Postmortem modifications of skeletal elements caused by common small southern African scavenging mammals found in a peri-urban environment

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Declaration

I, Roxanne Rebelo da Costa, declare that this Dissertation is my own, unaided work. It is being submitted for the Degree of MSc (Med) in Forensic Medicine at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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(Signature of candidate)

___18/01/2024_________________ in ___Johannesburg__________

Date Place

Dedication:

I would like to dedicate my dissertation to my parents, Natercia da Costa and Manuel da Costa, without their constant support and love this would not have been possible.

Abstract

The definition of taphonomy is everchanging and has been adapted from the original use to explain fossilization of animal remains to aiding in forensic investigations. Forensic taphonomy has helped estimate postmortem interval timelines and aid in understanding what happened to a body postmortem. A taphonomic variable of interest is animal scavenging. Animal scavenging can hinder forensic investigations through the alteration or deletion of evidence and the scattering of remains. The aim of the study was to describe the nature of postmortem modifications of skeletal elements caused by common small scavenging animals found in peri-urban environments in southern Africa. Understanding scavenging and scattering patterns of common animals found in a peri-urban environment in South Africa can aid in locating skeletal elements in forensic investigations. In this study, bovine skeletal elements were scattered at the National Zoological Gardens in Pretoria, in the enclosures of genets, servals, a warthog, and suricates. The elements remained in the enclosures for a week, after which they were collected, and the process was replicated three times. The samples were then macerated, analysed, and photographed at the Johannesburg Forensic Pathology Services. Scores were the most commonly observed postmortem modifications caused by all species studied and they were mainly superficial, indicating they were more likely caused by claws rather than the teeth of the animal. A chi-square test was conducted to test whether an association existed between the location on the skeletal element scavenged and the scavenging species. The statistic proved that there was an association and that each scavenging species studied have a preference for specific locations and skeletal elements that they scavenge on. A scoring system was developed to describe the intensity of modifications inflicted on the skeletal elements. The Cohen's Kappa coefficient showed that the scoring method produced reliable scores. This is the first forensic taphonomic study to describe the modifications caused by genets, servals, and suricates. The results of the study can assist forensic anthropologists in the assessment of postmortem taphonomic alterations to skeletal elements in peri-urban environments in Southern Africa.

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Chapter 1: Introduction

In 1940, palaeontologist I.A. Efremov defined taphonomy as the study of animal remains transitioning from the biosphere to the lithosphere (Lyman, 2010). The origin of the word stems from the Greek words *taphos* meaning burial and *nomos* meaning laws (Cadee,1991), therefore the literal translation meaning "the laws of burial" (Olson, 1980). Originally, taphonomy was used in science as a label for the laws of embedding (Lyman, 2010) and focussed on what had been removed from animal remains during the embedding or fossilization process (Lyman, 2010). Initially, taphonomy focussed on two stages occurring during the fossilization process namely biostratinomy and diagenesis (Lyman, 2010). Biostratinomy is the study of the environmental factors which affect animal remains between their death and their final burial (Lawrence, 1979a). It was also recognized that the remains of an animal could be buried, exposed, and then reburied multiple times (Lyman, 2010). Diagenesis is the fossilization factors that affect the animal remains after final burial to the time of recovery (Lawrence, 1979b). Identification of these stages were important as it allowed for the pre-burial, mostly biological processes (biostratinomic), and the post-burial, mainly geological and chemical processes (diagenetic), to be separated (Lyman, 2010). This separation allowed palaeontologists to reconstruct ancient ecosystems and the conditions that attributed to the preservation of fossils. Although the paleosciences acknowledged that changes occurred to the remains before and after the final burial, the focus was mainly on the potential data that had been removed from the remains and the alterations to paleontological records (Lyman, 2010).

As the field of taphonomy expanded, researchers recognized that the original definition of taphonomy and the evaluation of the fossil assemblages was biased towards fossils and the science of taphonomy was based around already fossilized remains, and not the process of remains becoming fossilized (Lawrence, 1979c). This bias that was introduced into the field of taphonomy was replaced with an optimistic perception that taphonomy provided information that explained the processes that allowed for the preservation of fossils, i.e. examining the processes that happen to remains after death (Behrensmeyer and Kidwell, 1985, Dominguez-Rodrigo *et al*., 2011). However, this definition still placed emphasis on the formation of fossils and taphonomic principles which had not yet been explored in a bioarchaeological or anthropological setting. In his final definition of taphonomy, Efremov (1940) stated the laws of embedding but did not specify the embedding of solely animal remains, leaving a broad definition of taphonomy. This allowed for non-organic materials of archaeological sites to also be explored taphonomically (Dominguez-Rodrigo *et al*., 2011). Importantly, through the evolution of the definition of taphonomy, it was no longer restricted purely to animal remains and allowed for human remains and all biological organisms to be explored.

It has been noted that archaeology has been a long contributor in widening the scope for taphonomy. From the 1980s onwards, researchers dealing with archaeological questions included taphonomy in their work and allowed for the frameworks for understanding natural bones in specific biomes, such as the African savannahs (Dominguez-Rodrigo *et al*., 2011). The other concepts focussed on in these archaeological studies were scavenging, human cultural practices on bones (such as butchering patterns), modifications on bones caused by carnivores, bone breakages, and more (Dominguez- Rodrigo *et al*., 2011). Therefore, these extended concepts allow for the taphonomic definition to not be limited to the study of physical remains of organisms but to include all things that extend from their somatic nature and behaviours which leave behind taphonomic prints (Dominguez-Rodrigo *et al.,* 2011). In conclusion, this suggests that the imprint of an organism can persist and be examined without its demise, encompassing behaviours like animal scavenging or human burials.

Forensic science has utilized this extension of the taphonomy definition and has examined how these taphonomic processes have altered evidence that is used in medico-legal investigations (Domiguez-Rodrigo *et al*., 2011). Forensic taphonomy examines the biotaphonomy, which includes the physical remains (if present), environmental and cultural factors. It also examines the geotaphonomy which includes disturbances present at a scene, disturbance of soil, modifications of soil, etc. (Haglund and Sorg, 1996). More recent studies and research have also adapted taphonomy to investigate processes that cause distress to any organism at a scene of death, including human remains, from time of death to time of recovery (Calce and Rogers, 2007). These processes include both neutral phenomena, such as floral, faunal, and environmental factors, as well as human interferences. There are several variables in forensic taphonomy that are studied to estimate time of death and to reconstruct postmortem events in order to conduct a full medico-legal investigation.

The first variable is the postmortem changes that occur to the physical remains of the carcass. Specific postmortem changes observed allow for the postmortem interval (PMI) or time since death to be estimated (Simmons and Cross, 2013). The stages of postmortem changes can be summarized into two phases, the first being the early changes which occur within two hour after death. These changes consist of a decrease in blood circulation and gravity, resulting in pallor (paleness), muscle relaxation, especially in the sphincter muscles and orbicularis oculi muscles, causing cornea drying (Simmons and Cross, 2013). Additionally, the influx of potassium ions into the vitreous humour is utilized to estimate the PMI. After two hours postmortem, late changes begin to occur, including livor mortis (skin discoloration due to blood pooling), rigor mortis (temporary muscle stiffness) and algor mortis (decrease in body temperature) (Simmons and Cross, 2013). Additional late stages that can and often do occur are skin slippage, putrefaction that leads to bloating and odour, insect colonization, the formation of adipocere and drying and mummification. All the above changes can be used as indications of the environment in which the death occurred, if human intervention occurred and if the body was moved from site of death, as well as determining PMI (Simmons and Cross, 2013). However, certain taphonmic influences, such as scavenging and insect colonization can lead to a disturbance in the environment of death, altering evidence that can be utilized in medico-legal examinations, and can cause postmortem modifications that can be mistaken for perimortem modifications.

Forensic taphonomy also investigates the impact of the environment on perimortem trauma. For example, Calce and Rogers (2007) conducted research to examine seven different taphonomic changes and how they altered the results of blunt force trauma to the skull in Southern Ontario, Canada. The seven factors were the freeze-thaw cycle observed in Southern Ontario, rodent gnawing, animal scavenging, movement, and displacement of the bones by scavengers, soil encasement or erosion, the presence and weight of rain and snow, bleaching, as well as vegetation staining. They concluded that weather alterations such as the freeze-thaw cycle and the effects of rain and snow, as well as soil erosion and the movement of the skulls caused the pre-existing trauma on the bone to be disguised. However, it was observed that animal scavenging did not disguise the pre-existing trauma on the bones (Calce and Rogers, 2007). Although pre-existing trauma on the bones were not disguised, damage caused to the soft tissue and additional marks on skeletal elements caused by scavenging animals could lead to the misinterpretations in forensic investigations and therefore require further exploration.

A variable of taphonomy, and the focus of the current study, is animal activity. The progression of decomposition may be altered due to the presence of animals and specially scavengers. Research on postmortem modifications caused by scavenging animals has mainly been conducted in the United States of America, where the most common scavenging animals includes wolves (*Canis lupus*), rodents, foxes, and coyotes (*Canis latrans*) (Young *et al*., 2014). However, research on animal scavenging and postmortem modifications of skeletal elements is limited in South Africa and is of particular interest as many human remains are found and recovered from veldts and peri-urban environments. Therefore, research on species-specific scavenging in southern Africa can be beneficial in aiding forensic anthropologists with forensic investigations. This can be accomplished through utilizing the knowledge of animal scavenging patterns in southern Africa to differentiate between postmortem trauma caused by animals and perimortem trauma caused by humans.

Chapter 2: Literature Review

2.1. What is scavenging?

A vital process in ecology is the transfer of energy between trophic levels and is commonly achieved through the consumption of one organism by another (Inger et al., 2016). The general assumption is that this energy transfer is accomplished through predation; however, many predators also scavenge, which is the opportunistic consumption of a carcass whose demise was for reasons not related to predation (Young et al., 2015). Facultative scavenging (i.e. opportunistic scavenging) is common in most predators as they do not exclusively rely on scavenging in order to survive, they simply utilize carcass when available abreast of their usual hunting (Inger et al., 2016). In some cases, scavenging is favoured over predation, as carcass mirrors resources of equal value in nutrition and energy to that acquired through predation at a lower expense of energy normally exerted through predation (Inger et al., 2016). Moreover, the energy consumption and risks, such as predators encountering other predation species or being killed during a hunt (Hebblewhite et al., 2005; Mumma et al., 2017) are drastically decreased with scavenging activities (Inger et al., 2016). Oppositely, obligative scavengers rely exclusively on carcass scavenging for survival, such as vultures (Inger et al., 2016). The significance of scavenging in the food web has been widely underestimated (Wilson and Wolkovich, 2011).

Aside from scavenging providing a purpose of energy transfer in trophic levels for animals, vertebrate scavengers also provide distinct ecosystem services (Inger *et al*., 2016). Firstly, there is stability within food webs due to increased connectivity provided by scavengers. Secondly, this connectivity allows for a widespread distribution of nutrients and energy within and across boundaries of the ecosystem. Lastly, scavenging provides a sanitary benefit as carcass are removed from the environment (Inger *et al*., 2016). The last ecosystem service mentioned is arguably the most important to humans, as carcass which have not been scavenged on become reserves for dangerous putrefactive bacteria (Oritz and Smith, 1994) and zoonotic pathogens which can be potentially fatal to humans, livestock, and wildlife (Sterne and Wentzel. 1949; Reed and Rocke, 1992; Monroe *et al*., 2015; Inger *et al*., 2016). Examples of these fatal impacts have been observed globally. In India the decrease in vulture numbers caused by global warming, has led to the decrease in obligate scavenging (where an animal relies solely on scavenging for survival), and resulted in increased populations of feral dogs and rats (Markandya *et al*., 2008). These populations of feral dogs and rats are often infected with rabies and leptospirosis which result in an estimated £10 billion (approximately R231 billion) per year in health costs (Markandya *et al*., 2008). In 2001, in Europe, an epidemic of bovine spongiform encephalopathy led to European Union regulations forcing farmers to prevent carcass being removed by means of scavenging and to be done in a controlled manner. This resulted in increased costs incurred by the farmers, major environmental impacts and the vulture population was adversely impacted as they could no longer scavenge on bovine carcass (Margalida, *et al*., 2010; Margalida and Colomer, 2012; Morales-Reyes *et al.,* 2015; Inger *et al*., 2016).

2.2. Factors that affect scavenging

Carcasses can be scavenged by invertebrate and vertebrate scavengers, although invertebrate scavengers (such as maggots and beetles) are more likely to scavenge on the flesh of the carcass, rather than the skeletal elements (Anderson *et al*., 2019). Vertebrate scavenging (such as by small mammals) can greatly alter remains, especially human remains through disarticulation, scattering and removal of soft tissue and skeletal elements, as well as personal belongings associated with the human remains (Young *et al*., 2014). Scavenging patterns can be influenced by a variety of factors, such as the availability of food, the presence of competition, and the behaviour of the scavenger.

One major factor that can affect scavenging patterns is the availability of food. If food sources are in abundance, scavengers will have a greater chance of finding a food source and will be less likely to compete with other scavengers. In a study involving vultures in India, it was found that vulture populations did not fluctuate in areas with higher livestock densities, indicating that the availability of food sources was an important factor in determining scavenging behaviours (Kanaujia and Kushwaha, 2013). Conversely, if food sources are scarce, scavengers will have to compete for limited resources, which can lead to changes in scavenging behaviours. For example, when multiple scavengers are present in an area, they may compete for the same food sources. This can lead to changes in scavenging behaviours, as scavengers may avoid certain areas or adopt different foraging strategies to avoid this scavening competition (Kanaujia and Kushwaha, 2013).

Seasonality will largely impact the scavenging activity of species. In a study conducted by Steadman *et al*. (2018), pig, rabbit and human carcasses were placed at the Anthropology Research Facility (ARF) in Tennessee, United States of America. The carcasses were placed in similar locations, at different times of the year and footage was recorded throughout the experiment. It was found that although raccoons (*Procyon lotor*) do not typically scavenge and are classed as facultative scavengers, the seasons impacted their scavenging patterns greatly in that raccoons were observed scavenging largely in the winter and colder months. The authors explained that this could be due to the carcasses remaining fresher for longer due to the colder temperatures; limited food sources being available to nonhibernating animals and decreased vertebrate competition, resulting in greater scavenging behaviours. It was further explained that during summer and hotter months, the chemical signals released during active decomposition are stronger and more repulsive to vertebrate scavengers, leading to bacteria and arthropods being more active in decomposing the carcasses (Steadman *et al.,* 2018).

The time of day also largely impacts the scavenging activity of species. In a study conducted by Schwartz *et al.* (2018), the authors simulated a roadkill incident through defeathered chicken heads being placed near cameras in different areas around the United Kingdom. The City of Cardiff was used, and 12 sites were set up, six being residential and six being park and public settings. Throughout the experiment, seven species were observed scavenging,namely, herring gull (*Larus argentatus*), lesser black-backed gull (*Larus fuscus*), carcass crow (*Corvus corone*), Eurasian magpie (*Pica pica*), red fox (*Vulpes vulpes*), domestic dog (*Canis familiaris*) and domestic cat (*Felis catus*). The birds observed in the study were primarily observed during daylight hours, with the exception of one carcass crow scavenging in the early hours of the night in an artificially lit residential area. Whilst the other animals (domestic dogs, domestic cats, and foxes) were observed to be scavenging in either the early hours of the morning (pre-sunrise) or in the evening (post-sunset). This is due to the sleeping patterns of the animals. The animal species observed scavenging in daylight hours are diurnal and will feed during the day and sleep at night and the animals that are nocturnal, will feed during the night and sleep during the day (Schwartz *et al*., 2018).

Lastly, the habitat of the scavenger can also affect scavenging behaviours. For example, scavengers that live in more open habitats may have a greater chance of locating food sources than scavengers that live in more enclosed habitats. A study of vultures in Africa found that vultures in savanna habitats were more likely to scavenge on large mammals than vultures in forest habitats (Owen-Smith *et al*., 2020).

2.3. Different types of scavenger species

The unique behaviours and patterns of scavenging animals are dependent on their local environments, therefore understanding these scavenging patterns have significant implications on forensic investigations (O'Brien *et al.,* 2010; O' Brien *et al.,* 2016). Therefore, regional studies are essential to allow for the application of scavenger research on forensically important cases. While it is commonly believed that larger and more recognizable scavenger species, like hyenas or foxes, dominate carcass scavenging, rodents have been frequently documented engaging in indoor scavenging (Tsokos and Schulz, 1999). Additionally, various studies have reported instances of herbivores participating in scavenging activities (Caceres et al., 2011), and others have observed avian scavenging behavior (Morton and Lord, 2006).

2.3.1. Avian scavengers

Vultures and other avian species are commonly in competition with mammalian scavengers for food and nutrients from carcass. In a study conducted by Morton and Lord (2006), small pig carcasses were scattered in a suburban area near Virginia, USA. The carcasses were placed in different positions, such as above ground, buried, and hung. The carcasses were also subjected to different conditions, such as being covered or wrapped in a carpet, to replicate cases of child abduction deaths. The study aimed to describe how scavengers cause disarticulation and dispersal of skeletal elements in a specific area and how this may differ from disarticulation and dispersal by an offender (Morton and Lord, 2006). It was concluded that different scavenger species were observed at the different carcasses, at different stages of decomposition, including red foxes (*Vulpes vulpes*), racoons (*Algonquian arathkone*) and turkey vultures (*Catharses aura*). Turkey vultures were the only species noted to scavenge on the body throughout the entirety of the day, while the other species would scavenge at night. Most of the skeletal elements from the carcasses that were placed above ground (either in different positions or were hung) were scattered within a radius of 15ft (4.6m) from the original disposal site. However, one of the skeletal elements (not specified by the authors) from a carcass that was buried, was dispersed 60ft (18.3m) away from the original disposal site (Morton and Lord, 2006). The authors did not specifically mention which animals were responsible for the scattering of which skeletal elements; however, they did mention that the red foxes and the turkey vultures removed the elements from the sites. Lastly, although the authors made special mention of the different scavenging species observed and that postmortem modifications such as gnaw and beak marks were observed, the authors did not explain these modifications in further detail.

The results of the study conducted by Komar and Beattie (2015) differed from the above study by Morton and Lord (2006) as remains were scattered more extensively by different bird species, rather than primarily vultures. Pig carcasses were also used as human proxies; however, full-sized pigs (weighing 80kg) were used instead of smaller pigs. The pig carcasses were scattered in both a field and woodlot biological research station in Edmonton, Alberta City. Most pig carcasses were fully dressed in clothing, including accessories, to mimic human remains. The remaining pigs were wrapped in plastic tarps or covered in synthetic fibre blankets. The most common bird observed scavenging on the pig carcasses were magpies (*Pica pica*). Other scavenging species observed were common American crows (*Corvus brachynochos*), common ravens (*Coruvus corax*), owls (order *Strigiformes*), coyotes, domestic dogs, deer mice (*Peromyscus maniculants*) and Red-Backed mice (*Clethrionomys gapperi*). Previous studies have concluded that birds act as important agents of transport and can hinder forensic investigations as they remove small elements from the carcass, such as hair or personal belongings, to utilize as materials for their nests (Haynes, 1983). This study also demonstrated that birds could transport larger elements from carcasses such as bones, particularly ribs and fragmented skeletal elements as well as clothing. Upon examination of the different magpie nests, there was an earring and rib bones taken from the carcass and placed in a nest that was located about 600m away from the disposal site. Furthermore, the formidable wingspan of a magpie and crow can produce sufficient air displacement during take-offs and landing to scatter skeletal elements up to a meter from a skeletonized carcass, which leads to the disruption of a crime scene and can lead to misinterpretations of the scene in a forensic investigation (Komar and Beattie, 2015).

In a study conducted by Keyes *et al*. (2021a), pig carcasses were used to examine animal scavenging in Lowveld areas in South Africa. The pig carcasses were deployed during different seasons and in different locations, such as under trees and the open veld (open grassland). For the study duration, a number of scavengers were observed around the carcasses, including the white-backed vulture (*Gyps africanus*), hooded vulture (*Necrosyrtes monachus*), lappet-faced vulture (*Torgos tracheliotos*), marabou stork (*Leptoptilos crumenifer*), common large-spotted genet (*Genetta tigrina*), African civet (*Civettictis civetta*), slender mongoose (*Galerella sanguinea),* banded mongoose (*Mungos mungo*), common warthog (*Phacochoerus africanus*), and honey badger (*Mellivora capensis*). The vultures were the most abundant scavengers observed in the Lowveld and were an important part in the skeletonization of the carcasses (Keyes *et al*., 2021a). The vultures skeletonized the pig carcasses in winter months between 20 and 98 minutes after the arrival of the first vulture, and in the summer the carcasses were skeletonized between 5 and 26 minutes after first arrival (Keyes *et al*., 2021a). Furthermore, scattering was a common behaviour observed by the vultures. The vultures initiated scattering, after which the skeletal elements were further scattered by other scavenging species (Keyes *et al*., 2021a). Very few marks were observed on the bones after scavenging by the vultures and the markings that did remain were superficial scores on the flat surfaces of the cranium, mandible, scapulae, and long bones (Keyes *et al*., 2021a). The transverse processes of the vertebrae displayed markings, as these processes were often removed, whilst a single carcass displayed large superficial pits on the humerus (Keyes *et al*., 2021a).

2.3.2. Herbivore scavenging

Taphonomic modifications observed on skeletal elements are most often associated with scavenging on the flesh of carcasses by carnivores and omnivores. However, a phenomenon known as osteophagia (scavenging of bones) has been observed in herbivores (Caceres *et al*., 2011). It was initially concluded that herbivorous animals used to scavenge on skeletal elements to replenish depleted calcium deficiencies that were related to the production of antlers in males and gestation periods in females in environments that were nutrient deficient (Fish, 1950). On the contrary, later studies, such as that conducted by Barrette (1985), suggested that this behaviour in herbivores is due to a deficiency in phosphorus and, to an extent a deficiency in sodium. He suggests that these compensations are due to the closely linked metabolism of phosphorus and calcium and as such, osteophagia is linked to maintaining the balance between these two minerals. Furthermore, a study conducted by Grasman and Hellgren (1993) highlighted the importance of the deficient substrate and the environment in which different species and populations live. In their study, different osteophagic behaviours were observed in various species of Cervidae (such as *Cervus elaphus* and *Dama dama*), accentuating the fact that dry environments lead to animals lacking phosphorus and calcium, and arctic tundra environments lead to deficiencies in calcium and sodium. This led to the assumption that osteophagia is more closely linked to nutritional deficiencies rather than antler reproduction and gestation periods (Grasman and Hellgren, 1993). Conversely, Mitchell *et al*. (2005) suggested that the most periodic practices of osteophagia occur during the gestation periods and after birth in female giraffes, and the periods synchronize with the time when environments are nutritionally sparse.

Modifications on skeletal elements caused by osteophagia was first published by Sutcliffe (1973; 1977), Brothwell (1976) and Johnson (1985). Forked bone morphology was traditionally understood to be related to osteophagia; however, in a study conducted by Caceres *et al*., (2011), it was further found that similar modifications can be caused by carnivorous scavengers, however, unique characteristics were observed. As herbivores do not hunt prey, the skeletal elements that are scavenged by herbivores are most often long bones that can easily be held in the mouth. This leads to the most frequently scavenged skeletal elements being metapodials, tibiae and radii, which are elements with a rectangular cross-section (Caceres *et al*., 2011). The authors of the study concluded that herbivores do not scavenge on fresh carcasses and will scavenge on bones that are cracked and weathered due to sub-aerial exposure. Due to the nature of the bones that herbivores choose to scavenge on, the unique forked morphology arises as they do not break bones or produce depressions or puncture marks on the bone (Caceres *et al*., 2011).

2.3.3. Domestic scavenging

A particular taphonomic variable that affects the scavenging patterns of an animal is the environment in which the carcass is undergoing decomposition. The main comparison is between an indoor and outdoor environment and although both have been researched, outdoor scavenging and taphonomic modifications are more frequently studied. The animals most commonly associated with indoor scavenging are rodents, such as rats and mice; however, cases have been noted of domestic animal scavenging. Furthermore, studies have shown that the reasons domestic animals scavenge on human corpses is either due to hunger and limited food availability or frantic behavioural patterns (Rothschild and Schneider, 1997; Tsokos and Schulz, 1999; Chute and Bready 2017). Due to the appearance of scavenging by domestic animals, natural or self-inflicted (such as suicide) deaths at home can often be mistaken for homicides, leading to misinterpretation by forensic investigators (Rothschild and Schneider, 1997).

In a case study reported by Chute and Bready (2017), a 63-year-old woman who had been deceased for several weeks and had begun to decompose, was found in her unlocked home. No signs of blood or blood splatter were present around the body; however, the deceased was found with amputations at the level of each elbow joint and irregular defects were found on her face and head. Upon further examination, two open dog cages were found, as well as faecal matter and two pit bull terriers. It was not stated whether the faecal matter at the scene was collected and tested; however, the medical examiner that worked on this case asked for the faecal matter of the dogs to be collected for several weeks after the incident. The faecal matter that was collected was radiographed and sifted and the following was found; six teeth (all belonging to the deceased), two fragments of an enamel surface of a tooth, 10 fingernails, and three earrings. Once all the examinations had been completed, the cause of death was attributed to chronic alcoholism and chronic obstructive pulmonary disease and the postmortem modifications observed on the body were due to scavenging by the pit bull terriers (Chute and Bready, 2017). Due to the long period of time between death of the victim and the body being found, the availability of food for the dogs had been depleted and scavenging on the decomposing corpse became the only food source available.

Tsokos and Schulz (1999) reported on a case study of a 40-year-old woman who was found dead in her apartment. When her body was discovered at the scene, her neck and face were almost completely skeletonized and there was minimal blood present at the scene. The apartment showed no signs of a struggle and was secure, indicating that she was not a victim of homicide (Tsokos and Shulz, 1999). At autopsy, it was concluded that the woman had died of natural causes and the external wounds were due to scavenging by the pit bull terrier that was found in the apartment at time of death, which had been estimated to one day earlier (Tsokos and Schulz, 1999). Although many cases of domestic scavenging are attributed to depleted food sources, this case had evidence of domestic scavenging due to social isolation from the deceased and the sudden cause of death (Rossi *et al*., 1994; Tsokos and Schulz, 1999).

Behaviour similar to that mentioned above was observed in another case report by Rothschild and Schneider (1997), except the deceased in question had not died of natural causes, but by suicide due to a self-inflicted gunshot wound to the head. The 31-year-old male, who lived with his mother, was found 45 minutes after he had shot himself. Upon discovery of the body, aside from the region located posterior to the exit wound, a small amount of blood was found around the body but large areas of skin and subcutaneous fatty tissue from the face and neck were missing (Rothschild and Schneider, 1997). At autopsy, the cause of death was attributed to a self-inflicted gunshot wound through the mouth and the postmortem modifications were caused by the Alsatian discovered at the scene. Further veterinarian examinations were conducted on the animal and even though the exact details of the examinations were not disclosed, it was concluded that the animal was well looked after, fed well, and did not show signs of behavioural disturbances; however, the scavenging on the body occurred within less than 45 minutes after the time of death. The authors concluded that the cause for the dog's mutilation of the owner was psychological and may have occurred due to the dog trying to wake up their owner and getting more aggressive and frantic, leading to the dog biting the owner in a state of panic (Rothschild and Schneider, 1997).

2.4. Globally relevant scavengers of forensic interest

The role of scavenging animals in forensic investigations can be important as they can provide valuable information about the timing and circumstances of death. Globally, several species of scavengers have been identified as being of forensic interest due to their ability to locate and consume human remains.

In Europe, a scavenger of forensic interest is the red fox (*Vulpes vulpes*). Studies have shown that red foxes are attracted to human remains and are capable of scavenging on both soft tissue and bones (Young *et al.,* 2015). In a study conducted by Young *et al*. (2015), red foxes were observed scavenging on human remains within 24 hours of death.

In North and South America, the American black bear (*Ursus americanus*) is considered a scavenger of forensic interest. Similar to the red foxes in Europe, studies have shown that black bears are attracted to human remains and are capable of consuming both soft tissue and bones (Moraitis and Spiliopulou, 2010). In one study, black bears were observed scavenging on human remains within 72 hours of death (Moraitis and Spiliopulou, 2010).

In Asia, a scavenger of forensic interest is the Asiatic jackal (*Canis aureus*). In one study, Asiatic jackals were observed scavenging on human remains within 48 hours of death (Young, 2015).

This quick consumption of remains can make it difficult for forensic investigators to determine the time of death, but the presence of red foxes, black bears and Asiatic jackals at a crime scene can indicate that the individual has been deceased for a relatively short period of time.

2.4.1. Scavengers of forensic interest in southern Africa

In 2018, Spies *et al*. (2018) described the patterns and behaviours of scavengers in Cape Town. The research was conducted at the South African Medical Research Council's secure research facility in Delft, Cape Town, South Africa, which was chosen due to the high murder rate in the surrounding area, which often results in bodies being recovered from this environment which has a specific vegetation subtype (Spies *et al*., 2018). The researchers utilised pig carcasses as human proxies. The only species observed to scavenge on the experimental pig carcasses was the Cape grey mongoose (*Galerella pulverulenta*), which was observed primarily in daylight hours (Spies *et al.,* 2018). Upon initial arrival to the carcass, the mongoose species attempted to find or scratch an opening through the skin. The first feeding was recorded near the anal area which led to the rapid exposure of the femora (Spies *et al*., 2018). The mongoose species was observed mainly in the early decomposition stages and decreased in the later stages of decomposition, except in rainy conditions when the dehydrated flesh was rehydrated and allowed for an increased food source. The authors did not mention the postmortem modifications which were observed on the skeletal elements. The study highlighted the lack of scavenger research in South Africa.

The animals in this study were of forensic interest as they are commonly found in these areas and would likely scavenge on human remains leading to misinterpretations in forensic investigations. Therefore, the understanding of their scavenging patterns could be utilized to differentiate between animal modification caused postmortem and human modification caused peri-or postmortem.

Keyes *et al*. (2021b), also explored the scavenging patterns in a Highveld peri-urban agricultural environment in South Africa. The experiment was conducted at the Miertjie Le Roux Experimental Farm, Pretoria, South Africa, and was chosen as it represents a typical agricultural environment in the Highveld of South Africa. The study utilized pig carcasses, which weighed between 40 and 80kg, as human proxies for small to medium-sized humans and were placed at different times of the year to examine how seasonality affects scavenging in South Africa. The researchers found that several animals including black-backed jackals (*Canis mesomelas*), slender mongoose (*Galerella sanguinea*), water mongoose (*Atilax paludompsusis*), Cape porcupines (*Hystrix africseaustralius*) and honey badgers (*Mellivora Capensis*) actively scavenged on the pig carcasses. Other animals including the yellow mongoose (*Cynictis penicillata*) and the serval (*Leptailurus serval*) were attracted to the carcasses, but they did not actively scavenge on them (Keyes *et al*., 2021b). The patterns of scavenging and the effects of seasons were discussed along with postmortem modifications on the bones and found that minimal damage was caused by black-backed jackals. The slender mongoose species produced jagged marks on the mandible and gnaw marks on the vertebral spinous process. The Cape porcupine produced gnaw marks on long bones and destroyed the ends of the tibia (Keyes *et al*., 2021b).

In another study by Keyes et al. (2019), species that were commonly known to exhibit scavenging behaviours in South Africa including wild dog (*Lycan pictus*), black-backed jackal (*Canis mesomelas*), caracal (*Caracal caracal*) and porcupine (*Hystrix africaeaustralis*)as well as uncommonly observed scavengers such as lion (*Panthera leo*), the spotted hyena (*Crocuta crocuta*) and the leopard (*Panthera pardus*) were studied to describe their specific postmortem modifications on bone. Although the lion, leopard and spotted hyena are not commonly found in the wild, they are still of forensic interest due to their modifications inflicted on skeletal elements. The study was conducted at the National Zoological Gardens of South Africa in Pretoria. Bovine bones were placed in the different animal enclosures and collected after two days. The felids (lions, leopard, and caracals) gnawed away at the greater tubercle of the humerus, which created deep, parallel furrows on the bone. The hyena caused massive destruction to the bone, as only one-third of the tibia shaft remained and possessed jagged fracture ends. Wild dogs and jackals did not leave any distinctive postmortem modifications on the bones. It was concluded that if the scavenging modifications on the bones are caused by light scavenging patterns, the species cannot be identified; however, if the scavenging pattern is more distinct, then the general type of perpetrating animal can be determined (Keyes et al., 2019).

2.5. Postmortem modifications on skeletal elements caused by scavengers

The postmortem modifications of skeletal elements, and the extent of the damage to the bone produced by scavengers, depends on the strength of the bone, the jaw mechanics and tooth morphology of the scavenging animal (Calce and Rogers, 2007). There are four categories that are often used to describe the postmortem modification of bones caused by animal bite marks. These are pits, furrows, punctures, and scores (Haglund *et al*., 1988; Young *et al*., 2015; Keyes *et al*., 2019).

Pits have been described as indentations in the surface of the bones which are made by individual tooth cusps that do not penetrate the cortex of the bone (Haglund *et al*., 1988; Young *et al*., 2015). Furrows have been described as longitudinal marks that penetrate the cortical bone into the trabecular bone, commonly located at the diaphysis of the bones, created by the cusps of a scavenger’s teeth whilst gnawing. This location has been shown to be more often preferred as animals who scavenge on the bones are attempting to access the marrow in the bones. Punctures often possess an irregular shape and are caused when the cortical bone is penetrated by a tooth. Canine and carnassial teeth can puncture a bone, even though they are often used to shear the soft tissue of an animal (Haglund *et al*., 1988; Young *et al*., 2015). Scores are described as any mark on the cortical bone, which has a length that is three times larger than the breadth, thus differentiating them from pits (Young *et al*., 2015).

Claw marks often result in the above postmortem modifications, and they are often found in concurrence with bite marks. Claw marks are formed as the animal attempts to hold or grab the bone while scavenging on the carcass (Calce and Rogers, 2007). Although claw marks create scores on the surface of the bone, they can be differentiated from bite marks as they are thinner than scores created by bite marks and often occur in parallel lines. It is of great importance that forensic anthropologists can identify and differentiate postmortem modifications caused by scavenging animals from trauma to bones caused by tools or other sharp force perimortem trauma. This will aid forensic experts in identifying if sharp force or blunt force trauma was inflicted to someone leading to an unnatural death and warranting a further investigation, or if someone died from natural causes and scavenging occurred.

Bite marks are fundamentally thought to be the most common postmortem modifications on skeletal elements as they are caused by scavengers that opportunistically use a corpse as a food source (Byrnes and Belcher, 2021). Past research often refers to the postmortem modifications in terms of the bite marks and bite patterns and isolating these to a specific species to aid in forensic investigations and skeletal recovery (Calce and Rogers, 2007; Byrnes and Belcher, 2021).

If the score observed is wide, it is most likely to have been caused by the tooth cusp, due to the width of the tooth cusp (Calce and Rogers, 2007; Byrnes and Belcher, 2021; Keyes *et al*., 2021a). If the score is extremely thin in width, it is most likely caused by the claw of an animal as the cusp of the tooth is too wide to produce fine, narrow scores (Calce and Rogers, 2007; Keyes *et al*., 2021a). For example, both tooth and hoof scores mentioned above were observed from the warthog sample, but the width dictates whether it was caused by the tooth or claw/hoof of the animal. Although the width of the score can be used to distinguish between teeth or claw marks, it is more difficult to distinguish between the scores made by the claw of animal whilst scavenging and scores induced by other sharp force trauma, such as a scalpel during the maceration of the remains for anthropological analysis (Keyes *et al*., 2021a).

2.5.3. Body region preferences of scavengers

Research has shown that scavengers display preferences for certain regions of the body when feeding on carcass. A study conducted by Gittleman (1986) found that the head and neck region of ungulate carcasses were preferentially selected by scavengers in a Kenyan savannah ecosystem. This preference was attributed to the relatively high density of muscle and connective tissue in these areas, which provide a higher caloric return for the scavengers. This study further found that the head and neck region of the carcasses were typically the first to be scavenged, and that the scavenging activity in these areas was concentrated within the first few days after the death of the animal. This suggests that scavengers may be able to locate and target these high-value body regions quickly and efficiently, in order to maximize their energy intake (Gittleman, 1986).

In another study by Kendall *et al*. (2012), the authors observed scavenging behaviour on ungulate carcasses in the Serengeti ecosystem of Tanzania. This research found that vultures preferentially fed on the hindquarters of the carcasses, while hyenas targeted the shoulders and ribs. It was suggested that these preferences may be related to the relative ease of accessing these body regions (Kendall *et al.,* 2012), as the hindquarters are typically more exposed, and the shoulders and ribs are often exposed after the hide and flesh have been removed by other scavengers. Furthermore, the study also found that the presence of large carnivores, such as lions, had an impact on scavenging behaviour (Kendall *et al*., 2012) as this led to competition between the species, leading to a decrease in scavenging behaviours by the vultures and hyenas.

The study mentioned above provides valuable insights into the scavenging behaviour of vultures and hyenas in the Serengeti ecosystem and highlights the importance of considering the relative ease of accessing different body regions in understanding scavenging preferences. It also suggests that the behaviour of scavengers is influenced by both the caloric returns and ease of access in selecting a specific body part of the carcass (Kendall *et al*., 2012). Furthermore, the study demonstrated that the order of scavenging on the carcass can vary between species, with vultures focusing on high-return areas and hyenas starting with the most easily accessible parts of the carcass.

Pereira *et al.* (2013) investigated the body region preference of scavengers in the forensic context. The study was conducted in a controlled environment using pig carcasses as proxies for human remains. The researchers found that the head, thorax, and abdominal regions were preferentially targeted by the scavengers, with the head being the most heavily scavenged. The authors suggest that this preference may be related to the higher densities of soft tissue, such as the eyes and the tongue, in these regions. The study found that the scavengers were able to access the soft tissue in the head region more easily due to the presence of natural openings such as the mouth and nose. The researchers also observed that the scavengers targeted the thorax and abdominal regions due to the presence of organs such as the lungs and liver which are rich in nutrients. Furthermore, it was found that the scavengers targeted the limbs of the carcasses less frequently, which the authors suggest may be due to the relative difficulty in accessing the soft tissue in these regions. Additionally, the researchers observed that the scavengers were able to remove the soft tissue from the carcasses in a relatively short period of time, with most of the soft tissue removed within 24 hours of exposure.

The findings of this study have important implications for forensic investigations, as the patterns of scavenging observed in the study can aid in the identification of scavenging activity on human remains (Pereira *et al*., 2013). By understanding the preferences of scavengers for specific body regions, forensic investigators can more accurately identify postmortem trauma caused by scavenging activity and differentiate it from perimortem trauma caused by other factors.

2.6. Implication of scavengers on forensic investigations

An important aspect of forensic investigations is the examination of human remains and the crime scene (Ubelaker and DeGaglia, 2020). Scavenging can have a significant impact on these investigations, as the act of scavenging can alter and destroy important evidence. The presence of scavengers at a crime scene can lead to the destruction of important physical evidence, such as bones, teeth, and hair (Haglund and Sorg, 1996), making it difficult for forensic scientists to determine the cause and manner of death. Scavenging can also lead to the scattering and displacement of remains, making it difficult to determine the original location of a body. Additionally, scavenging can make it difficult to determine the time of death (Ubelaker and DeGaglia, 2020), as the presence of scavenged remains can make it appear that the remains have been at the location for longer than they actually have been. The authors of the current study focussed on isolating the postmortem modification caused by animals commonly found in a peri-urban environment as peri-urban environments encompass a great part of the catchment area of the Gauteng FPS facilities (Keyes *et al*., 2021b). Therefore, isolating some of the commonly found animals may assist forensic investigations in the following manner:

In order to mitigate the impact of scavenging on forensic investigations, it is important for forensic scientists to carefully document and examine the animal modifications found at a crime scene (Ubelaker and DeGaglia, 2020). This can include identifying the species of scavengers present, determining the extent of scavenging, and analysing the remains to assess the time of death. Furthermore, in order to identify these scavenger species, it needs to be understood when scavenger species preferentially scavenge, what they preferentially scavenge on, the postmortem modification inflicted by scavenging species and the intensity of postmortem modification caused.

2.7. Aims and objectives

The aim of the study was to describe the nature of postmortem modifications of skeletal elements caused by common small scavenging animals found in peri-urban environments in Southern Africa.

The objectives of the study were as follows:

1. To describe the type of postmortem modifications caused by different scavenging animals on the skeletal elements (focussing on pits, furrows, punctures, and scores).
2. To describe the location of postmortem modifications caused by scavenging animals on different skeletal elements.
3. To describe the characteristics of the postmortem modifications caused by different scavenging animals on the different skeletal elements (focussing on depth, breadth, length, and shape).
4. To develop a system to score the intensity of postmortem modifications found on the skeletal elements.

This study is advantageous to the forensic anthropology and forensic pathology fields as the postmortem modifications on the skeletal elements can be used to identify their taphonomic alterations during forensic anthropological analysis.

Chapter 3: Materials and Methods

3.1. Study design

This was a prospective, observational study. The prospective nature of the study implies that the data collected for the study was completed in real-time, indicating that no follow-ups need to be completed to obtain the final results (Ranganathan and Aggarwal, 2018). The observational nature of the study implies that the results that were obtained were naturally, and the results from the study were descriptive and nonanalytical (Ranganathan and Aggarwal, 2018). The study design was chosen to allow for the scavenging patterns of the selected study species to be isolated per species without external intervention from the authors.

3.2 Sample

3.2.1. Study Material

The sample for this study included bovine skeletal elements which were fed to various scavenging animals found in a captive setting. A captive setting was utilized to allow for the animals used to scavenge on the skeletal elements without inter-species competition. This allowed the authors to isolate the taphonomic changes to individual species. Bovine skeletal elements were particularly selected as this was the usual food source for the animals at the National Zoological Gardens of South Africa. All bovine bones were purchased from a local licenced butcher and no bones with any signs of abnormalities or pathologies were used in the study. The skeletal elements that were used included the cervical and thoracic vertebrae, the pelvic bone (including the ilium and ischium), long bones (which included either a humerus and radius and ulna or a femur and tibia and fibula, as well as the carpals and patella), rib bones and a scapula (Figure 1). Vertebrae and the pelvis were selected for this study, as scavenging patterns on the axial skeleton is scarce and the specific scavenging patterns on these skeletal elements caused by the scavengers selected, had not yet been studied in a captive environment.

Figure 1. Placement of samples and set up of cameras in the suricate enclosure

3.2.2. Study Species:

The species of scavengers that were selected for this study included genets (*Genetta genetta*) (Figure 2a), servals (*Leptailurus serval*) (Figure 2b), warthog (*Phocohoerus africanus*) (Figure 2c), and suricates (*Suricata suricatta*) (Figure 2d). Genets are found throughout Southern Africa, across a variety of habitats with denser vegetation, which includes forests, woodlands, farmlands, and savannas (Widdows and Downs, 2017). Servals are also dispersed throughout southern Africa and are common in areas with lots of water, such as savannas and forests (Ramesh *et al*., 2015). Warthogs are found in moist areas and avoid dry areas, such as savannas (Hale *et al*., 2018). Suricates are spread throughout southern Africa, although they prefer arid and dry areas, such as the deserts in Botswana and the Karoo in the Western Cape (Doolan and Macdonald, 1996). They have also been found in more densely vegetated areas in Gauteng. Therefore, these species were selected as they are all commonly found in regions of dense vegetation, which relates to the peri-urban environment found in southern Africa where forensic cases are often found (Doolan and Macdonald, 1996; Ramesh *et al*., 2015; Widdows and Downs, 2017; Hale *et al*., 2018).Although studies have shown their behavioural patterns in the wild towards skeletal elements (Keyes *et al*., 2021b), the current study described the postmortem modifications caused by each scavenger without inter-species competitions while in captivity, as well as assisted in comparing the behavioural patterns of warthog, genet and serval to the field study conducted by Keyes *et al.* (2021b) pertaining to free roaming animals.

Figure 2. The animal species used in the study: **A**. genets (*Genetta genetta*), **B**. servals (*Leptailurus serval*), **C**. warthog (*Phacochoerus africanus*) and **D**. suricates (*Suricata suricatta*)

3.3 Site of study

This study was conducted at the National Zoological Gardens (NZG) in Pretoria, South Africa (232 Boom St, Daspoort 319-Jr, Pretoria, 0001). This specific site was chosen because it houses approximately 9087 animals of about 705 different species, which allowed for a variety of animals to be observed in captivity.

The maceration and analysis of the skeletal elements after scavenging was conducted at the Johannesburg Forensic Pathology Service (FPS) (25 Hospital St, Braamfontein, Johannesburg, 2000).

3.4 Methods

3.4.1. Materials and data collection

After purchasing the fresh, sparsely fleshed and disarticulated bovine bones, as described above (section 3.3.1), the bones were placed in double lined, thick black garbage bags. This was done to allow for easier and more sterile transportation of the bones from the butcher to the NZG. Each enclosure received the same number and the types of bones, which allowed the results to be comparable between the different species chosen. The bones were also placed with some distance between them, to reduce intra-species competition within enclosures that contained more than one animal (all except the warthog enclosure). This same process was followed in each enclosure. In Figure 1, the camera view and placement of bones in each enclosure is exemplified. Once the cameras (Figure 3) and bones had been placed in each enclosure, they remained in the enclosures for a week. Animal handlers had been asked to collect the scat for the different species each week and had been provided with clear zip lock bags, which had been labelled with the name of the species and dates for each day of the week, starting from the day after placement of the bones. After a week, the bones originally placed in the enclosures were collected and placed into new labelled double lined black bags and then placed into FPS body bags. The bones were transported and stored this way to contain any insects and maggots still on the bones to inside the bag. The collected bones were then deposited at the Johannesburg FPS, for maceration. The experiment was triplicated for replicability and to allow for statistical comparison to be made. New bones were deployed after the previous week's bones had been collected, using the same procedure as above.

After the collections, the bones were macerated (removal of soft tissue) by placing the bones in a 60L skeletal boiling pot with OMO washing powder (ratio of 1 cup OMO per 5L water), which was kept a constant temperature of 60˚C for 24 hours. Any soft tissue which remained on the bones was manually removed using forceps, brushes, scalpels, and scissors, being careful not to damage the bone or introduce new bone modifications.

The different types of postmortem modifications were described (focussing on; pits, furrows, puncture, and scores; in accordance with the definitions provided above (page 14)), as well as if the modifications were made by a tooth or claw, differentiation is described above (page 18). The skeletal elements were divided into different locations, these locations are specified on Tables 2, 3, 4 and 5 (Objective 2), and the same locations were utilized in Tables 6, 7, 8 and 9 (Objective 4). Tables 2-9 were mentioned before table 1, as Table 1 is presented before Tables 2-9 in the current research, however Table 1 is utilized for Objective 4 and is therefore discussed last in the current section. The characteristics of the postmortem modifications were described as follows; depth was noted as deep, shallow, or varying; breadth was noted as wide, narrow, or varying; length was noted as short, long or varying and shape was noted as linear, curved, fan-like or varying. When the term varying was noted, a combination of the characteristics was noted. Due to quantitative measurements not being noted, the above characteristics were noted according to the discretion of the author, utilizing knowledge from previous studies, such as one by Keyes *et al.,* 2019. Furthermore, specific measurements were not taken as previous studies have suggested that although the size of the tooth marks present can assist in determining the general size of the scavenger, it cannot be utilized to accurately identify the particular taxon of the scavenger (Coard, 2007). The current study only looked at small scavenger species, and therefore there was no value in measuring the size of the tooth marks. Photographs (using a Nikon D3300) were taken of the different postmortem modifications observed. For summary purposes, only the skeletal elements that displayed postmortem modifications due to scavenging were included in Tables 2-5. Skeletal elements that displayed no modifications were noted in the results section.

Broad descriptions of the intensity of bone modifications caused by scavenging were grouped to create a scoring system. The scores defined the different levels of intensity for the modifications made by the scavengers (i.e., mild, moderate, and severe). This criterion allowed the quantification of the severity of scavenging on the bone (Table 1). The intensity scoring criteria was based off the criteria used by Keyes *et al.* (2019) and was modified to be numerical and accounted for different locations on a skeletal element that ultimately assign a final intensity score to the overall bone.

Scoring criteria was used to score the intensity of each skeletal elements for each scavenging species. The average was calculated for the three weeks for different locations of the skeletal elements and was reported as a mean frequency for all three weeks, the averages of the different skeletal elements were then summarized as a score range from least intense to the most intense for that skeletal element (0.00 – 3.00). This score range can provide an indication of the intensity of modification inflicted on any skeletal element.

The authors studied 140 locations per week, leading to a total of 420 locations observed. Then an independent rater scored a subset of the sample (week two samples) to test the interobserver error of the scoring system. The independent rater looked at a total number of 140 locations. The independent rater observed 33.33% of the total sample locations.

Figure 3. Author is setting up the camera and locking the cage to the fence

Table 1. Description of postmortem modification intensity for the scoring system.

Intensity score (0-3)	Description of intensity
0	Indicating that there was no damage/ modification observed on the bone
1	Indicating that there were minor or insignificant modifications caused to the bones (i.e. superficial pits and scores)
2	Indicating that moderate modifications and noticeable alterations to the morphology of the bone (i.e. exposure of trabecular bone by furrowing, gnawing, etc., without deleting of >50% of the bone)
3	Indicating that there were severe modifications to the bones and the morphology of the bone was destroyed (i.e., deletion of the epiphysis and/ or any portion of the shaft of long bones or >50% of all bones)

3.4.2. Data Analysis

Chi-square tests were conducted to test for an association between firstly, the animal species and the skeletal element they scavenged on and the animal species and the location on the skeletal element they scavenged on. The skeletal elements that were not scavenged on at all throughout the three replicates were excluded from the chi-square test to avoid undefined results. The null hypothesis was that there is no association between the animal species that is scavenging and the skeletal element or location on the skeletal element. The alternative hypothesis was that there is an association between the animal species that is scavenging and the skeletal element or location on the skeletal element. If the latter hypothesis is true, it can be concluded that the animal species in the current study do have a preference for a specific skeletal element and the location on the skeletal element to scavenge on.

Cohen's Kappa coefficient was determined using the statistical programme R and was used to test for observer error and reliability. A significance level of 0.05 was used. The coefficient calculated determined whether the scoring criteria displayed no agreement (0.00), slight agreement (0.01-020), fair agreement (0.21-0.40), moderate agreement (0.41-0.60), substantial agreement (0.61-0.80), almost perfect agreement (0.81-0.99) and perfect agreement (1.00) (McHugh, 2012). A Cohen's Kappa of 0.61 and higher will indicate that the results obtained from the current experiment were reliable (McHugh, 2012).

3.5. Ethics

Ethics approval for this study was granted by the following agencies:

- Animal Research Ethics Committee from the University of Witwatersrand (Waiver 02-03-2021-O)
- Dr MD Nemudzivhadi, chief veterinarian (Appendix A) at the Department of Agriculture, Forestry and Fisheries, furthermore Section 20 permit for the Animal Diseases Act 1984 (Act no 35 of 1984) (Appendix B)
- SANBI approval (SANBI/RES/P/2021/13) (Appendix C)

Chapter 4: Results

4.1. Reliability and repeatability of the experiment

In the current study, Cohen's Kappa coefficient was used to test for observer error and reliability of the results. The coefficient was calculated as 0.68. According to the above, 0.61-0.80 is a substantial agreement between the author and independent rater. This indicates that the results obtained in the current study are reliable.

4.2. Types of postmortem modifications

In the current study, pits, scores, and furrows were the postmortem modifications observed across the animal species studied. Punctures were not observed. Of the total 95 skeletal locations that exhibited postmortem modifications (Tables 2-5), 87.4% were scores, 6.3% were furrows, 4.2% were a combination of pits and scores and 2.1% were a combination of furrows and scores.

4.2.1. Types of postmortem modifications caused by genets

Genets displayed the least variable types of postmortem modifications and 100.0% of the modifications observed were scores (Figure 4 and Table 2). A total of 23 skeletal locations exhibited postmortem modifications that were caused by genets. This indicates that the scavenging behaviours of genets will lead to scores being created on the skeletal elements on which they scavenge on.

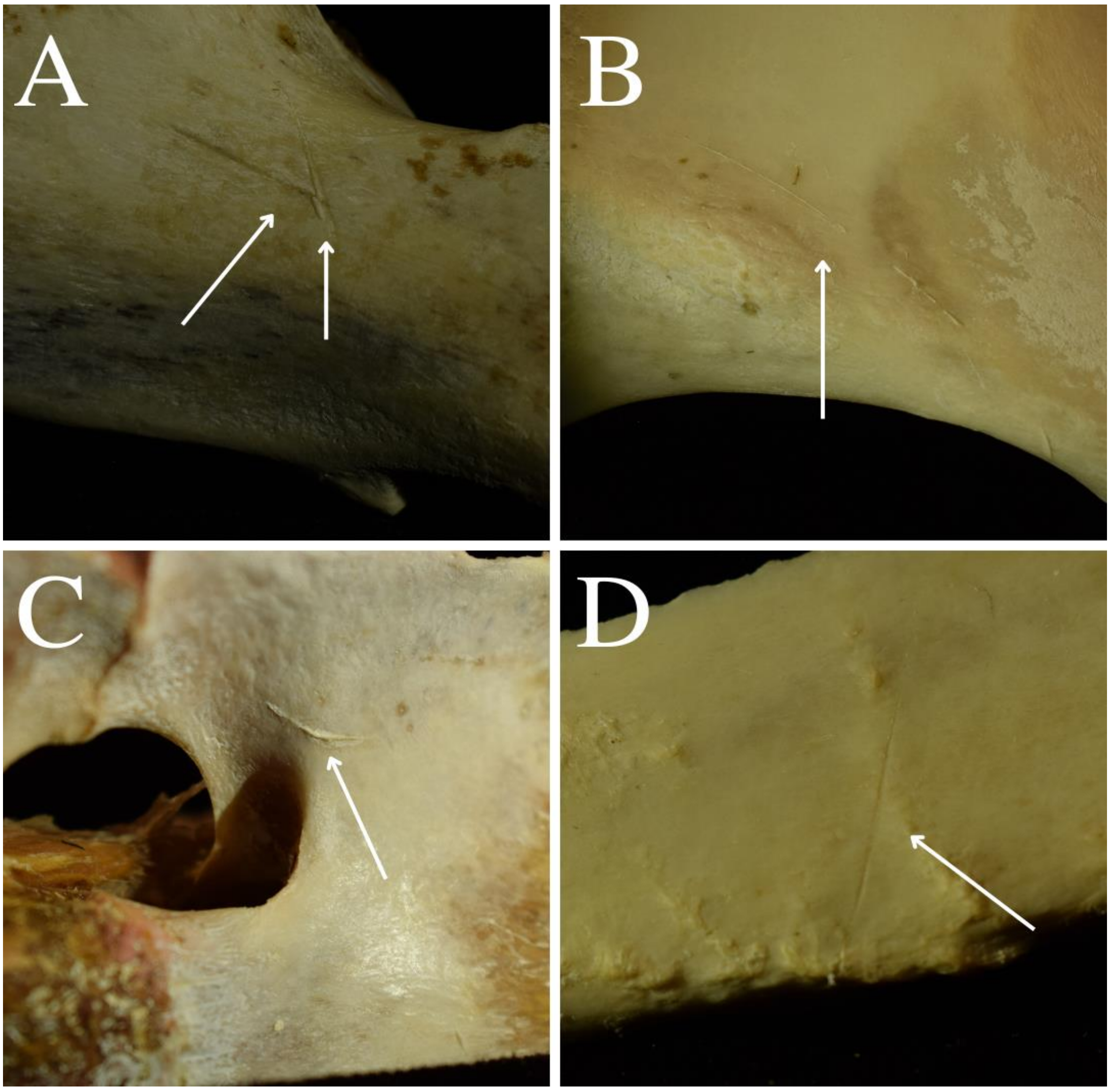

Figure 4. Postmortem modifications caused by genets: (A) multiple deep linear scores on the ilium of the pelvic bone, (B) a single long superficial score on the ilium of the pelvic bone, (C) a short, deep score on the sacrum of the pelvic bone with a slight curve in shape, (D) and a long superficial score on the spinous process of a thoracic vertebra

4.2.2. Types of postmortem modifications caused by servals

Servals displayed the most variable types of postmortem modifications, including pits, furrows, and scores (Figure 5 and Table 2). A total of 25 skeletal elements exhibited postmortem modifications that were caused by servals. The most common type of postmortem modification observed was scores. Of the 25 modifications observed on the different skeletal locations, 84.0% were scores, 8.0% were furrows, and a combination of pits and scores, and furrows and scores constituted 4.0% each. The skeletal element locations where furrows were observed were due to gnawing by the servals. The postmortem modification observed in Figure 5D was described as a result of gnawing and led to a minor deletion resulting in frayed edges being present on the spinous process of the thoracic vertebra.

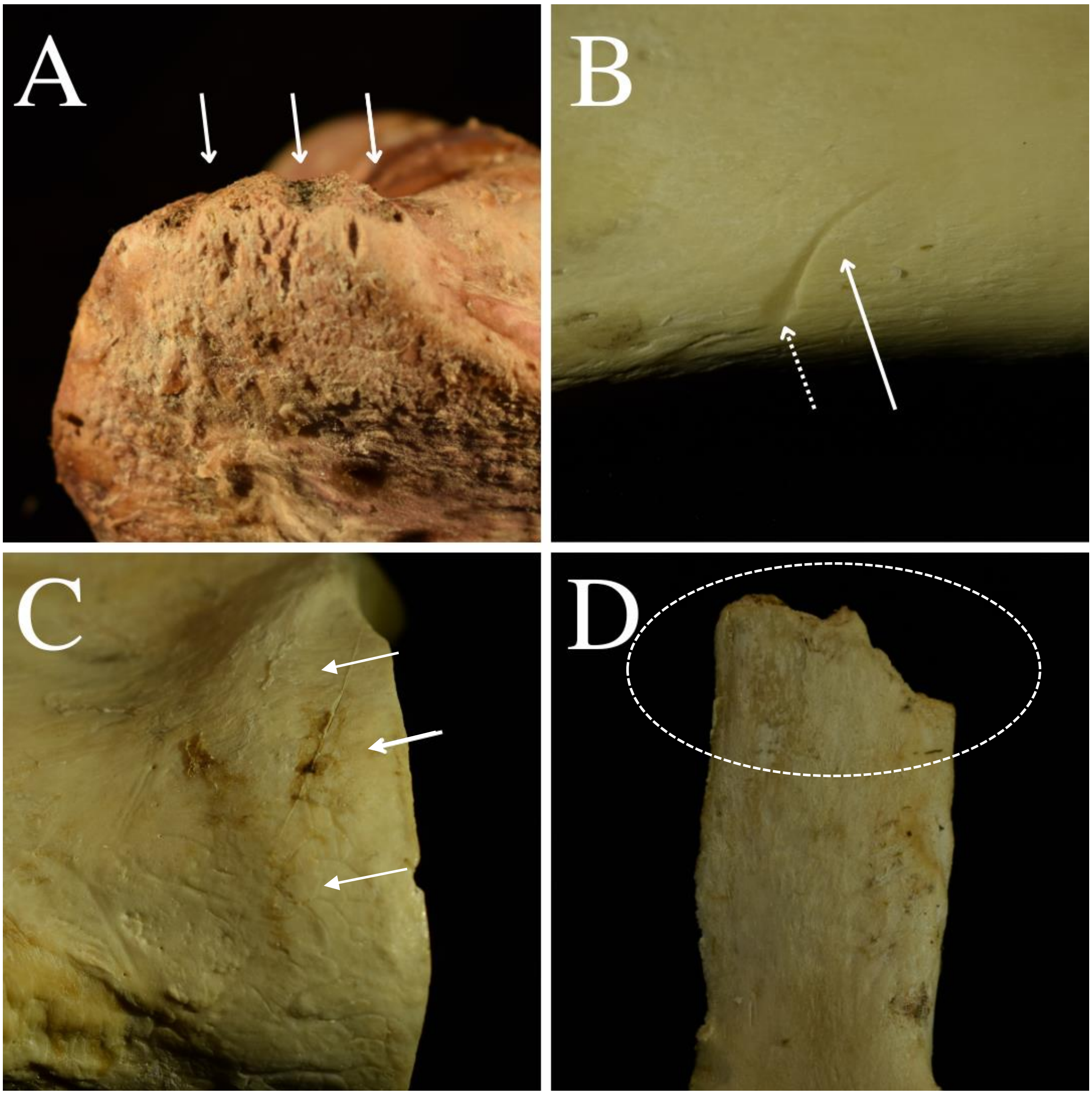

Figure 5. Postmortem modifications caused by servals; (A) gnawing with distinct furrows (solid white arrows) on the femoral proximal epiphysis, (B) a pit (dotted arrow) and a score (solid arrow) on the shaft epiphysis of the femur, (C) multiple narrow scores on the subscapular fossa of the scapula, (D) and frayed edges of the spinous process of a thoracic vertebra as a result of gnawing

4.2.3. Types of postmortem modifications caused by a warthog

The warthog created the fewest number of postmortem modifications but was the only animal species that caused deletion of the end on several skeletal elements (Figure 6 and Table 3). A total of 21 skeletal locations exhibited postmortem modifications that were caused by the warthog. The most common postmortem modification observed was scores and constituted 66.7% of the modifications observed. This was followed by furrows (23.8%), then a combination of pits and scores (4.8%) and a combination of furrows and scores (4.8%). The skeletal element locations where furrows were observed, were due to gnawing by the warthog and lead to four of the skeletal elements having deletions on the ends of the elements (Figure 6A).

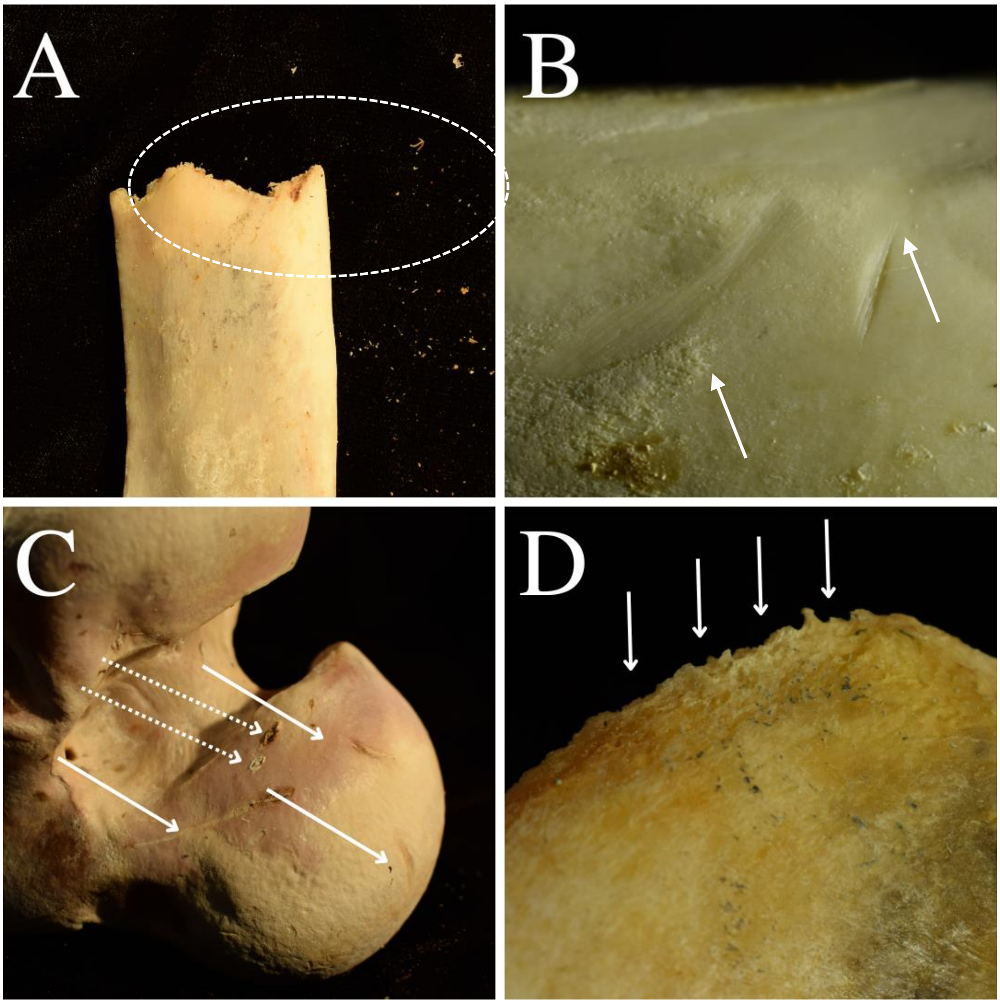

Figure 6. Postmortem modifications caused by a warthog: (A) jagged edges caused by the deletion of the end of the spinous process of the thoracic vertebrae due to gnawing, (B) wide fan-like score cluster caused by the teeth of the warthog (C), pits (dotted arrows) and scores (solid arrows) on the proximal end of the femur, (D) and jagged uneven marks on the ilium of the pelvic bone caused by gnawing

4.2.4. Types of postmortem modifications cause by suricates

Suricates displayed the highest number of postmortem modifications. A total of 26 skeletal element locations exhibited postmortem modifications that were caused by suricates (Figure 7 and Table 4). Although they displayed the highest number of modifications, they did not display high variability and did not display furrows. The most common postmortem modification observed was scores and constituted 96.2% of the modifications observed. A combination of pits and scores were also observed and constituted 3.8% of the modifications observed.

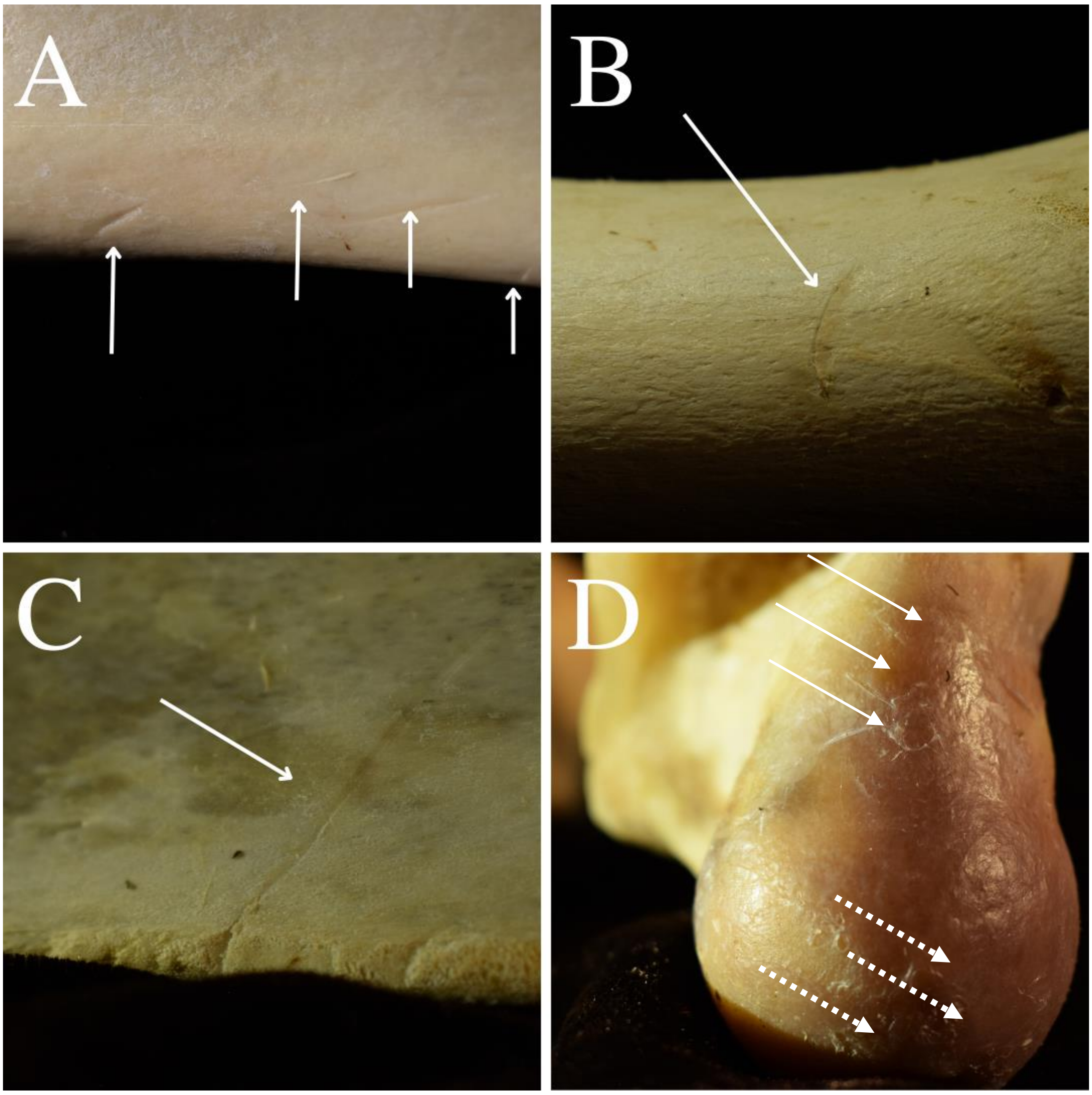

Figure 7. Postmortem modifications caused by the suricates: (A) scores of various lengths and depths on the supraspinous process of the scapula, (B) a wide score on the shaft of the tibia caused by a tooth, (C) a long deep score on the rib caused by a tooth, (D) and pits (dotted arrows) and scores (solid arrows) on the proximal end of the humerus

4.3. Location of postmortem modifications caused by different scavenging animals on different skeletal elements

The skeletal elements used in the current study included cervical and thoracic vertebrae, the pelvis, radius, ulna, humerus, tibia, rib bones and scapula. Throughout the duration of the study, no postmortem modifications were observed on the carpal bones and the patellae.

For this objective, Chi-tests were used to calculate two p-values. The first p-value calculated was significantly lower than the significant value of 0.05, indicating that the type of skeletal element scavenged on was significantly correlated to the species scavenging on that element. The second p-value calculated was also significantly lower that the significant value of 0.05, indicating that location on the skeletal element scavenged on significantly correlated to the species scavenging on that location on the skeletal element.

4.3.1. Location of postmortem modifications caused by genets

The scapula and pelvis displayed the highest number of modifications (Table 2), and both were scavenged on by genets in all three replicates. Specifically, the spine of the scapula and the ischium of the pelvis displayed these recurrent modifications. The scapula and pelvis both accounted for 39.0% of the skeletal locations that exhibited modifications caused by the genets, indicating that the genets preferentially scavenge on the scapula and pelvis. A postmortem modification of interest was the spine of scapula, as all three replicates displayed at least one score on the spine of the scapula.

Since either upper or lower limb long bones were randomly placed in the enclosures, a humerus, radius and ulna were placed in the enclosures for the first and second replicates, and only one modification was observed on the radius and ulna. A femur, tibia and fibula were placed for the third replicate and the femur displayed one score, whereas the tibia and fibula displayed no modifications. Concluding that as genets only created two scores to all long bones, they do not preferentially scavenge on these types of bones.

Throughout the three week replicates, the genets only scaveneged on one rib bone and one thoracic vertebrae, which also displayed modifications, and each accounted 4.4% of skeletal locations that exhibited modifications caused by the genet. The rib displayed a modification on the shaft and the thoracic vertebrae displayed a modification on the spinous process. The cervical vertebrae, carpal bones and patella displayed no signs of modifications for all three replicates. This indicates that the genets do not prefertially scavenge on rib bones, or irregular bones, with the exception of the pelvis. Furthermore, no skeletal remnants were observed in the scat of the genets.

4.3.2. Location of postmortem modifications caused by servals

The rib and long bones both accounted for the highest skeletal locations with serval modifications, and both accounted for 28.0% each of the total skeletal element locations scavenged on by servals. This indicates servals preferentially scavenge on the rib and long bones. As the bones were placed into the habitats at random, a femur, tibia and fibula were placed in the serval habitats for all three weeks. On the ribs, the most common postmortem modifications were observed on the shaft of the rib bones. Conversely, no modifications were observed on the sternal ends of the rib bones. Whereas on the long bones, equal amounts of modifications were observed on the proximal epiphysis as on the shaft, both accounting for 12.0% of the skeletal locations with serval modifcations. The distal epiphysis of the femur accounted for 4.0% of the skeletal locations with serval modifcations.

Following rib and long bones, the pelvis accounted for 24.0% of the skeletal locations that exhibited serval modifications, three modifications were obsereved on the sacrum, and the ilium, ischium and pubis all displayed one modifiction each. This indicates that the servals do have a preference to scavenge on the pelvis, however the rib and long bones have a higher preference. The vertebrae accounted for 16.0% of skeletal locations with serval modifications, with 12.0% on the spinous process of the thoracic vertebrae and 4.0% on the tranverse process of the cervical vertebrae. This indicates that there is not a high preference for servals to scavenge on the vertebrae. Only one modification was observed on the scapula, and no modifications were obsereved on the carpal bones or the patella, indicating that the servals do not preferentially scavenge on the scapula, carpal bones or patella. Furthermore, no skeletal element remnants were observed in the scat of the servals.

4.3.3. Location of postmortem modifications caused by a warthog

The long bones displayed the highest number of skeletal locations with warthog modifications (33.3%), indicating that the warthog preferentially scavenged on long bones. Since the long bones were randomly placed within the enclosures, a femur, tibia and fibula were placed in the warthog enclosure in the first and second week and a humeurs, radius and ulna was placed in the third week. Of the long bones, two modifications were observed on the shaft epiphyses, two modifications were observed on the proximal epiphyses and two modifications were observed on both the shaft and proximal epiphyses.

Following the long bones, the thoracic vertebrae accounted for 28.6% of the skeletal locations with warthog modifications. All modifications on the thoracic vertebrae were observed on the spinous process, all modifications observed were deletions of the spinous process. The pelvic bone accounted for 23.8% of the number of modifications, two of the modifications were on the illium, two were on the ischium and one was on the sacrum. Lastly, the rib bones accounted for 14.3% of the modifications, and all modifications were observed on the shaft of the rib bones. This indicates that there is also preferential scavenging on the vertebrae, pelvis and rib bones, however the long bones are more favored. Furthermore, although the long bones display a higher preference, the spinous process of the thoracic vertebrae displayed the most intense modifications caused by the warthog.

The scapula, cervical vertebrae, carpal bones and patella displayed no modifications in any of the replicates, inidcating no preference from the wartog to scavenge on these bones Furthermore, no skeletal remnants were observed in the scat of the warthog.

4.3.4. Location of postmortem modifications caused by suricates

The scapula displayed the highest number of skeletal locations with suricate modifications, and accounted for 38.5% of observed modifications. This indicates that the suricates preferentially scavenge on the scapula. Of the scapula modifications, three were observed on the subscapular fossa, two on the supraspinous fossa, one on the infraspinous fossa. Additionally, two longer scores were observed that affected both the spine and the infraspinous process, and another two that affected the spine and the supraspinous process (Figure 9). These marks do differ from the above-mentioned, and they are not isolated to the spine or the respective fossae, the scores are from the spine to some point on the fossas. The infraspinous fossa displayed modifications in all three replicates, indicating that suricates preferentially scavenge on this part of the scapula.

Figure 8. Score marks on the spine and supraspinous fossa of the scapula (dotted line to dotted line indicates the total score length) caused by the claws of the suricates

Following the scapula, the long bones accounted for 26.9% of the skeletal locations with suricate modifications. Since the long bones were randomly placed in the enclosures each week, a humerus, radius and ulna were placed in the enclosure in the first and third week and a femur, tibia and fibula were placed in the enclosure in the second week. Of the long bone modifications observed, five modifications were obserevd on the shaft epiphyses of the long bones, one on the proximal epiphyses and one of the distal epiphyses. This indicates that although there is a preference for the suricates to scavenge on the long bones, there is a higher preference for the scapula.

The rib bones accounted for 23.1% of the skeletal locations with suricate modifications, and all modifications were observed on the shaft of the rib bones. The vertebrae accounted for 11.5% of the modifications. The cervical vertebrae displayed two modifications, both on the transverse process and the thoracic vertebra displayed one modification on the spinous process. Although modifications were observed on both the rib bones and the vertebrae, only three modiciations were observed on the vertebrae indicating that the suricates do not prefrentially scavenge on these bones.

Furthermore, the suricates displayed no preference to scavenge on the carpal bones, patella or pelvis as no modifications were observed in the three replicates. The scat of the suricates could not be collected by the animal handlers, due to the suricates nature to burrow.

4.4. The characteristics of postmortem modifications caused by different scavenging species

The postmortem modifications were characrterised accoring to their depth, breadth, length and shape. It was also noted whether a single modification had been obsereved, or if it was multiple in a cluster at a single location on a skeletal element. A total of 95 skeletal locations exhibited postmortem modifications for all scavenging species studied, throughout all three replicates. For these skeletal location modifications caused by scavenging by the various study species, 4.2% of the modifications were complete deletions of the ends of a skeletal element, and 1.1% were minor deletions presented as frayed edges on the skeletal elements. These deletions were described as a deletion of the end or as frayed edges in Tables 2-5, if present. Of all the modifications observed at the different skeletal element locations, 55.8% of the skeletal elemental locations exbitied modifications that were multiple (or clustered), and 44.2% of the locations exhibited singular modifications.

In terms of depth of the scavenging modifications observed, 59.8% of the modifications observed at the various skeletal element locations were characterised as shallow, or superficial, 27.4% were characterized as deep and 11.6% were characterized as a combination of varying depths. The varying depths were exhibited in the different skeletal element locations with a cluster of modifications in one location on the skeletal element. In terms of the breadth of the postmortem modifications observed, 74.7% were characterised as narrow, 12.6% were characterised as wide, and 7.4% were characterised as a combination of varying breadths. As with the depth, the skeletal element locations that exhibited modifications of various breadths were due to a cluster of modifications being observed in those locations.

In terms of length of the modifications observed at the different skeletal element locations, 44.2% were characterized as long, 34.7% were characterized as short and 15.8% were characterized as varying lengths. The skeletal element locations that presented with long and short modifications included a singlular modification that was characterized as long or short, or it could have been a cluster of modification that all presented with similar lengths (long or short). The skeletal element locations that exhibited modifications with varying lengths were all clustered modifications.

In terms of shape of the scavenging modifications observed at the different skeletal element locations, 86.3% were characterized as linear in shape, 3.2% were characterized as curved, 2.1% were characterized as a cluster of modifications that exhibited modifications that were both linear and curved in shape, and 3.2% were characterized as a cluster of modifications at a location that exhibited modifications that were both linear and circular in shape. The cluster modifications of the skeletal elements that contained modifications that were linear and circular in shape can be indicative of pits and scores in one location. The bone could have been manipulated by the animal using its claws, resulting in scores and bites on the bone. This action could lead to the formation of pits or involve the animal biting the bone and subsequently dragging its teeth into the bone, especially after the pit has been formed.

4.4.1. Characteristics of the postmortem modifications caused by genets

Of the 23 skeletal element locations that exhibited postmortem modifications caused by the genets, the most common characteristics observed were clusters of superficial scores that were long in length. These postmortem modifications accounted for 34.8% genet modifications. Most of the modifications observed were linear in shape, however there was a modification characterised as curved in shape (Figure 5C). Due to the length of the modifications being long in length, the breadth being superficial and the shape being linear, could be indicative of majority of the modifications being caused by the retractable claws of the genets.

In each replicate, there was one postmortem modification of interest: the spine of the scapula exhibited at least one score, and the length of the score matched the length of the spine of the scapula. This is indicative of the genets scratching the scapula with their claws, as the scores were superficial in nature. Furthermore, the genets did not cause a deletion of the ends of any of the skeletal elements.

4.4.2. Characteristics of the postmortem modifications caused by servals

Of the 25 skeletal element locations that exhibited postmortem modifications caused by the servals, clusters of superficial scores with varying lengths were the most common and accounted for 24.0% of the serval modifications. All modifications, except two, were linear in shape. The proximal epiphysis of one of the long bones scaveneged on by the servals presented with a cluster of modifications with a combination of pits and scores. The cluster of modifications presented with varying depths, however the breadths were narrow and the shapes were a combination of linear and circular. The modifications in the cluster that were circular in shape, known as pits, were caused by the teeth of the servals due to biting on the skeletal element. Conversely, the modifications that were linear in shape, referred to as scores, were caused by the claws of the servals. Due to the short nature of the linear scores, it was likely caused by the animal holding the element with their claws and biting the epiphysis.

4.4.3. Characteristics of the postmortem modifications caused by the warthog

Of the 21 skeletal element locations that exhibited postmortem modifications caused by the warthog, single, superficial scores that were linear in shape were the most common and accounted for 42.9% of the warthog modifications. As warthogs have hooves and not claws, these modifications cannot be indicative of scratching by the claws as observed with the genets, servals and suricates. These scores are most likely indicative of scracthing on the floor whilst the warthog was moving the skeletal elements around the enclosure, as a source of enrichment due to the captive setting.

The warthog was the only animal species that caused complete and minor deletions of ends, and was observed on five of the skeletal elements scaveneged on by the warthog. The spinous process was completely deleted on four of the thoracic vertebrae and is indicative of biting and gnawing by the warthog. The illium of a pelvis exhibited a minor deletion due to gnawing by the warthog and this was presented as jagged edges on the skeletal element. These charactertic modifications were not observed by any other animal species in the current study.

Aside from the deletion of the ends (Figure 6A), and the jagged edges described above, the warthog also had a wide curved score cluster of modifications on the shaft epiphysis of one of the long bones. This modification was caused by the teeth of the warthog due to the width of the modification. A proximal epiphysis of one of the long bones presented with a cluster of modifications that were linear and circular in shape. This is indicative of biting by the warthog.

4.4.4. Characteristics of the postmortem modifications caused by the suricates

Of the 26 skeletal element locations that exhibited postmortem modifications caused by the suricates, clusters of superficial scores that were linear in shape were the most common and accounted for 26.9% of the suricate caused modifications. The most commonly observed shape in the skeletal element locations with surciate modifications was linear and accounted for 84.6% of the suricate caused modifications. However, variable shapes were observed. The shaft epyphysis of a long bone displayed a singular score which was curve shaped. The modification was superficial, narrow and long which is indicative of being caused by the claws of the suricates. Furthermore, there were two seperate clusters of scores on the scapula that presented with scores that were linear and curved in shaped. The depths and lengths of the modifications varied which is indicative of scratching by the suricate and potentially moving of the element to a different location. The distal epiphysis of a long bone also displayed a cluster of modifications that were linear and circular in shape. This is indicative of pits, caused by the teeth of the suricates while biting by the suricates. The suricates did not cause a deletion of the ends of any of the skeletal elements.

Table 2. Summary of postmortem modifications to bovine bones caused by genets

Bone	Sample set (1, 2 or 3)	Type of modification	Caused by	Location	Single or multiple	Depth	Breadth	Length	Shape	Figure
Rib	1	Scores	Claws	Shaft	Single	Shallow	Narrow	Long	Linear	
Pelvic bone	1	Scores	Claws	Ischium	Multiple	Shallow	Narrow	Varying	Linear	
Pelvic bone	1	Scores	Claws	Ischium	Multiple	Varying	Narrow	Varying	Linear	
Pelvic bone	1	Scores	Claws	Ilium	Single	Shallow	Narrow	Long	Linear	Figure 4B
Pelvic bone	1	Scores	Claws	Ilium	Single	Deep	Narrow	Long	Linear	
Pelvic bone	1	Scores	Claws	Sacrum	Multiple	Shallow	Narrow	Short	Linear	
Scapula	1	Scores	Claws	Subscapular fossa	Multiple	Deep	Narrow	Long	Linear	
Scapula	1	Scores	Claws	Spine	Multiple	Shallow	Narrow	Long	Linear	
Scapula	1	Scores	Claws	Spine	Multiple	Shallow	Narrow	Long	Linear	
Scapula	1	Scores	Claws	Spine and Supraspinous fossa	Single	Shallow	Narrow	Long	Linear	Figure 8
Radius and ulna	1	Scores	Claws	Shaft epiphysis	Multiple	Shallow	Narrow	Long	Linear	
Radius and ulna	1	Scores	Claws	Shaft epiphysis	Multiple	Shallow	Narrow	Long	Linear	
Pelvic bone	2	Scores	Claws	Ilium	Single	Deep	Narrow	Short	Linear	Figure 4A
Thoracic vertebrae	2	Scores	Claws	Spinous process	Multiple	Varying	Narrow	Varying	Linear	Figure 4D
Scapula	2	Scores	Claws	Infraspinous fossa	Multiple	Varying	Narrow	Short	Linear	
Scapula	2	Scores	Claws	Spine	Multiple	Shallow	Narrow	Varying	Linear	
Scapula	2	Scores	Claws	Spine and Supraspinous fossa	Multiple	Deep	Narrow	Varying	Linear	
Pelvic bone	3	Scores	Claws	Ischium	Multiple	Deep	Narrow	Long	Linear	
Scapula	3	Scores	Claws	Spine and Infraspinous fossa	Multiple	Shallow	Narrow	Long	Linear	
Scapula	3	Scores	Claws	Spine	Multiple	Shallow	Narrow	Long	Linear	
Femur	3	Scores	Teeth	Distal epiphysis	Multiple	Shallow	Wide	Short	Linear	
Pelvic bone	3	Scores	Claws	Sacrum	Single	Shallow	Narrow	Short	Curved	Figure 4C
Pelvic bone	3	Scores	Claws	Sacrum	Single	Shallow	Narrow	Long	Linear	

Table 3. Summary of postmortem modifications to bovine bones caused by servals

Bone	Sample set (1, 2 or 3)	Type of modification	Caused by	Location	Single or multiple	Depth	Breadth	Length	Shape	Figure
Femur	1	Scores	Teeth	Shaft epiphysis	Single	Deep	Wide	Short	Linear	Figure 5B
Femur	1	Scores	Claws	Shaft epiphysis	Multiple	Shallow	Narrow	Long	Linear	
Thoracic vertebrae	1	Scores	Claws	Spinous process	Multiple	Shallow	Narrow	Varying	Linear	
Thoracic vertebrae	1	Scores	Claws	Spinous process	Single	Shallow	Narrow	Long	Linear	
Rib	1	Scores	Teeth	Shaft	Single	Deep	Wide	Short	Linear	
Rib	1	Scores	Claws	Shaft	Single	Shallow	Narrow	Long	Linear	
Rib	1	Scores	Claws	Shaft	Single	Shallow	Narrow	Short	Linear	
Rib	1	Scores	Claws	Shaft	Single	Shallow	Narrow	Short	Linear	
Pelvic bone	1	Scores	Claws	Ischium	Multiple	Shallow	Narrow	Varying	Linear	
Pelvic bone	1	Scores	Claws	Pubis	Single	Shallow	Narrow	Short	Linear	
Pelvic bone	1	Scores	Claws	Ilium	Single	Deep	Narrow	Long	Linear	
Pelvic bone	1	Scores	Claws	Sacrum	Single	Shallow	Narrow	Long	Linear	
Scapula	2	Scores	Claws	Subscapular fossa	Single	Deep	Narrow	Long	Linear	Figure 5C
Pelvic bone	2	Scores	Claws	Sacrum	Multiple	Deep	Narrow	Short	Linear	
Pelvic bone	2	Scores	Claws	Sacrum	Multiple	Varying	Narrow	Short	Linear	
Femur	2	Furrows	Teeth	Proximal epiphysis	Multiple	Deep	Wide	Long	Linear	Figure 5A
Femur	2	Scores	Teeth	Proximal epiphysis	Single	Shallow	Wide	Short	Linear	
Femur	2	Scores	Claws	Distal epiphysis	Multiple	Shallow	Varying	Varying	Linear	
Rib	3	Scores	Claws	Shaft	Single	Shallow	Narrow	Short	Linear	
Rib	3	Scores	Claws	Shaft	Single	Shallow	Narrow	Long	Linear	
Rib	3	Scores	Claws	Shaft	Multiple	Shallow	Varying	Varying	Linear	
Femur	3	Scores	Claws	Shaft epiphysis	Single	Deep	Narrow	Long	Linear	
Tibia and fibula	3	Pits and Scores	Claws and Teeth	Proximal epiphysis	Multiple	Varying	Narrow	Short	Linear and circular	
Cervical vertebrae	3	Scores	Claws	Transverse process	Multiple	Shallow	Narrow	Long	Linear	
Thoracic vertebrae	3	Furrows and scores	Claws and Teeth	Spinous process	Multiple	Jagged ends	Jagged ends	Jagged ends	Jagged ends	Figure 5D

Table 4. Summary of postmortem modifications to bovine bones caused by the warthog

Bone	Sample set (1, 2 or 3)	Type of modification	Caused by	Location	Single or multiple	Depth	Breadth	LENGTH	SHAPE	Figure
Pelvic bone	1	Scores	Claws	Ischium	Multiple	Shallow	Narrow	Long	Linear	
Rib	1	Scores	Claws	Shaft	Multiple	Varying	varying	Short	Linear	
Thoracic vertebrae	1	Scores	Claws	Spinous process	Multiple	Shallow	Narrow	Varying	Linear	
Thoracic vertebrae	1	Furrows	Teeth	Spinous process	Deletion	Deletion	Deletion	Deletion	Deletion	Figure 6A
Tibia and fibula	1	Scores	Teeth	Shaft epiphysis	Multiple	Deep	Wide	Short	Curved	Figure 6B
Femur	1	Scores	Claws	Shaft epiphysis	Multiple	Varying	Varying	Varying	Linear	
Femur	1	Scores	Claws	Proximal epiphysis	Single	Shallow	Narrow	Long	Linear	
Pelvic bone	2	Scores	Claws	Ilium	Multiple	Shallow	Narrow	Short	Linear	
Pelvic bone	2	Scores	Claws	Ischium	Single	Shallow	Narrow	Short	Linear	
Pelvic bone	2	Furrows	Teeth	Ilium	Single	Jagged ends	Jagged ends	Jagged ends	Jagged ends	Figure 6D
Rib	2	Scores	Claws	Shaft	Single	Shallow	Narrow	Long	Linear	
Tibia and fibula	2	Scores	Teeth	Proximal epiphysis	Multiple	Deep	Wide	Short	Linear	
Femur	2	Scores	Claws	Shaft and Proximal epiphysis	Single	Shallow	Narrow	Long	Linear	
Femur	2	Scores	Claws	Shaft epiphysis	Single	Shallow	Narrow	Long	Linear	
Femur	2	Pits and Scores	Teeth	Proximal epiphysis	Multiple	Deep	Wide	Short	Linear and circular	Figure 6C
Thoracic vertebrae	2	Scores	Claws	Spinous process	Single	Shallow	Wide	Long	Linear	
Thoracic vertebrae	2	Furrows	Teeth	Spinous process	Deletion	Deletion	Deletion	Deletion	Deletion	
Rib	3	Scores	Claws	Shaft	Single	Deep	Varying	Long	Linear	
Pelvic bone	3	Furrows	Teeth	Sacrum	Deletion	Deletion	Deletion	Deletion	Deletion	
Thoracic vertebrae	3	Furrows and Scores	Teeth	Spinous process	Single	Shallow	Narrow	Long	Linear	
Thoracic vertebrae	3	Furrows	Teeth	Spinous process	Deletion	Deletion	Deletion	Deletion	Deletion	

Table 5. Summary of postmortem modifications to bovine bones caused by suricates

Bone	Sample set (1, 2 or 3)	Type of trauma	Caused by	Location	Single or multiple	Depth	Breadth	Length	Shape	Figure
Rib	1	Scores	Claws	Shaft	Multiple	Varying	Narrow	Short	Linear	
Rib	1	Scores	Claws	Shaft	Single	Deep	Narrow	Short	Linear	
Rib	1	Scores	Claws	Shaft	Multiple	Deep	Narrow	Short	Linear	
Rib	1	Scores	Claws	Shaft	Single	Deep	Wide	Short	Linear	
Radius and ulna	1	Scores	Claws	Shaft epiphysis	Single	Shallow	Narrow	Long	Linear	
Scapula	1	Scores	Claws	Subscapular fossa	Multiple	Deep	Varying	Long	Linear	
Scapula	1	Scores	Claws	Spine and Supraspinous fossa	Multiple	Shallow	Narrow	Long	Linear	Figure 9
Scapula	1	Scores	Claws	Spine and Infraspinous fossa	Multiple	Shallow	Narrow	Long	Linear	
Scapula	1	Scores	Claws	Supraspinous fossa	Multiple	Deep	Wide	Short	Linear	Figure 7A
Femur	2	Scores	Claws	Proximal epiphysis	Multiple	Deep	Varying	Varying	Linear	
Tibia and fibula	2	Scores	Claws	Shaft epiphysis	Single	Deep	Narrow	Long	Curved	Figure 7B
Cervical vertebrae	2	Scores	Claws	Transverse process	Multiple	Shallow	Narrow	Short	Linear	
Scapula	2	Scores	Claws	Subscapular fossa	Multiple	Shallow	Narrow	Long	Linear	
Scapula	2	Scores	Claws	Subscapular fossa	Single	Deep	Narrow	Short	Linear	
Scapula	2	Scores	Claws	Supraspinous fossa	Multiple	Varying	Narrow	Varying	Linear/ Curved	
Scapula	2	Scores	Claws	Spines and Supraspinous fossa	Multiple	Varying	Narrow	Varying	Linear/ Curved	
Scapula	2	Scores	Claws	Spine and Infraspinous fossa	Multiple	Varying	Narrow	Long	Linear	
Radius and ulna	3	Scores	Claws	Shaft epiphysis	Single	Shallow	Narrow	Long	Linear	
Humerus	3	Pits and Scores	Claws and Teeth	Distal epiphysis	Multiple	Shallow	Narrow	Short	Linear and circular	Figure 7D
Humerus	3	Scores	Claws	Shaft epiphysis	Multiple	Shallow	Narrow	Short	Linear	
Humerus	3	Scores	Claws	Shaft epiphysis	Single	Shallow	Narrow	Long	Linear	
Cervical vertebrae	3	Scores	Claws	Transverse process	Multiple	Shallow	Narrow	Varying	Linear	
Thoracic vertebrae	3	Scores	Claws	Spinous process	Multiple	Shallow	Narrow	Short	Linear	
Rib	3	Scores	Claws	Shaft	Multiple	Deep	Wide	Long	Linear	
Rib	3	Scores	Claws	Shaft	Multiple	Deep	Narrow	Short	Linear	
Scapula	3	Scores	Claws	Infraspinous fossa	Single	Shallow	Narrow	Long	Linear	Figure 7C

4.5. Scoring intensity of postmortem modifications used for different scavenging animals on different skeletal elements

The scoring criteria (Table 1) was used to score the intensity of scavenging modifications to different locations on different skeletal elements by the author on a scale of 0-3.

4.5.1. Scoring intensity of postmortem modifications used for genets on different skeletal elements

There were no skeletal element areas scaveneged on by the genets with a scoring intensity greater than 1 (Table 5). The scapula presented with the highest score range of 0.33 -1.00. This indicates that throughout the three weeks, each area of the scapula was scavenged on due to the lower range not being 0. This was not present in any other skeletal element scaveneged on by the genets. However, as the scoring intensty does not exceed a score of 1, the genets did not produce intense modifications and all modifications observed throughout the different skeletal elements were superficial in nature. These results agree with the findings discussed in objective 3. The postmortem modifications caused by the genet species are more superficial in nature and do not tend to exceed this level of intensity in terms of modification.

4.5.2. Scoring intensity of postmortem modifications used for servals on different skeletal elements

Although scores were the most common modification caused by servals on the skeletal elements, the most intense modifications scored were on the proximal epiphysis of the femur (Figure 5A) and on the thoracic vertebrae (Figure 5D), both with an intensity score of 2 (Table 6). The femur displayed furrowing on the proximal epiphysis (Figure 5A), exposing the trabecular bone. The end of the spinous process displayed a jagged, uneven fracture caused by gnawing of the bone, however no more than 50% had been deleted and therefore could not be scored with a 3. Although there was a skeletal element that presented with a score of 2, none of the skeletal elements presented with score range higher than 1, indicating that the intensity of the serval scavenging were superficial in nature.

Even though the trabecular bone of the proximal epiphysis of the femur was exposed, a range of 0.33-0.67 was obtained for the bone. This indicates that each area was scaveneged on at least once during the three replicates, however the intensity of the furrowing was not continous and consistent in all three replicates. The other long bone presented with a score range of 0.00-0.33, indicating that intense scavenging observed on the long bones is not consistent with the servals.

The highest score range was for the thoracic vertebrae and was 0.00-1.00. Although there was a minor deletion of the spinous process, the remaining areas of the bone were not scaveneged on (0) and the minor deletion was not continuously observed in all three replicates. This could indicate that although the serval caused the minor deletion of two skeletal elements, their postmortem modifications are more superficial in nature. The second thoracic vertabra and the cervical vertabrae both presented with a score range of 0.00-0.33. This indicates that the intensity of scavenging is not consistent for these bones and the minor deletion is not a common modification to be observed by servals on the vertebrae.

The pelvic bone presented with a score range of 0.33-0.67, this indicates that the servals scavenged on every area of the bone at least once in all three replicates. The upper end of the range indicates that one area of the bone was scavenged on in multiple replicates which could be due to preference. However, the scoring intensity is not consistent throughout the three replicates, indicating that they did not intensely scavenge on the pelvis.

The rib bone presented with a score range of 0.00-0.67, indicating that one area, the shaft, of the bone was scaveneged on multiple times in the three replicates (0.67) and one area, the sternal ends, of the bone was not scavenged at all (0.00). The Scapula presented with a score range of 0.00-0.33. Only one area, the subscapular fossa, of the four areas was scaveneged on once in the three replicates. This indicates that the scapula is not preferred by the servals.

4.5.3. Scoring intensity of postmortem modifications used for the warthog on different skeletal elements

The most severe modifications observed in all the study species, was caused by the warthog in all three replicates. The warthog caused the deletion of the spinous process of the thoracic vertebrae in all three replicates, allowing for the highest intensity score to be allocated (3) (Table 7).

Due to the consistent deletion of the spinous process, this allowed for the thoracic vertebrae to be scored with the highest score range observed throughout all the animal species in all three replicates, 0.00-3.00 and 0.00-1.33. This indicates that the warthog had a preference to scavenge on the spinous process of the thoracic vertebrae, however did not scavenge on any other location on the thoracic vertebrae.

A score range of 0.00-1.00 and 0.00-0.50 were observed for the femur and the tibia and fibula respectively, indicating that the warthog does not have a strong preference for long bones. The femur was placed in the warthog habitat on the first and second replicates. Consistent superficial modifications were observed on the shaft and proximal epiphysis, however consistent modifications were not observed on the same locations on the tibia and fibula, as well as no modifications being observed on the humerus, radius and ulna in the third replicate. This indicates that although there is a preference for warthogs to scavenge on the long bones, the intensity of the modification are only superficial.

The ribs also presented with a score range of 0.00-1.00. Superficial modifications were observed on the shaft of the rib bone in all three weeks, however no modifications were observed on the sternal ends of the ribs. This indicates that although there is some preference for the rib bones, the modifications caused to these bones are not more than superficial.

The pelvic bone displayed a wide variety of scores, as the sacrum in the third replicate had a deletion of less than 50%, resulting in a score of 2. Although a moderate score intensity was observed on the sacrum, the score range for the pelvis was 0.00-0.67. This indicates that although scavenging is observed on the pelvis, the modifications caused are not intense and are mainly superficial in nature.

4.5.4. Scoring intensity of postmortem modifications used for suricates on different skeletal elements

There were no skeletal element locations scavenged on by suricates that presented a scoring intensity greater than 1 (Table 8). The skeletal element with the most significant score range is the scapula, 0.67-1.00. As the lower end of the range is not 0, this indicates that every location on the scapula was scavenged on, and as it is higher than 0.33, it indicates that at least two of the replicates were scavenged on in each location. However, as the upper range is 1, this indicates that the scavenging modifications caused by suricates are superficial in nature. This was not observed in any other skeletal element that was scavenged on by the suricates. Furthermore, as no modifications exceeded a scoring intensity of 1, this indicates that suricates do not produce intense modifications and the modifications produced during scavening is superficial in nature.

Table 6.Scoring intensity of postmortem modifications of different skeletal elements caused by genets

Bone	Area on the bone	Sample 1 score	Sample 2 score	Sample 3 score	Average score per area	Score range for the skeletal element of the intensity inflicted on the different locations on the skeletal element.
		Total = 3	**Total =3**	**Total = 3**	**Total =3**	**0.00-3.00**
Femur	**Distal epiphysis**	N/A[1]	N/A	1.00	1.00	0.00-1.00
	Proximal epiphysis			0.00	0.00	
	Shaft epiphysis			0.00	0.00	
Radius and ulna	**Distal epiphysis**	0.00	0.00	N/A	0.00	0.00-0.50
	Proximal epiphysis	0.00	0.00		0.00	
	Shaft epiphysis	1.00	0.00		0.50	
Scapula	**Spine**	1.00	1.00	1.00	1.00	0.33-1.00
	Infraspinous Fossa	0.00	1.00	1.00	0.67	
	Supraspinous Fossa	1.00	1.00	0.00	0.67	
	Subscapular Fossa	1.00	0.00	0.00	0.33	
Ribs	**Sternal ends**	0.00	0.00	0.00	0.00	0.00-0.33
	Shaft	1.00	0.00	0.00	0.33	
Pelvic bone	**Ilium**	1.00	1.00	0.00	0.67	0.00-0.67
	Ischium	1.00	0.00	1.00	0.67	
	Pubis	0.00	0.00	0.00	0.00	
	Sacrum	1.00	0.00	1.00	0.67	
Thoracic vertebrae (1)	**Spinous Process**	0.00	1.00	0.00	0.33	0.00-0.33
	Transverse Process	0.00	0.00	0.00	0.00	
	Anterior Arch	0.00	0.00	0.00	0.00	
	Posterior Arch	0.00	0.00	0.00	0.00	

[1] N/A (not applicable) for the long bones means that, that specific long bone was not placed in the enclosure that week. The long bones were scattered at random.

Table 7. Scoring intensity of postmortem modifications of different skeletal elements caused by servals

Bone	Area on the bone	Sample 1 score	Sample 2 score	Sample 3 score	Average score per area	Score range for the average scoring intensity per area for the different skeletal elements.
		Total = 3.00	**Total =3.00**	**Total = 3.00**	**Total =3.00**	**0.00-3.00**
Femur	**Distal epiphysis**	0.00	1.00	0.00	0.33	0.33-0.67
	Proximal epiphysis	0.00	2.00	0.00	0.67	
	Shaft epiphysis	1.00	0.00	1.00	0.67	
Tibia and fibula	**Distal epiphysis**	0.00	0.00	0.00	0.00	0.00-0.33
	Proximal epiphysis	0.00	0.00	1.00	0.33	
	Shaft epiphysis	0.00	0.00	0.00	0.00	
Scapula	**Spine**	0.00	0.00	0.00	0.00	0.00-0.33
	Infraspinous Fossa	0.00	0.00	0.00	0.00	
	Supraspinous Fossa	0.00	0.00	0.00	0.00	
	Subscapular Fossa	0.00	1.00	0.00	0.33	
Ribs	**Sternal ends**	0.00	0.00	0.00	0.00	0.00-0.67
	Shaft	1.00	0.00	1.00	0.67	
Pelvic bone	**Ilium**	1.00	0.00	0.00	0.33	0.33-0.67
	Ischium	1.00	0.00	0.00	0.33	
	Pubis	1.00	0.00	0.00	0.33	
	Sacrum	1.00	1.00	0.00	0.67	
Cervical vertebrae (1)	**Transverse Process**	0.00	0.00	1.00	0.33	0.00-0.33
	Anterior Arch	0.00	0.00	0.00	0.00	
	Posterior Arch	0.00	0.00	0.00	0.00	
Thoracic vertebrae (1)	**Spinous Process**	1.00	0.00	2.00	1.00	0.00-1.00
	Transverse Process	0.00	0.00	0.00	0.00	
	Anterior Arch	0.00	0.00	0.00	0.00	
	Posterior Arch	0.00	0.00	0.00	0.00	
Thoracic vertebrae (2)	**Spinous Process**	1.00	0.00	0.00	0.33	0.00-0.33
	Transverse Process	0.00	0.00	0.00	0.00	
	Anterior Arch	0.00	0.00	0.00	0.00	
	Posterior Arch	0.00	0.00	0.00	0.00	

Table 8. Scoring intensity of postmortem modifications of different skeletal elements caused by the warthog

Bone	Area on the bone	Sample 1 score	Sample 2 score	Sample 3 score	Average score per area	Score range for the average scoring intensity per area for the different skeletal elements.
		Total = 3.00	**Total =3.00**	**Total = 3.00**	**Total =3.00**	**0.00-3.00**
Femur	**Distal epiphysis**	0.00	0.00	N/A[2]	0.00	0.00-1.00
	Proximal epiphysis	1.00	1.00		1.00	
	Shaft epiphysis	1.00	1.00		1.00	
Tibia and fibula	**Distal epiphysis**	0.00	0.00	N/A	0.00	0.00-0.50
	Proximal epiphysis	0.00	1.00		0.50	
	Shaft epiphysis	1.00	0.00		0.50	
Ribs	**Sternal ends**	0.00	0.00	0.00	0.00	0.00-1.00
	Shaft	1.00	1.00	1.00	1.00	
Pelvic bone	**Ilium**	0.00	1.00	0.00	0.33	0.00-0.67
	Ischium	1.00	1.00	0.00	0.67	
	Pubis	0.00	0.00	0.00	0.00	
	Sacrum	0.00	0.00	2.00	0.67	
Thoracic vertebrae (1)	**Spinous Process**	3.00	3.00	3.00	3.00	0.00-3.00
	Transverse Process	0.00	0.00	0.00	0.00	
	Anterior Arch	0.00	0.00	0.00	0.00	
	Posterior Arch	0.00	0.00	0.00	0.00	
Thoracic vertebrae (2)	**Spinous Process**	0.00	1.00	3.00	1.33	0.00-1.33
	Transverse Process	0.00	0.00	0.00	0.00	
	Anterior Arch	0.00	0.00	0.00	0.00	
	Posterior Arch	0.00	0.00	0.00	0.00	

[2] N/A (not applicable) for the long bones means that, that specific long bone was not placed in the enclosure that week. The long bones were scattered at random.

Table 9. Scoring intensity of postmortem modifications of different skeletal elements caused by suricates

Bone	Area on the bone	Sample 1 score	Sample 2 score	Sample 3 score	Average score per area	Score range for the average scoring intensity per area for the different skeletal elements.
		Total = 3.00	**Total =3.00**	**Total = 3.00**	**Total =3.00**	**0.00-3.00**
	Distal epiphysis	0.00		1.00	0.50	
Humerus	**Proximal epiphysis**	0.00	N/A[3]	0.00	0.00	0.00-0.50
	Shaft epiphysis	0.00		1.00	0,50	
	Distal epiphysis		0.00		0.00	
Femur	**Proximal epiphysis**	N/A	1.00	N/A	1.00	0.00-1.00
	Shaft epiphysis		0.00		0.00	
	Distal epiphysis		0.00		0.00	
Tibia and fibula	**Proximal epiphysis**	N/A	0.00	N/A	0.00	0.00-1.00
	Shaft epiphysis		1.00		1.00	
	Distal epiphysis	0.00		0.00	0.00	
Radius and ulna	**Proximal epiphysis**	0.00	N/A	0.00	0.00	0.00-1.00
	Shaft epiphysis	1.00		1.00	1.00	
	Spine	1.00	1.00	0.00	0.67	
	Infraspinous Fossa	1.00	1.00	1.00	1.00	
Scapula	**Supraspinous Fossa**	1.00	1.00	0.00	0.67	0.67-1.00
	Subscapular Fossa	1.00	1.00	0.00	0.67	
Ribs	**Sternal ends**	0.00	0.00	0.00	0.00	0.00-0.67
	Shaft	1.00	0.00	1.00	0.67	
	Transverse process	0.00	1.00	1.00	0.67	
Cervical vertebrae (1)	**Anterior Arch**	0.00	0.00	0.00	0.00	0.00-0.67
	Posterior Arch	0.00	0.00	0.00	0.00	

[3] N/A (not applicable) for the long bones means that, that specific long bone was not placed in the enclosure that week. The long bones were scattered at random.

Table 9.10 (continued). Scoring intensity of postmortem modifications of different skeletal elements caused by suricates

Bone	Area on the bone	Sample 1 score	Sample 2 score	Sample 3 score	Average score per area	Score range for the average scoring intensity per area for the different skeletal elements.
		Total = 3.00	**Total =3.00**	**Total = 3.00**	**Total =3.00**	**0.00-3.00**
Thoracic vertebrae (1)	**Spinous process**	0.00	0.00	1.00	0.33	0.00-0.33
	Transverse process	0.00	0.00	0.00	0.00	
	Anterior arch	0.00	0.00	0.00	0.00	
	Posterior arch	0.00	0.00	0.00	0.00	

Table 10 provides a summary of all the objectives utilized in the current study and summarizes them to the study species observed.

Table 110. Summary of the current studies objective results per animal species

Animal species	Objective 1: Most prevalent type of modification	Objective 2: Preference of skeletal element to scavenge on	Objective 3: Most prevalent characteristics from postmortem modifications	Objective 4: Skeletal element with score range
Genets	Scores	Scapula and pelvis	Superficial long score clusters, linear in shape	Scapula: 0.33-1.00
Servals	Scores	Rib and long bones	Superficial score clusters of varying length, linear in shape	Thoracic vertebra: 0.00-1.00
Warthog	Scores	Long bones	Single superficial long scores, linear in shape	Thoracic vertebra: 0.00-3.00
Suricates	Scores	Scapula	Superficial score clusters, linear in shape	Scapula: 0.67-1.00

Chapter 5: Discussion

The aim of this study was to describe the nature of the postmortem modifications of skeletal elements caused by small common scavenging animals found in a peri-urban environment in Southern Africa. The intention for the study was to determine if species-specific postmortem modifications can be identified after the bones have been scavenged to assist forensic investigations when skeletal elements are not found whole. The descriptions of scavenging modifications can assist forensic anthropologists in differentiating taphonomic alterations from peri-mortem trauma. If the modifications could be isolated to a specific species or family of species, further research can be conducted to link the scattering patterns for that species, which can be used to locate the remaining skeletal elements more efficiently and successfully (Calce and Rogers, 2007).

The objectives of this study focussed on the types of scavenging modifications to the skeletal elements, the location of the postmortem modifications on different skeletal elements, the characteristics of the postmortem modifications on the skeletal elements and the intensity of the scavenging on the different parts and of the whole skeletal element. The study focussed on four species that are both common to a peri-urban environment and are known to scavenge; this included servals, genets, a warthog, and suricates. The study was completed on animals in a captive environment as it eliminates inter-species competition, allowing for the postmortem modifications to be isolated to the species in the habitats.

5.1. Genet scavenging

The genets in the current study only caused superficial damage to the skeletal elements, as only scores of varying widths and lengths were observed. The most commonly observed scores were extremely long scores along the length of the spine of the scapula. This modification was observed consistently with the genet and to a lesser extent, with the suricates. However, although these scores were observed consistently, the modification is not distinctive enough to be isolated to the genet species. Not many studies have been conducted involving the isolation of the scavenging marks caused by genets.

5.1.1. Types and characteristics of the postmortem modifications caused by genets

It can be hypothesized that a lot of the scores observed on the samples scavenged by genets were caused by their claws, this can be said as the scores were too narrow to have been caused by the tooth of the genet (Keyes *et al.,* 2019). This hypothesis has been tested multiple times in the past, considering the impact claws have on soft bone, it prompts the question of whether they can also cause damage to compact bones. Rothschild *et al* (2013) further tested this theory using Moh's hardness scale, which in geology is a concept of hardness and the ability for one structure to scratch another. The scale was graded from 1 to 10, with 1 being the softest (talc) and 10 being the hardest (diamond), claws were graded as a 2.5 due to the keratin in the claws and bone was graded with a 5 (Rothschild *et al*., 2013). In theory, the claw is softer and should not be able to scratch and damage bone that is graded double in terms of hardness.

In a physical study conducted at the Sedgwick County Zoo, Wichita, Kansas, United States of America by Rothschild *et al*. (2013), bovine bones (specifically the femora) were completely defleshed prior to placement, and then bolted into a log and placed into the tigers' enclosure. Thus, the tiger had limited access to the bones, as it's snout could not reach into the log opening and it could only use its claws. The tiger expressed lots of interest in the bone and clawed heavily at it through the log. After this activity had been completed, the bone was unbolted and removed and then studied. The results indicated that scratches produced by the tiger were prominent on the bovine bone and that claws could produce damage to the bones despite the difference in hardness according to Moh's hardness scale (Rothschild *et al*., 2013). It was later explained that due to the kinetic energy produced by the claw strike, the claw can penetrate not only the soft tissue on the bone, but also the bone itself (Rothschild *et al*., 2013). Therefore, the long score marks observed in the spine of the scapula could be due to genets clawing at the scapula to either turn it for ease of access to other parts of the bone, to move it within its habitat, or for enrichment of natural instinct as often observed in captivity (Gidna *et al*., 2013; Rothschild *et al*., 2013).

In a study conducted by Keyes *et al.,* (2022), which aimed to identify scavenging animals of forensic significance in two different environments within South Africa, genets were observed scent marking on the carcasses, as seen with the servals, but were not seen scavenging on the carcass itself. Therefore, genet species-specific modifications could not be observed and noted. In another study conducted by Keyes *et al.,* (2021a), where the aim of the study was also to identify scavenging animals of forensic significance in a rural region in South Africa, genets were observed scavenging on the pig carcasses and were seen actively scavenging all year-round. The results did not note modifications specifically made by genets but did note that they observed scattering of the remains (Keyes *et al*., 2021a).

The genet species in the current study did not produce any modifications aside from the scores. Furthermore, the scores caused by the genets did not display any characteristics unique to the genet species. Therefore, their scavenging modifications cannot be used to isolate them as the perpetrating animal in a forensic setting and their scattering patterns cannot be utilized alone to locate the remaining skeletal elements if the elements are scattered. Furthermore, their modifications cannot be utilized alone to differentiate between perimortem and postmortem trauma.

5.1.2. Location of postmortem modifications caused by genets

In the current study, it was observed that the spine of the scapula and ischium of the pelvis displayed modifications in all replicates. The chi-square test conducted indicated that there is an association between the animal species that is scavenging and the location on the bone that is of preference to the species. The current study observed that the genet species displayed a preference to the scapula and the pelvis. Although a distinctive modification caused by the genets cannot be isolated, a scavenged scapula or pelvis with superficial scores and modifications can be indicative of genet scavenging and scattering. This preference can be beneficial in a forensic context, if skeletal elements are found in areas commonly known to have genet species inhabitants, such as the west-central part of KwaZulu-Natal and QwaQwa National Park in the Free State province, and a scapula or pelvis have been discovered, the scattering patterns of a genet can be utilized to minimise the time taken to locate the remaining skeletal elements.

There are no studies that have been conducted looking at the association between location on the skeletal elements and the scavenging species. In a study conducted by Keyes *et al.* (2021a), the authors observed the genet scavenging on the ribs of the pig carcass. It is important to note that there was a difference between the two studies. The current study used sparsely fleshed and articulated skeletal elements, whereas the study conducted by Keyes *et al.* (2021a) utilized whole pig carcasses. This difference has influenced the scavenging behaviours of the genets as the whole pig carcass offered soft tissue to be scavenged on that was not offered by the skeletal elements.

5.2. Serval scavenging

In the current study, the most common postmortem modifications observed that was caused by servals were scores. Pits, furrows, and gnawing was also observed on the skeletal elements. The most significant postmortem modification was the furrowing observed in Figure 4A. However, this modification is not distinctive enough to be isolated to the serval species. There have not been many studies conducted on the scavenging habits of the serval species.

5.2.1. Types and characteristics of the postmortem modifications caused by servals

In a study conducted by Keyes *et al*. (2019), the authors performed a study similar to the current study, however different animals were used. The animals of interest were the lion, leopard, and caracal (all part of the feline family) who all caused distinctive furrows in gnawed proximal ends of the long bones, such as the one observed in the current study (Figure A). Although this does not isolate the postmortem modification to the serval species, the modifications are distinctive enough to identify the general type of animals as being part of the cat family (Haynes, 1983; Keyes *et al*., 2019).

Apart from the distinctive furrowing modification observed above, servals are not commonly observed scavenging in the wild and little research is available regarding the modifications observed in other studies. In a research paper by Furstenburg (2008), the serval is described as an opportunistic feeder, but has to be lured with live bait as they do not scavenge and will not be lured by a carcass. However, in a study conducted by Keyes *et al.* (2021b), pig carcasses were placed in a semi-urban environment, as proxies for human remains, and the scavenging behaviours of wild animals were observed. The serval was seen marking itself in a process called scent marking. Scent marking is accomplished by an animal rubbing itself on the carcass (Keyes *et al*., 2021b) which provides the animal a means to defend resources (Bidder *et al*., 2020). Although this behaviour was observed, no serval specific modifications were noted on the skeletal elements of the pig carcass. This could be an indication that servals do not scavenge in the wild but will scavenge in captivity as a source of enrichment.

Although the furrowing modification defined above displays a unique characteristic to isolate it to the cat family, the modification cannot be isolated to the serval species and cannot be used in a forensic analysis. Due to the human intervention, peri-urban environments are less likely to have large carnivore species (Abay *et al.*, 2010), including large felids, and servals are amongst the one of many species in the cat family that can be abundantly found in these environments. Therefore, if a skeletal element is found with the characteristic modification described above, forensic experts can utilize the scattering patterns knowledge of the species that belong to the cat family that are known to be inhabitants of that area to minimise the amount of time taken to locate scattered remains. Furthermore, this modification can also be utilized to differentiate between perimortem, and postmortem modifications caused by animals or humans.

5.2.2. Location of postmortem modifications caused by servals

In the current study, it was observed that the servals scavenged largely on the shaft of the ribs and shaft epiphysis of the long bones. Although the chi-square test showed that there was an association and a preference between the scavenging species and the location on the skeletal elements, it is important to note that the above-mentioned locations were not scavenged on consistently in each of the three replicates. Therefore, it appears that the locations of scavenging modifications are opportunistic and not a species-specific pattern of scavenging behaviour. However, no previous studies have described the modifications of the servals or noted the specific location preference by servals. This means that the skeletal element scavenged on and the location on the skeletal element that was scavenged on cannot be used by forensic experts to indicate that servals were an engaging species at the crime scene.

5.3. Warthog scavenging

Similar to servals and genets, the most commonly observed modification by warthogs was scores, however the width of the scores were more variable that those observed with servals and genets. This could indicate that the warthog causes more modifications with its teeth than its claws. Furthermore, even though the warthog did not display the most variable types of modifications, other types of modifications, such as gnawing were observed more frequently.

5.3.1. Types and characteristics of postmortem modifications caused by warthogs

The most consistently observed modification was the deletion of the ends of the spinous process due to gnawing and was observed every week on at least one of the thoracic vertebrae placed in the enclosures. As warthogs are one of the most common scavengers found in the wild and peri-urban environment, they have been extensively researched in South Africa, including the modifications inflicted on skeletal elements.

In the study conducted by Keyes *et al.* (2021a), warthogs were observed scavenging on the pig carcasses once the carcasses were in the skeletonized stage of decomposition, and were observed to only scavenge in summer. It was noted that the warthogs in this study consumed whole skeletal elements and caused considerable damage to the skeletal elements, leaving only splintered and fragmented skeletal elements (Keyes *et al*., 2021a), which was also observed in the current study. Similar to the previous study, a study conducted by Field in 1970 showed consumption of skeletal elements by warthogs, however further research needed to be conducted into the species-specific modifications as that was not the aim of the study. Conversely, the current study observed a lot of scores on the bones that could have been caused by the teeth or claws of the warthog and a possible reason for this observation could be owing to the isolation of the warthog. At the time of the study, the warthog was the only species of its kind in its habitat at the NZG which eliminated all inter- and intra-species competition that is often observed in the wild. Furthermore, as the animals in the zoos are fed a strict and consistent diet, the warthog was not scavenging for the purpose of nutrition and obtaining a food source, they were scavenging for enrichment, which is also commonly provided to the animals through the placement of a horse head or other skeletal elements in the enclosure. The above-mentioned factors allow for the warthog to scavenge at a slower pace, allowing for more distinct and less intense modifications to be observed. Alternative possibilities for the additional scores, less intense modifications and lack of complete destruction of a skeletal element, could be due to different species of skeletal elements being used. The above-mentioned studies utilized pig carcasses, which are often used as human analogues due to size and weight similarities, ease of availability and decrease in ethical complications (Matuszewski et al., 2020, Keyes *et al.,* 2022).

The methodology used in the current research (using a captive warthog in isolation) may not allow for distinct modifications to be isolated to warthogs and a different approach is suggested for future research. However, the extent of modifications observed do suggest that warthogs inflict a greater level of postmortem modification to skeletal remains, which warrants their further investigation.

5.3.2. Location of postmortem modifications caused by warthogs

It was observed that the spinous process of the thoracic vertebrae was scavenged on in all three replicates. Unlike the servals and genets, multiple studies have been conducted on warthog scavenging and have noted the locations on the skeletal elements that the warthog scavenged on. However, the statistical correlation of the warthog and location on the bone scavenged has not been noted or explored in any previous studies. Keyes *et al.* (2021a) observed that the warthog scavenged mainly on the ribs and vertebrae of the pig carcass. Although this is similar to the current research (the vertebrae were both commonly scavenged on) the current research observed modifications on the spinous process on the thoracic vertebrae whereas Keyes *et al.* (2021a) observed modifications on the transverse processes. A possible explanation for these differences could be due to the skeletal elements in the current research being cut in half by the butcher prior to the skeletal elements being placed in the habitats, whereas the comparative study used a whole pig carcass.

Furthermore, the chi-square test conducted indicated that there was a preference that animal species have for the types of bones they scavenged on, as well as the location on the bone in which was scavenged. In the current study, it was observed that this association was between the warthog and the thoracic vertebrae. This can be beneficial to forensic investigations, as the intense modifications observed above, as well as the type of skeletal element found could be an indication of warthog scavenging, if found in areas known to have a large warthog population. This means that forensic investigators can utilize the pre-existing knowledge on warthog scavenging and scattering to differentiate perimortem and postmortem trauma, as well as minimise the time taken to locate the rest of the skeletal skeleton, if scattering occurred.

5.4. Suricate scavenging

The suricates displayed the same common modifications observed as the above-mentioned animals, which was scores. The only variation observed in modifications was one or two pits observed on the proximal epiphysis of a long bone. Similarly, to the genets, the scores that were observed were extremely narrow and most likely caused by the claws of the suricates rather than the teeth. Similar to the servals and the genets, not a lot of research has been conducted on the postmortem modifications caused by suricates in the wild or in a captive environment and the reason for this is unknown. However, suricates, more commonly known as meerkats, are part of the mongoose family, meaning that it may be possible to isolate modifications to a family rather than a species, as mentioned for servals and the cat family.

5.4.1. Types and characteristics of postmortem modifications caused by suricates

In a study conducted by Keyes *et al.* (2022), slender mongoose were the most abundant scavengers observed in the veld. The bite marks patterns were explored, however possible modifications by claws were not explored. The authors found that very few modifications were found on the skeletal elements. As these results are contradictory to the current study, the modifications caused by the suricates and the mongoose family cannot be classed together as seen with the servals. The modifications that were observed included consumption of the rib ends, and the transverse process of the vertebrae (Keyes *et al*., 2022). Another study conducted in Cape Town by Spies *et al.* (2018), studied the scavenging activities of the Cape grey mongoose. Due to the increased size of the Cape grey mongoose, the modifications to the bones were more damaging than that observed for the slender mongoose. The authors found that the epiphyseal ends of the long bones and vertebral spines were damaged, and the ribs were completely destroyed (Spies *et al*., 2018). The modifications observed for the suricates in the current study are not comparable to the studies mentioned above and therefore the scavenging modifications of the mongoose and suricates cannot be grouped.

In the current study, the suricates did not produce any modifications that are distinctive and variable from the rest of the animals, and modifications cannot be isolated to suricates. Therefore, it is recommended that in cases where superficial scores are observed on remains found in environments inhabited by suricates, their postmortem impact should be taken into consideration, especially when superficial sharp force trauma is evident on the remains.

5.4.2. Location of postmortem modifications caused by suricates

The infraspinous fossa of the scapula displayed consistent modifications in all three replicates. The scavenging modifications caused by suricates have not been previously studied and there is no available research on species-specific modifications caused by suricates, including the location on the skeletal elements. Therefore, the results of the present study are novel and warrant further investigation.

Furthermore, the chi-square test conducted indicated that there was a preference that animal species have for the types of bones they scavenged on, as well as the location on the bone in which was scavenged. In the current study, it was observed that this association was between the suricates and the scapulae. This information can be beneficial to forensic investigations, as scapulae found in areas known for high suricate populations can be studied and suricate scattering patterns can be utilized, along with additional retrieval methodologies, to locate the remaining skeletal elements, if applicable. Similarly, if the above occurs, forensic experts can differentiate between perimortem modifications and postmortem superficial modifications inflicted by the suricates, in areas densely populated with suricates.

5.5. The characteristics of postmortem modifications caused by the different scavenging species

Isolating specific characteristics of modifications to perpetrating scavenger species can be beneficial to forensic investigations as it can aid in identifying scavenger species and their scattering patterns. There is limited research that has investigated the characteristics of modifications caused by the species used in the current study.

The current study focussed on four different characteristics: width (narrow or wide), depth (shallow or deep), length (long or short) and shape. Understanding and isolating the characteristics of the postmortem modifications individually or grouped allows for the possibility to isolate scavenging patterns to specific scavenging species. Furthermore, it can also help provide a better understanding as to whether the modifications were caused by the tooth or claw of the animal, or possibly by human intervention.

In the current sample set, the warthog did produce narrow and shallow scores that are indicative of modifications using their claws, furthermore, as warthogs have larger claws the scores were not as narrow as ones observed in suricates, genets, and servals. This allows for differentiation between claw marks observed in suricates, genets and servals, and warthogs. Finally, claw marks are typically u-shaped in a cross-sectional profile and this characteristic can only be further explored if the bones are cross-sectioned. However, the shape difference could be beneficial in differentiating between a bite mark and a claw mark. A bite mark was differentiated from a claw mark in the current study based on the depth and width of the score or if there was a presence of pits. Genets, suricates, and servals produced slightly narrower scores that were a slightly deeper than those commonly observed in warthogs. However, the bite marks observed in genets, suricates and servals are often present in groupings and parallel to one another rather than overlapping and superficial.

The only characteristic that is not explored in literature is the length of the modifications. In the current study, a wide variety of scores of differing lengths were observed. The most characteristic lengths were observed by the genet and the suricates. Both species caused modifications on the scapula near the spine that were the length of the spine. Due to the shallow and narrow characteristics observed, the marks could have been caused from clawing by the animals, through the animal trying to grasp the skeletal element to obtain a grip on the skeletal element. Furthermore, it was noted that these characteristic modifications were observed on opposite ends of the spine of the scapula with the genets preferentially scavenging on the supraspinous fossa and the spine, whereas the suricates preferred the infraspinous fossa and the spine. These two events were not isolated, and modifications were also observed on the other fossa, however a possible preference was observed. Even though a preference was observed on the scapula and the same modification was observed in all three replicates for both the suricates and the genets, the modification does not display characteristics that are unique or distinct enough to allow for the genets and suricates to be defined as the perpetrating animal species. Therefore, all species studied did not display species-specific characteristics in length and further research will need to be conducted to explore these characteristics in a wild environment as opposed to a captive one.

5.6. Criteria used in scoring the intensity of postmortem modifications found on skeletal elements

The consistent scores obtained by the independent rater working alone suggest reliability and repeatability in the results of the current study, as indicated by Cohen's Kappa coefficient. As the criteria was uniquely developed for this study, the results of the intensity scores from the current research cannot be directly compared to other studies. The main aim in developing this criterion was to provide an additional tool for forensic experts to assess the intensity of damage done to skeletal elements due to scavenging. This could assist in identifying species responsible for scavenging by expanding and creating a database of scavenging intensity and comparing these scavenging intensities to active forensic investigations, to determine if scavenging activities could have taken place. This will allow forensic experts to differentiate between perimortem and postmortem trauma, as well as assist with identifying animal species for scattering pattern analysis and skeletal element retrieval.

Although the current criterion cannot be utilized to identify the animal as the perpetrating animal, it can provide forensic experts with a guide on modifications made through an overall look at different skeletal elements. For example, the thoracic vertebrae with a score intensity range of 0.00-3.00 can be indicative of warthog scavenging due to the complete deletion of the spinous process, or any other deletions that may be observed. Conversely, if skeletal elements are found in an area that is densely populated by genets, if the modifications present on the elements does not exceed 1 and are superficial in nature, the scavenging patterns of a genets can be used as an explanation for postmortem modifications in the forensic investigation. However, there is a wide range of irregularities in the current data set, where for example a location on a skeletal element was superficially scavenged on in one replicate and no other modifications were observed in the other replicates, or on any other areas. This means that confusions can arise with animals that do not present with consistent intense or superficial modifications in the same locations on the same skeletal elements. The above scenario is the biggest limitation observed in this current objective and with the scoring criteria. This is a limitation as the ranges of the scores do not positively reflect the intensity of the modifications caused to the bones.

A possible correction for this limitation would be to modify the criteria and allow for stricter scoring, i.e. a score of 1.00 will still be for minimal modifications that are not significant, but an additional criteria should be assigned for a score of 2.00 to account for more severe damages to the bone without removal of elements, i.e. more frequent, and deeper scores with possible gnawing and furrowing, then the score of 3.00 becomes the new score of 2.00 and a score of 4.00 becomes the new score of 3.00. This would have allowed for a higher score to be assigned to the removal of the spinous process, whilst the minimal scores observed on the scapula would remain at a score of 1.00.

Furthermore, the current criterion can be adapted to be utilized for more than scoring intensity on skeletal elements caused by scavenging and taphonomy influences. The criteria can be adapted to score the intensity of perimortem trauma through the refinement of the method for the different types of traumas, such as sharp force trauma. This can allow for further analysis, as well as comparison of intensity of modifications for postmortem trauma caused due to taphonomic influences.

Chapter 6: Conclusion

The aim of the current study was to describe the nature of postmortem modifications of skeletal elements caused by common small scavenging animals found in peri-urban environments in southern Africa. The authors utilized four study species commonly found in peri-urban environments in southern Africa, suricates, servals, genets and a warthog.

The current research explored four objectives to achieve the aim. The first objective explored the types of postmortem modifications caused by each scavenging animal. The most common modification observed throughout all the scavenging species observed was superficial scores and was observed by all scavenging animals studied.

The location of postmortem modifications on the different skeletal elements was statistically tested and the result indicated that there is an association between the scavenging animal and the location on the bone that the animal was scavenge on, indicating that there is often a preference.

The characteristics of the postmortem modifications were also described according to length, depth, breadth, and shape. The study also explored whether the modifications were often observed in singles or multiples. As most of the modifications observed were scores, the scores observed were mainly superficial suggesting that they were likely caused by the claws rather than the teeth of animal. The final objective was to develop a criterion that could be used to score the intensity of modifications caused by different scavenging animals. The criteria was used by the author to score the intensity on all the skeletal elements and then an independent rater was used to ensure the validity of the results using Cohen's Kappa. As the statistic was agreeable, the results are valid and repeatable.

Therefore, none of the species studied exhibited scavenging modifications that were species-specific or unique enough to identify the species. The descriptions and locations of the modifications described are indicative of scavenging modifications and are unique enough to not be confused with peri-mortem trauma. Furthermore, the current research did provide information regarding skeletal elements which were preferentially scavenged by each study species, and specific locations on the elements that are preferred by the different species.

6.1. Limitations of research

The research initially included an objective that studied the behavioural patterns of the animals in the enclosures. However due to the positioning of the cameras and the curiosity of the animals leading to interactions with the cameras, leading to the cameras being displaced from the original position and the images captured were not of the animal species scavenging, but rather the ground or the sky. Therefore, that objective was removed due to a lack of usable footage as the behavioural patterns of the animal species scavenging could not be studied

As the research was conducted in the NZG, which had strict rules surrounding the diet of the animals, pig carcasses could not be used. This would have been more ideal, as pig carcasses are often used as proxies for human carcasses due to the size of certain pig carcasses. If whole pig carcasses could have been used, objective 2 would have been more specific in terms of the results obtained. However, the use of pig or bovine skeletal elements would have been and was a limitation as their skeletal elements are vastly different to that of human skeletal elements in terms of structure of the bone.

6.2. Recommendations for future research

It is recommended that future research be conducted on the behavioural patterns of these animal species in a captive setting to better understand the modifications observed in the current study. This objective could be obtained by placing cameras off the ground from the different animal species, away from their reach.

This further research will also allow for the examination of intraspecies competition for species that have multiple of the same species in the same enclosure, as well as to see how the animals react with the skeletal elements in captive environment compared to in the wild.

It is recommended that the study be reconducted with a larger number of species per species group, as well as for a longer period to allow for more results to be obtained and more statistical comparisons to be conducted.

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Appendices

Appendix A: An Approval letter for the study by the chief director of veterinary services, Dr MD Nemudzivhadi

GAUTENG PROVINCE
AGRICULTURE AND RURAL DEVELOPMENT
REPUBLIC OF SOUTH AFRICA

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Enquiries:	Dr N Jordaan
Telephone:	0729042478
Reference:	Scavengers

Ms. Roxanne da Costa
Principal Investigator

Subject: Approval letter for the research study: Post mortem modifications of skeletal elements caused by common small Southern African scavenging mammals found in a peri-urban setting.

Dear Ms. Roxanne da Costa

The above matter has reference. This letter serves to confirm that the Gauteng Department of Agriculture and Rural Development is in support of Ms. Roxanne da Costa Section 20 application to the Department of Agriculture, Land reform and Rural development to perform research in respect to the study entitled: "Post mortem modifications of skeletal elements caused by common small Southern African scavenging mammals found in a peri-urban setting." This study is planned to start 1 August 2021 and run until 31 December 2021.

The sample of the study will be bovine bones sourced from a local butchery. The bite marks on the bovine bones caused by scavenging animals in enclosures at the National Zoological Gardens of South Africa will be examined.

All biological waste must be disposed of according to your protocol.

Trusting you will find this in order.

Yours faithfully

DR MD NEMUDZIVHADI
CHIEF DIRECTOR: VETERINARY SERVICES
DATE: 2021-07-12

Appendix B: Permit from the Agriculture, Land Reform and Rural Development Department of South Africa (Department of Agriculture, Forestry and Fisheries)

agriculture, land reform
& rural development

Department:
Agriculture, Land Reform and Rural Development
REPUBLIC OF SOUTH AFRICA

Directorate Animal Health, Department of Agriculture, Land Reform and Rural Development
Private Bag X138, Pretoria 0001

Enquiries: Ms Marna Laing • Tel: +27 12 319 7442 • Fax: +27 12 319 7470 • E-mail: MarnaL@dalrrd.gov.za
Reference: 12/11/1/1/18 (2059NC)

Responsible person: Ms. Roxanne da Costa
Institution: National Zoological Gardens, 232 Boom Street, Pretoria. Forensic Pathology Services(FPS), 25A Hospital street, Johannesburg.
Email: roxyrdc@gmail.com

Dear Ms. Roxanne da Costa

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

Title of research project / study: "Postmortem modifications of skeletal elements caused by common small Southern African scavenging mammals found in a peri-urban."

Your application, requesting permission under Section 20 of the Animal Diseases Act, 1984 (Act no 35 of 1984) to perform the research project or study stipulated above, refers.

Appendix C: Approval from the South African National Biodiversity Institute

SANBI
Biodiversity for Life
South African National Biodiversity Institute

SANBI/RES/P2021/13

27 August 2021

Roxanne da Costa
University of the Witwatersrand

OUTCOME OF RESUBMITTED RESEARCH PROPOSAL

This letter serves to inform you that your resubmitted research proposal titled "Postmortem modifications of skeletal elements caused by common small Southern African scavenging mammals found in a peri-urban environment" is **approved** by the SANBI NZG Animal Research Ethics and Scientific Committee (ARESC).

The following provisos should be taken into consideration:

1. Inform the ARESC of completion or termination (with reason) of your research at the SANBI.
2. Submission of an annual progress report in November of each year. Failure to submit a progress report may result in approval to be withdrawn.
3. Submission of a written request for any extension or modification of the research project.
4. SANBI should be acknowledged in all reports, scientific publications and conference contributions.

IMPORTANT: It is your responsibility to ensure compliance with Section 20 of the Animal Diseases Act 1984 (Act 35 of 84) that applies to "investigation, experiment or research" or any other relevant permits. For any adverse event during the research, you need to complete the adverse event form and submit it within 3 working days.

The research project is registered on the database as P2021/13. Please use this project number in all future correspondence.

Thank you for making use of SANBI NZG as a research platform.

Yours sincerely

Prof Antoinette Kotze
Chairperson: SANBI NZG Animal Research Ethics & Scientific Committee

Appendix D: Turnitin Report for the current research

Roxanne da Costa_1601262_final dissertation.pdf

ORIGINALITY REPORT

2%	2%	1%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

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