for due to the study design and limitation of the study duration at each research site by the site owners. However, the carcasses were placed at least 20 meters apart in an attempt to reduce this effect if it is an influencing factor on the scavenging.

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. The cameras also had infrared night vision capability which allowed the recording of nocturnal animal activity. Data from the cameras were downloaded every two weeks.

The photographs captured by the cameras were used to identify the scavenger species and describe their behaviour in regard to the time of day, the number of scavengers active at a given time, the season, the decomposition stage, and the body region it prefers to feed upon. A single visit was recorded as an animal's presence, captured by the cameras, with no more than 10 minutes between each camera recording. This included the animal's presence on or near each carcass and was not exclusive to active scavenging of the carcass.

The decomposition stages were assigned and adapted from the descriptions given by Michaud and Moreau [22]. and Galloway *et al*. [23]: 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.

The scatter direction and distance of each scattered element was measured once at the end of the data collection period for each pig carcass (i.e., once all skeletal elements were exposed in each pig and scattering of remains had notably ceased). Each surviving skeletal element was located using the walk-the-line method in a grid pattern. This method includes a group of searchers standing in a line, at an arm's width apart from each other. The line of searchers walked in a south to north direction and then covered the same searched area again but in an east to west direction. Each surviving element was flagged and then mapped using a grid pattern method. These search and mapping methods are common in archaeological and forensic anthropological practice.

The bones were macerated to remove all remaining soft tissues for scavenging modification 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 in general terms by classifying the modifications as pits, scores, punctures and/or furrows [12,14]. Pits are non-penetrating cortical indentations on the surface of the bone, which are caused by individual tooth cusps. Scores are superficial cortical marks in the bone surface where the length is greater than the breadth (i.e., a scratch); often caused by a tooth sliding after a pit has been created. Punctures are irregular-shaped, penetrating marks that extend into the trabecular bone, which are usually created by canine and carnassial teeth. Furrows are deep, longitudinal grooves that penetrate into trabecular bone, as a result of gnawing actions [12,14].

Results

Frankenwald Veldt

The slender mongoose (*Galerella sanguinea*) and water mongoose (*Atilax paludinosusis*) scavenged on the pig carcasses placed in the Frankenwald veldt. Additionally, common large-spotted genet (*Genetta tigrina*) and a number of local domestic dogs (*Canis familiaris*) were attracted to the carcasses and often marked the pig by rubbing themselves on the carcasses; 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 several smaller unidentified birds. Nocturnally, the spotted thick-knee (*Burhinus capensis*) was the only bird repeatedly attracted to the carcasses and remained for long periods, feeding on colonizing and migrating insects. Other smaller nocturnal mammals observed visiting the carcasses were the African 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 and multiple slender mongooses would scavenge together on rare occasions (Table 2).

The slender mongoose (Figure 2) was the most prolific scavenger at the Frankenwald site and, as such, its scavenging behaviour and scattering patterns will be highlighted. The slender mongoose mostly scavenged in isolation, although occasionally pairs would 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 stages of decomposition and would feed on colonizing insects. The slender mongoose often would leave distinctive holes in the ground or disturbed soil or fallen foliage around a pig carcass as they exposed burrowed insects (Figure 3). In the more advanced stages of decomposition, they would also burrow under the carcass to access and remove the ribs if the skin was too desiccated for them to eat through (Figure 3). The frequency of slender mongoose scavenging increased as the decomposition stages progressed, as indicated by the number of scavenging events on the five carcasses in the following decomposition stages: early stage (n=5; $\bar{x}$=1), bloat stage (n=2; $\bar{x}$=0.4), active stage (n=17; $\bar{x}$=3.4) and the advanced stage (n=307; $\bar{x}$=61.4). They showed a particular preference for the soft tissues of the abdomen (Figure 4). Disarticulated limbs and skeletonized scapula were selectively scattered away from carcasses. Individual skeletal elements that were favoured included the mandible (particularly the angle), ribs, limb bones and vertebrae (Figure 4). There were no apparent seasonal differences in the scavenging behaviours of the slender mongoose between the warm and cold months.

The slender mongoose was diurnal and active between 05h00 and 18h00, commonly observed scavenging between 10h00-10h59 and 14h00-16h59 (Figure 5). The duration of each scavenging event was very short in most cases. Visits ranged between 1-195 minutes, averaging 6.3 minutes (SD=12.37), with most visits not exceeding 1 minute (46% of visits). No seasonal differences were noted in their activity. There was only one other mongoose species noted - a water mongoose; however, it was only observed once. The water mongoose was nocturnal, active in summer only, and scavenged only on the soft tissues of the abdomen.

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. As time progressed, the scattered remains would increase in distance away from the original location; however, the direction of scatter for each element was not unidirectional. The remains were scattered over an area with a maximum radius of 10.5m/34.4ft (Figure 6). The skeletal remains were scattered in two general directions: towards the north and southeast (Figure 6). 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 seasonal differences noted in their scattering behaviour.

The slender mongoose did not often leave scavenging modifications on the skeletal elements; however, the few modifications that were observed were isolated to the ribs, vertebrae, scapula, and mandible (Figure 7). Gnawing on the mandible was concentrated on the gonial angle of the mandible with multiple parallel scores on the flat surfaces and the angle margin having a stepped appearance (Figure 7). The proximal border of one scapula exhibited a series of isolated gnaw marks in the form of furrows (Figure 7). The anterior and posterior ends of the ribs and the transverse processes of the vertebrae were gnawed off with a crushed appearance (Figure 7).

Abandoned Building

At the abandoned building complex in the city centre of Johannesburg, very little scavenging occurred on the pig carcasses. 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 and 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 to gain access to the insects within the carcasses. This included removing the lips (Figure 8) and creating numerous large holes in the skin of the pig carcasses (Figure 8). In a single instance the hadeda ibis was observed scavenging on a portion of the intestines (Figure 8). No scavenging on the pig skeletal elements was noted.

Discussion

This study has described the unique scavenging behaviours of animals in urban areas in Johannesburg, South Africa. The slender mongoose was the most prolific scavenger in a veldt environment and understanding its scavenging behaviour is of vast importance for forensic investigations for the reconstruction of postmortem events. The slender mongoose has a wide distribution throughout sub-Saharan Africa [24], but within South Africa it is restricted to the northern areas [25]. 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 [26]. Slender mongoose dens are often holes, dens, and warrens originally dug by other animals, often in old termite mounds [26]. Largely diurnal, the slender mongoose will on occasion hunt at night if it is warm and accompanied by bright moonlight [24]. They are generalist carnivores with a diet of small vertebrates and insects and will scavenge on the carcasses of mammals [27]. They typically scavenge on small carcasses (such as hyrax) and medium carcasses (such as antelope and wildebeest) [28]. Larger carcasses are often avoided, as they may be perceived to be a high risk for predation [29], but they have been observed scavenging on and around large carcasses (such as giraffe) [30].

The present study is the first study to describe the urban scavenging behaviour of the slender mongoose with a forensic perspective in South Africa. The only comparable studies are those by Spies *et al.* [11,31] performed in Cape Town, South Africa on the Cape grey mongoose (*Galerella purverulenta*), which has comparable scavenging and scattering behaviours to the slender mongoose [11]. Both mongoose species were observed to be mostly solitary, but they were social on occasion as multiple mongooses were noted scavenging together. Slender mongooses were observed scavenging in pairs and the Cape grey mongoose sometimes scavenged in groups of up to three individuals at a time [31]. Both the slender and Cape grey mongoose were diurnal [31], and 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 grey 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 species [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 grey 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 [25]. 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 [32]. Both species also scattered the remains of individual carcasses in two main directions: the slender mongoose scattered remains in a north and southeast 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. Additionally, some of the remains were scattered into dense undergrowth, similar to the observations described by Spies *et al*. [11]. This behaviour is likely to avoid detection by predators. The consistency in these scattering behaviours are likely common in numerous mongoose species throughout various environments across South Africa, and are important in forensic contexts.

Available comparative data, of a forensic nature, on small vertebrate scavengers and their behaviours are limited. Spies *et al*. [33] highlighted that, similar to the Cape grey mongoose in their study (which corresponds in many points to the slender mongoose in the present study), the Virginia opossum (*Didelphis virginiana*) in the USA has similar scattering patterns. The opossum also scatters porcine skeletal elements over a 5 m radius from the original deposition site [33]. Similar to mongooses in South Africa, the opossum is abundant throughout various habitats in the USA, including semi-urban environments [33]. The similar scattering distance is likely a result of the size of the scavenging animal, which suggests that many scavengers of similar size will have a limited scattering range.

This understanding of consistent scattering behaviours 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*. [31] noted that mongoose scavenging increased the decomposition rate by at least six-fold [31]. This alteration of the decomposition rate would lead to an overestimation of the postmortem interval if the influence of the mongoose activity was unknown [31]. This study was a preliminary investigation into identifying the most prevalent scavenger species in the urban Highveld of South Africa. As a result, the descriptions of the slender mongoose scavenging are broad. Since the slender mongoose, and mongooses in general, have been highlighted as forensically relevant, future studies can focus on this species and statistically describe their specific scattering behaviours, with special attention to recording the average distance of bone scatter and the effect of bone size on scatter distance and direction.

The scavenging modification patterns on the ribs and vertebrae of the slender mongoose and Cape mongoose were both non-specific and cannot be used diagnostically to identify the animals. The Cape 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 mongoose appears to be greater than that by the slender mongoose and could possibly be attributed to slightly larger size of the Cape 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 gnaw marks on the proximal 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 gnaw marks on the angle of the mandible, however, appears to be a distinct scavenging modification pattern of the slender mongoose. This, in addition to other markers of mongoose activity, could be diagnostic of slender mongoose activity, as it has been observed in mongoose scavenging in other environments in South Africa [34,35]. Additional indications of slender mongoose activity could include the multiple holes dug around the body and the presence of spoor near the body. The behaviour of digging holes around a carcass to excavate fly pupae has been previously observed and appears to be a unique feature of slender mongoose behaviour [30]. This behaviour was noted in the early, bloat and active stages of decomposition and were focussed on the soil surrounding the carcasses, without impacting directly on the carcasses. In one case, the slender mongooses dug holes beneath the carcass to gain direct access to the skeletal elements without gnawing through the skin in the in the advanced stages of decomposition. Similar digging behaviour was also noted in the Cape grey mongoose [31]. Spies *et al*. [31] suggested that the digging of soil from beneath a carcass may alter the decomposition process; however, the present study suggests that this may not have any major effect since this behaviour was only noted in the advanced stage of decomposition when most soft tissues have already decomposed, and desiccated skin and skeletal elements make up most of the remaining biomass.

Several 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 [31]. The common large-spotted genet, slender mongoose, and numerous dogs marked themselves with the pigs' scent by rubbing themselves on the carcasses. This behaviour, called interspecific scent marking, is widely recorded in carnivores [36] 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 [36]. Slender mongooses will often mark themselves with a scent after a genet has visited and marked a site [36]. It is unknown why slender mongooses and genets overmark each other's scents [36]. It is presumed that smaller mammals mark themselves with the scent of a dominant predator for protection, but it is unclear how the overmarking behaviour of dogs and small nocturnal genets would enhance the survival of diurnal mongooses [36].

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 [37]. They are typically associated with wetlands where they forage for insects in soft, moist soil [37]. 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 [37,38].

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 trauma. Also of note, to the knowledge of the authors, this is the only recorded instance of hadeda ibis actively scavenging on the soft tissue of carcasses. Hadeda ibis were observed to be attracted to carcasses in a Cape Town scavenging study by Spies *et al*. [39] but the hadeda ibis were not observed scavenging soft tissue in that study. Given the wide range and large number of hadeda ibis in South Africa, particularly in urbanized centres, it is important that their scavenging behaviours 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, but 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 controlling the rat population at the research site.

The present study has highlighted scavenging animal species that are of forensic interest; however, these animals were previously unknown to forensic specialists to have been present and scavenging on remains in urban areas. International studies have highlighted a variety of urban scavenging animals that are considered to be of forensic importance. In North America, such animals include coyotes (*Canis latrans*), racoons (*Procyon lotor*), opossums (*Didelphis marsupialis*), rodents, foxes (*Vulpes vulpes*), striped skunks (*Mephitis mephitis*) and crows (Cor*vus brachyrhynchos*) [16,40]. Carrion crows, Eurasian magpies, and European red foxes are common urban scavengers in the UK and Europe [4]. In Australia facultative avian scavengers consume most carrion [41], in addition to the Australian raven (*Corvus coronoides*), Chuditch (*Dasyurus geoffroii*), and red fox [42]. 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 in areas with human habitation [43]. Despite previous studies having identified which scavenging animals are present in an urban environment, it is suggested that future studies explicitly describe how their behaviours may impact forensic investigations.

The present study is one of the first to explicitly study urban scavenging in a heavily populated metropolitan, with a focus on forensic applications. The published literature to date has focused largely on peri-urban, semi-rural and rural environments [6, 12, 14, 16, 33-35, 40, 42, 44] and forensic studies on urban scavenging remains understudied. Although the results of the present study are region and species specific to the urban Highveld environment of South Africa, the study has highlighted that knowledge of animal scavenging can have forensic application [11, 42]. More ecological research, with a focus on forensic applications, needs to be performed in other unique regions.

The larger density of animals near human habitations is a global phenomenon, which may impact human remains. In North America black bear (*Ursus americanus*) populations are reported to be up to three times larger in human inhabited areas than natural areas and coyote populations (*Canis latrans*) are similarly larger in human inhabited areas [45-48]. Urban areas in Northern Israel hosts populations of red foxes (*Vulpes vulpes*) that are 15 times higher than in pristine environments [45-48]. Ethiopian urban areas have spotted hyena (*Crocuta crocuta*) in abundance (up to 15 times higher in regions than other natural locations) [1,49], as are populations of the African golden wolf (*Canis anthus*) [50]. Globally, urban rubbish dumps in particular have significantly increased concentrations of animal species, with some areas hosting large populations of red foxes, raccoons (*Procyon lotor*), bears, cats (*Felis catus*) and Eurasian badgers (*Meles meles*) [50-54]. The growing animal abundance in urban areas increases the chances of their scavenging human remains that may be under forensic investigation and is therefore an important field of taphonomic research that can be explored further in future research.

It is also suggested that future studies explore the effects of carcass swamping as this may influence the regularity of scavenger visitations. This will have implications for forensic scavenging studies and may inform future research methodology, in terms of the number of carcasses that can be placed simultaneously at a site and the minimum distance required between carcasses.

Conclusion

Animal abundance is often high in urban areas. Scavengers play an important role in urban ecosystems due to their general efficiency of carrion removal; however, these animals often impact human remains under forensic investigation via scavenging and scattering. Identifying scavengers and their behaviours will assist forensic investigators in the reconstruction of postmortem events and the recovery of remains for analysis. Slender mongooses (*Galerella sanguinea*) were the most prolific urban veldt scavengers at the veldt at the Frankenwald research site, in Johannesburg, South Africa. They scattered remains to a maximum distance of 10.5 meters in a north and/or south-east directions. 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 scavenging modification feature of the slender mongoose. Multiple holes in the ground surrounding a carcass are also suggestive of slender mongoose activity for carcasses found within the range occupied by these species. The hadeda ibis (*Bostrychia hagedash*) was the only avian scavengers recorded scavenging on the soft tissue of a pig carcass in the abandoned building complex within an urban setting. However, they favoured colonizing insects and created multiple, large holes in the skin and removed the lips to access the insects. The described scavenging behaviours will assist in the reconstruction of postmortem events in forensic cases and the location and collection of scattered remains. This study is one of the first urban scavenging studies of a forensic nature and the results will assist with assessing postmortem modifications to remains and their recovery. Further international research is warranted in unique locations and on scavenging species of forensic interest.

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Figure 1: Representation of how the pig carcasses were placed at the Frankenwald research site (top row) and abandoned hospital complex (bottom row) in locations with varying levels of exposure.

Figure 2: Pig carcasses were scavenged by slender mongoose (left) and water mongoose (right)

Figure 3: 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)

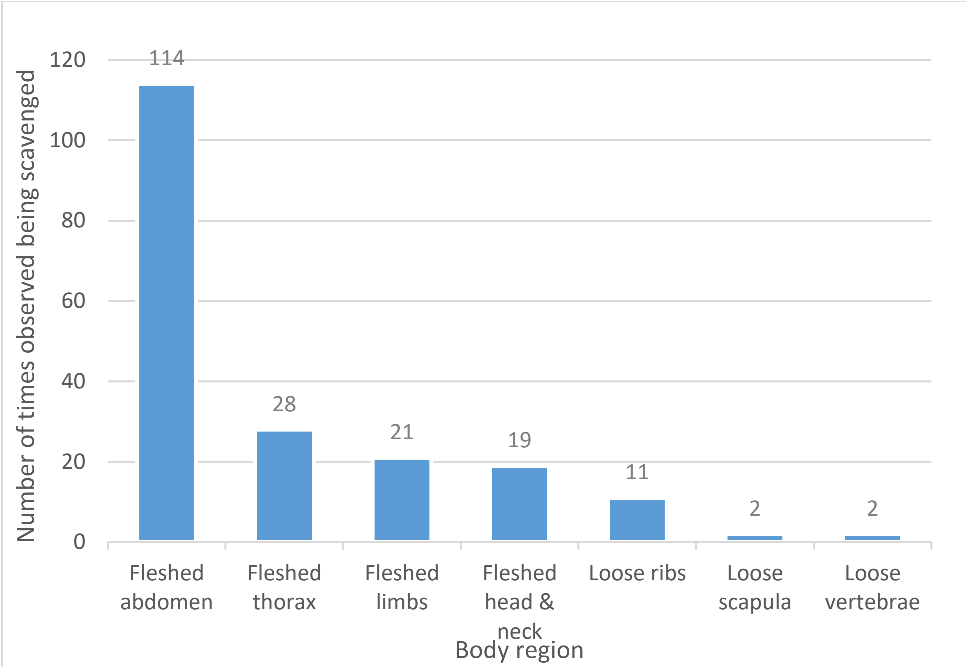

Figure 4: Slender mongoose scavenging preference of fleshed body regions and skeletal elements

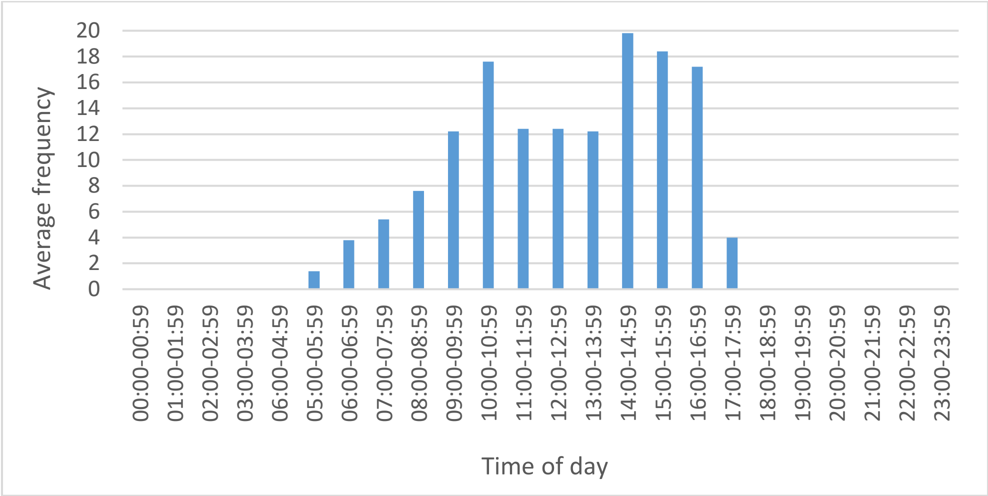

Figure 5: The hourly average frequency of slender mongoose scavenging of six pig carcasses

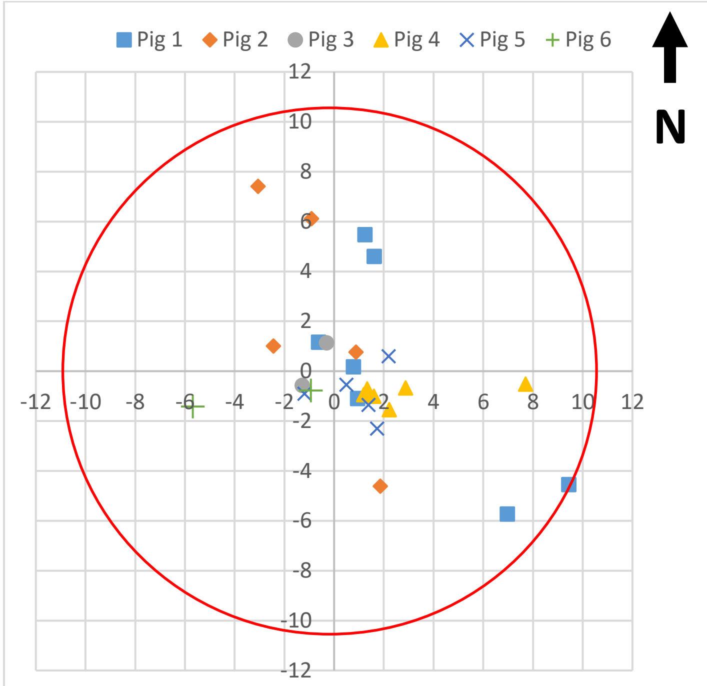

Figure 6: Scatter plot of the skeletal elements of six pigs by slender mongooses, showing distance (in meters) and direction of scattering. The origin (0;0) indicates the original position of each pig. Northern arrow indicates the relative scatter direction. Radius arrow indicate the maximum scatter radius (radius = 10.5m)

Figure 7: Slender mongoose scavenging modifications of the mandibular angle (top left – circled), transverse process of a vertebra (top right – circled), proximal border of a scapula (bottom left - arrows), and rib (bottom right - circled)

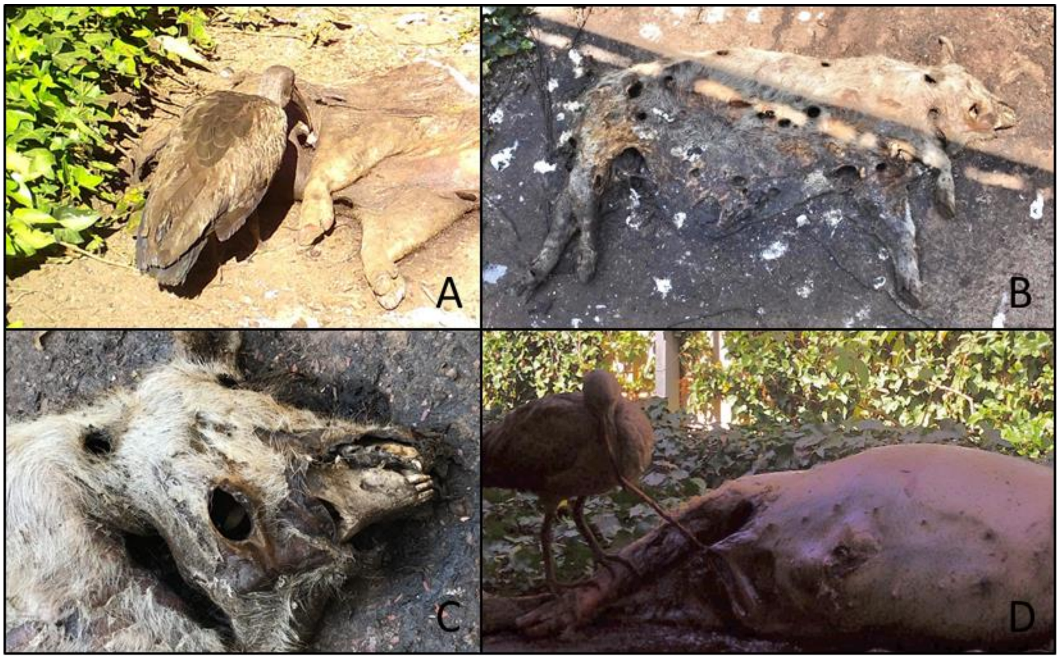

Figure 8: Hadeda ibis feeding on insects through a hole in the skin (A), multiple holes created in the skin by hadeda ibis (B), lips removed by hadeda ibis (C) and a hadeda ibis scavenging on pig intestines (D)

Table 1: Descriptions of pig carcass deployments

Pig	Location description	Approximate weight	Date of deployment	End of study/carcass reclamation
		Frankenwald veldt		
1	Completely exposed (no tree cover), enclosed by palisaded fencing. No obstruction to access by small-medium sized terrestrial scavengers due to the gaps between the fencing.	~35kg	15 March 2019	10 June 2019
2	Completely exposed (no tree cover), enclosed by palisaded fencing. No obstruction to access by small-medium sized terrestrial scavengers due to the gaps between the fencing.	~30kg	10 May 2019	30 September 2019
3	Beneath a thicket of trees with no obstruction to scavenger access.	~30kg	10 May 2019	11 December 2019
4	Partially exposed beneath a single tree with no obstruction to scavenger access.	~30kg	10 May 2019	11 December 2019
5	Partially exposed beneath a single tree with no obstruction to scavenger access.	~30kg	10 May 2019	11 December 2019
6	Partially exposed beneath a single tree with no obstruction to scavenger access.	~30kg	10 May 2019	11 December 2019
		Abandoned Hospital		
7	Inside building. 24hr darkness. Doors to building were open with no obstruction to scavenger access.	~35kg	15 March 2019	24 October 2019
8	Outdoors in a quart yard with partial aerial exposure. The quart yard opening directly to the garden with no obstruction to scavenger access.	~35kg	15 March 2019	24 October 2019
9	Inside building. 24hr darkness. Doors to building were open with no obstruction to scavenger access.	~30kg	14 June 2019	24 October 2019
10	Outdoors in a quart yard with partial aerial exposure. The quart yard opening directly to the garden with no obstruction to scavenger access.	~30kg	14 June 2019	24 October 2019
11	Outdoors in a garden with full exposure and no obstruction to scavenger access.	~66kg	14 June 2019	24 October 2019
12	Outdoors in a garden with full exposure and no obstruction to scavenger access.	~70kg	14 June 2019	24 October 2019

Table 2: The behaviours of animals attracted to carcasses in an urban veld in Johannesburg

Animal	**Maximum number of animals of the same species active at the same time at the same carcass**	**The number of carcasses each animal visited/ scavenged (n = 5)**	**Decomposition stage(s) attracted to carcass**	**Decomposition stage(s) with direct scavenging of the carcass**	**Time active**
Slender mongoose	2	5	All	Active & advanced	Diurnal
Water mongoose	1	1	Advanced	Advanced	Nocturnal
Common large-spotted genet	1	4	Early, active & advanced	NA	Nocturnal
Domestic dog	2	5	Bloat, active & advanced	NA	Diurnal & nocturnal
Swainson's spurfowl	1	1	Advanced	NA	Diurnal
Helmeted guineafowl	1	1	Advanced	NA	Diurnal
Pied crow	3	1	Advanced	NA	Diurnal
Hadeda ibis	1	2	Advanced	NA	Diurnal
African savannah hare	1	1	Early & bloat	NA	Nocturnal
South African pouched mouse	3	2	Advanced	NA	Nocturnal
Spotted thick-knee	2	3	Early, bloat, active & advanced	NA	Nocturnal