2025

Taphonomic analysis of Sus scrofa scavenging behavior and corresponding tooth mark patterns on skeletal remains

BOSTON UNIVERSITY

ARAM V. CHOBANIAN & EDWARD AVEDISIAN SCHOOL OF MEDICINE

Thesis

TAPHONOMIC ANALYSIS OF *SUS SCROFA* SCAVENGING BEHAVIOR AND CORRESPONDING TOOTH MARK PATTERNS ON SKELETAL REMAINS

by

AMANDA HARTMAN

B.A., Seton Hall University, 2021

Submitted in partial fulfillment of the

requirements for the degree of

Master of Science

2025

Approved by

First Reader

James Pokines, Ph.D.
Associate Professor of Anatomy and Neurobiology

Second Reader

Tara Moore, Ph.D.
Professor of Anatomy and Neurobiology

ACKNOWLEDGMENTS

I would like to thank Dr. James Pokines and Dr. Tara Moore for your guidance, knowledge, and feedback during the writing and editing processes of this thesis. This thesis would not have been completed without the support and the education you have given me throughout the past two years.

I would also like to thank Codman Community Farms for being so generous and allowing me to visit your farm to feed bones to your pigs. Thank you for taking the time and making sure I was safe while in the pig enclosure distributing and collecting the bones.

Special thanks to Nil and Pierre for their expertise in statistics and teaching me how to conduct and understand the statistical analyses.

I am also eternally grateful for my family and friends, both at home and at school, for pushing me to finish this thesis and encouraging me to try my best. Finally, I am grateful for my partner, who is my biggest supporter, for giving me the courage I needed to overcome challenges over the past two years.

TAPHONOMIC ANALYSIS OF *SUS SCROFA* SCAVENGING BEHAVIOR AND CORRESPONDING TOOTH MARK PATTERNS ON SKELETAL REMAINS

AMANDA HARTMAN

ABSTRACT

The present research examined the taphonomic effects of pig (*Sus scrofa*) scavenging on skeletal remains. There is extensive research about common vertebrate scavengers such as canids, felids, and rodents, but data on pig scavenging, especially in the United States, are limited. One way to differentiate between the scavenging activity of pigs and other vertebrates is to examine and measure tooth mark patterns and gnawing characteristics. The present study hypothesized that pigs create tooth marks that are located more frequently as well as are larger in size on the epiphyses of long bones, spinous processes of vertebrae, and sternal ends of ribs than the diaphyses, centra, and heads/shafts. It was also hypothesized that pigs damage bones in a manner that is distinguishable from other common scavengers such as canids.

In the present study, a sample of 100 Gloucestershire Old Spot heritage pigs from Codman Community Farms in Lincoln, Massachusetts were given a variety of white-tailed deer (*Odocoileus virginianus*) bones to gnaw on, after which their scavenging behavior was recorded. The pigs were fed 100 disarticulated long bones, 10 half rib cages, and 10 necks for a minimum of 575 elements. The bones were cleaned and analyzed for tooth pits, punctures, scores, and furrows, and other damage at Boston University, Chobanian and Avedisian School of Medicine. Photographs of the bones and tooth marks were taken and administered through the open-source imaging processing

program ImageJ to measure the length and breadth of each tooth mark. Statistical analyses were conducted to determine if the location of the bone was a statistically significant factor in the frequency and size of pig tooth marks, and to distinguish between pig and canid gnawing by comparing their tooth mark sizes and locations.

Pits were the most prevalent tooth mark produced by the pigs (63.5%), contrary to previous research. There was a statistically significant difference between the number of tooth marks and the location on the bone. Pits ($p = 0.042$), punctures ($p = <0.001$), and furrows ($p = 0.003$) on the long bones were more commonly found on the epiphyses; pits ($p = 0.038$) on the vertebrae were more commonly found on the spinous processes; and pits ($p = <0.001$) and scores ($p = <0.001$) on the ribs were more commonly found on the heads/shafts.

It was also found that the relationship between the size of tooth marks on long bones and the location of the bone was statistically significant. Pit length ($p = 0.032$), breadth ($p = 0.021$), puncture breadth ($p = 0.023$), and score length ($p = 0.017$) and breadth ($p = <0.001$) on the long bones were larger on the epiphyses than the diaphyses. Only score length ($p = 0.002$) on the ribs was significantly larger on the sternal ends than the heads/shafts, so the size of tooth marks on ribs was not dependent on the location of the bone. When comparing canid tooth marks from previous research (Andrés et al. 2012; Sala et al. 2014; Yravedra et al. 2014) and the pig tooth marks from the current study, the results indicated that the two scavenger taxa could be confidently distinguished if epiphyseal pit length and breadth ($p = <0.001$ to 0.002) are measured and compared. If pits on the diaphyses ($p = <0.001$ to 0.754) and score breadth on the diaphyses ($p =$

<0.001 to 0.437) were being used to compare, then caution should be taken. Overall, the average length (1.43 mm) and breadth (0.92 mm) of pits on the epiphyses produced by pigs were significantly smaller than canid pit length (2.40-3.61 mm) and breadth (1.90-2.70 mm).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

OR .... Olfactory receptor

PMI .... Postmortem interval

SD .... Standard deviation

SPSS .... Statistical Package for the Social Sciences

INTRODUCTION

Taphonomy and Scavenging

In forensic anthropology, the study of taphonomy is applied to reconstruct postmortem events that lead to the modification of recent human remains (Ubelaker 1997). Taphonomy originated as a branch of paleontology to describe the process of organic material decaying and fossilizing, but it can also be utilized to evaluate the postmortem interval (PMI), or the time between death and discovery, and distinguish between natural and human-induced trauma when human remains are discovered (Berryman 2002; Ubelaker and DeGaglia 2020). The postmortem modification of human remains makes it difficult to identify antemortem and perimortem trauma, so it is important to be familiar with the multiple taphonomic processes when examining human remains. In a medico-legal setting, taphonomy plays a significant role in characterizing the modifications made to human remains and provides an explanation for how and why those modifications took place (González et al. 2021). Taphonomy consists of biological processes such as scavenging, trampling, consumption, and dispersal of remains, as well as physical processes, such as weathering, diagenesis, burial, and water transport (Ubelaker 1997). These processes affect decomposition rates and make reconstructing the circumstances surrounding the death of a recovered decedent difficult (Indra et al. 2022).

The taphonomic process that was investigated in the present study is vertebrate scavenging. Scavenging causes soft tissue loss and skeletal element disarticulation, consumption, and dispersal, often leaving tooth marks on the bones that can be mistaken for sharp force trauma (Ubelaker 1997). Research has shown that there is an interspecific variation of tooth marks among scavengers that corresponds to their dental morphology and eating behavior, but it is still unknown whether tooth mark type alone is sufficient to identify scavengers correctly at the species level (Indra et al. 2022; Pobiner 2007; Young et al. 2015). However, there is evidence that species-typical tooth marks and damage to remains can be used to narrow down scavenger taxa if appropriate documentation methods, such as measuring the length and breadth of tooth marks, are used (Indra et al. 2022; Young et al. 2015). Scavenging can have a significant impact on the rate of decomposition and the condition of the remains. As a result, when performing the skeletal analysis, it is critical to be familiar with the indicators of scavenging activity. Scavenging is not limited to only carnivores, since omnivores and even herbivores have been documented gnawing on animal bones (Ubelaker 1997). Depending on the scavenger taxon, environmental factors such as rainfall and temperature will influence the rate and efficiency of scavenging. When resources are scarce, vertebrates will scavenge any carrion that they find if it has not already been fully decomposed by invertebrates (DeVault et al. 2003). Therefore, knowledge of specific and local scavenger taxon is necessary to identify damage caused by vertebrates.

The present study examined the taphonomic effects of pig (*Sus scrofa*) scavenging by observing their behavior, recording the degree and location of bone modification, and measuring tooth mark patterns. There has been previous research on pigs scavenging nonhuman remains (Brown et al. 2006; Domínguez-Solera and Domínguez-Rodrigo 2009; Fillios 2011; Galdikas 1978; Greenfield 1988; Indra et al. 2022; Wilcox and Van Vuren 2009), but there is limited evidence of their impact on human remains (Berryman 2002; Byrnes and Belcher 2021), indicating the need for further testing. Although there have been instances reported of pigs, both domestic and wild, attacking and killing humans in different circumstances, the bodies were recovered before the pigs could cause serious damage to the bones (Barss and Ennis 1988; Gitto et al. 2021; Manipady et al. 2006; Mayer 2013; Mayer et al. 2023; Mazingi et al. 2019). Pigs are omnivores and opportunistic feeders, so in the right conditions, they are known to consume human remains (Berryman 2002; Cameron 2010; DeVault and Rhodes 2002; McCann 2012). In cases where pigs have scavenged remains, it was noted that they may produce a distinct set of tooth marks and gnawing patterns that differ from those of carnivore scavengers such as canids (Greenfield 1988; Indra et al. 2022). Therefore, the tooth marks and patterns of pigs were compared to those of canids to determine if they are distinguishable from one another.

Canid Scavengers

The family Canidae includes coyotes (*Canis latrans*), wolves (*C. lupus*), domestic dogs (*C. familiaris*), and red foxes (*Vulpes vulpes*). Canids are among the most common carnivores found in North America and are frequently the taxon responsible for scavenging remains. Canids share similar scavenging behavior, such as means for dispersal, location and degree of bone modification, bite force, and patterns of consumption (González et al. 2021; Haglund et al. 1989; Haynes 1983; Indra et al. 2022; Pobiner 2007; Pokines 2022). However, there is currently inconclusive evidence available to distinguish fully interspecific tooth mark patterns between carnivore taxa, particularly canids, for multiple reasons. One is the lack of a standardized approach for conducting an experiment comparing tooth marks from carnivores, while another is the use of inconsistent methods for collecting and measuring tooth marks (Delaney-Rivera et al. 2009; González et al. 2021). For example, some studies will only collect data on one or two tooth mark types (pits, punctures, scores, and furrows) instead of all four, which makes it more difficult to distinguish between species. A third reason is the significant overlap in tooth mark sizes produced by different carnivore taxa (Andrés et al. 2012; Delaney-Rivera et al. 2009; Haynes 1983; Pobiner 2007).

Wolves and domestic dogs are two canid species that exhibit similar scavenging behavior and are two of the most commonly found carnivores that live in the same environments as pigs. Therefore, their tooth mark dimensions and scavenging behavior gathered from previous research was compared to that of pigs. More research on canid scavenging has been conducted than on pig scavenging, indicating that additional pig scavenging research as well as comparative studies are needed to help differentiate between the two taxa.

History and Evolution of *Sus scrofa*

The pig population in the United States is made up of wild, feral, domestic, and hybrid pigs (Evin et al. 2015; Gipson et al. 1998; Wood and Barrett 1979). Phylogenomic analyses of European and Asian domestic and wild boars concluded that wild boars first appeared in Southeast Asia during the early Pliocene 5.3-3.5 mya (Groenen et al. 2012). There was a phylogenetic split between European and Asian wild boars during the early

Pleistocene 1.6-0.8 mya, which caused distinct European and Asian lineages among boars. The split is thought to be caused from cold climates during the Calabrian stage, resulting in pig populations migrating throughout Eurasia, specifically western Europe and east Asia (Groenen et al. 2012). This theory is further supported by the appearance of *Sus scrofa* in the paleontological record during the early middle Pleistocene (800-900 kya) at Atapuerca, Spain and Zhoukoudian, China (Larson et al. 2007).

By 8000 BC Eurasian wild boars were domesticated when humans were transitioning from hunting-gathering to agriculture (Evin et al. 2015; Larson et al. 2005; McCann 2012). To adapt Eurasian wild boars to the new agricultural environment, humans started to breed pigs with preferred traits, and a gradual gene interchange resulted in domestication (Evin et al. 2015; Larson et al. 2005). After being domesticated, Polynesian settlers brought the Polynesian breed of pig to Hawaii around 900-1000 AD as a food source (Kirch 2011). Subsequently, in the 1700s, Captain James Cook and the first European settlers imported the European breed of pig to Hawaii to increase the food source (Nogueira-Filho et al. 2009). Domesticated pigs were also brought to the West Indies by Christopher Columbus in the 1490s and to the United States mainland by Francisco Coronado and Hernando de Soto from Mexico City in 1540 and 1541, respectively (Seward et al. 2004). In 1912, wild pigs were transported from Europe and Asia to Hooper Bald, NC, a shooting preserve, to increase the pig population for sport hunting (Wood and Barrett 1979). Feral pigs were once domestic pigs that now live in the wild. As explorers traveled, pigs were frequently left behind or escaped, resulting in the first populations of feral pigs in the United States (Seward et al. 2004; Wood and Barrett

1979). The pig population in the United States also increased due to natural dispersal and reproduction, escaping from commercial producers, human-mediated transportation, and the country's inability to control the current population (Gipson et al. 1998; Wood and Barrett 1979).

All subspecies of *Sus scrofa* interbreed, resulting in hybrids (Evin et al. 2015; Gipson et al. 1998; McCann 2012; Wood and Barrett 1979). After centuries of interbreeding, the existence of true wild pigs is unknown in the United States and the rest of the world, so the umbrella term "feral pigs" is used to refer to both wild boars and feral pigs, since hybridization is frequent, and it is difficult to differentiate between the two (Wood and Barrett 1979). Pigs also have short gestation periods, with an average of 7.5 pigs per litter twice a year, which greatly contributes to the increasing population (McCann 2012; Seward et al. 2004). Figure 1.1 depicts the population of wild/feral pigs in the United States as of 2023. There are an estimated 6 million wild/feral pigs, with most residing in the southern states as well as Hawaii. Compared to wild/feral, domestic pigs have the largest population of 72.5 million on US farms as of 1 June 2022 (Figure 1.2).

As omnivores and opportunistic feeders, a pig's diet can consist of anything that they consider edible, but they mainly consume foliage, fruit, roots, and invertebrates. However, pigs have been documented scavenging vertebrate carcasses (Berryman 2002; Brown et al. 2006; Domínguez-Solera and Domínguez-Rodrigo 2009; Wilcox and Van Vuren 2009) and sometimes hunting vertebrates (Choquenot et al. 1997; Pavlov and Hone 1982). One trait that aids pigs in their search for food is their enhanced sense of

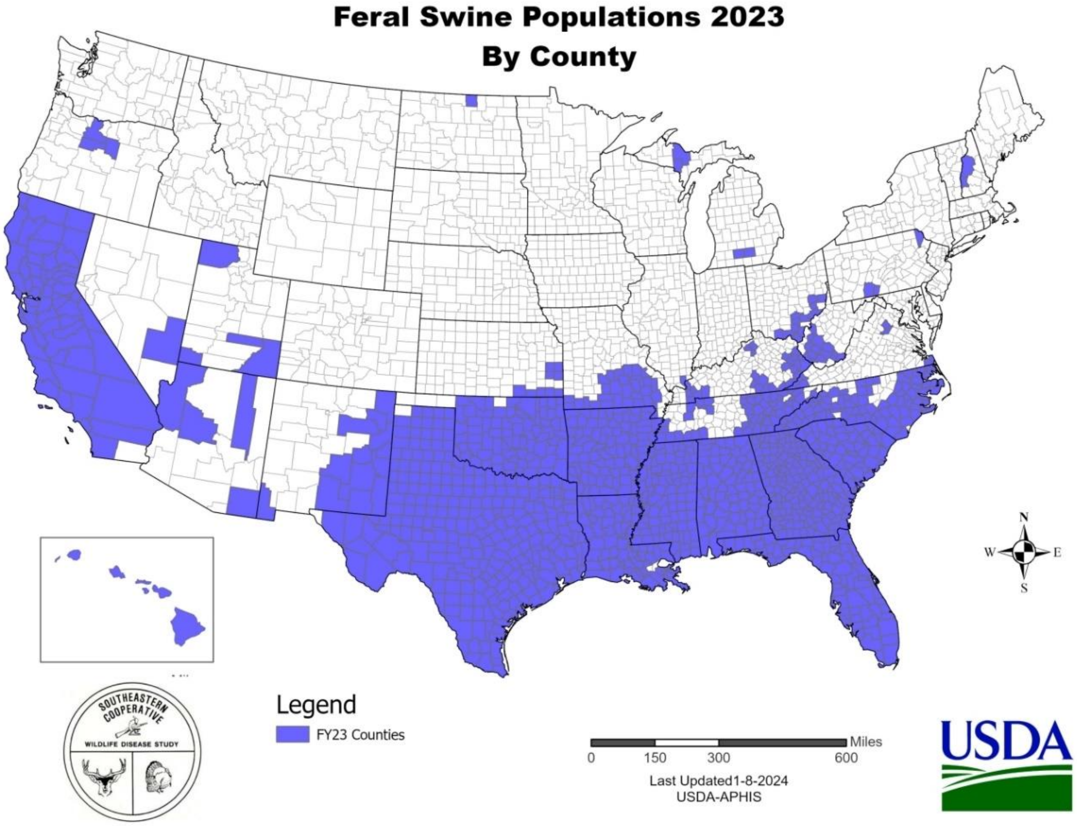

Figure 1.1. Distribution of wild/feral pig population in the United States in 2023 (USDA APHIS 2024).

smell. Pigs possess one of the largest repertoires of functional olfactory receptor (OR) genes, with 1,301 OR genes, of which 1,113 are functional, in comparison to cattle, dogs, and human, with an OR repertoire of approximately 970, 811, and 681, respectively (Glusman et al. 2001; Groenen et al. 2012; Kang et al. 2023; Nguyen et al. 2012). It has been documented that they can smell food up to one meter below the surface (Brinkley 2012; Domínguez-Solera and Domínguez-Rodrigo 2009). Pigs forage for food, such as roots and invertebrates, by rooting, or sticking their snouts beneath the ground, which can increase the likelihood of discovering human remains placed in a shallow grave (Brinkley

2012; Wilcox and Van Vuren 2009). Nevertheless, their heightened sense of smell may give pigs an advantage over other scavengers when locating carcasses.

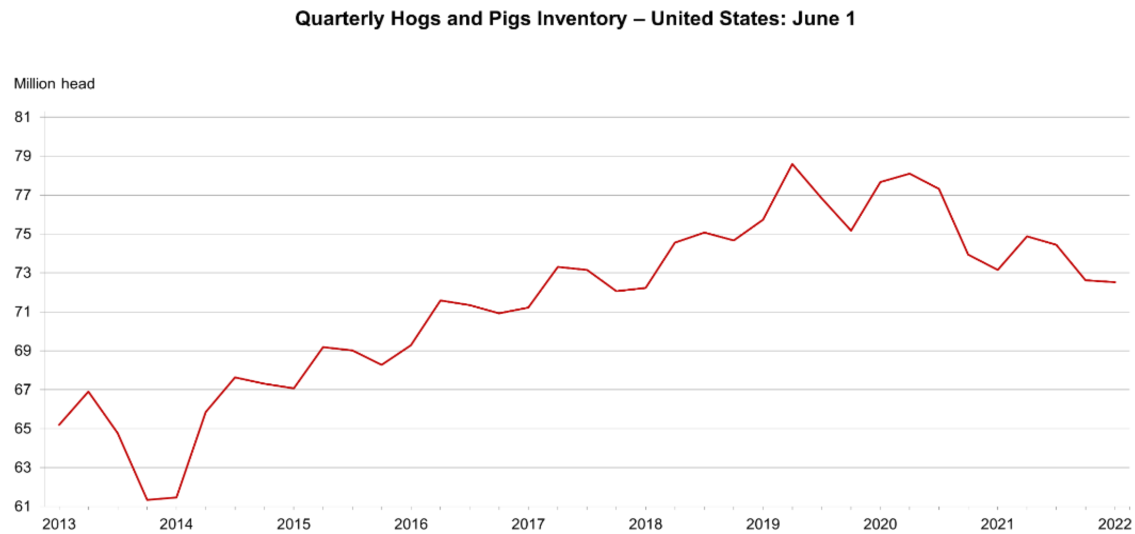

Figure 1.2. Population of domestic pigs on US farms from 2013 to 2022 (Matlock 2022).

Environmental Impact of *Sus scrofa*

Pigs pose a significant risk to wildlife communities due to their large population and dispersal (Loggins et al. 2002). Pigs compete with other animals for food and have access to invertebrates that are underground and thus not readily available to other animals, giving pigs a nutritional advantage due to their diverse diet (McCann 2012). Pigs also prey on other species, which can harm native populations (DeVault and Rhodes 2002; Domínguez-Solera and Domínguez-Rodrigo 2009; Loggins et al. 2002; Wilcox and Van Vuren 2009). For example, in the southern United States, pigs will prey on bobwhite quail (*Colinus virginianus)* and marine turtle populations (Chelonioidea), thus threatening and endangering those species (Seward et al. 2004).

In addition to negatively impacting wildlife, native plants are at risk of being destroyed and going extinct due to the intrusive eating behavior of pigs. When pigs are rooting for food, they damage tree seedlings along with hinder tree and other plant growth (Loggins et al. 2002; Seward et al. 2004). Agriculture is also greatly affected by pigs. It is estimated that pigs cause more than $1.5 billion in damages every year due to the destruction of property, crops, and preying on livestock (USDA APHIS 2020). Due to their extensive population and rapid reproduction rates, it is difficult for farmers to control the amount of pig damage to their property. Some farmers have attempted to build fences around their farms and implement other management strategies, but pigs continue to invade and kill their crops and farm animals (Seward et al. 2004).

Pigs can adapt to a wide range of environments, have a lack of natural predators other than humans, and are being relocated from other countries for recreational hunting, which inevitably expands and protects the pig population (Brinkley 2012; Seward et al. 2004). In addition to fencing, other efforts have been made to maintain and decrease the pig population, such as hunting, trapping, and leg snares, but no method has been effective enough to make a difference (McCann 2012; Seward et al. 2004).

If modified remains are discovered in an area known to be inhabited by pigs, they should be considered the primary scavenger until proven otherwise. The purpose of the present research is to determine the extent of bone modification and gnawing patterns of pigs to determine if they differ from canids. This will provide the forensic anthropologist with more reliable data on pig tooth mark measurements as well as information on how to distinguish scavenger species during their analysis.

Hypotheses of Current Study

It was hypothesized that pigs modify bones and provide visible tooth marks that are located more frequently as well as larger in size on the epiphyses of long bones, spinous processes of vertebrae, and sternal ends of ribs than the diaphyses, centra, and heads/shafts. It was also hypothesized that pigs produce tooth marks on bones that are distinguishable from other scavengers, especially carnivores such as canids. The tooth marks of pigs and canids were distinguished by comparing the tooth mark location and measurements based on data from the current study and previous research on canid scavenging.

PREVIOUS RESEARCH

Tooth Mark Classification

Tooth mark types, summarized by Pokines (2022), include pits, punctures, scores, and furrows. Pits are circular to oval superficial indentations on the bone surface that do not penetrate the bone interior, and they can be produced from either gnawing or grasping onto the bone. Punctures leave deeper depressions that penetrate the cortical bone into the cancellous bone. They are also circular to oval and can better preserve the tooth shape than pits. Binford (1981) stated that the size of punctures depends on the strength and size of the scavenger, implying that larger animals will produce larger and deeper punctures compared to smaller animals. It has been observed, however, that smaller animals can produce punctures that are just as large as those of larger animals, if not larger (Delaney-Rivera et al. 2009). One theory regarding this overlap is that smaller animals spend more time gnawing on the bone to compensate for their weaker bite force (González et al. 2021; Young et al. 2015). Scores do not penetrate the cortical bone, but the dragging of the teeth leaves linear striations typically perpendicular to the long axis of the bone that are three times longer than they are wide (Haglund 1997). Scores often mimic cut marks, but scores follow the contours of the bone, whereas cut marks do not (Binford 1981; Haglund 1997). Furrows penetrate the cortical bone also due to dragging of the teeth and leave marks three times longer than they are wide. Furrows are deep channels in cancellous bone, and extensive furrowing can obliterate previously made tooth marks as the bone is being gnawed on (Binford 1981; Pokines 2022).

Other Scavenger Gnawing Characteristics

In addition to tooth marks, scavengers can produce other types of modifications to bones including bone cylinders, crenellated edges, and edge polish. A bone cylinder occurs when the epiphyseal ends are scooped out and destroyed to access the bone marrow for nutrients (Haynes 1983; Pokines 2022). Crenellated edges have a chewed and crushed appearance, and they are often present on the margins of bone cylinders, but they can also appear when only some areas of the epiphyseal ends are broken off before it has the chance to become a cylinder. Furthermore, crenellated edges can be smoothed over due to licking and tooth wear to produce edge polish (Haynes 1983; Pokines 2022).

The ability to differentiate between scavenger taxa utilizing only tooth mark types and gnawing characteristics has yet to be examined thoroughly. There is significant overlap between tooth mark types and sizes among different species of carnivores that contributes to the difficulty of identifying the responsible scavenger. Therefore, the number of tooth marks, anatomical distribution of the tooth marks, bone fragmentation, dispersal patterns, degree of gnawing, and disarticulation pattern could potentially be used in conjunction to form a more accurate conclusion (Domínguez-Rodrigo and Piqueras 2003; González et al. 2021; Pobiner 2007). Other methods used to identify scavengers can also be applied, such as searching for hair/fur, track marks, droppings, urine, and saliva near the scene (Berryman 2002; Galdikas 1978; Pokines et al. 2017).

Jaw Morphology of Pigs and Canids

Tooth marks can vary in size and type depending on the scavenger's jaw morphology. Pigs have the most teeth of any domestic mammals (44 total), with a dental formula of 3/3, 1/1, 4/4, 3/3, or three incisors, one canine, four premolars, and three molars on both sides of the maxilla and mandible (Sack 1982). The lower incisors project outwards and are straight, whereas the upper incisors are curved for grasping, and the upper canines, or tusks, persistently grow throughout life but are reduced in size in domestic pigs (Hillson 1986; Sack 1982). The lower canines are robust and are used to sharpen the upper canines. Additionally, pigs have brachydont crowns and bunodont cusps, which are typical for omnivores, meaning the occlusal surface of their teeth are low-crowned and rounded for crushing and grinding food (Hillson 1986).

Dogs and wolves have a dental formula of 3/3, 1/1, 4/4, 2/3, so they only have two upper molars on both sides of the maxilla and mandible compared to pigs, which have three (Fonseca et al. 2015; Hillson 1986). Their incisors are close together and spatulate in appearance, and their canines are slightly curved, long, and pointed (Fonseca et al. 2015; Hillson 1986). Canid canines are also typically larger than domestic pig canines but smaller than boar canines, which grow upwards and projects outside the mouth (Hillson 1986). However, the main feature that differentiates canid from pig teeth are the carnassial teeth in the former. Carnassial teeth are cheek teeth that evolved into blades to rub against each other to cut through soft tissue (Hillson 1986; Pokines 2022). The maxillary fourth premolar and mandibular first molar are enlarged and their cusps are pointed to tear through skin and meat better (Haglund 1997). Additionally, canids have mesodont crowns and secodont cusps, i.e., their teeth are medium-crowned. and the cusps are sharper and more suitable for tearing compared to pigs, whose teeth are more adapted for crushing (Haglund 1997).

Pig Gnawing Characteristics

The most common tooth mark reportedly made by pigs are scores, and pigs have been observed creating pits, punctures, and furrows as well but not as often (Berryman 2002; Domínguez-Solera and Domínguez-Rodrigo 2009; Indra et al. 2022; Pobiner 2007; Pokines 2022). The scores are produced primarily from dragging their incisors over the bone to tear off soft tissue, and the scores are also broader and flatter than those of carnivores, which could be used to help identify the scavenger as a pig (Berryman 2002; Byrnes and Belcher 2021; Domínguez-Solera and Domínguez-Rodrigo 2009; Indra et al. 2022; Pokines 2022). If they gnaw hard enough, and especially on cancellous bone, the incisors could also create pits and punctures (Hillson 1986). Punctures and pits are also produced by premolars and molars, and they have been documented to be L-shaped in some cases (Byrnes and Belcher 2021; Domínguez-Solera and Domínguez-Rodrigo 2009; Pokines et al. 2017). Pigs are more likely to gnaw on the soft epiphyseal ends of the bone for easy access to the bone marrow, therefore requiring less bite force and time gnawing to reach the marrow cavity (Domínguez-Solera and Domínguez-Rodrigo 2009; Indra et al. 2022; Pokines 2022). Additionally, since the epiphyses are softer and easier to gnaw on than the diaphyses, tooth marks will be larger in size on the former (Delaney-Rivera et al. 2009; Domínguez-Rodrigo and Piqueras 2003). Small, thin bones such as ribs, facial bones, and vertebrae are likely to be destroyed and possibly consumed whole if the pigs spend a significant amount of time gnawing them (Pokines 2022). Furrows can be produced from repeatedly dragging either the incisors, canines, or premolars across cancellous bone, and pits and punctures are also produced by teeth other than the incisors (Byrnes and Belcher 2021). Since pigs may modify bones mainly with their incisors, they have a smaller bite force compared to other animals, since they usually use the teeth furthest away from the temporomandibular joint. Another bone modification observed from pig scavenging is surface peeling, which is characterized by thin cortical bone being peeled away and removed from the underlying cancellous bone on long bone epiphyses (Pokines 2022). While these traits have been identified as damage from pig scavenging, there is not enough data to conclude that pigs are the only animals with these traits, emphasizing the need for more research on pig scavenging behavior.

Carnivore Gnawing Characteristics

The varying jaw morphologies of pigs and canids may lead to differences or similarities in the tooth marks that they produce and the function of their teeth. As discussed in Indra et al. (2022) and Pokines (2022), canids produce predominantly pits, which can be created with the canines or carnassial teeth (Pobiner 2007). When more pressure is applied with the canines and carnassial teeth, then it will penetrate the cortical bone and create a puncture (Haglund 1997). Canids also use their incisors to tear off soft tissue and leave scores, similar to pigs (Burke 2013). However, canids have been observed leaving deeper scores compared to the shallow and broad scores left by pigs (Indra et al. 2022).

Canids produce more severe gnawing damage, because they use the teeth closest to the temporomandibular joint and have a larger bite force compared to pigs, who usually use the teeth furthest away (Pokines 2022). For example, furrows and punctures are more common with canid scavenging behavior compared to pigs, since it is easier for canids to produce those types of tooth marks (Haglund 1997). The stronger bite force of canids also contributes to their tendency to create bone cylinders with crenellated edges and edge polish, whereas pigs have not been observed creating bone cylinders nor edge polish, but crenellated edges can still be present on areas of the bone that the pigs gnawed on (Domínguez-Rodrigo et al. 2012; Pokines 2022). Canids will typically lay down, hold the bone with their front legs, turn their head to the side, and gnaw on the bone with their posterior teeth, which also creates scores on the diaphyses from their nails gripping the bone (Burke 2013; Pokines 2022). Pigs have been observed holding down carcasses with their front legs to help in ripping the soft tissue off, but they have not been reported to hold individual bones while gnawing on them (Pavlov and Hone 1982). Both canids and pigs prefer to gnaw on the less dense epiphyseal ends of long bones to access the bone marrow easily. Therefore, both species distribute tooth marks in similar areas (Abellán et al. 2021; Indra et al. 2022; Pokines 2022; Young et al. 2015). Another reason why bones are gnawed on for long periods of time is because of boredom. “Kennel pattern” describes the excessive gnawing done by domestic or captive animals when they have nothing else to do, which causes more damage to the bone than expected (Haglund 1997; Pokines 2022).

Another common scavenger, rodents will gnaw on bones with their incisors to gain nutrients and sharpen their teeth in the process, while also leaving striations perpendicular to the long axis of the bone as seen in pig gnawing (Pokines 2022). However, pig and rodent gnawing can be differentiated, since rodents will form broader and larger scores than pigs (Indra et al. 2022; Pokines 2022; Pokines et al. 2017; Ubelaker and DeGaglia 2020).

Pigs Scavenging Human Remains

Scavenging evidence in forensic cases is common when human remains are recovered from an outdoor site and postmortem damage is extensive. Examining the size and type of damage done to the remains can help identify the scavenger taxon. Ubelaker and DeGaglia (2020) examined 107 cases from the FBI from 1975 to 2019 that were reported to have nonhuman scavenging activity. The thorax was the most prevalent body region scavenged, and larger scavengers were the most common (69%). Pigs are considered large scavengers and are known to scavenge remains to access the viscera, which results in fractures to the thorax, facial bones, and pelvic girdle to break open the chest cavity (Berryman 2002; Galdikas 1978; Pavlov and Hone 1982; Pokines 2022; Ubelaker and DeGaglia 2020).

Berryman (2002) investigated a case in which human remains were thought to have been scavenged by domestic pigs. Human remains in an early stage of decomposition and surrounded by animal feces were found near an active pig pen. The facial bones, cervical vertebrae, left hand, and three fingers on the right hand were missing. The anterior midline was the area most damaged, with the sternum, ribs, clavicles, and pubic bones crushed. The ribs were also rotated outward so the scavenger could access the thorax and viscera. The tooth marks present were punctures and scores. The scores were made by the pig's mandibular incisors, which stripped the soft tissue from the bone and left broad, parallel marks. The scores are consistent with pig gnawing characteristics (Pokines 2022) and were found on the cranial vault, right pelvis, both clavicles, right rib 4, and left tibia.

Gitto et al. (2021) presented a case study of a man who was killed by a domestic pig in the pigsty of his farm. Although domestic pigs are known to be mostly placid, they can attack if provoked or when they are being captured, transported, or slaughtered. The injuries that he sustained were concentrated in the face and the upper and lower extremities as a result from blunt force trauma and bite marks. The blunt force trauma was caused by trampling, which resulted in multiple linear and parallel lacerations as well as bruises shaped like hoof marks on the skin. The forearms contained the most injuries, with fractures and the muscles, tendons, and nerves protruding from the lacerations, the latter of which most likely resulted from the victim trying to defend himself. Additionally, the lower extremities had abrasions and contusions most likely from the pig charging into the victim. The thorax had no evidence of damage or blunt force injuries, which could be due to the victim wearing clothes that covered his torso but left his arms and legs exposed. Pig biting can result in a “hole and tear” injury in the soft tissue, because pigs will typically bite the skin and then pull, causing a puncture wound in the skin that is then ripped away. Carnivores also can produce a “hole and tear” injury, except they will shake their head after gripping onto the skin instead of pulling away (Bury et al. 2012; Indra et al. 2022). Domestic pig attacks are not often fatal, but they can lead to serious injuries from the pig trampling, kicking, and biting the victim. It is important to be familiar with not only the way pigs modify bones, but also soft tissue, so pig attacks can be differentiated from a homicide.

A case where a wild pig attacked and killed a human in India was presented by Manipady et al. (2006). Wild pigs will use their tusks when charging to injure their opponent, resulting in them aiming for the legs of adults and the abdomen of children. Since the victim was squatting down during the attack, the pig charged into his abdomen and caused evisceration, which has been reported happening before in other pig attacks (Barss and Ennis 1988; Mayer et al. 2023; Mazingi et al. 2019). Manipady et al. (2006) also compared the injuries in this case to those caused by carnivores. Since carnivores attack with their upper canines, the direction of the injury would be downwards from above, and pigs would attack upwards from below, because they put their head down and aim up with their tusks. The lacerations were described as having rugged edges and there were no defensive injuries, which ruled out potential homicide.

Fatal pig attacks initially believed to be homicides were presented by Mayer et al. (2023). Between 2000 and 2019 in 57 nations, there were 163 reports of fatal pig attacks resulting in 172 deaths, with three of those deaths investigated as homicides. Each case involved the victims being reported missing for hours to a day, and one case resulted in the death of two people. In the first instance, the victim had lacerations and punctures that were thought to be caused from a sharp-force object, but pig tracks around the victim indicated that it was a pig attack. The two victims in the second instance also had lacerations and punctures, but a wild pig with blood on its face charged at the investigators, which confirmed that it was also a pig attack. In a medico-legal setting, being familiar with the local fauna and their behavior is critical in investigating a crime scene, since animal attacks can often be overlooked as homicides.

Pigs Scavenging Nonhuman Remains

Greenfield (1988) was among the first to investigate the taphonomic impact of domestic pig scavenging. Pig and cattle (*Bos taurus)* bones were given to domestic pigs in a pig enclosure for two experiments, the first lasting two days and the second a week, to observe their scavenging behavior and record the tooth marks. In the first experiment, the pigs preferred to gnaw on the smaller pig bones over the larger cattle bones, so only one pig bone remained, and the majority of the cattle bones were still in the enclosure. The only cattle bones that disappeared were vertebrae and a sacrum, and the remaining bones were discovered close to their original location, indicating that pigs will not disperse large bones, because they are too large for them to carry in their mouths and travel long distances. The results were nearly the same for the second experiment, with the pig bones almost completely consumed as well as the cattle vertebrae and a sacrum. Most of the bones stayed within 10 m of their original location, but a cattle humerus was discovered farther away. However, this could have been caused by the pigs pushing the bone down a slight hill in the enclosure. Greenfield (1988) also discovered long, shovel-shaped tooth scores on the bones that were not consumed. According to the findings of the two experiments, pigs prefer low density and soft cancellous bones to larger, more dense bones. Greenfield (1988) demonstrated that if pigs can completely consume pig-sized bones, then they are capable of severely modifying and consuming human remains.

Galdikas (1978) described an encounter that she and her researchers had with pigs scavenging orangutan (*Pongo pygmaeus*) remains in a rainforest in Borneo. The remains were found on the rainforest floor twelve hours after it died, and it was partially consumed by Bornean bearded pigs (*Sus barbatus*), with the body cavity ripped open and ribs missing. Pig tracks and drag marks were found surrounding the remains, indicating that pigs were the primary scavengers. While researchers were observing the scene, a pig grabbed the orangutan carcass by the arm and began dragging it away, loosening and dislodging a rib and the left humerus from the carcass. On a separate occasion, pigs were also seen killing and consuming two ducks, an infant orangutan, as well as scavenging the remains of pig carcasses. Pigs are efficient scavengers, according to Galdikas (1978), and are responsible for the continuous disappearance of orangutan and other animal remains.

Pavlov and Hone (1982) provided another example of pigs preying on animals by observing feral pigs chasing and killing domestic sheep (*Ovis aries*) in New South Wales, Australia. Four adult boars and eleven sows were placed in a large paddock with sheep and lambs to study their interactions with each other. The pigs were 20-30 months old, a mixture of male and female, and weighed 41.3-59.5 kg. The attacks occurred between

1700 and 2200 pm every night, which is usually when pigs are known to be the most active. There were 32 cases of pigs chasing but failing to catch the lambs, which lasted for an average of 5-20 seconds over 20-60 m, and all but two of the chases were by male pigs. Additionally, there were ten successful chases in which the pigs killed and consumed the lambs after catching them, with five different pigs participating and only one being a female pig. All successful chases lasted no longer than 10 seconds, and the average feeding time was 20.4 minutes, with one pig completely consuming a lamb in 45 minutes. Pavlov and Hone (1982) demonstrated that pigs are active predators that will kill and eat vertebrate carcasses when given the chance.

Domínguez-Solera and Domínguez-Rodrigo (2009) conducted a larger study on bone modification by wild, hybrid, and domestic pigs in Spain. In their experiments, lamb, pig, and calf bones were given to the pigs in different conditions. The bones were either fleshed or defleshed long bones, half a sheep carcass, broken diaphyses with the bone marrow taken out, or axial elements. The defleshed limb bones were given to the pigs without disrupting their regular eating schedule, so they were not overly hungry. The pigs only showed interest in the bones for 1.5 hours, and then the bones were taken out after another half hour. The pigs were uninterested in the fleshed bones after all the soft tissue had been consumed. The axial elements consisting of lumbar vertebrae and pelves were completely consumed except for a single bone. The calf bones were unbroken but heavily modified, compared to the smaller pig and lamb bones which were highly damaged. For the whole long bones, many of the epiphyses were completely consumed, given their preference for less dense cancellous bone to access the bone marrow. The diaphyses that were broken with the marrow taken out still had grease on them, making them appealing to the pigs and resulting in tooth marks on 67.6% of the shafts. Additionally, L-shaped punctures were observed on some of the bones that were believed to be from gnawing with the premolars, but more research is needed to confirm if this is typical of pig gnawing. Domínguez-Solera and Domínguez-Rodrigo (2009) demonstrated that the extent to which pigs modify bones depends on the carcass size, since the pigs more heavily modified the pig and lamb bones compared to the calf bones. Therefore, pigs cannot be ruled out as potential scavengers of larger carcasses, but they can be distinguished from canids based on bone damage. Additionally, it depends on the condition of the bones. If the long bone is whole, then pigs prefer the epiphyses, but a bone with retaining grease is just as favorable and will still be modified.

Carnivore Scavenging

Carnivores, especially canids, are the most reported scavengers responsible for modifying human remains in North America (Haglund 1997). It is essential to investigate and study the effects that canids have on bones and soft tissue to better comprehend the taphonomic significance of scavenging on crime scenes. Haynes (1983) believed that carnivores could be distinguished by the amount of damage that they inflict on bones and their distinctive gnawing patterns. However, slight damage by large-sized felids such as lions (*Panthera leo*) can look similar to damage by medium-sized canids and felids.

Pobiner (2007) quantified and analyzed the degree of bone modification and tooth mark patterns inflicted by large carnivores, such as lions and spotted hyenas (*Crocuta*

crocuta), on small to large-sized carcasses to determine if carnivore taxa could be distinguished by the amount and type of damage they inflict on different sized carcasses. The degree of bone damage inflicted by lions on small carcasses is similar to the damage inflicted by spotted hyenas on large carcasses, and spotted hyenas also produce larger pits and punctures than lions. Pobiner (2007) concluded that larger carnivores with greater jaw strength, such as spotted hyenas, modify bones more intensely than lions. This study demonstrated that analyzing degree of bone modification and comparing tooth mark sizes are sufficient methods for differentiating between carnivore taxa.

Young et al. (2015) investigated whether tooth marks could be distinguished between multiple species---red foxes, Eurasian badgers (*Meles meles*), and small (4-8 kg) to large (10-17 kg) dogs---solely by measuring their length and breadth. Although red foxes and dogs are members of the same family, they, along with Eurasian badgers, have different body sizes, jaw sizes, and bite forces that could aid in distinguishing their tooth marks. Deer bones were distributed as a proxy to human remains and were scavenged by at least six wild red foxes for an average of 81 days and a large dog breed---Staffordshire Bull terrier---for 1.5 hours, whereas the wild Eurasian badgers were observed near the carcasses but did not scavenge the remains. Another feeding experiment was conducted with captive red foxes and Eurasian badgers as well as small and large domestic dogs receiving dried pig bones for two weeks. Digital calipers were used to measure the tooth marks and the location of the tooth marks on the bone, such as on the epiphysis or diaphysis, were not analyzed due to using different kinds of bones other than long bones. They concluded that there was a significant difference in pit size between the wild and captive red foxes, although this difference may have been caused by comparing fresh and dry bones, as well as those red foxes created smaller tooth marks than the small and large dogs. They also concluded that the small dogs produced pits and scores larger than the large dogs, but this could be from the majority of tooth marks produced by the large dogs being located on the diaphyses, since tooth marks are typically smaller on the diaphyses than the epiphyses. Finally, they concluded that although Eurasian badgers have a stronger bite force than dogs, their pit sizes were smaller than those of the larger dogs. They concluded that using tooth mark dimensions alone is insufficient to identify scavenger taxa confidently, and that more research is required to comprehend scavenger behavior better.

Domínguez-Rodrigo and Piqueras (2003) used tooth pit sizes of different carnivores—lions, jackals, bears, spotted hyenas, domestic dogs, and baboons (*Papio anubis* and *P. hamadryas*)—to determine if they could be distinguished. Bovid or equid bones were given to the carnivores in different feeding experiments, and molds were made of the tooth marks to measure with binocular lenses and digital calipers. The pits were separated based on bone density, or the epiphyses and diaphyses, and the length and breadth of the pits were measured. As supported by previous research, pits on the epiphyses were larger than those on the diaphyses, because less pressure is required to leave a mark on the softer cancellous bone (Domínguez-Solera and Domínguez-Rodrigo 2009; Indra et al. 2022; Pokines 2022). They found that the size of the pit corresponded to the size of the carnivore's teeth, so that the larger the pit, the larger the scavenger. On the epiphyses, pit lengths under 4 mm are indicative to small canids and middle-sized felids, between 4-6 mm are indicative of middle to larger-sized carnivores, and above 6 mm are indicative of large carnivores, mainly lions and hyenas. Score length and breadth were also measured, but because scores do not correlate to tooth size as well as pits, pits became the primary focus. Similar to the findings of Young et al. (2015), tooth marks alone are insufficient to identify carnivore taxa, but they discovered that the body size of the carnivore can be predicted based in tooth pit size.

Fosse et al. (2012) utilized 56 kill and scavenging sites in Poland to study the taphonomic effect of wolves on medium-to-large-sized carcasses and compare it to wolves from North America and hyenas from Republic of Djibouti. The wolves were fed European bison (*Bison bonasus*) and red deer (*Cervus elaphus*) bones that were left for either a few hours or two to three weeks in the winter to study the rate of bone modification. The bison bones only retained six punctures, four pits, nine scores, and the epiphyses of four bones were scooped out, whereas the red deer bones retained 17 punctures, 18 pits, 12 scores, and the epiphyses of two bones were scooped out, with most of the damage located on the axial skeleton. The bones were also dispersed up to 500 m away from the kill site. When compared to the North American wolves, it was discovered that they have a similar cranial/postcranial ratio of deer carcasses in kill sites, with most of the legs remaining at the site. Fosse et al. (2012) concluded that wolves do not leave as many tooth marks as hyenas. The wolves only modified 20% of the long bones, whereas hyenas modified 25 to 30% of the entire skeleton. Fosse et al. (2012) also reported several factors that can affect carcass consumption: the number of predators consuming, the size of the prey, the time span of consumption, temperature, snow cover, and invertebrate scavengers.

Yravedra et al. (2011) studied the degree of bone modification by wild wolves in Spain to add to their referential framework. They also emphasized the importance of studying wild wolves as opposed to captive, since captive wolves live in controlled environments. The researchers observed horses (*Equus caballus*) either dying of natural causes or being hunted and killed by wolves, and then the carcasses were collected after the wolves finished scavenging. There were 17 horse carcasses collected, including both colts and adult mares. They recorded the number of wolves scavenging at a time, which ranged between 10 and 15. For the analysis, the length and breadth of pits and scores were measured with a 10-20x hand lens and digital calipers, and their location on the bone was recorded. Carcasses that were scavenging and collected in the winter showed significantly less damage due to the body being better preserved in the cold weather. However, those carcasses were also adult, and the rest were either infant or up to eight months old, so it would have also taken more time and effort to modify fully developed muscles and bones compared to those of newborns and juveniles. Furthermore, the carcasses that were hunted and visited in multiple events experienced more destruction of the epiphyses and a higher tooth mark frequency, whereas those that were scavenged or had only one consumption event had higher skeletal representation and fewer tooth marks. Between 11% and 100% of the carcasses had tooth marks spread throughout the appendicular and axial elements as well as on both the epiphyses and diaphyses, and bone cylinders were observed for some of the long bones. For the tooth mark measurements, the pit sizes were larger on the carcasses that were more intensely modified, and the scores were wider on the epiphyses than the diaphyses. Yravedra et al. (2011) concluded that the frequency of tooth marks and the intensity of destruction depends on the size of the carcass and consumption pattern: carcasses with a mass of 400 kg are less likely to be significantly modified, and carcasses consumed on multiple occasions are more likely to be significantly modified than those consumed only once.

Yravedra et al. (2014) performed a similar study in Spain with captive African wild dogs (*Lycaon pictus*) to analyze the taphonomic impact of another carnivore that has not gotten as much attention as hyaenids and felids. For a maximum of two months, 72 adult horse long bones were given to the dogs before being collected, and tooth pits were measured with 10-20x hand lens and digital calipers. Furrowing was also recorded as present or absent, since it could be a possible indicator of the carnivore that altered the bone. Tooth marks were on 77.7% of the bones, but no bones were fractured, deleted, or turned into bone cylinders. Pits and scores were distributed across the epiphyses and diaphyses, with the former receiving the majority of the marks, with an average of less than ten per bone. Additionally, pits were more frequent than scores, but scores were produced more on the diaphyses than pits. Furrowing was present with a frequency of more than 50% on the proximal epiphyses of the tibia, ulna, and distal epiphysis of the femur, but less than 12% for the remaining bones. However, bone modifications by the dogs were low to moderate, since none of the epiphyses of the bones were destroyed and no large tooth marks such as punctures were present. The pits and scores produced by the dogs were smaller and narrower when compared to the tooth mark sizes of captive wolves, which is consistent with the fact that African wild dogs are typically smaller carnivores than wolves. When comparing the frequency of furrowing, captive wolves are more destructive and create more bone cylinders. Yravedra et al. (2014) concluded that African wild dogs do not modify bone as intensely or leave as many tooth marks per element as other canids. They hypothesized that this was because they prefer to consume soft tissue rather than spend time gnawing on bones for nutrients. Additionally, since the African wild dogs and the wolves were both captive, boredom could have influenced the degree of bone modification for each species. Finally, the small size of the dog's tooth marks is similar to those produced by small felids, which could hinder scavenger identification as a result.

Rather than comparing two different species, Sala et al. (2014) analyzed the taphonomic impact between captive and wild members of the same species. Captive wolves from Spain and the USA and wild wolves from Canada and the USA were given ungulate carcasses of three different sizes: small, medium, and large. The exposure time of the remains ranged from either a day, a few weeks, or several years so all the soft tissue and bone marrow could be completely consumed from the carcasses. A total of 687 bones were recovered, with only 71 being from the wild wolves. The tooth pits, punctures, and scores were measured with digital calipers, and their location on the bone was recorded. Only the breadth was measured for scores, since it has a stronger correlation to tooth size than score length. The captive wolves produced significantly more damage and tooth marks than their wild counterparts, resulting in bone cylinders and fractures reducing the bones to splinters or small fragments. For both captive and wild wolves, the pits and scores were primarily concentrated on the cortical bone, whereas the punctures were mostly on the cancellous bone. There are two reasons why the captive wolves produced more damage than the wild wolves. First, the captive wolves had access to significantly more carcasses than the wild wolves, and the wild wolves only consumed medium-to-large-sized carcasses that require more effort and time to modify than smaller carcasses. Second, the wild wolves were only able to completely consume the soft tissue and bone marrow from 28 bones compared to over 300 for the captive wolves. Therefore, the captive wolves had more time to modify their carcasses until maximum damage was done. The tooth mark sizes of the captive and wild wolves compared to those of other large carnivores revealed that they differ from lions and bears but are similar to hyenas. Sala et al. (2014) emphasized that more research is necessary to understand the taphonomic effects of captive vs wild scavengers, and that size of prey and time of exposure are important factors to consider when making comparisons.

Andrés et al. (2012) focused on comparing tooth mark measurements, specifically pits and scores, to differentiate carnivore taxa. They compiled metrical data from multiple studies, including Yravedra et al. (2011) and Domínguez-Rodrigo and Piqueras (2003), that measured the length and breadth of pits and scores produced by spotted hyenas, wolves, foxes, baboons, dogs, lions, and humans with 15-20x hand lens and digital calipers. The carnivores were separated by body size, with those less than 40 kg considered small and those over 40 kg large. In Domínguez-Rodrigo and Piqueras' (2003) study, they used molds of the bones and only measured the conspicuous tooth marks visible to the naked eye, but Andrés et al. (2012) obtained the original bones and re-measured all the tooth marks including the smaller, inconspicuous marks that were not included in the first study. Thus, the average tooth mark sizes were found to be smaller by Andrés et al. (2012) than they were by Domínguez-Rodrigo and Piqueras (2003). Overall, comparing the pit length on the diaphyses demonstrated the least amount of overlap between small (subadult spotted hyenas, foxes, humans, and baboons) and large (adult dogs and wolves, spotted hyenas, and lions) carnivores. Additionally, score breadth on either the epiphysis or diaphysis may also be an indicator of scavenger size if the breadth is above 1 mm. Andrés et al. (2012) also noted difficulties with comparing carnivore scavenging studies. The first challenge is the use of small sample sizes for either the number of bones analyzed or the amount of tooth marks on the bones, and the second is the use of small carcasses that do not require as much effort to modify as large carcasses. In conclusion, comparing carnivore taxa with pit length on the diaphysis and score breadth results in the least overlap among carnivores, and using a large sample and appropriately sized carcasses, along with additional bone modification variables, may further aid in differentiating carnivore scavengers.

Domínguez-Rodrigo et al. (2012) experimented with more bone modification variables by analyzing the furrowing patterns on epiphyses as well as the frequency of bone completeness and tooth mark types on diaphyses between wild felids, hyaenids, and canids. They emphasized that the best way to distinguish which carnivore modified bone is by using the same size and type of bones from the same carcasses in experiments. Lions, wolves, and spotted hyenas were given 79 horse carcasses, and the upper and lower appendicular elements were collected and analyzed for furrowing. They demonstrated that hyenas produce the most furrows and bone cylinders, while wolves moderately produce furrows, and lions produce furrows the least. If there is furrowing present on the distal humerus and proximal and distal radius, then hyenas are likely the carnivore responsible. Hyenas are most likely to modify the bones until the epiphyses are deleted, and wolves will typically abandon a carcass before all the elements are destroyed. Wolves produced furrows on up to 77.8% of the proximal ulnae, 80% of the proximal humeri, 93% of the proximal femora, and 66.7% of the proximal tibiae. Lions also are known to eat the soft tissue off bones, therefore producing more scores than pits from their teeth dragging on the bone surface to scrape the soft tissue, and then they abandon the bones. Since wolves and hyenas are more prone to consuming bone, they will produce more pits than scores. Experiments attempting to differentiate between carnivore taxa are most accurate when a multivariate analysis is performed, such as analyzing furrowing patterns, degree of destruction, and frequency of tooth mark types together, rather than focusing on one variable at a time.

Suspected Multi-Agent Pig and Dog Scavenging

Byrnes and Belcher (2021) described a case study from the island of Kaua'i in Hawaii where skeletal remains were found and recovered in 2017. Feral dogs and pigs are among the most common scavengers in Hawaii. In this case, the remains had evidence of bone modification possibly related to dog or pig scavenging. The majority of the skeleton was recovered, and the bones were observed with digital calipers, a 20x hand lens, and a stereo microscope to determine the tooth mark types. The characteristics of the tooth marks such as the shape and location were also used to determine the scavenger taxa responsible for modifying the remains. Pits, punctures, scores, and furrows were observed throughout the skeleton, with most of the tooth marks on the epiphyses, which is characteristic of both pig and canid scavenging. There was also diaphyseal fracturing on some of the thinner long bones, such as the ulna and fibula, with adjacent tooth marks, which can be indicative of dog scavenging (Young et al. 2015). A puncture on the scapula was also believed to be from dogs due to the size of the mark corresponding to a dog's canine tooth. On the other hand, L-shaped punctures and broad scoring were observed on the acromial end of the clavicle, which can be indicative of pig scavenging (Pokines 2022; Pokines et al. 2017). The skull was not heavily modified, but the thorax was considerably damaged, with most of the ribs missing, and the remaining ribs were either fractured or partially missing. This can be classified as pig scavenging, since it more closely follows the scavenging or disarticulation sequence introduced by Pavlov and Hone (1982).

Additionally, Byrnes and Belcher (2021) stated that the police believed that pigs might have modified the body due to an active feral pig trail directly transecting through the site and the discovery of fetal pig skeletal remains near the human remains. Skeletal elements were dispersed as far as 54 m from the main concentration, which could have been caused by the body's proximity to an active feral pig trail. Evidence of trampling by pigs was observed on the right os coxa characterized by multiple, shallow, linear, thin scratches parallel to each other on the ilium. They could be mistaken for scores, but the trampling marks vary too much in depth and breadth to be consistent with the scores found elsewhere on the body. These bone modifications can be compared to the patterned skin lacerations caused by pig trampling seen in Gitto et al. (2021), which had a similar appearance to the scratches on the bone. Additionally, the right os coxa was dispersed approximately 25 m from the main concentration and adjacent to the pig trail, which is another indication that trampling from the pigs caused the dispersal. Some of the scores were narrow, which can imply that dogs were also gnawing on the remains. However, no tooth mark measurements were made, so the bone damage could not be distinguished between pig or dog based on tooth mark dimensions. Despite the lack of eyewitness reports of pigs or dogs scavenging the remains, there was substantial evidence that suggested the body had been modified by one, or both, of the species.

Scavenging/Disarticulation Sequence

When remains are discovered before they have been fully skeletonized and there is still soft tissue remaining, the scavenging/disarticulation sequence can be determined. The scavenging/disarticulation sequence is a pattern of soft tissue and skeletal damage that scavengers typically follow to gain the most nutrients for the least effort (Haglund et al. 1989; Pobiner 2007; Pokines 2022). Haglund et al. (1989) presented a five-stage scavenging and disarticulation sequence for wolves. Stage zero includes the removal of soft tissue with damage to the skeleton or disarticulation. Stage one describes that the first part of the body damaged is the face and neck, followed by the anterior thorax, the sternum, sternal end of the ribs, and removal of one or both upper extremities. Stage two has partial disarticulation of the lower extremities. Stage three has almost full disarticulation, with only some of the vertebral column articulated. Stage four describes complete disarticulation and dispersal of the remains, with only fragments and small skeletal elements recovered. A theory that supports why canids prefer to scavenge the head and neck first is that people are most likely wearing clothing that covers or restricts access to the thorax, and the first available area to scavenge is the head (Pokines 2022).

Pavlov and Hone (1982) observed and recorded feral pigs' feeding pattern on the captured lambs described above and categorized it into six stages. During the first stage (10 seconds after death), the pigs bit through the anterior thorax and placed their front feet on the body to help tear the lamb open. In the second stage (12 seconds to 10 minutes), the internal viscera were removed from the lamb, and the third stage (11 to 20 minutes) involves eating the sternal end of the ribs, breaking the spine, and removing muscle tissue from the scapulae, humeri, and radii. The fourth stage (21 to 30 minutes) included consuming the muscle of the anterior spine, the remainder of the ribs, and the legs, exposing the knee joints. Subsequently, in the fifth stage (31 to 37 minutes), the skull was crushed, and the brain, eyes, tongue, and some of the skin, were consumed along with the tibiae. In the sixth stage (38 to 45 minutes), only the metatarsi, phalanges, fragments of the skull, and other bones remained. The first stage described by Pavlov and Hone (1982) is similar to what Berryman (2002) reported, with the anterior thorax being the access point to the viscera and the first part of the body destroyed.

Based on the findings of Haglund et al. (1989) and Pavlov and Hone (1982), the scavenging or disarticulation sequence for wolves and pigs is somewhat similar. While the wolves begin with the face and neck area and then continue to the anterior thorax, the pigs immediately start with the thorax. They both destroy the sternal end of the ribs and upper extremities in the early stages and then move onto the lower extremities. The main difference between the two sequences is that pigs start to attack the face in the second to last stage compared to the second. The last stage for both sequences include full disarticulation and only bone fragments remaining.

Dispersal

If bones are missing from skeletal remains, then it could be indicative of either dispersal or consumption. When extensive dispersal is present at a scene, survey techniques, such as cadaver dogs and grid searches, are needed to recover the remaining elements so that a more precise skeletal analysis can be completed (Pokines 2022). Depending on scavenger taxa, elements can be dispersed at various distances. Carnivores are known to disperse bones an average of 30 m and as high as 500 m from their original location, and they will carry the carcass to dens to feed their young (Fosse et al. 2012; Pokines 2022). In comparison, pigs have been documented to disperse bones 2-54 m away, but there is no evidence that pigs will transport food to their young (Brown et al. 2006; Byrnes and Belcher 2021; Fillios 2011; Greenfield 1988). Pigs also have been observed completely consuming small and medium elements, contributing to their deletion from the assemblage (Domínguez-Solera and Domínguez-Rodrigo 2009; Fillios 2011; Greenfield 1988; Wilcox and Van Vuren 2009). Therefore, knowing the dispersal patterns and the prevalence of bone consumption for local scavenger taxa can improve the search and recovery of skeletal elements as well as provide more information on the decomposition rate for the skeletal analysis (Brinkley 2012; Indra et al. 2022; Kjorlien et al. 2009).

Pig Stomach Content Analysis

One method of evaluating pig scavenging is by examining the stomach contents of pig carcasses. Loggins et al. (2002) and Wilcox and Van Vuren (2009) both performed stomach content analysis of pig carcasses in California, USA, to record what proportion of their diet is animal material. Loggins et al. (2002) separated the stomach contents into five groups: herbaceous vegetation, bulbs and roots, mast, animal remains, and unidentifiable debris. Primarily during summer and autumn, the pig stomachs were more likely to contain animal remains, and eight out of the 53 stomachs examined had animal remains: two had vole (*Microtus californicus*) remains, one had mule deer (*Odocoileus hemionus*) remains, and five had squirrel (*Otospermophilus beecheyi*) remains. Wilcox and Van Vuren (2009) studied the contents of 104 pig stomachs and reported that 42 contained animal material. Of those 42 stomachs, 167 individual animals were identified, with the most frequent animal being voles (65%). Wilcox and Van Vuren (2009) also reported that animal material was present in stomach contents during the summer and autumn. Both Loggins et al. (2002) and Wilcox and Van Vuren (2009) inferred that active predation was most likely occurring due to the diversity of prey, the need for more protein intake in the autumn, and the consumption of small vertebrate populations. Although it is hard to verify if the pigs acquired the remains through predation or scavenging (DeVault and Rhodes 2002; DeVault et al. 2003), stomach content analysis provides more evidence that pigs scavenge animal remains and should be considered primary scavengers in any region they inhabit.

Additional Factors Influencing Pig Scavenging

When analyzing the degree of scavenging activity, it is important to note environmental factors that have been observed to influence their behavior, such as depletion of resources, temperature, seasonality, rainfall, and decomposers (Brown et al. 2006; DeVault and Rhodes 2002; DeVault et al. 2003; Fillios 2011; Selva et al. 2005). Physical factors such as the pigs' size, age, sex, and level of hunger are also important to note. During periods of low rainfall and dry weather, scavenging may be more prevalent, since high rainfall is likely to prompt vegetation growth, providing enough food to forage instead of searching for prey or carrion to eat (Brown et al. 2006; Fillios 2011; Selva et al. 2005). Higher temperatures are associated with higher scavenger activity, with summer and autumn being when scavengers are more likely to feed on animal material to increase their protein intake (DeVault and Rhodes 2002; Loggins et al. 2002; Wilcox and Van Vuren 2009). In addition, invertebrates will quickly migrate to a carcass and can start the decomposition process, leaving the carcass unappealing to scavengers as high concentrations of toxins can make it unsafe to eat (DeVault et al. 2003; Fillios 2011; Selva et al. 2005). However, scavengers will also feed on carrion if it is in the early stages of decomposition (Ubelaker and DeGaglia 2020). Wilcox and Van Vuren (2009) indicated that female pigs are more likely to scavenge for extra protein to accommodate for the energy cost of reproduction during the summer-fall peak, but no statistical difference was reported between the diets of females and males. Although there has been previous research detailing the importance and effects of these factors, more in-depth analyses and testing of multiple variables are needed to fully understand how temperature, rainfall, sex, and other factors described above influence the scavenging impact of pigs.

METHODS

For the present study, 100 pasture-raised heritage breed pigs (Figures 3.1 and 3.2), consisting of Tamworth and Gloucestershire Old Spot pigs, from Codman Community Farms in Lincoln, MA were fed white-tailed deer (*Odocoileus virginianus*) bones. The pigs were a mix of male and female and around four to five-months old of varying sizes that roamed freely on a pasture surrounded by a 78 x 68 x 40 x 90 m perimeter electric fence. The bones were retrieved from A. Arena & Sons Butcher Shop in Hopkinton, MA on December 3, 2022, and brought to the Boston University Outdoor Research Facility in Holliston, MA where they were kept in bags in a freezer. The sample included one hundred disarticulated and partially fleshed appendicular body parts, consisting of 25 humeri, 25 radii and ulnae, 25 femora, and 25 tibiae, with associated elements, including patellae, carpals, and tarsals, for a minimum of 175 elements. There were also 10 partially fleshed half rib cages, each consisting of 13 thoracic vertebrae that were cut longitudinally through the centra, 13 ribs, and 7 sternebrae, for a total of 330 elements from the half rib cages. The sample also included 10 fleshed necks, each consisting of 7 cervical vertebrae, for a total of 70 cervical vertebrae. Therefore, a minimum of 575 elements were given to the pigs. Before distributing the bones to the pigs, photographs were taken of the exposed bones to record any damage inflicted by the butcher so as not to mistake them for tooth marks. Some butcher marks included shallow transverse cut marks on the visceral surface of the ribs (Figure 3.3) and saw marks on the ends of the long bones and ribs and down the midline of the vertebrae.

Figure 3.1. Pigs in enclosure.

Figure 3.2. Pigs in a different part of the enclosure.

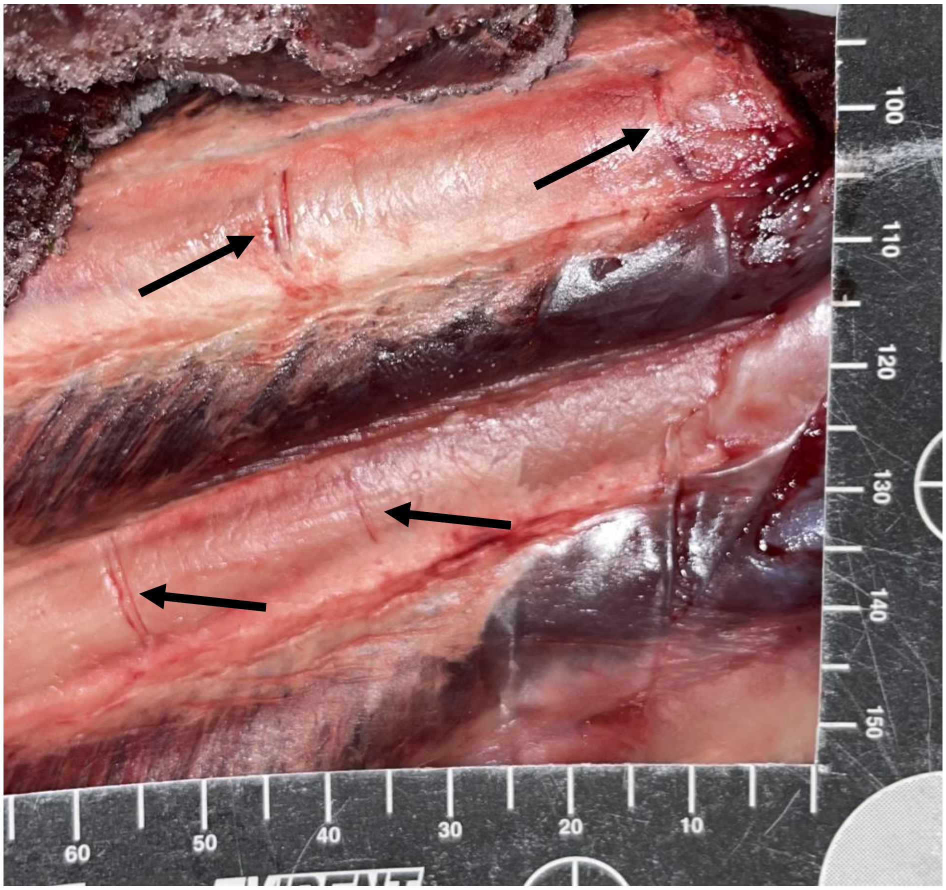

Figure 3.3. Transverse cut marks from the butcher on the visceral surface of the ribs (black arrows).

On June 27, 2023, at approximately 1400, all bones were given to the pigs in the northeast corner of the enclosure, since this is where the pigs stayed most often, and the bones remained there for two weeks so that the pigs could sufficiently gnaw and modify the bones (Figure 3.4). Subsequently, on July 11, 2023, a grid surface search of the pasture was conducted by the author to recover the bones (Figure 3.5). To measure how far the bones were dispersed, the bones' original locations were approximated, and a reel tape measure was used to measure the distance.

Figure 3.4. Bones in pig enclosure before modification.

The bones were then transported to Boston University Chobanian & Avedisian School of Medicine where they were stored in a freezer until they were cleaned. To clean the bones of soft tissue, soil, plant material, and grease, the bones were macerated. Two large crockpots were filled with 13 L of water, 130 cc of Biz® detergent, and 130 cc of Dawn® Professional Heavy-Duty Degreaser. Individual bones were placed in individual mesh bags, and approximately six bones were placed in each crockpot at a time. The lids were placed on the crockpots, the temperature was set to 79^{o}C (175^{o}F), and the bones were macerated for a maximum of 48 hours. Some of the bones such as the vertebrae

Figure 3.5. Bones in pig enclosure after modification.

needed to be macerated longer than the long bones. After the bones were macerated, they were removed from the crockpot, and the remaining soft tissue was removed by hand or carefully with a scalpel, so no cut marks were added. The bones were then placed back into the crockpot with 13 L of water and 130 cc of Dawn® Professional Heavy-Duty Degreaser at 79^{o}C (175^{o}F) for a maximum of 24 hours to further degrease them. Once the bones were fully degreased, they were placed on a tray under a drying hood for 24 hours and then placed in a numbered plastic bag.

Each bone was examined for any tooth marks and areas that appeared to have been gnawed on, and the bones were separated into groups of bones with and without gnawing damage. The bones with gnawing damage were photographed with a Nikon (model D5200) digital camera. An overview shot was taken of each bone first, and then each tooth mark and gnawed area were photographed individually. The photographs for each bone were placed into a folder on the computer that corresponded with the bag number and the type of bone. Using a 10x hand lens, the bones were examined, and the number of tooth marks, their location, crenellated edges, edge polish, and fractures were recorded. Any butcher marks, such as saw or cut marks, were also recorded so that they were not mistaken for gnawing damage.

To measure the tooth marks, the open-source image processing program ImageJ was used to create an outline of the tooth mark and measure the length and breadth. The length was calculated by drawing a line between the outline's farthest points, while the breadth was calculated by drawing a line perpendicular to the previous line (Figures 3.6-3.9). Each measurement was rounded to its nearest hundredth millimeter. For punctures, any cortical edge flaking was incorporated in the measurement to include the crushed margins or any other surface modification produced by the tooth (Andrés et al. 2012). Once each tooth mark was measured, it was classified as either a pit, puncture, score, or furrow and recorded on a spreadsheet. The location of the tooth marks on the long bones was categorized by bone density zone: the epiphysis (thin cancellous bone) or the diaphysis (dense cortical bone). The location of tooth marks on the vertebrae was categorized by the spinous process or the centrum. The location of tooth

Figure 3.6. Pit outlined in ImageJ.

Figure 3.7. Puncture outlined in ImageJ.

Figure 3.8. Score outlined in ImageJ.

marks on the ribs was categorized by the sternal end or the head/shaft. The tooth marks on the patellae, sternebrae, and calcanei associated with some of the femora, ribs, and tibiae, respectively, were categorized as present or absent. The average length and breadth of the pits, punctures, scores, and furrows as well as the maximum and minimum length and breadth were calculated separately for each location on the long bones, vertebrae, and ribs, and the tooth marks on the patellae, sternebrae, and calcanei were also measured.

Tooth mark data from previous research on canid scavenging that included the number of tooth marks, tooth mark type (pit, puncture, and score), their dimensions

Figure 3.9. Furrow outlined in ImageJ.

(length and breadth), and their location (epiphysis or diaphysis) were compiled. For dog scavenging, data from Andrés et al. (2012) and Yravedra et al. (2014) included the average length and breadth of pits and scores on the epiphyses and diaphyses. Andrés et al. (2012) re-analyzed the data originally reported in Domínguez-Rodrigo and Piqueras (2003) and added to the number of tooth marks. For wolf scavenging, data from Andrés et al. (2012), originally from Yravedra et al. (2011), included the average length and breadth of pits and scores on the epiphyses and diaphyses. Sala et al. (2014) included the average length and breadth of pits and punctures on the epiphyses and diaphyses and the average breadth of scores on the epiphyses and diaphyses.

Statistical analyses were conducted on the statistical software, Statistical Package for the Social Sciences (SPSS) (version 29.0.2.0), to determine the relationships between the pig tooth mark types, sizes, and their location on the epiphyses or diaphyses as well as the pig tooth mark sizes and location with those of canid tooth marks. A normality test was first run to determine if the data were normally distributed, which indicated that the data is not normal; therefore, nonparametric tests were used for the analyses. Furrows were not included in the latter two of the statistical analyses, since they are only present on the epiphyses and because there are no previous canid studies that analyzed furrow dimensions. An Independent-Samples one-tailed t-test was run to compare the frequency of four pig tooth mark types---pits, punctures, scores, and furrows---to where they are most frequently found on the bone to determine if pigs have a specific preference where they gnaw bones. The bones were also separated by type---long bones, vertebrae, and ribs---since the vertebrae and ribs are smaller and flatter bones. For example, the total number of pits on the 34 long bones, 6 vertebrae, and 19 ribs with tooth marks were compared to where they are located on the bone, either the epiphysis or diaphysis, spinous process or centrum, or sternal end or head/shaft, respectively. It was hypothesized that the number of tooth marks will be greater on the epiphyses, spinous processes, and sternal ends, than the diaphyses, centra, and heads/shafts. The null hypothesis was that the number of tooth marks was distributed evenly between each location.

Additionally, since the condition for normality failed, a Kruskal-Wallis One-Way ANOVA test was used to compare the pig tooth mark sizes to their location on the bone to determine if there is a significant difference between the size of the tooth mark and the density of the bone. The location is considered the independent variable, and the tooth mark size is dependent. The tooth marks were divided by the type of bone---long bones and ribs---and 12 separate tests were run: the pit length, pit breadth, puncture length, puncture breadth, score length, and score breadth on the two locations for the long bones, and then repeated for the ribs. It was hypothesized that the tooth marks on the epiphyses and sternal end should be larger in size than those on the diaphyses and heads/shafts, since it requires less bite force to modify the thinner parts of bones. The null hypothesis was that the tooth mark sizes on each location were not significantly different.

A Summary Independent-Samples t-test was used to compare the average size and location of the pig tooth marks to the average size and location of the canid tooth marks from previous research. First, the average length and breadth as well as the standard deviation (SD) were determined for each tooth mark type on both locations from the pig scavenged long bones, vertebrae, and ribs to compare to the canid data. It was hypothesized that the dimensions of tooth marks produced by pigs were different than those produced by canids. The null hypothesis was that the pig and canid tooth mark dimensions were not significantly different. The significance level was set at 0.05, so if all the analyses result in a p-value of below 0.05, then the null hypotheses are rejected, and the samples were considered to be significantly different.

RESULTS

Count Data

Out of 120 body parts distributed to the pigs, 70 were recovered (58.3%), and 43 had tooth marks on at least one element (35.8%). Out of the 575 elements distributed, 146 were recovered (25.4%) and 69 (12%) had tooth marks. Out of the 100 appendicular body parts distributed to the pigs, 60 were recovered (60%) and 38 had tooth marks (38%). Out of the 175 elements of the appendicular body parts, 83 were recovered (47.4%) and 42 had tooth marks (24%). Out of the 42 elements that had tooth marks, 34 were long bones accompanied by 2 patellae and 2 calcanei, and 4 were patellae not accompanied by femora. The 34 long bones consisted of 13 femora, 14 tibiae, 2 humeri, 4 ulnae, and 1 radius. The 22 appendicular body parts that were recovered with no tooth marks or gnawing damage consisted of 5 femora, 4 humeri, 4 tibiae, 8 radii/ulnae, and 1 radius that were accompanied by 1 patella, 9 sets of carpals, and 3 sets of tarsals. The total number of elements recovered without tooth marks from the appendicular body parts was 41.

Out of the 10 half rib cages, 9 were recovered (90%) with 5 containing tooth marks (50%). Out of the 330 elements of the half rib cages from the original sample, 57 were recovered (17.3%), and 27 (8.2%) had tooth marks. The elements from the 5 half rib cages with tooth marks consisted of 6 vertebrae, 19 ribs, and 2 sternebrae. The portions of the 4 half rib cages that were recovered with no tooth marks or gnawing damage consisted of 22 vertebrae and 8 ribs. The total number of elements recovered without tooth marks from the half rib cages was 30.

Only 6 out of the 70 cervical vertebrae were recovered (8.6%), but they did not contain any tooth marks or gnawing damage. The lack of recovered cervical vertebrae could be because they were fully fleshed; therefore, the pigs would spend more time with them than the other bones with less soft tissue. The bones not recovered could be due to bones either being completely consumed or being taken to where the pigs liked to congregate and sleep. The nine necks that were not recovered were likely completely consumed, since they had the greatest amount of soft tissue, and the long bones and half rib cages were likely under the elevated platform or in the corner of the enclosure where the pigs congregated and were unable to be recovered safely.

Number and Location of Tooth Marks

Although only 69 of the elements were modified, there was a total of 1,009 tooth marks: 641 pits (63.5%), 216 scores (21.4%), 138 punctures (13.7%), and 14 furrows (1.4%). There were 407 total tooth marks located on the 34 long bones, with an average number of 11.9 tooth marks per long bone. On the epiphyses of the long bones, the average number of tooth marks was 8.9, with a range of 1-56. The diaphyses of the long bones had an average of 3 tooth marks, with a range of 1-43.

For the long bones, 160 out of 206 pits were located on the epiphyses (77.7%) and 46 on the diaphyses (22.3%). Out of the 107 punctures, 97 were on the epiphyses (90.6%) and 10 on the diaphyses (9.4%). Out of the 80 scores, 34 were on the epiphyses (42.5%) and 46 on the diaphyses (57.5%). All 14 furrows were on the epiphyses (100%).

For the 6 vertebrae, there was a total of 100 tooth marks, with an average of 16.6 tooth marks per bone, and a range of 1-52. All the tooth marks were present on the spinous processes, and the centra of the vertebrae had no tooth marks. There were 70 pits, 4 punctures, and 26 scores on the spinous processes.

For the 19 ribs, there was a total of 409 tooth marks, with an average of 21.5 tooth marks per bone. On the sternal ends of the ribs, there was an average of 2.3 tooth marks, with a range of 2-36. The heads/shafts of the ribs had an average of 19.2 tooth marks, with a range of 4-48. For the ribs, 34 out of 310 pits were located on the sternal ends (11%) and 276 on the heads/shafts (89%). Out of the 3 punctures, 2 were on the sternal ends (66.7%) and 1 was on the head/shaft (33.3%). Out of the 96 scores, 8 were on the sternal ends (8.3%) and 88 on the heads/shafts (91.7%).

The 6 patellae had a total of 57 tooth marks, with an average of 9.5 tooth marks per bone, and a range of 4-16; there were 34 pits, 17 punctures, and 6 scores present on the patellae. The 2 calcanei had a total of 27 tooth marks, with an average of 13.5 tooth marks per bone, and a range of 7-20; there were 17 pits, 3 punctures, and 7 scores present on the calcanei. The 2 sternebrae had a total of 9 tooth marks, with an average of 4.5 tooth marks per bone, and a range of 3-6; there were 4 pits, 4 punctures, and 1 score present on the sternebrae.

The frequency of each tooth mark type for each bone and its location is presented in Table 4.1. Overall, there were more tooth marks on the ribs than any other element (40.5%). The majority of tooth marks on the ribs were located on the heads/shafts (89.2%). Out of the 19 ribs, 3 had sternal ends that were butchered previously (15.8%), and 12 had sternal ends that were gnawed off (63.2%). Therefore, the pigs did not produce tooth marks on three of the sternal ends, and any tooth marks that could have been present on the sternal ends of the remaining ribs were obliterated from subsequent gnawing damage. For the long bones, only 4 out of 34 had tooth marks on the distal epiphyses (11.8%), whereas 27 long bones had tooth marks on the proximal epiphyses (79.4%). Additionally, patellae had the most tooth marks out of the three smaller elements (61.3%). However, this could be because there were more patellae, with 6 in total, than calcanei and sternebrae, with 2 each.

Table 4.1. Frequency of tooth marks on the long bones, vertebrae, ribs, patellae, calcanei, and sternebrae.

Element	Location	Pit	Puncture	Score	Furrow	Total
Long Bones	**Epiphysis**	160	97	34	14	305
	Diaphysis	46	10	46	0	102
Vertebrae	**Spinous Process**	70	4	26	0	100
	Centrum	0	0	0	0	0
Ribs	**Sternal End**	34	2	8	0	44
	Head/Shaft	276	1	88	0	365
Patellae	**All**	34	17	6	0	57
Calcanei	**All**	17	3	7	0	27
Sternebrae	**All**	4	4	1	0	9
	Total	**641**	**138**	**216**	**14**	**1,009**

Size of Tooth Marks

The pits and punctures (Figure 4.1) varied in size from circular to ovoid, and the scores ranged from narrow to wide and were oriented perpendicular to the long axis of the bone (Figure 4.2). The broadest score was 1.61 mm on the proximal epiphysis of a femur (Figure 4.3). Only 16 out of 216 scores were over 1 mm wide, so the majority of scores were not significantly broad. The only tooth mark that resembled an L-shape was a puncture on the proximal epiphysis of a femur (Figure 4.4). Furrows were only present on the epiphyses of the long bones and were mostly isolated from other furrows (Figure 4.5). Based on the average measurements (Table 4.2), pit length (1.78 ± 0.76 mm) and breadth

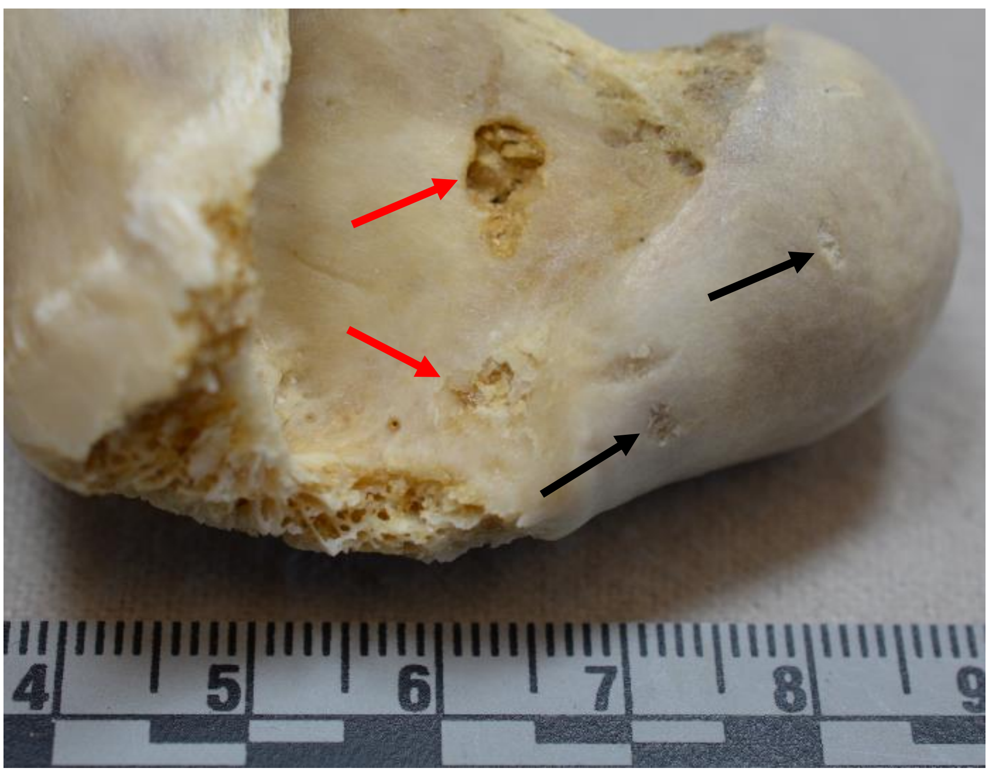

Figure 4.1. Pits (black arrows) and punctures (red arrows) on the proximal epiphysis of a femur.

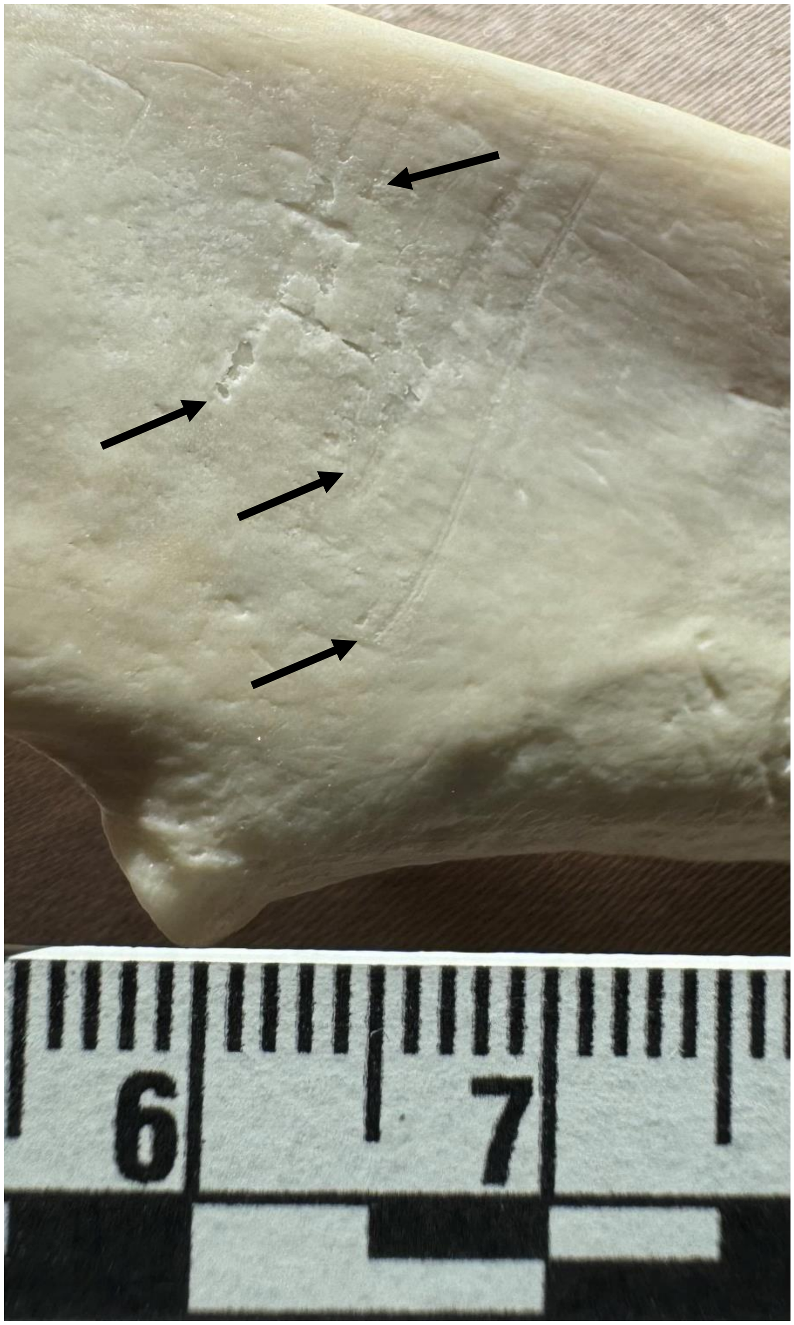

Figure 4.2. Perpendicular scores (black arrows) on the spinous process of a thoracic vertebra.

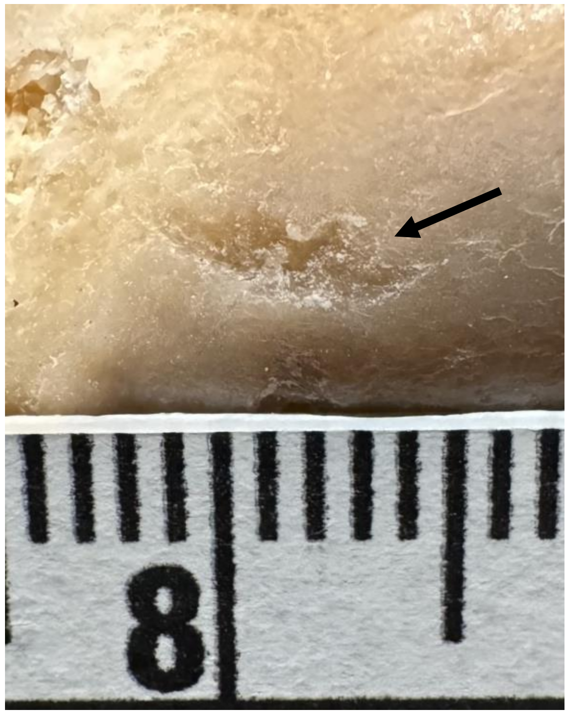

Figure 4.3. Broad score (black arrow) on the proximal epiphysis of a femur.

Figure 4.4. Puncture on the proximal epiphysis of a femur with a slight L-shape.

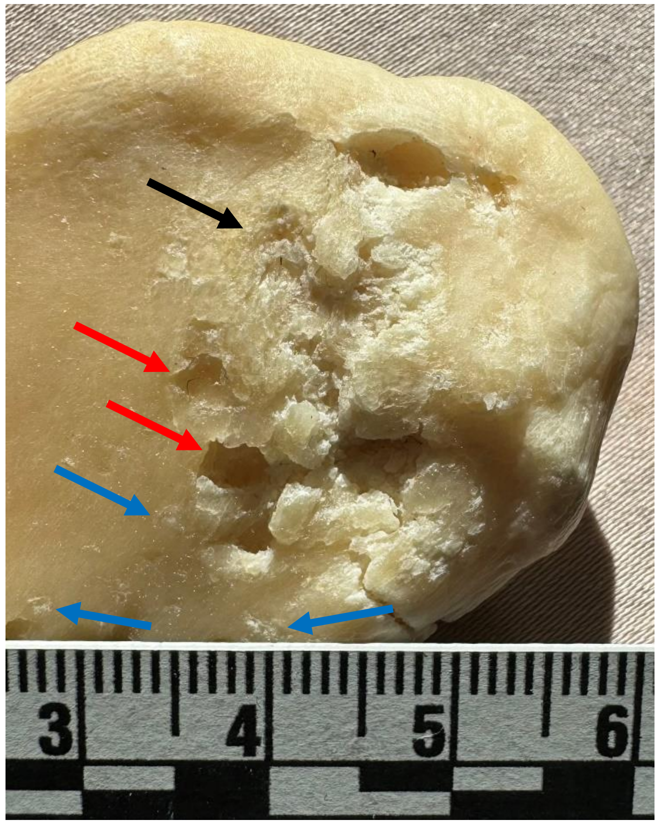

Figure 4.5. Furrow (black arrow), punctures (red arrows), and pits (blue arrows) on the proximal epiphysis of an ulna.

(1.14 ± 0.50 mm) were the largest on the patellae, followed by the long bone epiphyses (1.66 ± 0.95 mm and 1.05 ± 0.59 mm**)**. Additionally, puncture length (4.02 ± 2.00 mm) and breadth (2.89 ± 1.99 mm) on the calcanei were slightly larger than they were on the long bone epiphyses (3.98 ± 2.03 mm and 2.77 ± 1.45 mm). However, there were only three punctures on the calcanei, compared to 97 punctures on the long bone epiphyses. Score length was largest on the rib sternal ends (8.32 ± 3.27 mm), but score breadth was largest on the patellae (1.13 ± 0.45 mm).

Table 4.2. Average measurements of each tooth mark type distinguished between type of bone and bone location.

Element	Location	Tooth Mark Type	Length (mm)	SD (±)	Breadth (mm)	SD (±)
Long Bones	Epiphysis	Pit	1.66	0.95	1.05	0.59
		Puncture	3.98	2.03	2.77	1.45
		Score	4.53	3.47	0.95	0.76
		Furrow	13.81	6.19	3.71	1.99
	Diaphysis	Pit	1.36	0.77	0.86	0.53
		Puncture	3.58	3.14	2.38	2.30
		Score	6.67	4.23	0.45	0.20
Vertebrae	Spinous Process	Pit	1.16	0.56	0.76	0.30
		Puncture	2.22	0.85	1.52	0.78
		Score	6.58	4.54	0.44	0.24
Ribs	Sternal End	Pit	0.92	0.31	0.62	0.24
		Puncture	2.90	0.23	1.68	0.99
		Score	8.32	3.27	0.52	0.15
	Head/Shaft	Pit	1.01	0.51	0.61	0.27
		Puncture	3.00	---	2.19	---
		Score	4.11	3.97	0.47	0.24
Patellae	All	Pit	1.78	0.76	1.14	0.50
		Puncture	2.94	1.24	1.82	0.63
		Score	4.94	1.61	1.13	0.45
Calcanei	All	Pit	1.44	0.55	0.81	0.27
		Puncture	4.02	2.00	2.89	1.99
		Score	3.42	1.16	0.69	0.29
Sternebrae	All	Pit	1.38	0.64	1.03	0.40
		Puncture	3.25	1.90	1.91	0.66
		Score	3.87	---	0.36	---

Description of Pig Scavenging Behavior on Bones

Effects of Pig Gnawing on Bones

The epiphyses of the long bones were gnawed on, but none to the point of destruction where it would result in a bone cylinder forming. The epiphyses of the long bones were frequently gnawed on, with crenellated edges (52.9%), such as the distal epiphyses of 2 femora (Figure 4.6) and the proximal epiphyses of 9 femora (Figure 4.7), 2 ulnae, 2 humeri, and 4 tibiae (Figure 4.8), although they were not accompanied by any edge polish. There were also crenellated edges with no edge polish on 4 patellae (66.6%) (Figure 4.9) and 1 calcaneus (50%) (Figure 4.10). The spinous processes of all 6 vertebrae (100%) (Figure 4.11), the shafts of 12 ribs (63.2%) (Figure 4.12), and 1 sternebra (50%) (Figure 4.13) also had crenellated edges with no edge polish. A total of 42 out of 69 elements (60.9%) had crenellated edges with no edge polish.

Two tibiae and one femur were fractured on the diaphyses, possibly as a result of trampling. One tibia had a segmented fracture and was broken into three pieces, and the proximal epiphysis of the femur was broken off, leaving only the diaphysis and distal epiphysis. The other tibia was fractured near the distal diaphysis, leaving the rest of the diaphysis and the proximal epiphysis. There were also tooth marks near the fracture margin of the two former bones. The tibia had only 5 tooth marks, 4 pits, and 1 score near the margin, whereas the femur had 43 tooth marks, 30 pits, and 13 scores concentrated near the fracture margin (Figure 4.14). Although the fractures occurred from a process other than gnawing, the tooth marks indicate that the pigs were interested in the diaphyses following the fracture, possibly for the bone marrow.

Figure 4.6. Distal epiphysis of a femur gnawed on with crenellated edges.

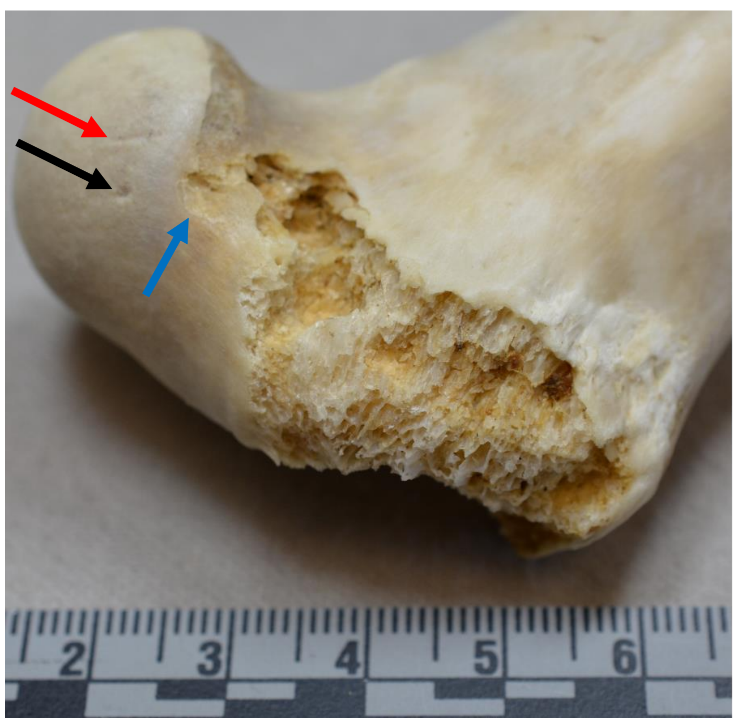

Figure 4.7. Proximal epiphysis of a femur gnawed on with crenellated edges with a pit (black arrow), score (red arrow), and puncture (blue arrow).

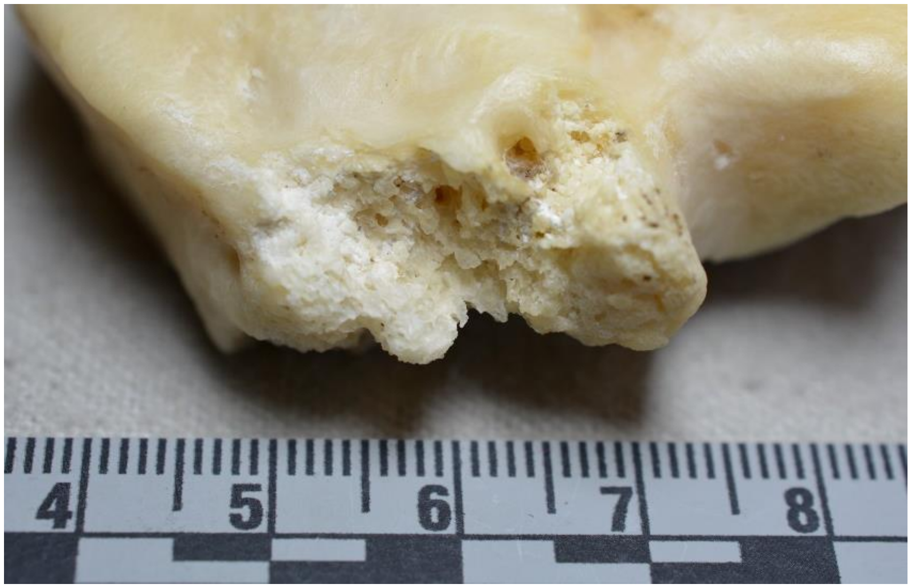

Figure 4.8. Proximal epiphysis of a tibia gnawed on with crenellated edges.

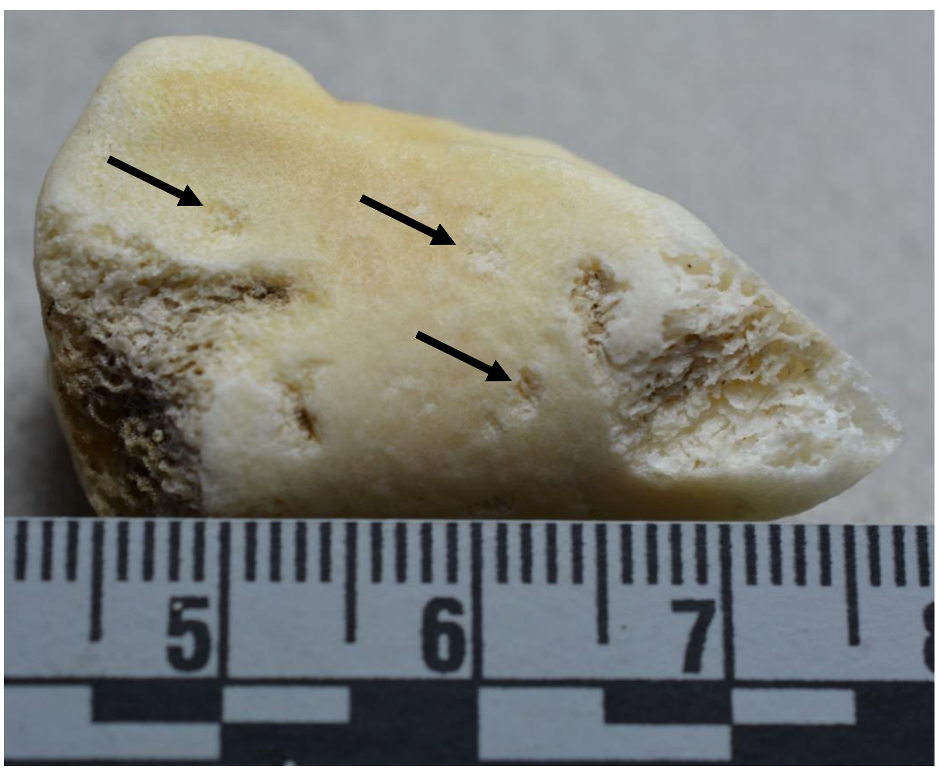

Figure 4.9. Patella gnawed on with crenellated edges and pits (black arrows).

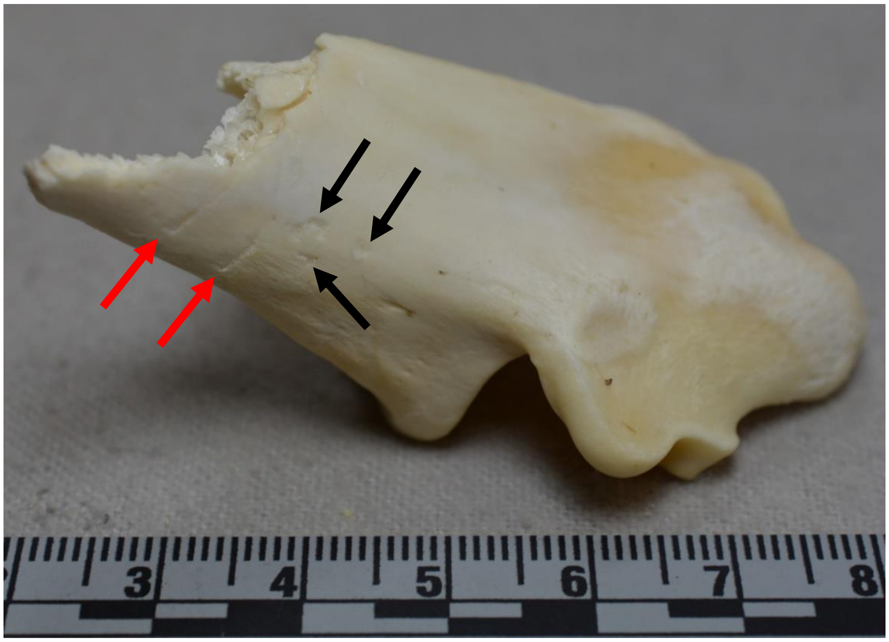

Figure 4.10. Calcaneus gnawed on with crenellated edges, pits (black arrows), and scores (red arrows).

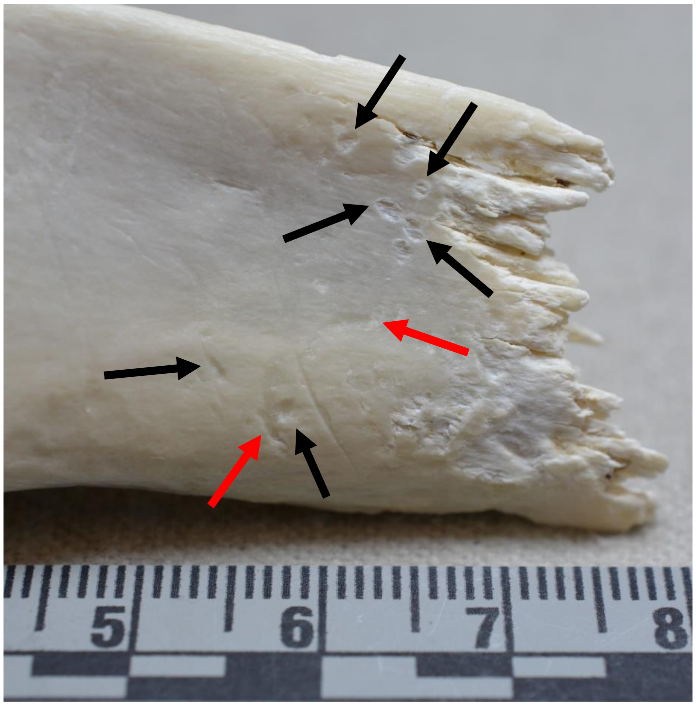

Figure 4.11. Spinous process of a thoracic vertebra gnawed on with crenellated edges, pits (black arrows), and scores (red arrows).

Figure 4.12. Shaft of a rib gnawed on with crenellated edges and pits (black arrows).

Figure 4.13. Sternebra gnawed on with crenellated edges.

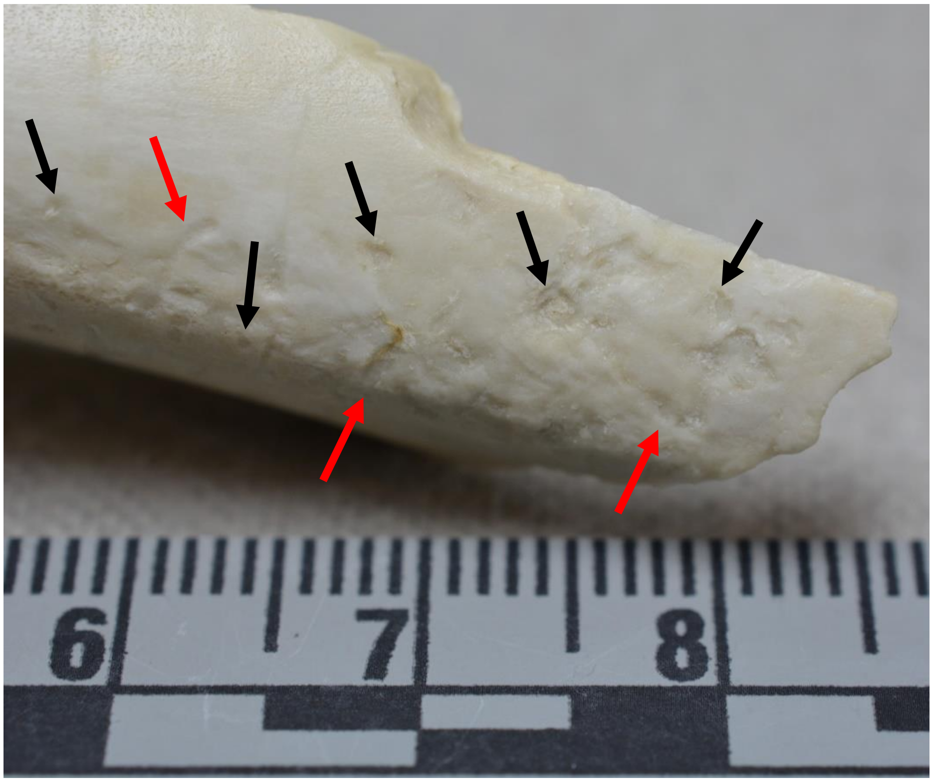

Figure 4.14. Pits (black arrows) and scores (red arrows) concentrated near fracture margin on diaphysis of a femur.

Whereas a single long bone may have multiple tooth marks that are spread around or isolated, the tooth marks on the vertebrae and ribs were more concentrated together. The ribs had only two more tooth marks (409) than the long bones (407), but there were almost twice as many long bones (34) than there were ribs (19). Additionally, the ribs had slightly more crenellated edges (63.2%) than the long bones (58.8%). Therefore, this may indicate that the pigs preferred to gnaw on smaller rib bones rather than larger long bones, and that they caused more gnawing damage to the former.

Behavior of Pigs While Scavenging

The pigs were interested in the bones and would often push them around with their snouts (Figure 4.15). They smelled one bone then moved on to another, only spending a few seconds at a time at each bone. The pigs also walked over, and on top of, the bones as they were investigating. One pig was observed carrying a tibia in its mouth and transporting it to where the pigs liked to congregate and sleep (Figure 4.16). Additionally, a maximum of two pigs were observed gnawing at one bone at the same time (Figure 4.17). The pigs would gnaw on one bone for a few seconds before they lost interest and started to gnaw on another bone, which is similar to their behavior when smelling the bones.

Figure 4.15. Pig smelling and pushing a long bone with its snout.

Figure 4.16. Pig transporting a tibia in its mouth.

A half rib cage was dispersed the farthest away, at approximately 21 m, from its original location, and most of the bones were still within 1-15 m from their original location. The half rib cages were recovered intact, since there was still a moderate amount of connective tissues on the long bones and half rib cages that allowed the carpals, tarsals, patellae, and sternebrae to stay attached to their respective bones. However, four patellae and three proximal ulnae were found isolated on the ground around pig feces.

Figure 4.17. Two pigs gnawing a half rib cage simultaneously.

Statistical Analysis

A normality test was conducted to determine if the location and size of the tooth marks were equally distributed. If skewness and kurtosis are between -1 and 1, then the data are considered normally distributed. The two locations of the pits, punctures, scores, and furrows on each bone type were tested. The only tooth mark location considered normally distributed was the heads/shafts of the ribs for pits. All other tooth marks and their locations for each bone type were not normally distributed. Additionally, the length and breadth of pits, punctures, scores, and furrows on the epiphyses and diaphyses of the long bones, spinous processes and centra of the vertebrae, sternal ends and heads/shafts of the ribs, and patellae, sternebrae, and calcanei were tested. The samples that were considered normal for the long bones were pit length, puncture length and breadth, and furrow length on the epiphyses, and only pit breadth on the diaphyses. None of the samples for the vertebrae were considered to have a normal distribution. For the ribs, the only normally distributed samples were pit length and breadth and score length on the sternal end, and pit breadth on the head/shaft. Additionally, only pit and puncture length on the patellae, puncture and score length on the calcanei, and puncture breadth on the sternebrae were normally distributed. Since all the data were not consistently normally distributed, nonparametric tests were used for the following analyses.

The first statistical test in SPSS 29.0 was an Independent-Samples one-tailed t-test to test whether the number of tooth marks was equally distributed between two populations of some bone types, the epiphyses and diaphyses for the long bones, the spinous processes and centra for the vertebrae, and the sternal ends and heads/shafts for the ribs (Table 4.3). The first analyses conducted were between the total number of pits, punctures, scores, and furrows on the long bones to the epiphyses and diaphyses. The tests that compared the number of pits, punctures, and furrows between locations were statistically significant, with $p = 0.042$, <0.001, and 0.003, respectively. The test for comparing scores was not statistically significant, with $p = 0.290$. The results indicate that the number of pits, punctures, and furrows on the epiphyses were significantly greater than those on the diaphyses, so the null hypothesis was rejected. For the scores, the null hypothesis was not rejected, since there was no significant difference between the number of scores on the epiphyses or diaphyses. The pigs were more likely to produce pits, punctures, and furrows on the epiphyses, and scores were distributed evenly throughout the epiphyses and diaphyses.

The next analyses conducted were with pits, punctures, and scores on the vertebrae and ribs. For the vertebrae, the only tooth mark type that yielded $p < 0.05$ was pits at $p = 0.038$. Punctures and scores were not statistically significant with $p = 0.072$ and 0.058, respectively. The pigs were more likely to produce pits on the spinous processes of the vertebrae; therefore, the null hypothesis was rejected for pits, but it was not rejected for punctures and scores. Pits ($p = <0.001$) and scores ($p = <0.001$) on the ribs were statistically significant, but the punctures were not statistically significant ($p = 0.329$). The pigs produced a significantly greater number of pits and scores on the heads/shafts than the sternal ends of the ribs; therefore, the null hypothesis was rejected for pits and scores since they were not evenly distributed between the two locations.

Table 4.3. Statistical p-values for the Independent-Samples one-tailed t-test. The locations of the long bones being compared are the epiphyses and diaphyses, the locations of the vertebrae being compared are the spinous processes and centra, and the locations of the ribs being compared are the sternal ends and heads/shafts. P-values that are statistically significant are in bold.

Element	Pit	Puncture	Score	Furrow
Long Bones	**0.042**	**<0.001**	0.290	**0.003**
Vertebrae	**0.038**	0.072	0.058	**---**
Ribs	**<0.001**	0.329	**<0.001**	---

The second statistical test conducted was a Kruskal-Wallis One-Way ANOVA to determine if there was a statistically significant difference between the tooth mark sizes and bone location (Table 4.4). The length and breadth of pits, punctures, and scores were compared separately to the epiphyses and diaphyses for the long bones and the sternal ends and heads/shafts for the ribs. The two locations of the vertebrae, spinous process and centrum, were not compared in this test, because there were no tooth marks on the centra to compare with the tooth marks on the spinous processes. The tooth mark size may in part correspond to the density of the bone; therefore, it was hypothesized that the tooth mark sizes would be greater on the epiphyses of the long bones and the sternal ends of the ribs.

The outcome of the test indicated that pit and score length and breadth, as well as puncture breadth, on the long bones were statistically significant; therefore, the lengths of pits and scores, and the breadths of pits, scores, and punctures, were significantly larger on the epiphyses than the diaphyses of the long bones. The p-values of the pit length (0.032), pit breadth (0.021), score length (0.017), score breadth (<0.001), and puncture breadth (0.023) were below the significance level of 0.05. For the ribs, only score length was statistically significant, with $p = 0.002$, so score length was the only tooth mark measurement that was significantly larger on the sternal end than the head/shaft of the ribs. As a result, the null hypothesis was rejected for pit and score length and breadth and puncture breadth on the long bones, but it was not rejected for the ribs. The sizes of the tooth marks on long bones that were statistically significant were found to be dependent on the density of the bone, with larger tooth marks being created on the softer, less dense parts of the bones.

Table 4.4. Statistical p-values for the Kruskal-Wallis One-Way ANOVA. P-values that are statistically significant are in bold.

Element	Tooth Mark Type	Length	Breadth
Long Bones	**Pit**	**0.032**	**0.021**
	Puncture	0.134	**0.023**
	Score	**0.017**	**<0.001**
Ribs	**Pit**	0.870	0.699
	Puncture	1.000	1.000
	Score	**0.002**	0.208

The final statistical test conducted was a Summary Independent-Samples t-test to compare the average length and breadth of the pits, punctures, and scores produced by pigs to those produced by canids from previous research. The dimensional data for the long bones, vertebrae, and ribs were combined, and the two locations for each bone were labelled epiphysis and diaphysis to compare them to the canid data, since the specific bone type used in the canid studies were not always explicitly stated. For example, Yravedra et al. (2014) used long bones instead of carcasses, unlike Andrés et al. (2012) and Sala et al. (2014). For the pig tooth marks, the average dimensions of the three tooth mark types, pits, punctures, and scores, and the SD for each were calculated, and the sample number (n) was reported for each bone location (Table 4.5). The average length and breadth for each tooth mark were greater on the epiphyses than the diaphyses. The tooth mark with the greatest length was scores on the epiphyses, and punctures on the epiphyses had the greatest breadth.

Table 4.5. Average measurements of pig tooth marks on long bones, vertebrae, and ribs.

Element	Location	n	Average Length (mm)	SD (±)	Average Breadth (mm)	SD (±)
Pit	**Epiphysis**	264	1.43	0.85	0.92	0.52
	Diaphysis	322	1.06	0.56	0.64	0.34
Puncture	**Epiphysis**	103	3.89	2.01	2.70	1.45
	Diaphysis	11	3.53	2.99	2.37	2.18
Score	**Epiphysis**	68	5.76	4.07	0.70	0.61
	Diaphysis	134	4.99	4.23	0.46	0.22

The canid samples include dog data from Andrés et al. (2012) and Yravedra et al. (2014) (Table 4.6), and wolf data from Andrés et al. (2012) and Sala et al. (2014) (Table 4.7). For the dog data, all pit and score sizes, except for score length from Yravedra et al. (2014), were larger on the epiphyses than the diaphyses. Overall, the tooth marks reported by Andrés et al. (2012) were greater in size than those by Yravedra et al. (2012), except for pit length and breadth on the epiphyses and score length on the diaphyses.

For the wolf data, all tooth marks, pits, punctures, and scores, were larger in size on the epiphyses than the diaphyses for both Andrés et al. (2012) and Sala et al. (2014), which is similar to the dog sample. All pit and score measurements reported by Andrés et al. (2012) were greater in size than those by Sala et al (2014). Additionally, Sala et al.

(2014) was the only study to measure puncture length and breadth and omit score length from their analysis.

Table 4.6. Average measurements of dog tooth marks from previous research.

Source	Tooth Mark Type	Location	n	Average Length (mm)	SD (±)	Average Breadth (mm)	SD (±)
Andrés et al. (2012)	**Pit**	**Epiphysis**	19	2.40	1.14	1.90	0.76
		Diaphysis	66	1.77	0.91	1.36	0.66
	Score	**Epiphysis**	45	5.95	2.90	0.81	0.36
		Diaphysis	164	5.06	2.76	0.66	0.30
Yravedra et al. (2014)	**Pit**	**Epiphysis**	274	2.66	1.76	2.02	1.41
		Diaphysis	21	1.10	0.56	0.76	0.35
	Score	**Epiphysis**	147	5.10	3.16	0.70	0.68
		Diaphysis	78	5.43	3.50	0.42	0.42

The average measurements of the pig and canid tooth marks were compared using the Summary Independent-Samples t-test, and since the bones gnawed on by the pigs and canids come from different populations, unequal variances were assumed (Table 4.8). When comparing the pig data to the dog data from Andrés et al. (2012), the test concluded that five out of the eight tests conducted were statistically significant: pit length ($p = 0.002$) and breadth ($p = <0.001$) on the epiphyses, pit length ($p = <0.001$) and breadth ($p = <0.001$) on the diaphyses, and score breadth on the diaphyses (<0.001). When comparing the pig data to the dog data from Yravedra et al. (2014), the test concluded that two out of the eight tests conducted were statistically significant: pit length (p = <0.001) and breadth (p = <0.001) on the epiphyses. When comparing the pig data to the wolf data from Andrés et al. (2012), the test concluded that all eight tests conducted were statistically significant, with p = <0.001. The test for Sala et al. (2014) concluded that seven out of the ten tests conducted were statistically significant, with p = <0.001.

Table 4.7. Average measurements of wolf tooth marks from previous research.

Source	Tooth Mark Type	Location	n	Average Length (mm)	SD (±)	Average Breadth (mm)	SD (±)
Andrés et al. (2012)	**Pit**	**Epiphysis**	129	3.61	1.63	2.70	1.25
		Diaphysis	236	2.49	1.15	1.80	0.97
	Score	**Epiphysis**	78	10.76	4.97	2.92	1.63
		Diaphysis	306	8.62	4.31	1.68	1.12
Sala et al. (2014)	**Pit**	**Epiphysis**	54	2.81	0.68	2.31	0.59
		Diaphysis	218	2.11	0.64	1.65	0.53
	Puncture	**Epiphysis**	60	4.35	1.04	3.34	0.93
		Diaphysis	21	3.56	1.24	2.73	1.13
	Score	**Epiphysis**	33	---	---	2.35	1.38
		Diaphysis	161	---	---	1.29	0.87

Based on the results of the Summary Independent-Samples t-test, pig gnawing can be distinguished from canid gnawing when comparing epiphyseal pit length and breadth. Caution should be taken when comparing diaphyseal pit length and breadth and score breadth. Pig gnawing cannot be confidentially distinguished from canid gnawing when comparing epiphyseal score length and breadth, diaphyseal score length, and puncture length and breadth on both the epiphyses and diaphyses. Overall, the majority of the tooth marks produced by pigs were smaller than those produced by canids, with epiphyseal pit length and breadth being significantly smaller for pigs than canids. Between dogs and wolves, pigs were more distinguishable from wolves, especially when comparing pits and scores. Therefore, under certain circumstances, there is sufficient evidence to reject the null hypothesis and support the alternative hypothesis that pig gnawing is distinguishable from canid gnawing.

Table 4.8. Statistical p-values for the Summary Independent-Samples t-test comparing the pig data from the current study to dog and wolf data from previous studies. P-values that are statistically significant are in bold.

Tooth Mark Type	Location		Dog Data		Wolf Data	
			Andrés et al. (2012)	Yravedra et al. (2014)	Andrés et al. (2012)	Sala et al. (2014)
Pit	Epiphysis	Length	**0.002**	**<0.001**	**<0.001**	**<0.001**
		Breadth	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	Diaphysis	Length	**<0.001**	0.754	**<0.001**	**<0.001**
		Breadth	**<0.001**	0.141	**<0.001**	**<0.001**
Score	Epiphysis	Length	0.773	0.240	**<0.001**	---
		Breadth	0.231	1.000	**<0.001**	**<0.001**
	Diaphysis	Length	0.869	0.415	**<0.001**	---
		Breadth	**<0.001**	0.437	**<0.001**	**<0.001**
Puncture	Epiphysis	Length	---	---	---	0.056
		Breadth	---	---	---	**<0.001**
	Diaphysis	Length	---	---	---	0.975
		Breadth	---	---	---	0.617

DISCUSSION

The data obtained from analyzing the morphological damage of pig gnawing on bones in the current study led to some different findings from previous research (Berryman 2002; Domínguez-Solera and Domínguez-Rodrigo 2009; Indra et al. 2022; Pobiner 2007)). For example, scores were reported to be the most prevalent tooth mark produced by pigs. However, in the current study, the pigs produced more pits than scores. Although scores were the second-most produced tooth mark type (216), pits (641) far exceeded that total. The average breadth of the scores ranged from 0.36 mm to 1.13 mm depending on the bone type and location in the current study, but other authors have described pig scores as broad and shallow. The scores were observed to be shallow, but they were not significantly broad as determined metrically. Additionally, when comparing score breadth produced by pigs and canids, the wolves studied by Andrés et al. (2012) and Sala et al. (2014) produced scores that were significantly broader than those produced by pigs. Therefore, it is suggested that wide breadth of scores is not sufficiently diagnostic of pig scavenging.

Another pig gnawing characteristic reported in the present study that is contradictory is the absence of surface peeling. Pokines (2022) stated that surface peeling can occur with pig scavenging, but it was not observed on any of the bones in this study. The gnawing damage included the cortical and cancellous bone being removed together, rather than the cortical bone being peeled away from the underlying bone. Furthermore, only one L-shaped puncture was observed in the current study, a result that is inconsistent with the findings of other authors (Byrnes and Belcher 2021; Domínguez-Solera and

Domínguez-Rodrigo 2009). The L-shape of the puncture is believed to be a pig gnawing characteristic produced from the shape of their premolars and molars that is not observed with other scavengers. However, since they were not consistently present throughout the sample, this could not be confirmed.

Previous research on pig scavenging also suggested that pigs prefer to gnaw on the cancellous parts of the bone such as the epiphyses of long bones, spinous processes of vertebrae, and the sternal ends of ribs (Domínguez-Solera and Domínguez-Rodrigo 2009; Indra et al. 2022; Pokines 2022). In the current study, the epiphyses of long bones had significantly more pits, punctures, and furrows than the diaphyses. The vertebrae had zero tooth marks on the centra, which could be due to their bulky and irregular shape, which makes it harder to hold them in the mouth and gnaw on them, in contrast to the thin and straight spinous processes. However, the diaphyses of long bones had more scores, and the heads/shafts of the ribs had significantly more pits and scores than the sternal ends. Teeth dragging over the bone when picking it up is a possible explanation for the majority of scores being located on the diaphyses of long bones. Additionally, 15 out of 19 ribs had the sternal ends removed, either by the butcher or by gnawing, so any tooth marks that might have been present on the sternal ends were unable to be counted.

If the long bones were fractured, the diaphyses have a higher chance to be modified and have tooth marks, since it gives the pigs easy access to the bone marrow. Two of the three long bones that were fractured had tooth marks near the fracture margins, with 43 tooth marks on one of the bones. Although the epiphyses of long bones were commonly targeted, none of the bones exhibited any signs of forming a bone cylinder. The greater trochanters of four femora were partially or completely gnawed off, with crenellated edges, but the epiphyses were still intact. The distal epiphyses of only four femora had tooth marks, and the lateral condyle of two were gnawed on with crenellated edges. The lack of tooth marks on the distal epiphyses of the long bones could be attributed to the tough connective tissues that were still attached to some of the long bones when they were recovered.

An unexpected finding from the current study was the low amount of damage inflicted on the recovered bones. Normally, the severe bone damage associated with kennel pattern can exceed the damage produced by wild counterparts (Haglund 1997; Pokines 2022), but that level of damage was not observed in the current study. Although the epiphyses were not fully destroyed, there was still light gnawing damage with crenellated edges on the proximal epiphyses of 9 femora, 4 tibiae, 2 ulnae, 2 humeri, and the distal epiphyses of 2 femora. The ribs had more tooth marks than the long bones and a significant amount of damage, with 63.2% of the sternal ends gnawed off with crenellated edges, leaving only a small portion of the rib head/shaft (Figure 5.1). Crenellated edges are also a characteristic of canid gnawing that is also accompanied by edge polish, but edge polish was not present in the current study (Domínguez-Rodrigo et al. 2012; Pokines 2022). Therefore, the absence of edge polish on crenellated edges produced by pigs could be an indication of pig scavenging.

An indication that bones were completely consumed was the low number of necks recovered. Since the necks were fully fleshed, they were more likely to be completely consumed than the appendicular body parts or half rib cages that had minimal soft tissue.

The long bones, ribs, and vertebrae were not severely damaged enough to imply that the pigs may have eaten some of them whole. The remaining bones that were not recovered were likely under the elevated platform where the pigs liked to rest, which was not able to be safely searched. Therefore, kennel pattern did not play a part in the number of unrecovered bones since there was not enough evidence to suggest that the pigs completely consumed them.

Figure 5.1. Ribs with sternal ends gnawed off.

The current study was conducted during the middle of the summer in Lincoln, Massachusetts, USA, an area known to reach high temperatures and humidity during the summer months. The average temperature from June 27 to July 11, 2023, was 76.8˚ F, with a maximum of 79.9˚ F and a minimum of 66.1˚ F. There was also a small amount of rainfall over those two weeks, with a maximum of 1.31 inches in a single day. Since scavenging activity has been reported as increasing during times of low rainfall and higher temperature, it was expected that two weeks would have been enough time for the bones to be significantly modified (Brown et al. 2006; DeVault and Rhodes 2002; Fillios 2011; Loggins et al. 2002; Selva et al. 2005; Wilcox and Van Vuren 2009). However, the weather did not seem to have an impact on the scavenging activity in the current study since the bones were only slightly modified and the pigs did not seem interested enough to tear through the cartilage and ligaments still attached to some of the bones. Additionally, there was an equal mix of male and female pigs around the same age, so the influence of those factors was not able to be fully evaluated.

It was anticipated that the pigs would heavily modify the bones during two weeks of exposure. However, since they had to be fed a regular diet, the pigs were not inclined to break open the epiphyses and access the bone marrow for nutrients. Similar to the findings of Brown et al. (2006) and Domínguez-Solera and Domínguez-Rodrigo (2009), the pigs seemed to modify smaller bones such as the axial elements more than the larger bones. In the current study, tooth marks on the vertebrae and ribs were concentrated closely together, and the tooth marks on 83.3% of the vertebrae and 63.2% of the ribs were adjacent to crenellated edges. In Domínguez-Solera and Domínguez-Rodrigo's (2009) experiments, the sheep and pig bones were significantly modified and fragmented after only two hours. They observed the tooth marks to be most prominent on both ends of the femora and proximal epiphyses of the tibiae, similar to what was observed in the current study, which had most of the tooth marks on the proximal epiphyses of the femora (23.5%) and proximal epiphyses of the tibiae (26.5%). During their first experiment, Domínguez-Solera and Domínguez-Rodrigo (2009) calculated that 53.0% of their sample had tooth marks, 47.8% of the bones had tooth marks located on the epiphyses, and 76.8% of the bones had tooth marks on the diaphyses. In contrast, the current study had tooth marks on 34% of the long bones, with 75.0% of the tooth marks on the epiphyses and 25.0% on the diaphyses. In Domínguez-Solera and Domínguez-Rodrigo (2009), the low percentage of tooth marks on the epiphyses is due to most of the epiphyses being destroyed and consumed by the pigs, which still supports the conclusion that pigs prefer to gnaw on the epiphyses.

From the current study, five out of the 69 total bones had only one tooth mark and often with no other gnawing damage. The most tooth marks recorded for a single bone was 56 on the proximal epiphysis of an ulna. Overall, the average number of tooth marks per bone was 14.6. When comparing this to the average number of tooth marks produced by African wild dogs (Yravedra et al. 2014), it is slightly larger. Yravedra et al. (2014) reported that the average number of tooth marks per bone was less than ten, with the majority of the pits on the epiphyses and scores on the diaphyses. In the current study, pigs produced 77.7% of the pits on the epiphyses of the long bones, and 57.5% of the scores on the diaphyses, which is similar to what the African wild dogs produced in Yravedra et al. (2014). They also counted the amount of furrows present, with more than 50% on the proximal epiphyses of tibiae, ulnae, and the distal epiphyses of femora. Only eight bones (11.6%) in the current study had furrows, and they were located on either the proximal epiphysis of one humerus, two ulnae, two tibiae, or three femora. The wild dogs also did not produce any bone cylinders or destroy the epiphyses, which categorizes their scavenging impact as low to moderate compared to other carnivores. However, this puts them in the same category as pigs, who only gnawed off the greater trochanters of four femora and did not produce bone cylinders. Additionally, the statistical test comparing the sizes of tooth marks from the African wild dogs to the pigs indicated that only two out of the eight tests conducted were statistically significant, which was the least reported among the other comparisons. There was only a difference between the pit length and breadth on the epiphyses between the two scavenger species. Therefore, the tooth mark sizes produced by pigs and African wild dogs are also similar. Based on the results of the comparative test, it is difficult to distinguish pig gnawing from African wild dog gnawing unless pits on the epiphyses are compared.

Haynes (1980) noted furrow dimensions in in his study, but he only gave a range for the length and breadth and did not specify the furrows' locations. He stated that furrows produced by adult wolf teeth are 20-40 mm long and 4 mm wide. To compare, the average length and breadth of furrows calculated in the current study were 13.81 mm and 3.71 mm, respectively. The length never exceeded 27.88 mm, but the largest breadth was 9.20 mm. Based on the range provided by Haynes (1980), there is a possibility that pig furrows could be distinguished from wolf furrows, but additional factors of bone modification should be analyzed to make the most accurate estimate possible. Although the dimensions of furrows were not incorporated into the statistical analyses, they can still be compared to previous studies that analyze furrows based on their presence or absence and where they are located on the bone. Based on the first statistical analysis conducted in this study, there is a significant difference between where furrows are located on the bone, with all 14 of the present furrows located on the epiphyses.

Domínguez-Rodrigo et al. (2012) stated that furrows present on the proximal ulnae, humeri, femora, and tibiae are indicative of wolf gnawing, which are also where pigs produced furrows in the current study. Out of the 64 long bones retrieved from the farm, nine were radii, with only one having tooth marks but no furrows. Therefore, pigs are likely to produce furrows on most long bones other than radii. Although pig and canid gnawing cannot be distinguished based on the presence and location of furrows, the current study provided evidence that pigs can produce furrows on the epiphyses of most long bones.

Domínguez-Rodrigo and Piqueras (2003) correlated the size of the carnivore to the size of the tooth mark. They categorized epiphyseal pits under 4 mm, between 4-6 mm, and over 6 mm as produced by small canids, medium-to-large-sized canids, and large carnivores, respectively. However, the canid tooth marks collected from previous studies (Andrés et al. 2012; Sala et al. 2014; Yravedra et al. 2014) all reported pit lengths smaller than 4 mm, even though the canids they researched were mostly medium-sized and should not be placed in the same category as small canids, such as foxes and small domestic dogs. An explanation for this discrepancy is because smaller, inconspicuous marks were not included in the sample, as reported by Andrés et al. (2012). If pigs were to be categorized based on the dimensions reported by Domínguez-Rodrigo and Piqueras (2003), then they would be in the same category with the small canids, since the average epiphyseal pit length produced by pigs was 1.66 mm. However, adult wild boars and domestic pigs can weigh between 250 to 700 pounds, and sometimes even more; therefore, their body size prevents them from being paired with small canids that can weigh from 5 to 50 pounds. Other researchers (Andrés et al. 2012; Sala et al. 2014) prioritized score breadth over score length when comparing tooth marks sizes, because they believe that it is more suggestive of the scavenger's tooth size.

The dispersal of skeletal elements by pigs reported in this study overlaps with the documented distance of dispersal from previous research. Pigs were known to disperse elements from at least 2 m (Brown et al. 2006), 10 m (Greenfield 1988), 10-50 m (Fillios 2011), and 25-54 m (Byrnes and Belcher 2012). The pigs in the present study dispersed the bones from approximately 1 m to 21 m. Canids are more likely to disperse remains slightly further than pigs (Fosse et al. 2012), but they are also capable of dispersing remains distances similar to pigs. However, medium-to-larger-sized elements are easier for canids to disperse than pigs, who prefer the smaller-to medium-sized elements (Brown et al. 2006; Fillios 2011). A half rib cage was dispersed the farthest away at 21 m from its original location. The half rib cage was lighter in mass than the long bones, so it was easier for the pigs to disperse it farther away than the other bones.

Comparative Studies

There are many challenges when comparing scavenger studies to distinguish between scavenger taxa. Some challenges include researchers using different methods and materials in their studies. There are two main methods for measuring tooth marks: calipers or a computer software like ImageJ. The present study and Delaney-Rivera et al. (2009) used ImageJ, whereas others like Domínguez-Rodrigo and Piqueras (2003), Young et al. (2015), Yravedra et al. (2011, 2014), and Sala et al. (2014) used calipers.

Domínguez-Rodrigo and Piqueras (2003) also created molds of the bones to measure instead of the bones themselves, which could have affected the results. Several studies also analyzed different combinations of tooth mark types, mainly pits and scores. Punctures are seldom included in metric analyses and furrows even less. Additionally, the location of the tooth marks was often not reported, such as by Haynes (1980) and Young et al. (2015); therefore, local bone density is not included as a factor that can influence the size of tooth marks.

Another challenge is the time of exposure that the scavengers have with the bones. The timing varies between studies, with exposure ranging from a day to more than a year, therefore greatly influencing the amount of damage possible to the remains. The species fed to the scavengers also varied between studies. Whole carcasses or isolated bones of different species and sizes are distributed ranging from small cervids to large bovids and equids. Smaller remains are more easily destroyed than larger remains and can skew results based on how much damage is done to the bones. Comparing domestic to wild animals may greatly affect the amount of damage they inflict on remains. Domestic animals can cause a kennel pattern and, out of boredom, produce more damage than their wild counterparts. However, wild species are more inclined to scavenge and consume prey if it is their primary source of food and can produce severe damage while feeding.

The current study was compared to the methods and results of Andrés et al. (2012), Yravedra et al. (2014), and Sala et al. (2014), who all had different methods and materials. For example, Andrés et al. (2012) analyzed the bone modification of domestic dogs and wild wolves using medium-sized bovid and equid carcasses for the dogs and small-to-medium-sized equid carcasses for the wolves. There was no time of exposure specified for the dogs, but the carcasses were exposed to the wolves for either one day or throughout the summer or winter seasons. Yravedra et al. (2014) gave African wild dogs medium-sized equid long bones for up to two months of exposure. Additionally, Sala et al. (2014) analyzed wild and captive wolf modifications to small- medium- and large-sized ungulate carcasses for days, weeks, and up to years. They separated the carcasses by long bones and flat bones for reporting tooth mark frequency. The bone type was not specified for the tooth mark measurements, but the tooth mark location was reported. It is important to take into consideration these factors that can heavily influence the outcome when comparing studies. Out of all the previous research, the closest equivalent to the domestic pig used in the current study was the domestic dog examined by Andrés et al. (2012). Additionally, the two weeks that the bones were exposed to the pigs in the current study overlap among the exposure times established in the canid studies, but there were still outliers such as a single-day and years-long studies. Therefore, no clear comparison can be made regarding how much damage was done to the bones based on the timing of the experiments. The prey size in the canid studies varied from small to large, with the cervid bones used in the current study falling into the small-to-medium-sized range, thus allowing them to be compared with each other.

The pig tooth marks were overall smaller in size than the canid tooth marks. The only exceptions were the score length on the epiphyses and score breadth on the epiphyses and diaphyses (Yravedra et al. 2014). The average score length on the epiphyses and average score breadth on the diaphyses produced by pigs were 0.66 mm and 0.04 mm, respectively, larger than those produced by the African wild dogs. The average score length on the diaphyses were the same for both the pigs and African wild dogs (0.70 mm). When comparing the pig tooth mark sizes to all four canid studies combined, only the pit length and breadth on the epiphyses were statistically different. However, if the pig tooth mark sizes are compared to the canid studies individually, then the results are different. For example, there is a significant difference between pig tooth marks from the current study and wolf tooth marks from Andrés et al. (2012) for all tooth mark dimensions and locations. Apart from puncture length on the epiphyses and length and breadth on the diaphyses, there was a significant difference between pig tooth marks and wolf tooth marks from Sala et al. (2014). All pit dimensions and locations and score breadth on the diaphyses were significantly different between pig and dog tooth marks from Andrés et al. (2012). The least amount of difference was between the pig tooth marks and the African wild dog tooth marks from Yravedra et al. (2014), since only pit length and breadth on the epiphyses were statistically different. Despite having tooth mark sizes similar to African wild dogs, there is still a chance to distinguish pig from canid gnawing if epiphyseal pit length and breadth are compared.

CONCLUSIONS

Based on the results of the current study, pigs predominately produce pits (63.5%) and are more likely to produce pits (77.7%), punctures (90.7%), and furrows (100%) on the epiphyses of long bones than on the diaphyses, except for scores (42.5%). It was determined that there was a statistically significant difference between the number of pits ($p = 0.042$), punctures ($p = <0.001$), and furrows ($p = 0.003$) and their location on long bones; therefore, tooth marks on long bones are more likely to be concentrated on the epiphyses. This conclusion supports previous research (Domínguez-Solera and Domínguez-Rodrigo 2009; Indra et al. 2022; Pokines 2022) that pigs prefer to gnaw on the soft cancellous bone of the epiphyses than the hard cortical bone of the diaphyses. Although the epiphyses of the long bones had more tooth marks than the diaphyses, the damage was not significant enough to destroy the epiphyses and create a bone cylinder. Therefore, pigs are capable of modifying remains, but they would not be considered severe agents of bone modification, since only 47.3% of the recovered bones had tooth marks and no bones were destroyed beyond recognition. There was also a statistically significant difference between the location of pits ($p = 0.038$) on the vertebrae and the location of pits ($p = <0.001$) and scores ($p = <0.001$) on the ribs. There were zero tooth marks on the centra of the six vertebrae, but the spinous processes had 100 tooth marks, mainly pits (70) and scores (26), indicating that the pigs are more likely to produce tooth marks on the thin spinous processes rather than the bulky centra. The sternal ends of the ribs were largely deleted, either from butchering (15.8%) or gnawing (63.2%), so there were more tooth marks located on the heads/shafts of the ribs. The pigs also produced more damage to the ribs than the long bones, since only small portions of 12 ribs remained after being gnawed on. The ribs had more crenellated edges than the long bones as well, with 63.2% and 52.9%, respectively.

Additionally, for long bones, the size of pig tooth marks is dependent on the location on the bone. On the long bones, there was a statistically significant difference between pit length ($p = 0.032$) and breadth ($p = 0.021$), score length ($p = 0.017$) and breadth ($p = <0.001$), puncture breadth ($p = 0.023$), and the location on the bone. Therefore, pig tooth marks are more likely to be larger on the epiphyses than the diaphyses of long bones. Furthermore, the only significant difference for the ribs was between score length and the location on the bone ($p = 0.002$), so there is not enough evidence to state that the size of pig tooth marks on ribs are larger on the sternal ends than the heads/shafts.

Pig tooth marks are able to be distinguished from canids if the epiphyseal pit length and breadth are analyzed. There was a statistically significant difference between the size of the pig pits from the current study and the canid pits on the epiphyses from all previous canid studies (Andrés et al. 2012; Sala et al. 2014; Yravedra et al. 2014). Pigs produced smaller tooth marks overall, but only the pits located on the epiphyses ($p = <0.001$ to 0.002) were different enough from the canid pits to be distinguishable. Three out of four of the canid studies found pit length and breadth on the diaphyses and score breadth on the diaphyses to be statistically different from pigs, so it might be possible to distinguish pigs from canids when using a combination of pit length and breadth on the epiphyses and diaphyses as well as score breadth on the diaphyses, but additional factors other than tooth mark size should also be included in the analysis.

Furthermore, the pigs in the current study were not observed to modify bones as heavily as wolves and dogs, which could have been because they were fed a regular diet and were less interested in the bones for nutrients. The pigs produced crenellated edges on 60.9% of the bones, but there was no edge polish present, which may be useful to distinguish between pig and canid scavenging, since canids are often known to produce edge polish along with crenellated edges (Domínguez-Rodrigo et al. 2012; Pokines 2022). Pigs are more likely to scavenge and disperse smaller carcasses than larger ones. Pigs are also more likely to tooth mark axial elements heavily compared to long bones. Out of three of the four canid studies, scores produced by pigs were found to be significantly smaller than those produced by canids, which disproves the theory that pigs produced broader scores than canids. If these different factors of bone modification were analyzed together, then the scavenger taxa could be more accurately identified.

In North America, pigs are an invasive species whose population is steadily increasing. Therefore, there is a chance that they could be potential scavengers when modified human remains are discovered in an area where pigs are known to inhabit. There has been limited taphonomic research on pig scavenging of human remains, which can delay an investigation if suspected pig scavenging is not recognized at a crime scene. Although it is a myth that pigs can completely consume a body, they can still do considerable damage to the remains that may make it difficult to determine PMI. Scavenging damage can also obscure potential evidence such as human-induced sharp or blunt force trauma. Several authors (Barss and Ennis 1988; Gitto et al. 2021; Manipady et al. 2006; Mayer 2013; Mayer et al. 2023; Mazingi et al. 2023) have mentioned wounds from pig attacks that resemble blunt and sharp force trauma from trampling or the pigs ramming their tusks into the body and tearing through soft tissue. Overall, pigs should be regarded as primary scavengers, and their taphonomic impact needs to be researched further so that they can be more easily distinguished from other vertebrate scavengers.

Limitations and Future Studies

One of the main limitations when trying to distinguish between scavenger taxa is the tooth mark size overlap. Many scavengers of the same body size have similarly sized jaws and teeth, therefore producing tooth marks that can overlap in size (Andrés et al. 2012; Delaney-Rivera et al. 2009; Domínguez-Rodrigo et al. 2012; Young et al. 2015). It is difficult to distinguish scavengers with tooth marks alone, but analyzing other factors of bone modification may aid in narrowing down the scavenger responsible.

One limitation of the current study was the use of domestic pigs instead of wild. Wild pigs have larger tusks than domestic pigs, which could impact the size of tooth marks as well as the degree of modification if their jaws have different strengths. Domestic and captive animals have been observed to modify bones to the same extent or greater than their wild counterparts due to boredom, but that was not the case in this study. If human remains were found in an area inhabited by wild boars instead of domestic pigs, the taphonomic signature might look different than what was reported in the current study. However, analyzing domestic pig scavenging is still necessary, since there have been reports of human remains found in or near domestic pig enclosures (Berryman 2002; Cameron 2010; Gitto et al. 2012). Wild boars were not able to be analyzed in this study due to budget, time, and accessibility. Often, the wild boar's tooth mark sizes were not measured in studies that analyzed their scavenging behavior (DeVault and Rhodes 2002; Domínguez-Solera and Domínguez-Rodrigo 2009; Byrnes and Belcher 2021). Therefore, future studies should study the scavenging patterns of wild boars and measure the tooth marks produced on the bones.

Another limitation is the regular diet given daily to the pigs. This likely impacted their scavenging behavior, since they were not hungry nor inclined to consume the bones for nutrients. The epiphyses of the bones were not gnawed on to the point of destruction, indicating that they were not interested in accessing the bone marrow. Previous studies (Domínguez-Solera and Domínguez-Rodrigo 2009) that analyzed pig scavenging behavior reported that the epiphyses were destroyed, and the marrow cavity was accessed, which implies that pigs are able to heavily modify bones if they needed to. Future studies should conduct a study similar to the current one, except the pigs should not be fed anything other than the bones to ensure a more accurate representation of their behavior when they need to scavenge for food. Additionally, the pigs were not able to be observed modifying the bones throughout the two weeks, since a field camera was not allowed. Therefore, future studies should implement a field camera to record what happens or employ multiple researchers to watch the pigs in shifts.

Future studies should also continue to analyze the tooth mark dimensions produced by pigs. Their scavenging behavior has been researched before, but the specific measurements of their tooth marks have not be thoroughly investigated. A standard should be created that includes the tooth mark dimensions of different vertebrate scavengers. Therefore, if human remains are discovered with tooth marks, then the dimensions could be compared to the standard that has the average size of tooth marks for any available scavenger. However, since many of the tooth mark sizes overlap among scavengers, other factors of bone modification, such as degree of damage and time of exposure, need to also be considered.

The pattern of pig scavenging and bone modification observed in the present study include a higher frequency of pits than scores and three out of the four tooth marks (pits, punctures, and furrows) located mainly on the epiphyses of long bones. The length and breadth of pits and scores and the breadth of punctures on long bones are also larger on the epiphyses than the diaphyses, since the soft cancellous bone is easier to modify than dense cortical bone. On vertebrae, tooth marks are concentrated on the thinner spinous process, since the centra are too irregular for the pigs to hold in their mouths. Tooth marks on the ribs are mainly on the heads/shafts, since the majority of the sternal ends were destroyed, but there is no difference between the sizes of the tooth marks and their location on the bone. Domestic pigs are not severe bone modifiers and are more likely to leave tooth marks on bones than destroy the epiphyses to access the bone marrow. There was no surface peeling present, and the shape of punctures from pigs ranged from circular to ovoid, with only one bone displaying an L-shaped puncture, which were found to be common occurrences in previous studies.

Finally, pig gnawing may be distinguishable from canid gnawing based on the smaller length and breadth of pig tooth pits. Pig tooth scores are also narrower on the diaphyses, which contradicts previous research that indicated that pig scores are broader than canid scores. Punctures may be able to distinguish between pigs and canids based on epiphyseal breadth, but more research is needed to confirm this assumption. Although the pigs were expected to heavily modify the bones, they were still able to produce a significant amount of all four tooth mark types. Utilizing these data on pigs and continuing to study their taphonomic impact on remains and bones will provide forensic anthropologists the information necessary to distinguish pig scavenging from other agents of bone modification.

BIBLIOGRAPHY

Andrés M, Gidna AO, Yravedra J, Domínguez-Rodrigo M. 2012. A study of dimensional differences of tooth marks (pits and scores) on bones modified by small and large carnivores. *Archaeological and Anthropological Sciences* 4:209-219.

Abellán N, Jiménez-García B, Aznarte J, Baquedano E, and Domínguez-Rodrigo M. 2021. Deep learning classification of tooth scores made by different carnivores: achieving high accuracy when comparing African carnivore taxa and testing the hominin shift in the balance of power. *Archaeological and Anthropological Sciences* 13:1-14.

Barss P, Ennis S. 1988. Injuries caused by pigs in Papua New Guinea. *The Medical Journal of Australia* 149:649-656.

Berryman H. 2002. Disarticulation pattern and tooth mark artifacts associated with pig scavenging of human remains: A case study. In: Haglund WD, Sorg MH, editors. *Advances in Forensic Taphonomy: Method, Theory, and Archaeological Perspectives*. Boca Raton, FL: CRC Press. pp. 487–495.

Binford LR. 1981. *Bones: Ancient Men and Modern Myths*. New York, NY: Academic Press. pp. 35-81.

Brinkley A. 2012. *The Taphonomic Effects of Feral Hogs (Sus scrofa) and Vultures on Carrion.* Master's thesis, University of Houston, Houston.

Brown OJ, Field J, Letnic M. 2006. Variation in the taphonomic effect of scavengers in semi-arid Australia linked to rainfall and the El Niño Southern Oscillation. *International Journal of Osteoarchaeology* 16:165–176.

Burke CC. 2013. *A Study of Carnivore Modification in North American Archaeology: Perspectives on Neotaphonomy, Carnivore Use of Carrion, and Great Plains Bison Bonebeds*. Doctoral dissertation, University of Nevada, Reno.

Bury D, Langlois N, Byard RW. 2012. Animal-related fatalities—part I: characteristic autopsy findings and variable causes of death associated with blunt and sharp trauma. *Journal of Forensic Sciences* 57:370-374.

Byrnes JF, Belcher W. 2021. Multi-agent scavenging patterns in Hawai'i: A forensic archaeological and skeletal case study. *Science and Justice* 61:723-734.

Cameron S. 2010. *On the Farm: Robert William Pickton and the Tragic Story of Vancouver's Missing Women*. Toronto: Knopf Canada.

Choquenot D. 1998. Testing the relative influence of intrinsic and extrinsic variation in food availability on feral pig populations in Australia's rangelands. *Journal of Animal Ecology* 67:887-907.

Delaney-Rivera C, Plummer TW, Hodgson JA, Forrest F, Hertel F, Oliver JS. 2009. Pits and pitfalls: Taxonomic variability and patterning in tooth mark dimensions. *Journal of Archaeological Science* 36:2597-2608.

DeVault TL, Rhodes Jr. OE. 2002. Identification of vertebrate scavengers of small mammal carcasses in a forested landscape. *Acta Theriologica* 47:185-192.

DeVault TL, Rhodes Jr. OE, Shivik JA. 2003. Scavenging by vertebrates: Behavioral, ecological, and evolutionary perspectives on an important energy transfer pathway in terrestrial ecosystems. *Oikos* 102:225–234.

Domínguez-Rodrigo M, Gidna A, Yravedra J, Musiba C. 2012. A comparative neo taphonomic study of felids, hyaenids and canids: An analogical framework based on long bone modification patterns. *Journal of Taphonomy* 10:151-169.

Domínguez-Rodrigo M, Piqueras A. 2003. The use of tooth pits to identify carnivore taxa in tooth-marked archaeofaunas and their relevance to reconstruct hominid carcass processing behaviours. *Journal of Archaeological Science* 30:1385-1391.

Domínguez-Solera SD, Domínguez-Rodrigo M. 2009. A taphonomic study of bone modification and of tooth-mark patterns on long limb bone portions by suids. *International Journal of Osteoarchaeology* 19:345-363.

Evin A, Dobney K, Schafberg R, Owen J, Vidarsdottir US, Larson G, Cucchi T. 2015. Phenotype and animal domestication: A study of dental variation between domestic, wild, captive, hybrid and insular *Sus scrofa*. *BioMed Central Evolutionary Biology* 15:1-16.

Fillios M. 2011. Testing the impact of environmental zone on experimental taphonomic faunal models. *Environmental Archaeology* 16:113-123.

Fonseca GM, Mora E, Lucena J, Cantin M. 2015. Forensic studies of dog attacks on humans: A focus on bite mark analysis. *Research and Reports in Forensic Medical Science* 5:39-51.

Fosse P, Selva N, Smietana W, Okarma H, Wajrak A, Fourvel JB, Madelaine S, Esteban Nadal M, Cáceres I, Yravedra J, Brugal JP, Prucca A, Haynes G. 2012. Bone modification by modern wolf (*Canis lupus*): A taphonomic study from their natural feeding places. *Journal of Taphonomy* 10:197-217.

Galdikas BM. 1978. Orangutan death and scavenging by pigs. *Science* 200:68–70.

Gipson PS, Hlavachick B, and Berger T. 1998. Range expansion by wild hogs across the central United States. *Wildlife Society Bulletin* 26:279-286.

Gitto L, Bonaccorso L, Bryant SM, Serinelli S. 2021. Death caused by a domestic pig attack. *Forensic Science, Medicine and Pathology* 17:469-474.

Glusman G, Yanai I, Rubin I, Lancet D. 2001. The complete human olfactory subgenome. *Genome Research* 11:685-702.

González VT, Ojeda FO, Fonseca GM, García-Ruiz C, Pérez-Lloret P. 2021. Analysis of tooth mark patterns on bone remains caused by wolves (*Canis lupus*) and domestic dogs (*Canis lupus familiaris*) for taxonomic identification: A scoping review focused on their value as a forensic tool. *Applied Animal Behavior Science* 240:1-12.

Greenfield HJ. 1988. Bone consumption by pigs in a contemporary Serbian village: implications for the interpretation of prehistoric faunal assemblages. *Journal of Field Archaeology* 15:473-479.

Groenen MA, Archibald AL, Uenishi H, Tuggle CK. 2012. Analyses of pig genomes provide insight into porcine demography and evolution. *Nature* 491:393-398.

Haglund WD. 1997. Dogs and coyotes: postmortem involvement with human remains. In: Haglund WD, Sorg MH, editors. *Forensic Taphonomy: The Postmortem Fate of Human Remains*. Boca Raton, FL: CRC Press. pp. 367-381.

Haglund WD, Reay DT, Swindler DR. 1989. Canid scavenging/disarticulation sequence of human remains in the Pacific Northwest. *Journal of Forensic Sciences* 34:587-606.

Haynes G. 1980. Evidence of carnivore gnawing on Pleistocene and recent mammalian bones. *Paleobiology* 6:341-351.

Haynes G. 1983. A guide for differentiating mammalian carnivore taxa responsible for gnaw damage to herbivore limb bones. *Paleobiology* 9:164-17.

Hillson S. 1986. *Teeth*. Cambridge: Cambridge University Press. pp. 90-92.

Indra L, Errickson D, Young A, Lösch S. 2022. Uncovering forensic taphonomic agents: animal scavenging in the European context. *Biology* 11.

Kane M, Byeongyong A, Youk S, Jeon H, Soundarajan N, Cho E, Park W, Park C. 2023. Individual and population diversity of 20 representative olfactory receptor genes in pigs. *Scientific Reports* 13:1-11.

Kirch P. 2011. When did the Polynesians settle Hawai'i? A review of 150 years of scholarly inquiry and a tentative answer. *Hawaiian Archaeology* 2:3-26.

Kjorlien YP, Beattie OB, Peterson AE. 2009. Scavenging activity can produce predictable patterns in surface skeletal remains scattering: Observations and comments from two experiments. *Forensic Science International* 188:103-106.

Larson G, Dobney K, Albarella U, Fang M, Matisoo-Smith E, Robins J, Lowden S, Finlayson H, Brand T, Willerslev E, Rowley-Conwy P, Andersson L, Cooper A. 2005. Worldwide phylogeography of wild boar reveals multiple centers of pig domestication. *Science* 307:1618-1621.

Larson G, Cucchi T, Fujita M, Matisoo-Smith E, Robins J, Anderson A, Rolett, Spriggs M, Dolman G, Kim T, Thuy N, Randi E, Doherty M, Due RA, Bollt R, Djubiantono T, Griffin B, Intoh M, Keane E, Kirch P, Li K, Morwood M, Pedriña LM, Piper PP, Rabett RJ, Shooter P, Van den Bergh G, West E, Wickler S, Yuan J, Cooper A, Dobney K. 2007. Phylogeny and ancient DNA of *Sus* provides insights into neolithic expansion in Island Southeast Asia and Oceania. *PNAS* 104:4834-4839.

Loggins RE, Wilcox JT, Van Vuren DH, Sweitzer RA. 2002. Seasonal diets of wild pigs in oak woodlands of the central coast region of California. *California Fish and Game* 88:28-34.

Manipady S, Menezes RG, Bastia BK. 2006. Death by attack from a wild boar. *Journal of Clinical Forensic Medicine* 13:89-91.

Matlock T. 2022. United States hog inventory down 1%. *United States Department of Agriculture: National Agricultural Statistics Service Information*. Electronic document, accessed 28 November 2022.

Mayer JJ. 2013. Wild pig attacks on humans [Paper Presentation]. *Proceedings of the 15th Wildlife Damage Management Conference.* J. B. Armstrong, G. R. Gallagher, editors. pp. 17-35.

Mayer JJ, Garabedian JE, Kilgo JC. 2023. Human fatalities resulting from wild pig attacks worldwide: 2000–2019. *Human-Wildlife Interactions* 17:3-20.

Mazingi DS, Mutambanengwe P, Zimunhu T, Gwatirisa T, Mbuwayesango BA, Munanzvi K, Muparadzi C, Moyo M, Mwanza Y. 2019. Intestinal evisceration in children from the bite of the domestic pig, *Sus scrofa domesticus*: A report of two cases. *Wilderness and Environmental Medicine* 30:454-460.

McCann BE. 2012. *Genetic Relationships of Wild Pigs (Sus scrofa) in the United States: Geographic Origins and Genotypic Distribution of the Species with Implications for Management*. Doctoral dissertation, University of North Dakota. pp. 1-41.

Nguyen DT, Lee K, Choi H, Choi M, Le MT, Song N, Kim J, Seo HG, Oh J, Lee K, Kim T, Park C. 2012. The complete swine olfactory subgenome: Expansion of the olfactory gene repertoire in the pig genome. *BioMed Central* 13:1-12.

Nogueira-Filho SLG, Nogueira SSC, Fragoso JMV. 2009. Ecological impacts of feral pigs in the Hawaiian Islands. *Convention on Biological Diversity* 18:3677-3683.

Pavlov PM and Hone J. 1982. The behavior of feral pigs, *Sus scrofa*, in flocks of lambing ewes. *Australian Wildlife Research* 9:101-109.

Pobiner BL. 2007. *Hominin-Carnivore Interactions: Evidence from Modern Carnivore Bone Modification and Early Pleistocene Archaeofaunas (Koobi Fora, Kenya; Olduvai Gorge, Tanzania).* Doctoral dissertation, Rutgers University, New Brunswick. pp. 163-226.

Pokines JT. 2022. Faunal dispersal, reconcentration, and gnawing damage to bone in terrestrial environments. In: Pokines JT, L'Abbé EN, Symes SA, editors. *Manual of Forensic Taphonomy*. Boca Raton, FL: CRC Press. pp. 295-359.

Pokines JT, Sussman R, Gough M, Ralston C, McLeod E, Brun K, Kearns A, and Moore T. 2017. Taphonomic analysis of rodentia and lagomorpha bone gnawing based upon incisor size. *Journal of Forensic Sciences* 62:50-66.

Sack W. O. 1982. *Essentials of Pig Anatomy*. Ithaca, NY: Veterinary Textbooks.

Sala N, Arsuaga JL, Haynes G. 2014. Taphonomic comparison of bone modifications caused by wild and captive wolves (*Canis lupus*). *Quaternary International* 330:126-135.

Selva N, Jędrzejewska B, Jędrzejewski W, Wajrak A. 2005. Factors affecting carcass use by a guild of scavengers in European temperate woodland. *Canadian Journal of Zoology* 83:1590-1601.

Seward NW, VerCauteren KC, Witmer GW, and Engeman RM. 2004. Feral swine impacts on agriculture and the environment. *Sheep & Goat Research Journal* 19:34-40.

Ubelaker DH. 1997. Taphonomic applications in forensic anthropology. In: Haglund WD, Sorg MH, editors. *Forensic Taphonomy: The Postmortem Fate of Human Remains*. Boca Raton, FL: CRC Press. pp. 77–90.

Ubelaker DH, DeGaglia CM. 2020. The impact of scavenging: perspective from casework in forensic anthropology. *Forensic Sciences Research* 5:32-37.

United States Department of Agriculture: animal and plant health inspection service. 2020. *Feral Swine Damage*. Electronic Document, accessed 28 November 2022.

United States Department of Agriculture: Animal and Plant Health Inspection Service. 2024. *History of Feral Swine in the Americas*. Electronic Document, accessed 4 October 2024.

Wilcox JT, Van Vuren DH. 2009. Wild pigs as predators in oak woodlands of California. *Journal of Mammalogy* 90:114–118.

Wood GW, Barrett RH. 1979. Status of wild pigs in the United States. *Wildlife Society Bulletin* 7:237-246.

Young A, Stillman R, Smith MJ, and Korstjens AH. 2015. Scavenger species-typical alteration to bone: using bite mark dimensions to identify scavengers. *Journal of Forensic Sciences* 60:1426-1435.

Yravedra J, Andrés M, Domínguez-Rodrigo M. 2014. A taphonomic study of the African wild dog (*Lycaon pictus*). *Archaeological and Anthropological Sciences* 6:113-124.

Yravedra J, Lagos K, Bárcena F. 2011. A taphonomic study of wild wolf (*Canis lupus*) modification of horse bones in Northwestern Spain. *Journal of Taphonomy* 9:37-65.

CURRICULUM VITAE

[redacted]