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

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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.

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 Bronkhorstspruit 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).

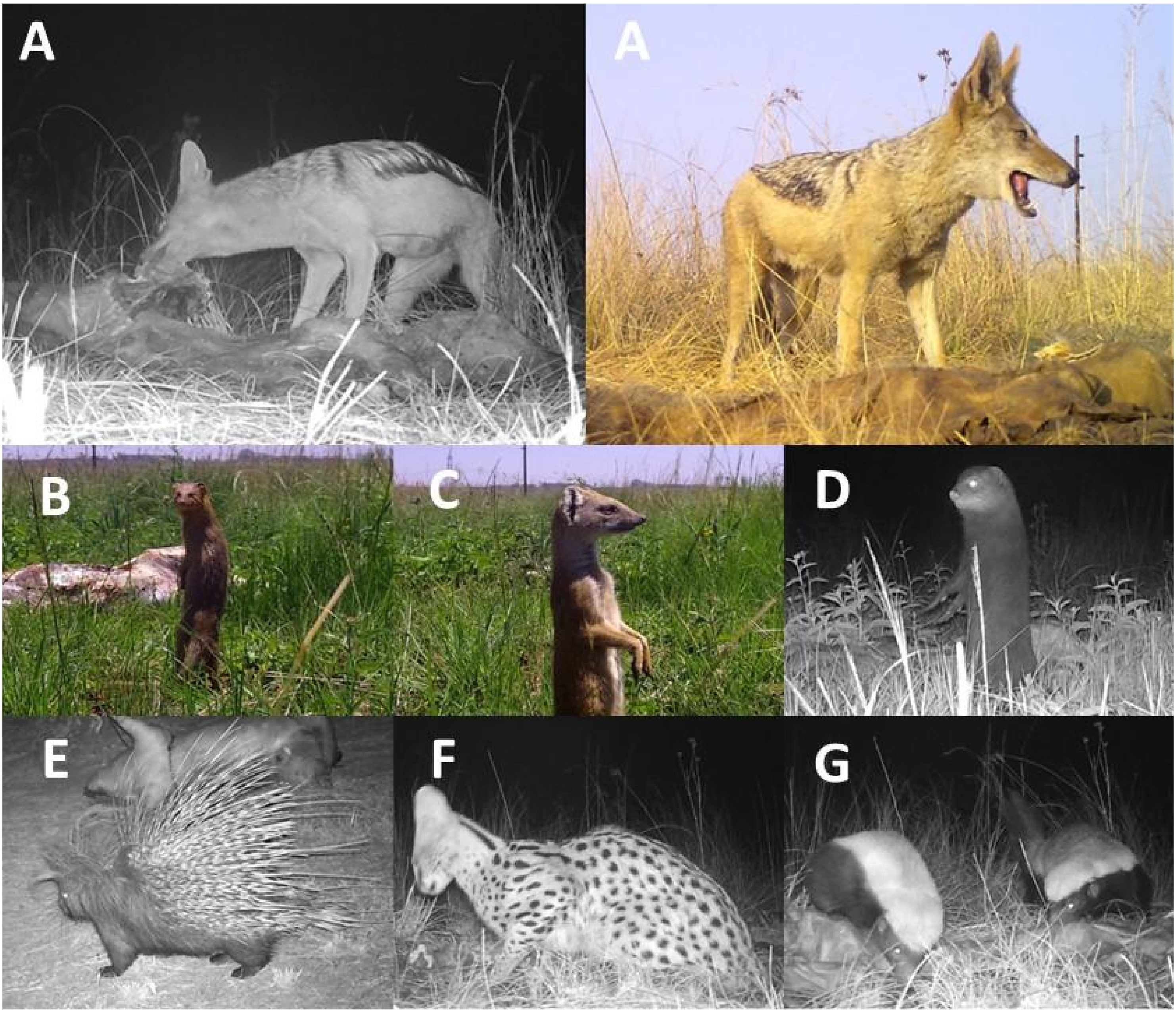

Fig 2. Animals that were attracted to, or scavenged on, pig carcasses, including black-backed jackals (A), slender mongoose (B), yellow mongoose (C), water mongoose (D), Cape porcupine (E), serval (F), and honey badgers (G).

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 paludinosusis*) (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.

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*

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 (Pig 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).

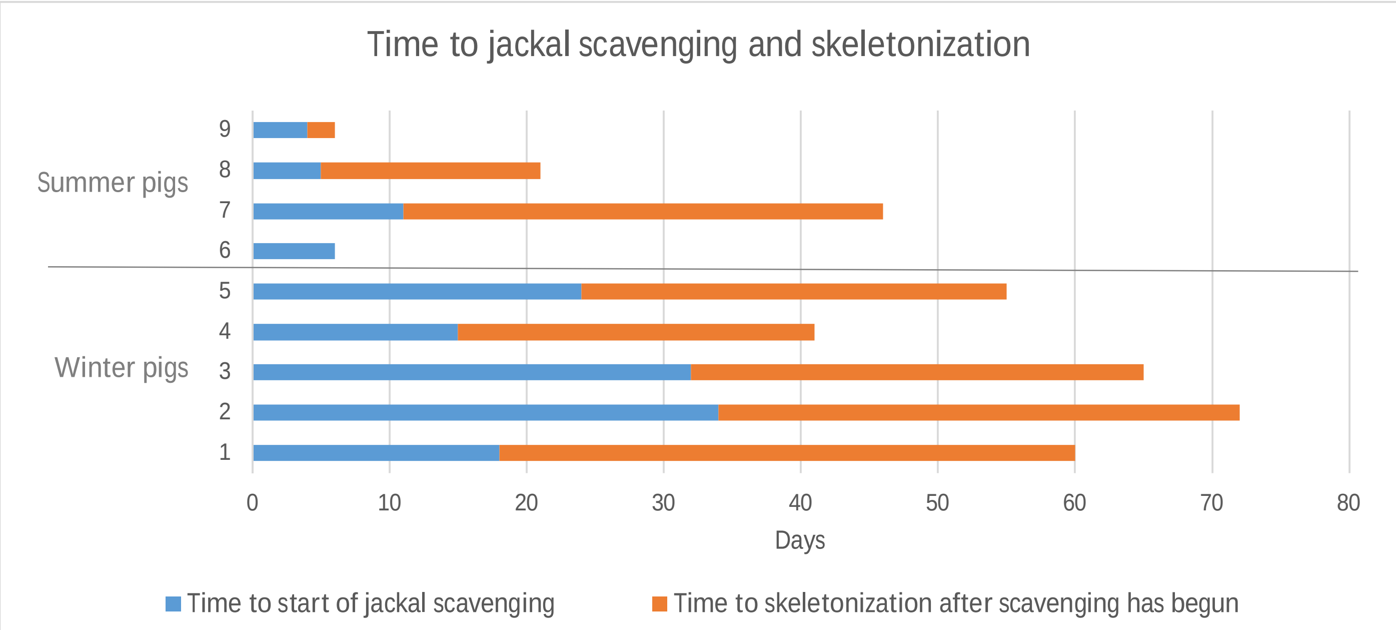

Fig 3. Comparison of time of jackal scavenging onset to skeletonization of pig carcasses

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).

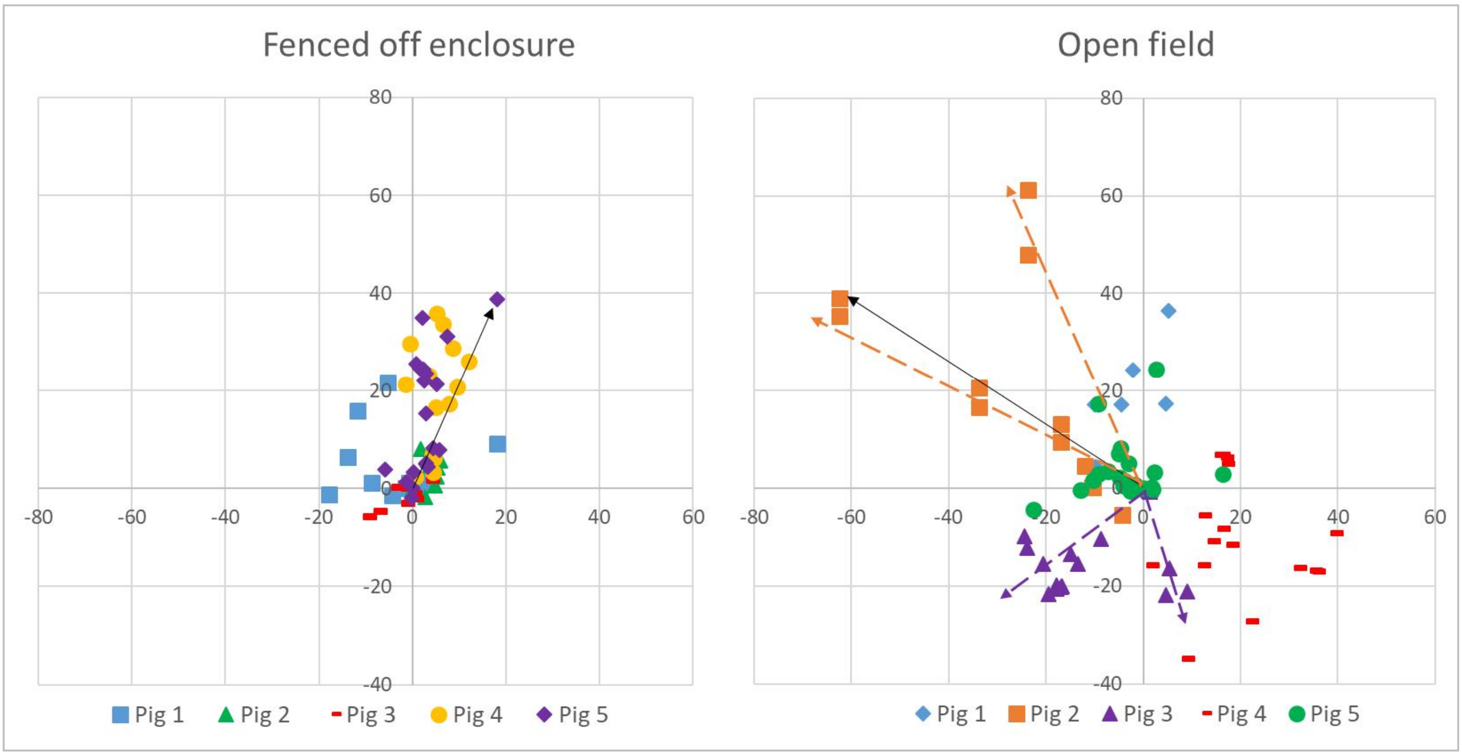

Fig 4. Scatter plot of the skeletal elements of ten pigs, five in a fenced off enclosure (left) and five in open fields (right), scattered primarily by black-backed jackals, showing distance (in meters) and direction of scattering. The origin (0;0) indicates the original position of each pig. Northern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

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.

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).

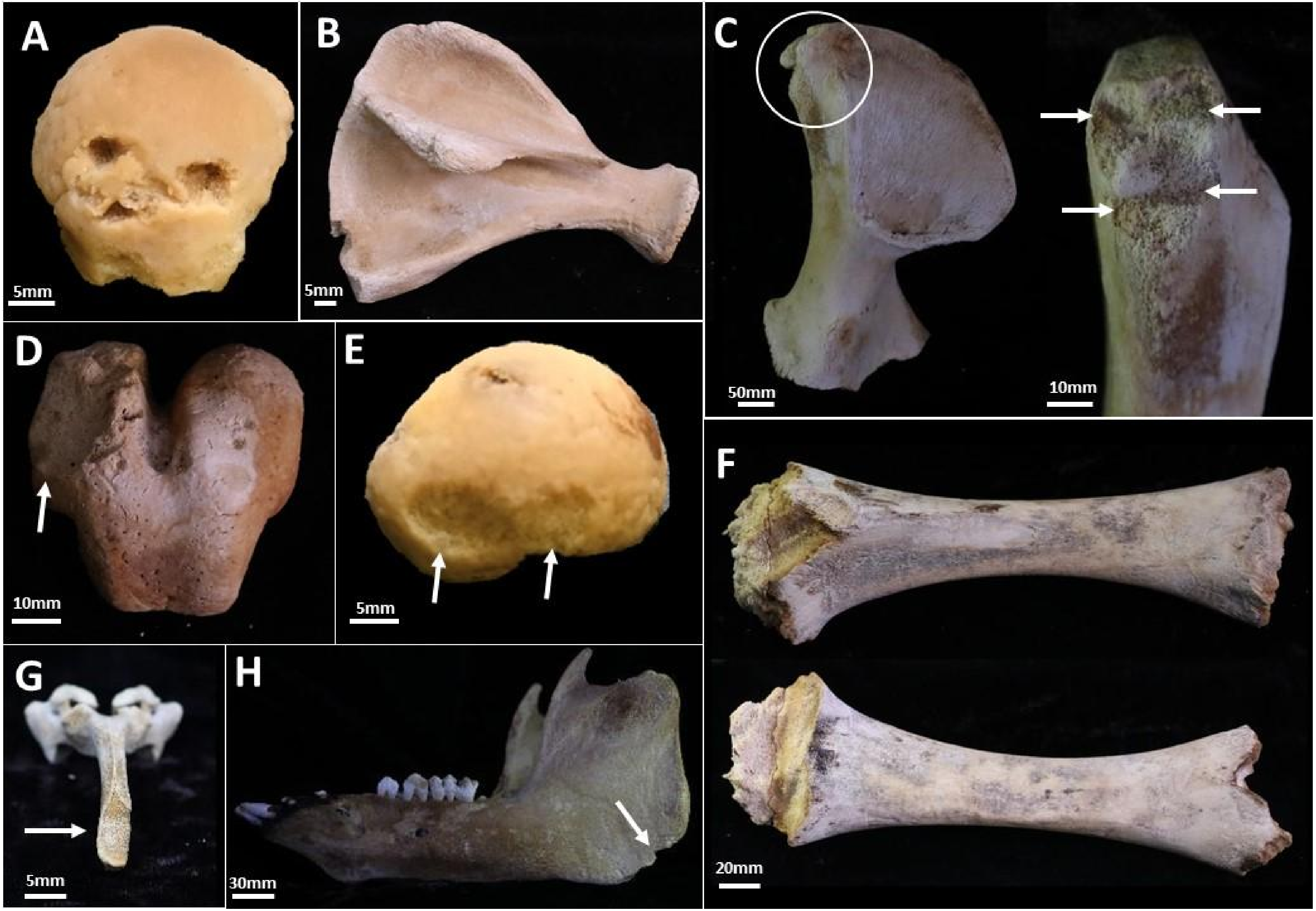

Fig 5. Damage caused by scavenging animals: A) black-backed jackal punctures in the head of humerus, B) black-backed jackal puncture in the medial boarder of the scapula, C) black-backed jackal furrows in the cranioventral spine of the ilium (left picture is the ventral view of the ilium with circle 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

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 were 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.

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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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