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Multi-agent scavenging patterns in Hawaiʻi: A forensic archaeological and skeletal case study

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Case Study

Multi-agent scavenging patterns in Hawai'i: A forensic archaeological and skeletal case study

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Abstract

Knowledge of the behavior of local fauna can aid forensic investigators in developing awareness of site formation processes. In Hawai'i, little has been published on the effects of feral domestic pig (*Sus scrofa*) and feral domestic dog (*Canis familiaris*) scavenging and bone dispersal on field recovery and laboratory observations. In this Pacific tropical setting, the most consequential terrestrial taphonomic agents are pigs and dogs, both in terms of hard tissue modification and dispersal of remains across the landscape. In 2017, an archaeologist discovered the remains of an unidentified decedent on the island of Kaua'i, State of Hawai'i during a cultural resource management survey. Subsequently, a forensic recovery team in conjunction with Kaua'i police and crime scene investigators used archaeological techniques, including pedestrian survey, tape-and-compass, and GPS mapping, to map and recover the remains. A feral pig trail transected various areas of the recovery site and corresponded with the distribution pattern of recovered skeletal material,

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including both the main concentration more broadly dispersed skeletal elements. While much of the skeleton was present, missing or unrecovered skeletal elements are consistent with expectations based on existing literature. Much of the postmortem bone deformations were characteristic of marks related to feral dog and/or feral pig scavenging. These results assisted local investigators in deciding the manner of death, as well as providing the family with an accounting of the decedent's remains for burial. Thus, forensic anthropologists and archaeologists need to understand and develop knowledge of local animal behavior to recover and interpret human remains of medicolegal significance.

Keywords: Forensic anthropology, Forensic archaeology, Hawai'i taphonomy, Pig/suid scavenging, Dog/canid scavenging, Multi-actor scavenging

1. Introduction

Forensic taphonomy has many foci within the forensic anthropological community [1–5]. Originally, taphonomy was defined by Efremov [6] as "laws of burial"; however, this discipline currently encompasses all processes, both natural and cultural phenomena, that affect skeletal and artifact material from the time of deposition/death to the time of recovery. Additionally, Haglund and Sorg [7] define "taphonomy" as the study of death assemblages modified by burial processes as well as the accumulation processes and modification of osseous materials from a site formation perspective [8]. Haglund and Sorg [7] provide a more specific definition for forensic taphonomy as "... the use of taphonomic models, approaches, and analyses in forensic contexts to estimate the time since death, reconstruct the circumstances before and after deposition, and discriminate the products of human behavior from those created by the earth's biological, physical, chemical, and geological subsystems..."

Currently, one of the main foci of forensic taphonomy is to differentiate between human-induced trauma and pseudo-trauma created by non-human agents. This is important as many taphonomic processes may mimic signatures of various forms of trauma, which, in turn, may affect the interpretation of cause and manner of death. This differentiation is aided by a familiarity with taxon-specific patterns of skeletal and soft-tissue modification [9]. However, this retrospective process of determining specific actors can be difficult to tease apart and is made more difficult with multiple agents (e.g., animals, climate/weather, insects, vegetation actions, etc.). Knowledge of the local fauna and environments can aid in both the forensic recovery as well as the subsequent analysis of human remains and material evidence [9–12]. Drawing from the zooarchaeological literature, forensic anthropologists can frame their investigation of the local taphonomy that produced the case through a nested system, which links the trace observed on the bone (e. g., furrow), to its causal process (e.g., gnawing), to the effector (e.g., the incisor tooth), to the actor (e.g., feral pig), to the actor's behavioral (e.g., omnivorous scavenging) and ecological (e.g., tropical scrub forest) context [13]. We will use the term "trace" as defined by Gifford- Gonzalez [13], which is "the product of a causal process" (p.62) or the mark(s) left on bones as a result of an actor's action(s). A forensic taphonomy version of this approach and interpretative process is discussed at length by Sincerbox and DiGangi [12].

1.1. Review of taphonomic agents in Hawai'i

Applying Gifford-Gonzalez's recommendations, the authors first considered the taphonomic agents that could have potentially contributed to the site formation processes [13]. Taphonomic research in Hawai'i primarily has focused on entomology and postmortem microbiology [14,15]. One notable exception was Dibner and colleagues' [16] study on scavenging patterns of the small Asian mongoose (*Herpestes javanicus*). They observed that the small Asian mongoose initially feed off the larval masses in the first few days postmortem, and also scavenged during a later phase on the remaining dried skin and soft tissue. This was the only vertebrate scavenger observed in their study that directly interacted with the carcass remains. The researchers also observed that the mongooses scattered small bones (i.e., ribs and bones of the hands and feet) away from the primary deposition site. This scavenging behavior is similar to the Cape gray mongoose (*Galerella pulverulenta*) [17,18]. In Spies and colleagues' study in South Africa [17], they found that the forelimb bones were the first to be disarticulated and scattered. The maximum distance from the primary deposition area was 12.67 m, but the skeletal elements did remain in closely spaced clusters. The researchers found that there was a correlation in scattering, in which the elements scattered were moved under dense cover such as bushes and thickets, and not along existing animal trails, likely for protection during feeding. Additionally, the Cape gray mongoose did not leave diagnostic patterning that was species-specific on the bones (e.g., canine punctures) [17,18]. Although, they acknowledge that due to the age of the pig specimens, this may be a consequence of cartilaginous bones from the juvenile remains. The mongooses feeding pattern started at the anal region, then the hindlimbs, abdomen, ribcage, and spinal column, and subsequently the forelimbs, neck, and head. Interestingly, they observed that the mongooses primarily focused on the skeletal muscles and would leave most of the viscera. Since the mongoose is a small mammalian carnivore, they are limited in the weight and size of elements that they can manipulate compared to larger canids. This is supported in case studies presented by Spies and colleagues [18], in which mongooses scavenging human remains focused on the smaller elements of the body such as the hands and feet. In a study by Davis and Goff [19] on intertidal decomposition, they observed the small Indian mongoose around the pig carcasses as well as two bird species, *Paroaria coronate* (red-crested Cardinal) and *Acridotheres tristis* (Common Myna). However, they did not detail the scavenging of these animals since this was not the foci of their study.

While these studies contain important insights into the processes of soft tissue decomposition, various terrestrial mammals in the island ecosystem, including feral domestic dogs (*Canis familiaris*) and feral cats (*Felis catus*), rodents (Rodentia sp.), and feral pigs (*Sus scrofa*) [20], are more likely to produce hard tissue modifications. According to Sincerbox and DiGangi [12], domestic cats tend to leave minimal traces on hard tissue, nor can they disperse remains. Rodents produce significant and highly diagnostic bone surface modifications and can also transport remains; however, they are unable to disperse remains significantly larger than their relatively small body size [12]. Avian scavengers in Hawaii that are also part of the scavenger guild include owls. While Davis and Goff's [19] study is the only published research naming birds as possible scavengers in the Hawaiian Islands, according to Allen and colleagues [21] many types of owls scavenge opportunistically. Allen and colleagues found in their literature review that owls primarily were observed scavenging mammalian carrion species. As well, the carrion species' mass was typically larger than the owl who was scavenging. Allen and colleagues suggest that owls primarily consume soft tissue of larger carcasses due to the size differential as well as that they are opportunistic scavengers when energetically stressed. The two owl species present across the Hawaiian Islands are the introduced Barn owl (*Tyto alba*) and the endemic Typical owl or *pueo* (*Asio flammeus sandwichensis*) [20]. Osteologically, avian scavenging marks are usually limited to scratches on the bone surface with the occasional puncture on thin cortical bones [22]. It is possible that significant tree cover in the primary deposition area of a body may lead to a lack of avian activity (e. g., [17]).

On Kauai, black-tailed deer (*Odocoileus hemionus*) were introduced for sport hunting in the mid-20th century [23]. While deer are not typical scavengers due to their herbivore diet, according to Kierdorf sometimes deer will chew on dry bones, or osteophagy, producing a distinctive fork formation at the bone ends [24]. This was directly observed at the Forensic Anthropology Center at Texas State University on a human cadaver [25].

Feral pigs and dogs elsewhere in Oceania have been documented destroying and scattering osseous materials during scavenging activities [26–28]. Thus, pigs and dogs are arguably the most influential terrestrial taphonomic agents in Hawai‘i based on their dispersal capabilities and destructive scavenging behavior. Canids, in particular domestic dog, wolves, and coyotes, share similar scavenging behavior and taphonomic signatures [12]. However, due to the dominance of feral pigs in Hawai‘i, a more detailed discussion of their taphonomic agency is prudent.

Wildlife biologists have examined Hawaiian feral pig biology, ecology, and behavior for decades. Recent genetic research suggests that most modern Hawaiian feral pigs are primarily descended from domestic pigs first introduced by ancient Polynesians and later admixed with European and Asian pig variants [29]. Average sounder size in the Hawaiian Islands has been reported to range from solitary boars to groups of 10, with mixed ages [30,31]. Hawaiian feral pigs weigh on average 59 kg (130 lbs.), with a body weight range between 30 kg (66 lbs.) to 100 kg (220 lbs.), depending on their age and sex [30]. Feral pigs typically root and disturb the forest floors and pasture lands and are considered extremely aggressive in scavenging and rooting behavior [32]. They consume an omnivorous diet dominated by plant matter but also including carrion [32,33].

Dogs (*Canis familiaris*) in Hawaii have a long history stemming from Polynesians bringing dogs to Hawaii as well as European influences. Most published studies focus on human use of dogs in pre-contact Polynesia, since the Polynesian dog is considered extinct [33]. Thus, there is relatively little published on the feral or stray dogs living in Hawaii today. These dogs are mostly derived from the larger European stocks of dogs brought during the colonial period. According to Tomich [33], some examples of captured feral domestic dogs in Hawaii were medium in size, averaging around 45–50 lbs. Like other domestic dogs, they subside on an omnivorous diet although they have a carnivorous evolutionary history [12]. This includes scavenging carrion when the opportunity arises.

1.1.1. Taphonomic evidence from feral dogs and pigs

Taphonomists have developed methods for inferring the actors involved in the multiagent disaggregation and destruction of vertebrate remains by non-human animals [5,34,35]. Gifford-Gonzalez [13] thoughtfully divides this process into two categories based on intentionality: dismemberment and disarticulation. Dismemberment is understood as the intentional disaggregation of carcasses by humans or non-human animals. Disarticulation refers to the unintentional dispersal of a carcass by biotic, abiotic, or cultural processes [13]. Given the presence of feral dogs and feral pigs in the Hawaiian environment, evidence of their involvement in dismemberment and disarticulation may be taphonomically discernible. The taphonomic evidence for these two actors can be parsed into three types: (1) the bone surface modification, or traces, made through intentional carcass handling (e.g., kill and/or consumption); (2) destruction or removal of entire elements during consumption, also referred to as deletion; and (3) the presence of pseudo-cut marks and spatial disaggregation associated with ungulate trampling and unintentional disarticulation of remains [13,35].

1.1.2. Traces

Gifford-Gonzalez defined several types of scavenging traces and associated causal processes, including tooth pits, tooth scores, punctures, crenulations, chipping-back, and furrows [13]. The most relevant traces, as they pertain to this current case study are pits, scores, punctures, and furrowing:

1. Tooth pits are found in cortical tissue and produced primarily by anterior premolars and carnassial teeth of canids. These tend to be relatively small in area and do not penetrate past the cortical bone; they are commonly found on the diaphyseal shafts. They are typically triangular- or diamond-shaped. However, individuals with worn or broken teeth can produce tooth pits that are rounded or irregular. Tooth pits are typically associated with tooth scoring.
2. Tooth scores are grooves produced in cortical tissue by tooth cusps dragging over the cortical bone surface, often trailing from the initial pit. The cross section varies depending on the effector that produced it (e.g., a broad suid incisor versus a narrow canid carnassial).
3. Tooth punctures are holes punched through the thin overlying cortical tissue into the underlying cancellous tissue or cavity. The outer layer of cortical bone can become displaced into the underlying cancellous tissue or marrow cavity. In canid scavenging, these marks are typically produced by canines or premolar cusps and they appear circular or ovoid. With pigs, premolars produce L-shaped punctures [36].
4. Tooth furrowing occurs within cancellous bone and is the result of repeated scraping of teeth, such as canines, premolars, and/or incisors across trabeculae. This action in canids produces high and low rows within the trabeculae, resulting from using the side of their mouths with premolar and canine cusps. In suids, this action produces long, shovel-type furrowing, resulting from scraping of the mandibular incisors [36].

1.1.3. Consumption and dispersal by canids and suids of human remains

Carcass consumption by feral dogs and suids follow a typical sequence. For pigs, they typically start with the softer, easily accessible tissues of the thorax and abdomen and then move on to large muscle masses of the appendicular skeleton, and finally less dense muscle masses [37,38]. This consumption sequence is slightly different for feral dogs when scavenging human remains. According to Haglund [39] feral dogs and coyotes will generally begin scavenging the throat/neck and face of human remains, followed by the thorax/abdomen, and subsequently disarticulation of the upper and then the lower limbs. This variation in consumption sequence is hypothesized to be the result of clothing on human remains blocking access to the viscera. Intra- and inter-specific competition in scavenging can truncate or accelerate this process [40,41].

Bone reduction via feral domestic dog scavenging starts in a predictable sequence, summarized by Pokines [35], but based on Blumenschine [40,42] and Haynes [41], starts with the skull and proceeds to the vertebrae, ribs, and then long bones. Carnivores, such as domestic dogs, depending on their body size, are capable of bone dispersal far away from the initial site of death/deposition [41,43]. In the presence of competing scavengers, dogs will be more inclined to disperse disarticulated remains away from the original body location [39,35]. While the sequence for canid scavengers, including feral dogs, is well known, similar patterns of bony consumption for suids is not well understood.

Consumption of boney tissues typically occurs in the following sequence for dogs, coyotes, and wolves related to body part consumption and disarticulation [13,35,40,41,44]:

1. Least dense and most porous bones, cartilaginous ends and then bones of ribs, vertebrae, scapulae, innominates (*os coxae*), and other bones corresponding to the throat area and thorax;
2. Slightly more dense cancellous epiphyses of long bones; during disarticulation and dispersal, the epiphyses are easily gnawed to gain access to the fatty and blood-rich tissues and the compact bone is relatively thin over the epiphyses;
3. Denser compact bone elements enclosing edible soft tissue, such as marrow and other fats.

1.1.4. Trampling and disarticulation

Distribution of bones and modification through trampling, dragging, or carrying remains are important taphonomic indicators of postmortem modification and dispersal [13,35,45–47]. Trampling is of particular importance as it can produce “pseudo-cut marks” [45,13], which could be mistaken for cutmarks. These pseudo-cut marks can possess irregular cross sections with interior striae and can be the result of direct contact with angular single-sediment sand grains. However, the examination of patterning is important to distinguish trampling signatures from cutmarks. This is especially true as Behrensmeyer *et al.* [45] report that marks made by sand grains may mimic stone tool cutmarks at magnifications up to 400×. Additionally, any original and true cutmarks may be obscured by trampling and contact with angular sand grains. However, true cutmarks usually are associated with patterned disarticulation or dismemberment, while trampling marks may appear randomly oriented and more often occur on convex portions of cortical bone surfaces.

Ungulates traveling via game paths can also disperse remains [13]. In addition, animal trampling can cause damage to the remains in regions with frequently used game trails [45]. While body weight of the carcass can be an important variable, pigs have been documented intensively scavenging carcasses that are small to medium sized (<100 kg or < 220 lbs) [36,48], which would include all but the largest humans. Domínguez-Solera and Domínguez-Rodrigo [36] as well as Berryman [37] found that suids do not typically disperse remains far away from the initial deposition site.

1.2. Case study from Kaua'i

The current state of taphonomic research in Hawai‘i, specifically related to mammalian faunal scavenging, is minimal, at best. This paper presents a forensic case study from the island County of Kaua‘i to elucidate the scavenging patterns of Hawai‘i's feral pig and dog populations. This investigation and recovery operation provided an opportunity to examine a specific case of scavenging activities and reconstruct the site formation processes. The main objectives of this paper are to compare the Hawaiian feral pig scavenging behaviors with previous research findings, present findings of multi-agent feral dog and pig scavenging, and to characterize local mammalian scavenging patterns in Hawai‘i to assist in future forensic recoveries and analyses.

Fig. 1. Google Earth, view of the Island of Kauai. Recovery site represented by yellow star.

2. Methods

2.1. Field recovery and analysis

The recovery was carried out in the Poʻipū region of Kauaʻi County (**Fig. 1**). The surveyed area of the private land parcel was relatively flat and on the boundary between an open field and a more densely vegetated area at an elevation of approximately 6 to 7 m above Mean Sea Level (MSL). Much of the scene was situated in a scattered scrub forest, primarily consisting of invasive koa haole trees (*Leucaena leucocephala*), with additional unvegetated areas and small brush (e.g., **Fig. 2**). The case focuses on skeletal remains discovered in early 2017 by an archaeologist surveying the privately owned parcel for cultural resources management.

In general, the recovery team implemented archaeological pedestrian survey/reconnaissance and mapping techniques as described below [49,50]. The two authors (both forensic anthropologists and archaeologists) led a team of 10 Kauaʻi Police officers and criminalists

Fig. 2. Portion of recovery area, view to southeast. Photo credit Kauai Police Department.

to conduct a line-abreast pedestrian survey, sweeping East to West with one-arm length between participants. All potential evidence and skeletal material were marked with pin flags and evaluated by one or both forensic anthropologists prior to recovery. This survey covered approximately 2,650 m^2. Once the extent of the surface scatter was determined, two horizontal mapping data points (**Fig. 3**) were established, and their locations were recorded with a Garmin GPSmap 60CSx receiver using Universal Transverse Mercator (UTM) coordinates and the North American Datum of 1984 (NAD 84). Azimuth mapping techniques, using compass and tape, were used to record the locations of recovered skeletal remains and non-osseous evidence. All materials were collected in accordance with crime scene protocols by the Kauaʻi County criminalists. While mapping, at least one visible feral pig trail was noted transecting the recovery site; this trail was documented using GPS track recording with the GPS receiver. This pig trail was identified by one of the authors as well as the Kauai police detectives, all of whom had extensive experience in pig behavior or pig hunting/tracking on Kauaʻi or Oʻahu.

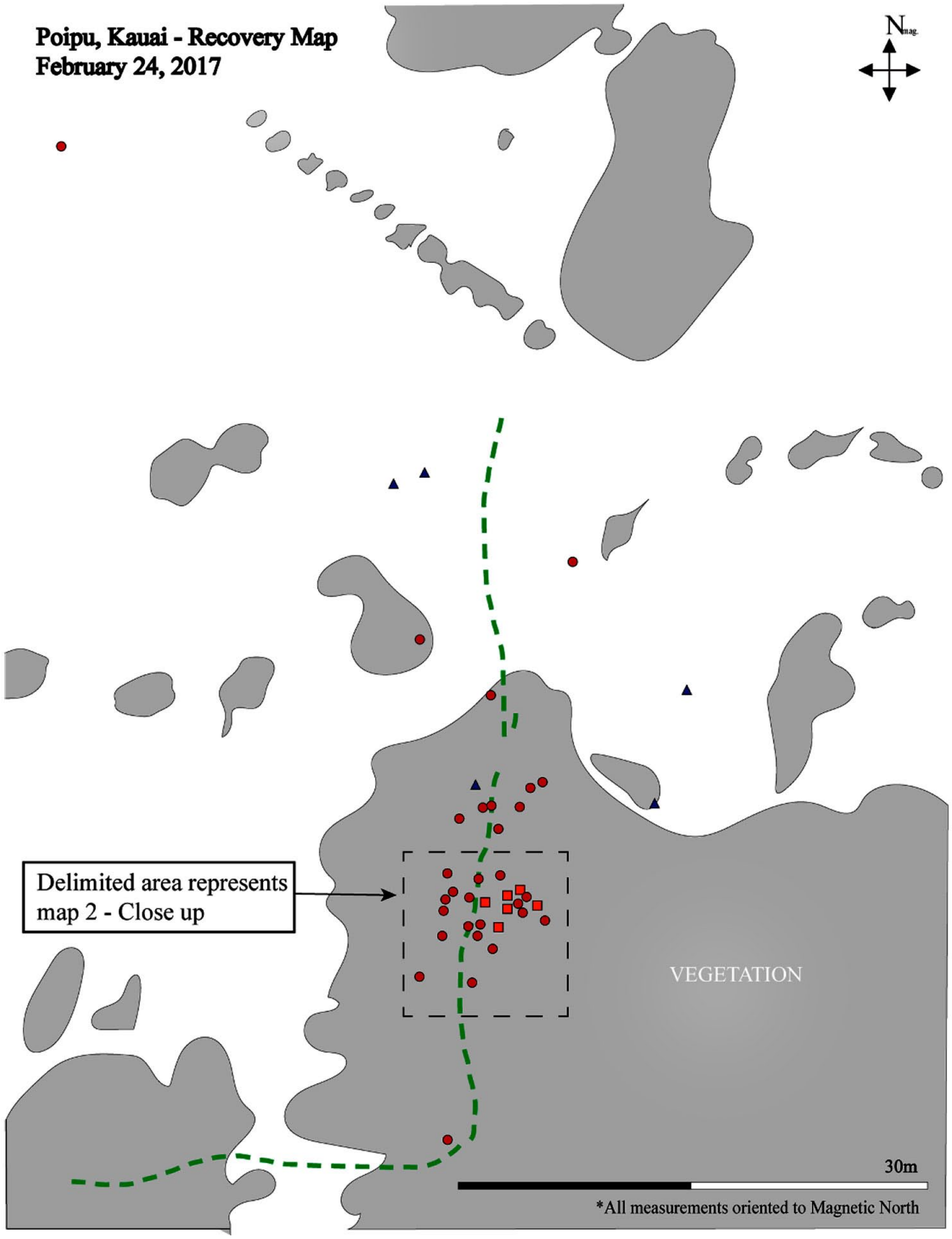

Fig. 3. Overall recovery site map: Key - Red dots = Single bone element; Orange Squares = Cluster of bone elements; Blue Triangles = Non-osseous Material; Green Dashes = Pig Trail; Gray fill = small tree cover/vegetation.

While the team attempted to control the survey, certain standard police protocols could not be implemented (e.g., crawling on hands and knees for a more thorough survey, etc.) due to the limited time on the ground, the limited amount of daylight, as well as the density of *koa haole* trees over much of the area. The team only had approximately 6 h in which to conduct the survey and recovery for the Kaua‘i Police Department which continued well past dusk with the use of floodlights once the major areas were covered in terms of pedestrian survey. The authors are confident that the team recovered all the large remains that were present; however, it is possible that some smaller bone elements and fragments were missed. Subsequent impromptu examination of the site area by Kauai Police officers has not yielded any additional remains.

2.2. Laboratory analysis

The senior author performed a skeletal inventory and developed a biological profile. Careful consideration was given to taphonomic signatures on the osseous material, focusing on alterations due to suspected scavenging. Potential perimortem trauma and postmortem damage modifications to skeletal elements were observed and recorded using gross examination in conjunction with low- and high-powered magnification of bone surfaces [5,34]. Recorded bone modifications were compared to extant literature, including published photographs and descriptions [37,51,52] for confirmation of suspected scavenging alteration. Using digital calipers, a 20× magnifying glass, and a stereo microscope, these modifications were classified into morphological trace types (e.g., pit, score) and then assigned to probable taxonomic association (e.g., pig, dog, or rodent) based on morphological and metric characteristics such as size, shape, location, and patterns. Rodent signatures cannot at this time be distinguished to species but could include the roof rat [*Rattus rattus*], the Norway or brown rat [*R. novegicus*], the Polynesian rat [*R. exulans*], and the house mouse [*Mus musculus*]. Pokines [53] and Pokines et al. [54] have done preliminary research and observations to correlate gnawing patterns to specific rodents. All bone modifications interpreted as scavenging or trampling were photographed and recorded. A digital skeletal diagram depicting location and type of postmortem modification, as well as missing skeletal elements, was generated using Adobe Illustrator (Fig. 5).

2.3. Data analysis

Data points collected during the archaeological survey and recovery were mapped digitally using Adobe Illustrator to observe patterns of scavenging over the landscape. Overall and close-up digital maps were created to illustrate the scattering of the remains. Postmortem alterations including furrowing, scoring, pits, punctures, trampling marks, and bone absence/presence were mapped onto the digital skeletal diagram to observe bony traces and patterning of scavenging within the skeleton. These were ultimately used to help interpret the possible taxa involved in the scavenging of this case study, alongside ecological and behavioral information known of Hawaiian terrestrial animals. We obtained written and verbal permission from the Kauai County Police Department to use this case for educational purposes via this publication.

3. Results

Skeletal elements from the lower spine, left lower limb, and sternum were found to be dispersed in a broad, patterned distribution corresponding closely to the game trail, extending as far as 54 m from the primary concentration of skeletal material (Fig. 3). One area, measuring approximately 105 m^2, contained the highest concentration of skeletal material (**Fig. 4**). This area was in a more densely vegetated area with small trees and brush. The game trail ran directly through this brush and skeletal cluster. During the recovery, neonatal pig skeletal remains also were located within this high concentration area. These remains were identified by one of the senior authors, who has significant experience analyzing various archaeofaunal assemblages.

The skeleton was approximately 85% complete. Although most of the skeletal elements were recovered either fragmentary or relatively complete, some elements and portions of other elements were not identified in the field (**Fig. 5**). Fragmentary recovered remains including the ribs, the right fibula, the left ulna, the left clavicle, two lumbar vertebrae, the left metatarsal V, the right scapula, a left metatarsal, and a left proximal hand phalanx. The skeletal elements that were absent included the right clavicle, 19 ribs, C4 and C6 vertebrae, the sacrum and coccygeal vertebrae, the xiphoid process, all the left carpals

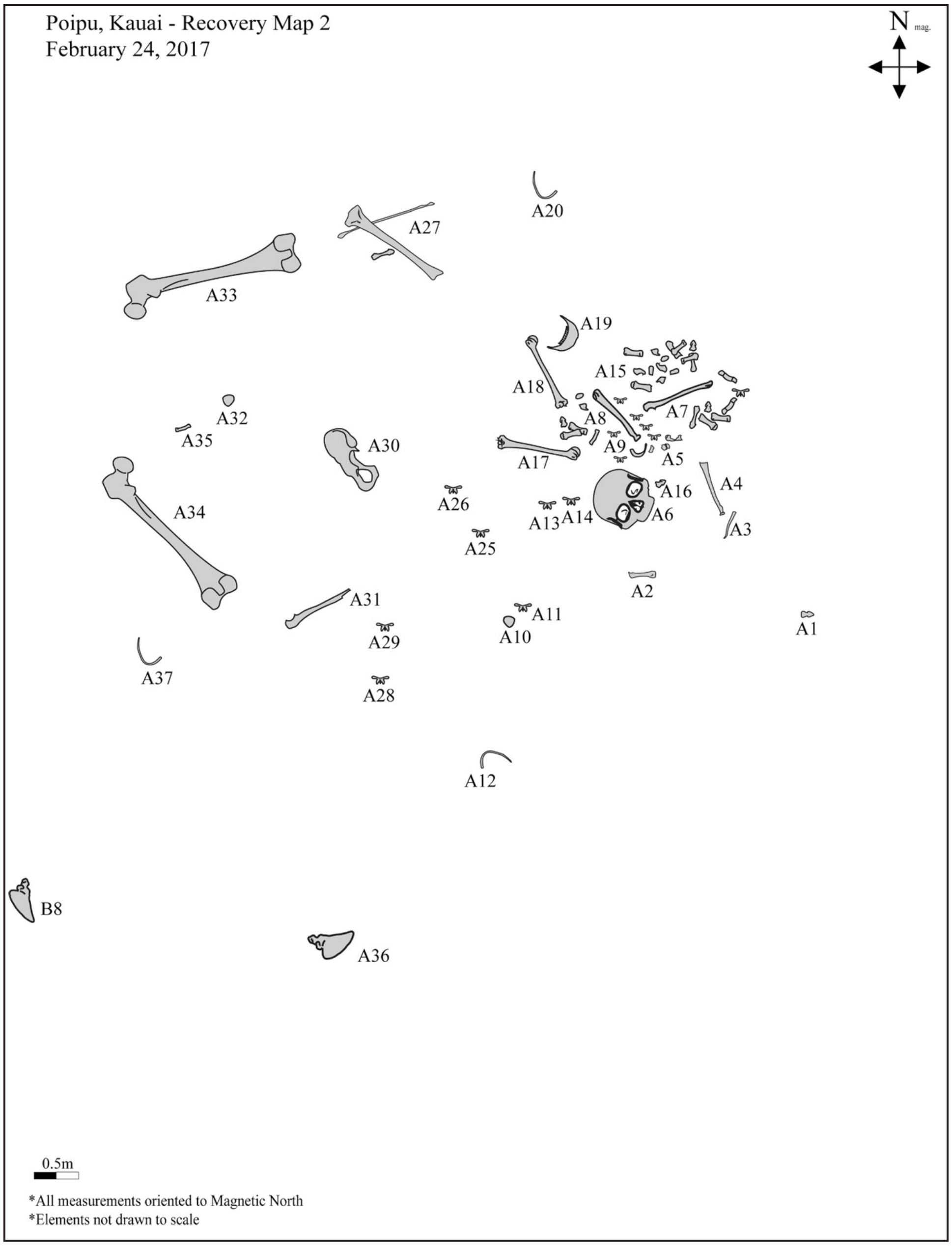

Fig. 4. Close-up map of delineated area from Fig. 3. Alphanumerics are related to evidence catalog system.

with the exception of the triquetrum, left metacarpals I, IV, and V, left proximal hand phalanges IV and V, all left middle phalanges, right pisiform and trapezoid, right metacarpal V, right proximal hand phalanges I and II, all right middle hand phalanges with the exception of digit II, seven distal hand phalanges, left calcaneus and cuboid, left

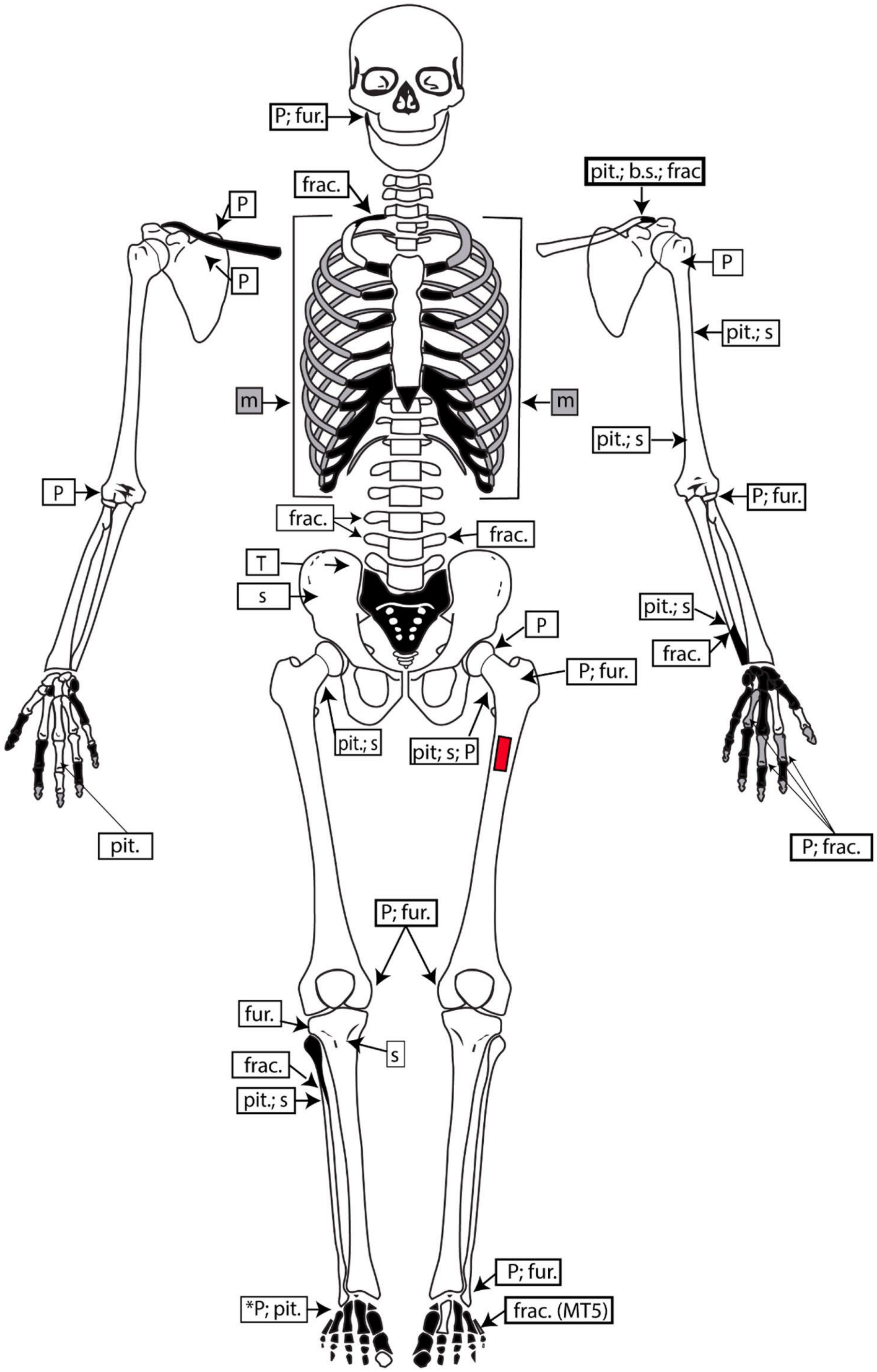

Fig. 5. Distribution of scavenging marks, unidentified fragmentary elements, and missing/unrecovered elements. Key – "T" = Trampling; "P" = Puncture; "pit." = Pitting; "s" = Scoring; "b.s." = broad score; "fur." = Furrowing; "frac." = Fracture with some bone reduction; "m" = Fractures with major bone reduction; Black = Missing/unrecovered elements; Gray = Unidentified fragmentary elements; Red = DNA sample. Labels modified from Berryman [37]. *Cuboid.

metatarsals I, II, and IV, all left foot phalanges, right navicular and all cuneiforms, all right metatarsals, all right foot phalanges except for distal digit I (Fig. 5).

Throughout the skeleton, the authors documented extensive bone modifications interpreted as evidence of non-human animal scavenging and trampling. Macroscopic skeletal analyses revealed evidence of pits, punctures, furrows, and scoring distributed throughout the skeleton (Fig. 5). Multiple bones or portions of bones were not recovered and presumably deleted by animal activity. This interpretation is supported by the previously mentioned tooth traces located adjacent to the missing portions. There was also fracturing of long bone ends and ribs, with and without associated tooth traces.

3.1. Upper limbs and hands

Many of the long bone epiphyseal ends had some type of scavenging trace except for the right proximal humerus, the right ulna and radius, the left distal radius, the left proximal ulna, and the left medial clavicle. The traces observed were typical of disarticulation efforts on epiphyses and gripping marks on diaphyses. Some of the scores were located randomly on the diaphyseal shafts, such as the left humerus (e.g., **Fig. 6**), representing “gripping marks” [35]. As well, there was a canine tooth puncture on the superior section of the right scapula (**Fig. 7**).

As well, there were a few long bones that displayed partial deletion of their epiphyseal ends with fracturing, including the right proximal fibula, left distal ulna, and the acromial end of the left clavicle. These partial deletions of the bone epiphyses into the diaphyses were accompanied by tooth traces in the adjacent remaining bone cortex. The left ulna displayed tooth pits with scoring adjacent to the fractured region of bone deletion. According to both Haglund [39] and Young and colleagues 47], these smaller long bones displaying diaphyseal fracturing are commonly observed in canids. The left clavicle displayed pits and broad scoring (**Fig. 8**).

The left hand displayed more bone elements that were deleted and/or displayed more scavenging damage than the right-hand bones. This corresponds with more scavenging traces on the left upper limb when compared to the right upper limb.

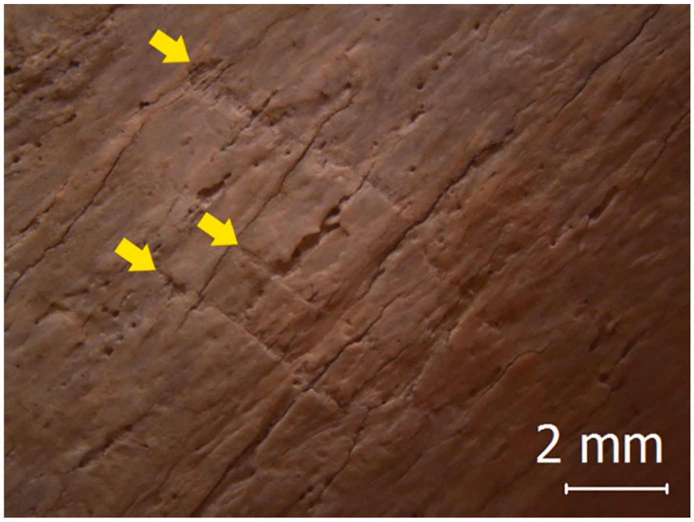

Fig. 6. Close up photo of tooth pits and scores on left humeral diaphyseal shaft. Yellow arrows identifying pits/scores.

Fig. 7. Right scapula, anterior view with superior angle at top of photo. Red circle identifying puncture typical of canid canine tooth cusp. Scale in cm.

Fig. 8. Acromial end of left clavicle, inferior view. Overview (scale in cm.) and close-up of broad scoring.

3.2. Vertebral column

Few traces were observed on the vertebrae that were recovered. T4 had probable scavenging damage to the left transverse process. L3 had probable scavenging damage to the right transverse process. L4 had probable scavenging damage of both transverse processes and inferior edge of inferior articular facet. All bone traces were in the form of fractures and were likely produced by animal teeth, but no definitive traces were left on the bone to discern taxa. The lumbar vertebrae and T12 were found further away from the main skeletal cluster. Along with the absence of the sacrum, this could indicate that this segment of the lower spine from T12 to the sacrum and coccyx was transported away from the body as a single unit initially. This transportation of this vertebral segment likely resulted in the damage observed to L3 and L4, as well as the absence of the sacrum and coccyx.

3.3. Ribs

Most of the ribs were missing, and the few that were recovered displayed partial bone deletion and fracturing. The singular left rib that was recovered had sternal end fracturing and partial bone deletion but was intact at the vertebral end. The four right ribs that were recovered all displayed fracturing and partial bone deletion of the sternal and vertebral ends to varying degrees. Lastly, there was also a lower right rib that was either #11 or 12 recovered further away from the main skeletal cluster, which may have been attached to T12 if it was the 12th right rib. No definitive traces were observed to discern taxa.

3.4. Os coxae

Evidence of trampling was limited to one skeletal element: the right *os coxa*. Multiple parallel and subparallel, shallow, fine, linear striations on the ilium, just medial to the auricular surface, are suggestive of ungulate, which includes pigs, trampling (**Fig. 9**). These bony traces are consistent with what Behrensmeyer and colleagues refer to as “trample scratches” [45]. Although morphologically like intentional cut marks, the striations on the ilium appear on a flat bone surface and vary in depth, width, and orientation and, suggesting abrasion against the recovery area substrate, which includes angular gravel. Moreover, this bone was one of the only elements displaced to the South of the main skeletal cluster, adjacent to the pig trail. Thus, it is likely this bone reached its final position because of ungulate trampling. It is of note that there were Stage 1 weathering cracks present extending across the striations [55], suggesting that trampling and potentially displacement preceded weathering in place (Fig. 9).

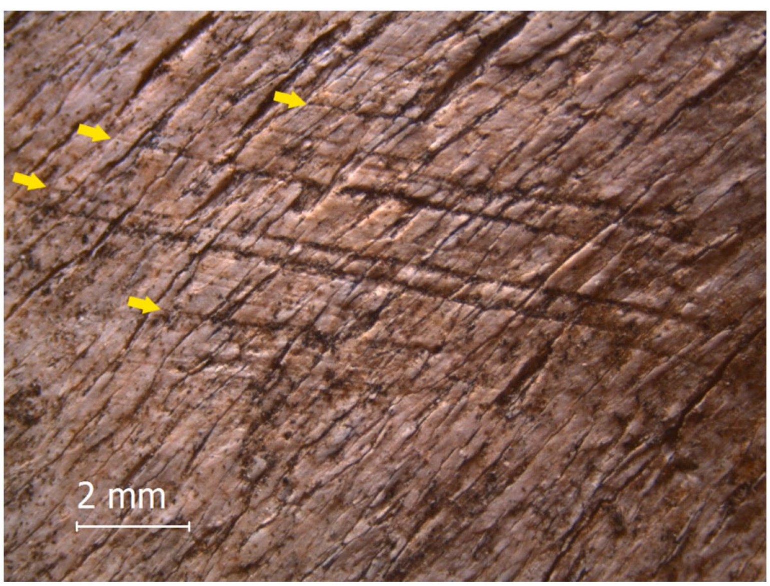

Fig. 9. Right ilium, medial view (from iliac fossa). Multiple striations represented by shallow, fine linear defects potentially produced by trampling. Yellow arrows pointing to trampling striations. Note weathering cracks extend across striations, suggesting trampling preceded weathering in place.

3.5. Lower limbs and feet

Many of the lower limb long bone epiphyseal ends had some type of scavenging trace except for the left tibia, the left proximal fibula, and the right distal fibula. The right fibula displayed tooth pits with scoring adjacent to the fractured region of bone deletion. Based on existing literature [39,47], most of the tooth pits, scores, and punctures observed were characteristic of canid dentition, particularly canine tooth cusps (e. g., **Fig. 10**). One L-shaped puncture mark on the cuboid (**Fig. 11**) is likely the result of a suid premolar and is characteristic of suids [36]. A wide, shallow furrow on the distal end of the left femur is consistent with suid incisor tooth traces (**Fig. 12**), as opposed to canids who produce a series of denticulate scores within the cancellous bone as a result of using the side of their mouth with carnassial teeth [36,39]. Another likely suid-produced puncture-furrow was observed on the anterior surface of the left proximal femur (**Fig. 13**), in which the suid incisor(s) were dragged across the bone in a superior to inferior direction. As outlined by other researchers, the specific dimensions (e.g., size) of tooth markings that produce bone modifications may not necessarily identify a specific scavenger due to various extrinsic and intrinsic factors [56,47].

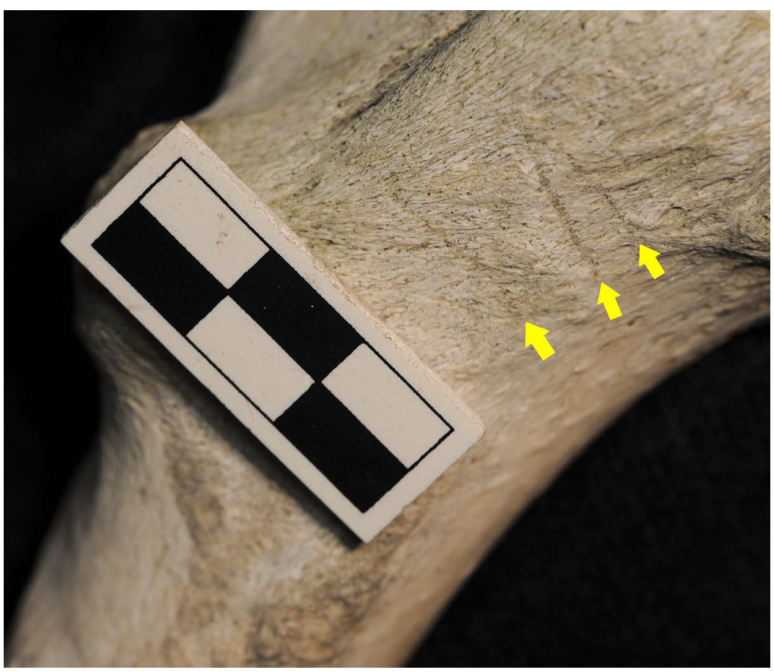

Fig. 10. Proximal end of right femur, posterior-medial view. Yellow arrows point to scores. Scale in cm.

Fig. 11. Right cuboid with L-shaped puncture mark on dorsal surface. Scale in cm.

Fig. 12. Distal end of left femur, anteriomedial view. Red box outlining puncture marks and furrow at site of bone deformation. Scale in cm.

Fig. 13. Proximal left femur, anterior oblique view. Red oval outlines furrow deformation. Scale in cm.

4. Discussion

While controlled taphonomic studies, such as those at decomposition facilities, continue to produce useful and important information for forensic anthropologists, this study highlights the significant contributions from drawing on case studies as well as taphonomic literature in related fields [57]. The authors documented taphonomic patterns consistent with both feral pig and dog scavenging, as reported in the forensic and zooarchaeological literature [37,51,36,39,44]. At least one feral pig trail traversed the recovery site corresponding with the distribution pattern of recovered skeletal material, including both the main concentration as well as more broadly dispersed skeletal elements (see Fig. 3). This is consistent with other findings that ungulate travel via trails play an important role in scattering remains in outdoor scenes [13,45]. The absence of ribs and small bones of the hands and feet is consistent with other published observations of mammalian scavenging patterns, where the bones of the thorax are typically consumed while animals seek access to the viscera as well as low density bones such as the small bones of the hands and feet [39,48,57,58].

Zooarchaeologists and forensic anthropologists have noted that small, less dense bones are less likely to be recovered in the field than larger denser bones. In an examination of dog fecal assemblages at the Neolithic site of Çatalhöyük, Russell and Twiss [59] documented that animal hand and foot bones (e.g., carpals, tarsals, and phalanges) were more likely to be consumed, digested, and passed through the gastrointestinal tract. They argue that this is due to the small size of these bones, and these elements are easier for the dog to swallow, since dogs tend to ingest food chunks. This is a similar pattern observed in the current case study, whereby many of the small bones of the hands and feet are absent and were likely consumed whole. Considering that there were several small bones, such as the hyoid, recovered in the primary concentration in Fig. 4, if other small bones had been present, then the authors likely would have recovered them as well. However, it is possible that these elements were defecated outside the range of the archaeological search and recovery area, and thus not recovered. The authors also noted the absence of some lumbar vertebrae transverse processes, less dense long bones, such as the right clavicle, proximal ulna, and the proximal rib ends of the five remaining ribs [39,47]. These bone deletion patterns are not unique to feral dogs and can also be produced by suids [48]. Greenfield [48] and Domínguez-Solera and Domínguez-Rodrigo [36] also note that suid scavenging significantly destroys bones, particularly transforming long bones into numerous fragments or destroying smaller bones such as the hand and foot bones.

The skeletal elements that were dispersed outside the primary skeletal cluster were those of the left leg (left tibia, fibula, and five tarsals), the lumbar vertebrae, T12, manubrium and sternum, a lower right rib, and the right *os coxa*. The lower spine was likely removed during advanced decomposition to the North of the main portion of the body, and the sacrum was either carried off outside of our survey area or destroyed during scavenging due to its low bone density [60,61]. The knee joints were gnawed on at strategic locations in a likely effort to disarticulate the thighs from the legs, as displayed from the furrows and punctures on both the distal femora and the proximal right tibia and fibula. These dispersal/scattering patterns could have been made by either a pig or dog, as they are both capable of dragging or carrying bones and/or body segments large distances away from the original body deposition [38,44]. Dogs tend to transport, or scatter remains more heavily than suids; however, with the pig trail traversing the scene, the authors argue there is evidence to support that suids also transported remains along the existing trail in conjunction with dogs [48].

As Sincerbox and DiGangi aptly noted [12], the published literature on taphonomic effects of pig scavenging is sparse. Greenfield's [48] work illustrated pig tooth traces on long bone epiphyses, revealing pits while other bones showed traces related to the pigs' broad, shovel-like incisors, probably attempting to remove any remaining fat from marrow cavities. As well, Greenfield found that pigs prefer bones they can pick up and chew, leading to complete deletion of lower density bones in some cases. Similarly, Domínguez-Solera and Domínguez- Rodrigo [36] examined variables related to animal size, suggesting that pigs will severely modify and consume bones of animals<100 kg and will modify, but not as extensively, animals larger than 100 kg in weight. Additionally, they suggest that most of the tooth traces are produced by suid incisors rather than premolars or molars, thus creating shallow, flat furrows within trabecular bone and long flat scores within denser cortical bone. Pig premolar and molar cusps can also inflict punctures and large pits on the bone surfaces, similar to dogs, but can have an L-shaped appearance [36].

Laboratory analysis documented bone deformations characteristic of tooth traces associated with suid [37,36,48] and domestic dog scavenging [5,10,51,52]. The broad linear punctures and shallow shovel-like furrows found on the epiphyseal end of the left femur (Fig. 12) were consistent with scavenging traces of suid incisors. The puncture of the dorsal surface of the right cuboid (Fig. 11) was also consistent with suid premolar puncture shape [36]. According to Greenfield [48] and Domínguez- Solera and Domínguez-Rodrigo [36], one of the primary differences between dog and pig scavenging marks is that pigs will leave "long shovel-type" or furrow marks on bone, usually on the long bone epiphyses, and no puncture marks; however, as discussed above in this specific case, the left femur exhibits punctures leading into the furrow. This specific marking was observed on both the distal medial condyle of the left femur (Fig. 12) as well as the proximal anterior surface of the left femur (Fig. 13). Another common tooth trace from pigs are long, broad, shallow scores with flat bottoms on compact bone [37,36]. The authors observed this modification on the left clavicle's acromial end (Fig. 8). Recovery of a nearly complete piglet skeleton further suggests this area was important ground for local suid sounders.

Modifications to epiphyseal ends and peripheral margins of bones, in addition to the types of tooth traces and areas of bone reduction, are like those noted in a case study presented by Berryman [37] regarding the disarticulation of human remains by suids in western Tennessee. Similarities found within these cases are consistent with pig and dog scavenging patterns despite the distance between, and climate dissimilarities, of these two geographical locations. Additionally, in the rural forests of western Tennessee (United States), Berryman [37] noted that prior knowledge of free-ranging domestic hogs, and evidence found in their scat, can be used to aid in the analysis of recovered remains.

Most of the pit-scores recorded throughout the skeleton were narrow, and consistent with canine and carnassial tooth traces from a dog (e.g., Figs. 6 & 10). Punctures located on the superior region of the right scapula (Fig. 7) and dorsal surface of the right calcaneus are consistent with traces left by the canine and carnassial teeth of a dog [39]. Other alterations, while consistent with traces left by scavengers, could not be specifically assigned to an animal family. This included crushing and fracturing of long bone epiphyses, vertebrae, and rib ends. The acetabula and proximal femoral heads displayed no scavenging traces, which is consistent with other published literature stating that these joints are tightly bound and usually are disarticulated later in advanced decomposition 44]. There were narrow pit-scores on the femoral necks characteristic of dogs, and a few punctures and furrows on the left proximal femur below the neck; however, overall, the proximal femora were not extensively damaged from scavenging.

Lastly, studies have found that pigs and domestic dogs will only extensively or heavily scavenge carcasses if they have limited food resources [36,39,12]. The skeletal remains were not heavily scavenged, revealing that the animals that scavenged the body likely had other food resources available to them. It is likely that the remains were scavenged over a period of weeks rather than months, while the remains were still in the nutritive phase [62].

5. Conclusion

Zooarchaeological and forensic anthropological literature was used to decipher site formation sequence as well as the actors involved.

Knowledge of the local fauna is vital to the success of a forensic recovery for the fullest possible accounting of remains. This allows the analysts to predict the distribution of remains across a landscape in accordance with a variety of taphonomic factors, including, but not limited to, scavenging behavior of local taxa. This is an important component in understanding any transformations that have occurred at a forensic scene. Understanding faunal scavenging and bone modification patterns can aid the investigator in predicting and recognizing distribution patterns of material, as well as knowing if these traces were human-induced or non-human induced to assist in the manner of death determination. In addition, this knowledge can be key in assisting the investigator with the forensic laboratory analysis of perimortem and postmortem changes to the skeletal elements. This was most apparent in the traces of trampling on the right ilium in this case, in which pseudo-cut marks were observed and based on previous literature interpreted to be striations consistent with trampling while the bone was still fresh. In cases with suspected multiple animal actors in the postmortem period, it is important to document the taphonomic history to exclude the possibility of perimortem trauma.

CRediT authorship contribution statement

Jennifer F. Byrnes: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing.

William R. Belcher: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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