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An Experimental Study of Invertebrate Damage to Bone and its Application to Archaeology



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A Dissertation submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Master of Science

Faculty of Science

School of Geography, Archaeology and Environmental Studies

School of Animal, Plant and Environmental Sciences

Declaration

I, Tawfeeq Mahomed, declare that this dissertation “An experimental study of invertebrate damage to bone and its application to archaeology” is my own unaided work. It is being submitted for the Degree of Master of Science in Archaeology at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

TMahomed

26/09/2022

Tawfeeq Mahomed

Date

Abstract

The field of forensic entomology stemmed from the presence of specific insects providing crucial information with regards to the context and timing of death. More specifically, insects are largely responsible for the removal of soft tissue, along with other tissues, such as hair, nails and bone. This feeding activity has two outcomes; they may be used to acquire valuable information regarding the circumstances around death, and they may produce alterations and modification of the body which may be misconstrued as an act of violence prior to death. Additionally, insect damage on bone may take the form of discolourations, holes, scratches and tunnels which may be mistaken as intentional anthropogenic modification, or pathologies. Within the archaeological field, damage by insects upon archaeological material, specifically bone, is seldom described, as forensic entomology studies generally focus on soft tissue evidence. Here the author shows that some families of beetle are able to inflict damage on bone, contributing to the fairly limited literature and highlighting the need for more research to be done. Raw and roasted chicken and lamb bones were exposed to three species of beetle and two species of fly. Results from experiment 1 indicated that *Dermestes maculatus* larvae and adults produced bore holes, destruction, gnawing and surface tunnel damage on the bone samples, whereas experiment 2 showed no macro or micro indicators of dermestid beetle damage. Results from experiment 1 indicated that *Anomalipus elephas* and *Zophobas morio* larvae produced destruction damage on the bone samples, whereas experiment 2 indicated that tenebrionid beetles and larvae additionally produced destruction, gnawing and surface tunnel damage. Results from experiment 1 and 2 showed that *Omorgus (Afromorgus) melancholicus* and *Omorgus (Afromorgus) squalidus* did not macroscopically or microscopically damage the bone samples. Results from experiment 1 and 2 showed that *Calliphora vomitoria* did not macroscopically or microscopically damage the bone samples. Similarly, experiment 1 and 2 showed that *Megaselia scalaris* did not macroscopically or microscopically damage the bone samples. Bone density is described as the ratio of a bones mass to volume, with less dense skeletal elements comprising more blood, grease and marrow, making them more susceptible to gnawing and destruction than elements of a greater density. Results have shown that the epiphysis shows a higher frequency of damage markers over the diaphysis for both chicken and lamb bones.

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Every single day you give me the courage and motivation to carry on. None of this would be possible without you. I am grateful to call you my mother.

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Chapter 1: Introduction

Within the discipline of forensics, the sub discipline of forensic entomology has become formalized to describe the relationship between corpses and insects (Wrobel & Biggs 2018). Insects, categorised within the phylum Arthropoda, are distinguished by having six legs and a body divided into the head, thorax and abdomen, and represent approximately 75% of living animals on earth (Byrd & Castner 2001b; Vanin & Huchet 2017). Forensic entomology arose due to the presence of particular insects providing vital information with regards to the context and timing of death (Byrd & Castner 2001a, 2001b; Pokines & Symes 2013; Rivers & Dahlem 2014; Wrobel & Biggs 2018). Within the field of archaeology, damage by insects upon archaeological material, specifically bone, is seldom described, as forensic entomology studies generally have focused on soft tissue evidence (Wrobel & Biggs 2018). Forensics and taphonomy have changed the way that archaeologists have interpreted animal and human bone material recovered from their sites. The few experimental archaeological studies that have been done have shown that insects do alter bone and that this damage can be misinterpreted but if correctly understood this information can be valuable (Backwell *et al*. 2012; Parkinson 2012; Dirks *et al*. 2015; Wrobel & Biggs 2018). Ultimately, archaeologists diligently search for evidence of predator damage but seldom look for insect damage to bone.

1.1. Aim

This project aimed to document and catalogue damage/marks on raw and roasted de-fleshed bone exposed to three families of beetle (Family Dermestidae, Trogidae and Tenebrionidae) and two families of fly (Family Calliphoridae and Phoridae).

1.2. Research questions

1. What form of damage do the three beetle families inflict on raw and roasted de-fleshed bone?
2. What form of damage do the two fly families inflict on raw and roasted de-fleshed bone?
3. What applications does this have to archaeology?

1.3. Rationale

During the decomposition process, insects are largely responsible for the removal of soft tissue, in addition to other tissues, such as hair, nails and bone (Vanin & Huchet 2017). This feeding activity of insects has two outcomes, firstly, they may be used to obtain valuable information regarding the circumstances around death, and secondly, they may produce alterations and modification of the body which may be misinterpreted as an act of violence prior to death (Vanin & Huchet 2017). In addition, insect damage on bone may take the form of discolouration, holes, scratches and tunnels which could be misconstrued as intentional anthropogenic modification, or pathologies (Huchet *et al.* 2013; Wrobel & Biggs 2018). Therefore, the understanding of insect damage on bone may assist in differential diagnosis, functioning to distinguish between intentional and unintentional body, and bone, alterations (Wrobel & Biggs 2018). Although possessing elements of forensic entomology, the research for this project is principally an archaeological study.

1.4. Dissertation organisation

There are six chapters in this dissertation. Chapter 1 comprises the introduction, aim, research questions and rationale. Chapter 2 comprises seven sections which form the literature review: invertebrate damage to bone, entomology, mouthparts, bone composition, taphonomy and observed marks, followed by a summary for the chapter. Chapter 3 comprises the methodology utilised for this study and comprises five sections; pre-experiment, experimental and analytical protocol, followed by a list of invertebrates used, the tank identification number, along with their initial and final numbers. The final section describes the damage to the bone by utilising the terminology of Parkinson (2012). Chapter 4 comprise the results obtained from both experiments and consists of four sections. The first section briefly discusses the control. The results of experiment 1 are reported, comprising the identification of damage by the beetles and flies. Following this, experiments 2s results are reported. Lastly, the results of both experiments are compared. Chapter 5 consists a discussion of the results of the previous chapter and consists of four sections: bone density, previous experiments of invertebrate damage to bone, comparison of invertebrate damage with other forms of damage and a summary of the chapter.

Chapter 6 comprises the conclusion

Chapter 2: Literature Review

The damaging effects of invertebrates on soft tissue, and other tissues such as hair and nails, is widely understood by researchers, as insects are largely responsible for the removal of these tissues during the decomposition process. In contrast, the damaging effects of invertebrates on bone is less well understood. This research study does not aim to provide a final conclusion to understanding invertebrate damage to bone, but rather contribute to the fairly limited literature towards providing a growing understanding of invertebrate damage to bone.

2.1. Invertebrate damage to bone

For the most part, bioarchaeological, forensic and palaeontological literature based on damage to bone by insects is ascribed to dermestid beetles, which produce distinctive ovoid-shaped pits during the pupation stage (Huchet *et al.* 2013; Wrobel & Biggs 2018). For example, the skeletal remains of approximately 25 human individuals from the Maya mortuary cave of Je'reftheel, located in west central Belize, display evidence of taphonomic modifications which have been attributed to insects, with dermestid beetles and termites being identified as the plausible modifiers (Wrobel & Biggs 2018). The presence of pupation chambers represents a visual indicator of dermestid activity, with the longitudinal profile of the pits being cone-shaped or cylindrical (Huchet *et al.* 2013; Wrobel & Biggs 2018). Cone-shaped chambers ranged between 2.3 mm-5.6 mm in diameter and between 2.4 mm-4.0 mm in depth, whereas cylindrical chambers ranged between 2.1 mm-2.9 mm in diameter and 4.1 mm-5.3 mm in depth (Huchet *et al.* 2013; Wrobel & Biggs 2018). Additionally, the chambers produced by the dermestids pierced through the cortical area to the medullary cavity (Huchet *et al* 2013).

Approximately 1550 bone specimens, from at least 15 individuals, were found in the Dinaledi Chamber within the Rising Star cave, South Africa (Dirks *et al.* 2015). Most of the bones (*n* = 553) display clear indications of invertebrate activity, including microscopic removal of the bone surface and multiple uniformly spread out parallel striations, associated with smooth based pits; a damage pattern consistent with damage made on bone by modern gastropods (Dirks *et al.* 2015). Sixty two of the bones exhibit large individual arrow shaped striations which are variable and randomly

orientated, with this damage pattern being consistent with damage made on bone by modern beetles (Dirks *et al.* 2015). A controlled experiment was conducted to compare the observed features on the Dinaledi chamber bones with surface modifications produced by 16 invertebrates fresh, dry and fossil bones were placed into separate tanks with each vertebrate type, with data of the subsequent modifications being recorded after a four month period (Dirks *et al.* 2015). Results from the experiment show that land snails (*Achatina* sp.), garden snails (*Helix aspera*), hide beetles (*Omorgus squalidus* and *Dermestes maculatus*) and the larvae produced a comparable set of modifications to those which were observed on the Dinaledi chamber specimens (Dirks *et al.* 2015).

Termites may also damage bone. Backwell *et al.* (2012) used the harvester termite (*Trinervitermes trinervoides*) (Sjöstedt) (Isoptera: Termitidae) to conduct actualistic experiments in the Sterkfontein Valley, South Africa. The samples originated from medium and large sized bovid, chicken (*Gallus domesticus*) and sheep (*Ovis aries*) skeletal remains (Backwell *et al.* 2012). Fossil specimens that were used originated from *ex situ* contexts at Gladysvale Cave and fresh bones were bought at a community butchery (Backwell *et al.* 2012). Within a six month period, all bones were more or less enveloped with a dark surface residue, etched surface appearance and boreholes and destruction, predominantly located on less dense elements and epiphyses. Clusters of sub-parallel striations, edge gnawing and star-shaped marks on the periosteal surface were indistinct after six months, however, after 12 months became unmistakably evident and more abundant, as termites are more active in austral autumn and spring (Backwell *et al.* 2012). The experiment has confirmed that harvester termites are able to modify bone in all preservation stages, with fresh, thin cortical and spongy bone with meat and marrow being favoured (Backwell *et al.* 2012).

Backwell *et al.* (2012) utilised an actualistic approach towards studying invertebrate damage on bone. Parkinson (2013) and Dirks *et al.* (2015) utilised a controlled laboratory based experimental approach towards studying invertebrate damage on bone. This research project followed Parkinson's (2013) controlled laboratory based experimental approach.

2.2. Entomology

Descriptions and characteristics of the invertebrates utilised for this research are discussed below.

2.2.1. Beetles

Beetles, Order Coleoptera, are the largest insect order, and comprise approximately 1.5 million species (Stork *et al.* 2015; Krinsky 2019). Beetles are characterised by hard wing covers, known as elytra, which cover and safeguard membranous hind wings that are utilised for flying (McHugh & Liebherr 2009; Krinsky 2019). Adult beetles possess chewing mouthparts, with their feeding habits being varied (Byrd & Castner 2001a; Krinsky 2019). Beetle larvae are known as grubs and vary broadly in appearance, however a common aspect of the larvae is a visible head and six legs (McHugh & Liebherr 2009).

Dermestid beetles, Family Dermestidae, are a family comprising more than 1600 species which are found globally (Háva consulted May 2019). Nearly all species are scavengers which feed on various varieties of dried animal material (Smith 1986; McHugh & Liebherr 2009). Dermestid beetles, specifically in the *Dermestes* genus, are of forensic importance, with sufficient numbers described as reducing a human body to a skeleton in approximately 24 days (Byrd & Castner 2001a). Larvae are usually found on carcasses during the stages of skeletal decomposition (Arnett & Jacques 1981; Smith 1986; Byrd & Castner 2001a). Presence of dermestid beetles or their faecal material, known as frass, indicating that a considerable amount of time has passed since death (Smith 1986; Byrd & Castner 2001a).

Hair beetles, Family Trogidae, are a family comprising approximately 330 species and are generally drawn to dry remains and are found during the later stages of decay (Arnett & Jacques 1981; Borror *et al.* 1989; Strümpher *et al.* 2014). Trogidae are recognised for their specialisation of feeding on and digestion of keratin (Strümpher *et al.* 2014). Tok-tokkie beetles, comprising approximately 15 000 species, inhabit southern Africa and are a member of the Tenebrionidae family, which are categorised as detritivores (Watt 1974; Bouchard *et al.* 2005).

2.2.2. Flies

Flies, Order Diptera, are an insect order comprising over 86 000 species, found in most habitats and are categorised by a single pair of wings, with a second pair developing as knob-like organs, known as halters, for the purpose of stabilisation during flight (Arnett & Jacques 1981; Borror *et al.* 1989; Cumming & Monty Wood 2017). Flies possess sizeable compound eyes with a variety of mouthparts, yet the majority of flies associated with a carcass possess a sponging mouthpart (Arnett & Jacques 1981; Borror *et al.* 1989; Byrd & Castner 2001a). Fly larvae are called maggots and are distinguished by being soft, legless, cream in colour and lacking a visible head (Arnett & Jacques 1981; Borror *et al.* 1989; Cumming & Monty Wood 2017). Many flies play a significant role as scavengers by removing decomposing animal and plant material from the environment (Byrd & Castner 2001a).

Blow flies, Family Calliphoridae, are a large family of medium sized flies, comprising over 1500 species, found globally (Merritt *et al*. 2009). Blue bottle flies (genus *Calliphora)*, Green bottle flies (genus *Lucilia)*, and screwworm flies (genus *Cochliomyia)* comprise the calliphorid family (Borror *et al.* 1989; Merritt *et al.* 2009). Flies of the calliphorid family are drawn to carrion and faeces, with some species exploiting open wounds (Smith 1986; Byrd & Castner 2001a). In addition to their forensic importance of accurate post mortem interval estimation, calliphorids are beneficial for nutrient recycling and community ecology, due to their breakdown and removal of vertebrate carcasses (Arnett & Jacques 1981; Smith 1986; Borror *et al.* 1989; Byrd & Castner 2001a, Merritt *et al*. 2009). Calliphorid flies have been recorded as the first insects to locate and colonise human or animal remains, with this process possibly taking minutes (Smith 1986; Byrd & Castner 2001a, Merritt *et al*. 2009). A significant amount of eggs are laid within orifices, such as the eyes, nose or any open wounds (Smith 1986; Byrd & Castner 2001a). Consequently, mass formations of maggots, in addition to the irregular defleshing of the carcass are indicators of pre or peri mortem trauma (Smith 1986; Byrd & Castner 2001a).

Coffin flies, Family Phoridae, are a large family, comprising more than 4000 species, found globally and are often associated with buried remains (Smith 1986; Byrd & Castner 2001a, Merritt *et al*. 2009). Coffin fly eggs are laid atop the soil surface, with

the larvae then burrowing down to colonise buried remains (Smith 1986; Byrd & Castner 2001a).

2.3. Mouthparts

The destructive nature of invertebrates on soft and other tissues are widely understood, and in the case of dermestid beetles, utilised for the removal of tissue for skeletal collections, with the primary element responsible being their mouth parts (Weichbrod 1987). A significant attribute of an insects' head are its mouthparts, however, in certain species, which do not feed as adults, the mouthparts may be vestigial or altogether non-existent (Byrd & Castner 2001b). Insect mouth parts comprise five rudimentary elements; the labrum, or upper lip, the hypopharynx, a tongue-like structure, the maxilla, the labium, or lower lip and the mandible, also known as the jaw (Gullan & Cranston 2010) (Figure 1). The mandible is a paired structure which occurs on both sides of the mouth and is responsible for tearing and biting pieces of food off and then grinding or chewing it to a suitable consistency for the insect to digest (McHugh & Liebherr 2009).

For the most part, adult insects possess characteristic mouthparts, with its form and morphology being indicative of the food type the insect consumes (Byrd & Castner 2001b). The chewing mouth part variation, also known as a mandibulate, can be described as the most primitive and frequently observed and can be found in approximately all forensic important adult beetles, in addition to the majority of larval insects which are associated with carrion (Byrd & Castner 2001b). Fly larvae possess hardened pairs of mouth hooks which tear and cut into the carrion upon which they feed, with the mouth hooks frequently exhibiting a distinguishing shape which can be used for identifying the fly larvae to species (Byrd & Castner 2001b).

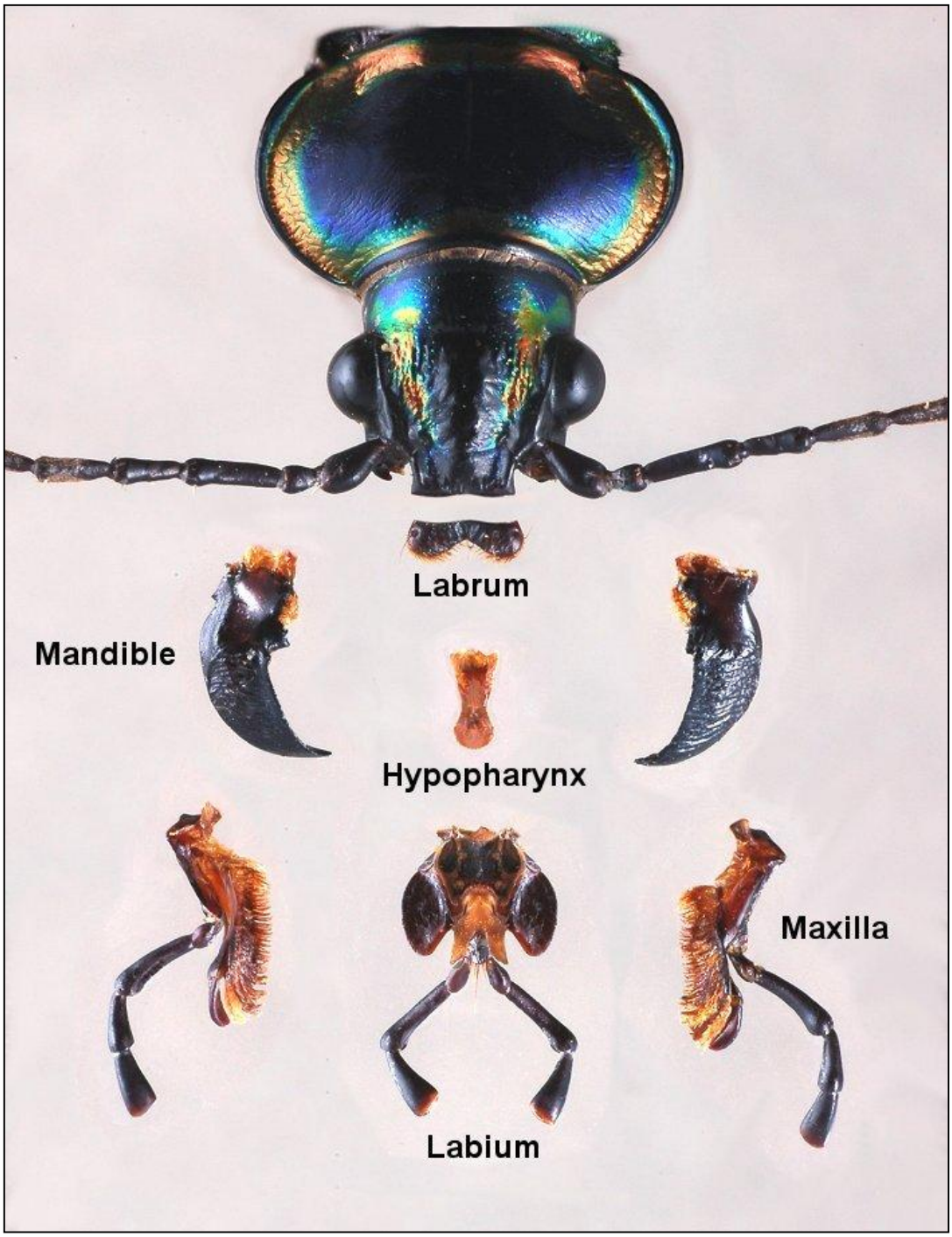

Figure 1. Five elements of insect mouth parts (North Carolina State University 2015).

In contrast, numerous insects consume liquid rather than solid food, with the nourishing liquid taking the form of flower nectar, sap from the plants vascular system, or blood from an animal, or human, vascular system (Byrd & Castner 2001b). Most species of fly which are attracted to human remains exhibit a sponging mouth type, with the tip consisting of a fleshy lobe or lobes which are crossed with grooves (Byrd

& Castner 2001b) (Figure 2). Capillary action is used to draw the liquid into these grooves which then moves into the flies' food channel (Byrd & Castner 2001b). Additionally, the secretion of saliva onto the food by the fly assists with the breakdown and liquefaction of the food in order for it to be sucked up easily (Byrd & Castner 2001b).

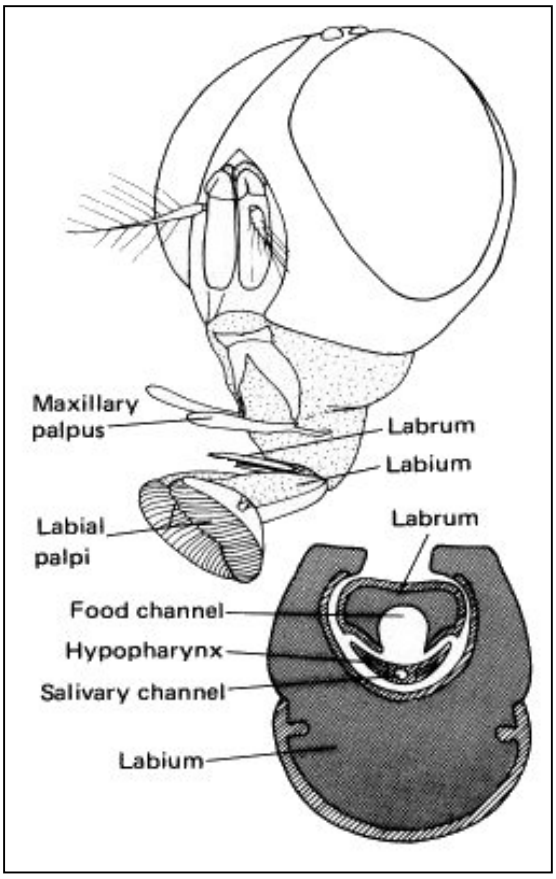

Figure 2. Sponging mouth type (North Carolina State University 2015)

During the research phase of this literature review, it became evident that apart from a general overview of invertebrate mouthparts, a more specialised understanding of the damage caused by these mouthparts to bone was not extensive. This may be a factor of research not being conducted or not being readily available due to it being unpublished.

2.4. Bone composition

The composition of bone can be attributed to ten fundamental elements; cancellous bone, cartilage, cortical bone, diaphysis, endosteum, epiphyses, medullary cavity, periosteum, red marrow and yellow marrow (White & Folkens 2005; Christensen & Passalacqua 2018) (Figure 3). Cancellous bone is a porous network which fills the interior of bone, with the interstices of this network being filled with marrow, while cartilage is a flexible connective tissue, which exhibits characteristics that are not as hard, or rigid, as bone but is stiffer than and not as flexible as muscle (Siegel 2010; Christensen & Passalacqua 2018)

The diaphysis is the shaft, or central part, of a long bone and comprises cortical bone, the smooth and while outer layer of bone, which regularly encompasses a central medullary cavity (Houck & Siegel 2010; Christensen & Passalacqua 2018). It is within this cavity that red marrow, the location in which red blood cells, platelets and most white blood cells are produced, and yellow marrow, consisting largely of fat cells, is stored (White & Folkens 2005). The walls of the medullary cavity comprises cancellous bone which is lined with the endosteum, the covering of the inner surface of all bones (White & Folkens 2005).

Epiphyses are the end part of a long bone which primarily develops separate from the shaft, by a layer of cartilage, with the fusing of the two elements occurring through ossification (White & Folkens 2005; Houck & Siegel 2010). The periosteum is a membrane consisting of dense irregular connective tissue which covers the outer surface of all bones, with an exception of the joints of long bones (White & Folkens 2005; Christensen & Passalacqua 2018).

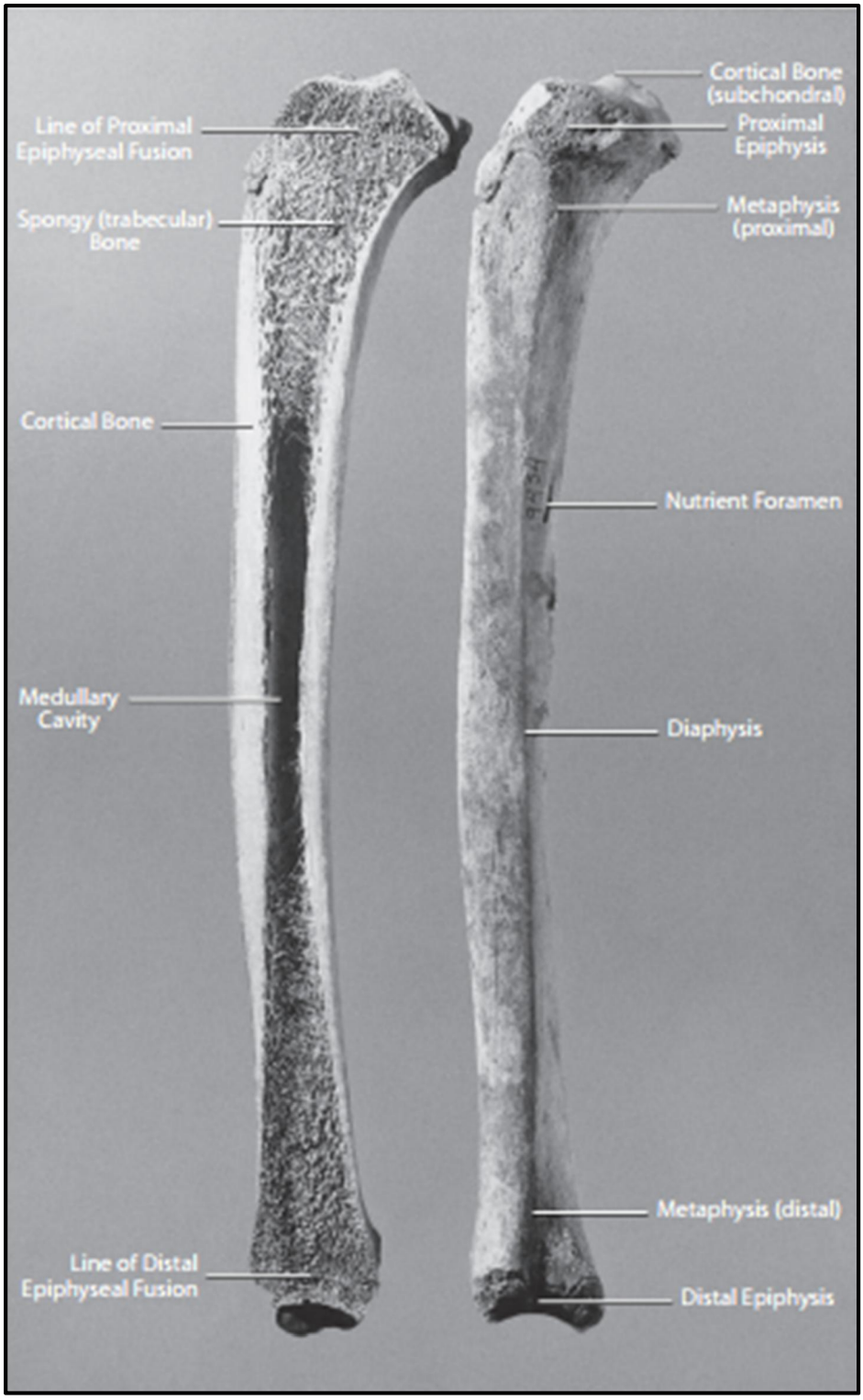

Figure 3. Composition of bone (White & Folkens 2005).

2.5. Taphonomy

Taphonomy is a concept formulated by palaeontologist I.A. Efremov (1940) to describe the study of an organism's transition from death, through decomposition to when it becomes part of the archaeological or palaeontological record. This concept has been embraced by a number of disciplines with slight modifications to Efremovs' original definition (Efremov 1940; Lyman 1994, 2010; Turner *et al* 2013; Schotsmans *et al* 2017). Johnson (1985: 158) categorises the period between death and the organism assimilation into the ground as biostratinomy, and the period between burial to the organisms re-exposure as biodiagenesis. Taphonomy often involves the study of preservation processes and its effect on the material (Behrensmeyer & Kidwell 1985). From a forensic perspective, Haglund and Sorg (1997) define taphonomy as the utilisation of taphonomic models, methods and analyses within a forensic context to approximate time since death, reconstruct the conditions pre- and post-decomposition, and distinguish the consequences of human behaviour from those created by the earth's biological, chemical, geological and physical subsystems.

O'Connor (2000) highlights seven distinct stages in the taphonomic process, which affect a bone assemblage. *Biotic* processes are all the processes which result in a specific assemblage of animals or humans being together at a particular place and time prior to the death of the animal/s (O'Connor 2000: 20). *Thanatic* are those processes that result in the death of an animal or human and the deposition of their remains (O'Connor 2000: 20). *Perthotaxic* are processes, such as fluvial action or sub aerial weathering, which result in the movement and damage of bone before its incorporation into a forming deposit (O'Connor 2000: 20). *Taphic* processes are the intricate set of physical and chemical agents which act upon the bone after its burial, and is the primary factor which may result in a bone being well or poorly preserved (O'Connor 2000 : 20). *Anataxic* are those processes by which the buried bone are re-exposed to fluvial action, sub aerial weathering and other attritional processes (O'Connor 2000: 20). *Sullegic* processes are archaeological activities such as sampling decisions (O'Connor 2000). Lastly, *trephic* processes are the curatorial and research decisions made relating to bones sorting, recording and publication (O'Connor 2000: 20).

A number of experiments have been conducted since to further explain taphonomic processes. For example, Marean *et al.* (1992) simulated an archaeological assemblage of defleshed hammerstone-broken, and unbroken bones, which they exposed to captive spotted hyaenas, and Capaldo (1998) simulated the processing of whole carcasses by hominins and carnivores.

Various factors may produce similar results to the damage on bone caused by invertebrates, and the author acknowledges that this may be one of the limitations of this study. However the author will draw on published literature to compare to the bone damage and modification observed in this study.

2.6. Observed marks

2.6.1. Linear marks

Linear marks are a form of surface modification which can be identified as marks which possess a length which is four times its breadth or greater **(**Fernández-Jalvo & Andrews 2016). The key attribute which differentiates distinctive forms of linear marks lies with their cross section morphology **(**Fernández-Jalvo & Andrews 2016). The cross sectional morphology categories are centred on the shape, width and degree to which the mark is rounded, resulting in a linear mark being identified as possessing v-shaped cross section, or a u-shaped cross section **(**Fernández-Jalvo & Andrews 2016). The two primary agents of linear marks with a v-shaped cross section are the defleshing or disarticulation of bone by a bladed tool, also known as cut marks, and trampling, which produces marks as a result of the long bone rotating around its axis due to the trampling (Bunn 1981; Potts & Shipman 1981; Fisher 1995; Domínguez-Rodrigo *et al*. 2009; Fernández-Jalvo & Andrews 2016). The two primary agents of linear marks with a u-shaped cross section are a result of animal chewing and root etching (Johnson 1985; Haglund *et al.* 1988; Lyman 1994; White & Folkens 2005; Andrés *et al.* 2012).

2.6.1.1. Cut marks

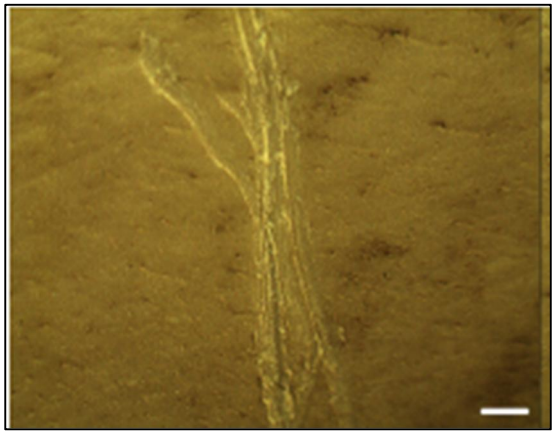

Figure 4. Cut mark on bone, scale 500 µm (Domínguez-Rodrigo *et al*. 2009).

The aim of defleshing or disarticulation by a bladed tool is the removal of soft tissue, and the scraping of this tool on the hard bone results in the reduction of the edge's sharpness (Olsen & Shipman 1988; Fernández-Jalvo & Andrews 2016) (Figure 4). As a result, cut marks have a tendency to be fewer in number, in contrast to trampling marks which may be numerous (Andrew & Cook 1985; Lyman 2008; Fernández-Jalvo & Andrews 2016). Orientations of cut marks and trampling marks, relative to the bones' long axis are also different (Fernández-Jalvo & Andrews 2016). Cut marks are primarily located in close proximity to the epiphysis and its articular surface, with their orientation being oblique to the long axis of the bone shaft and the cut mark reaching 4 cm or greater in length (Fernández-Jalvo & Andrews 2016).

2.6.1.2. Chopping and scraping

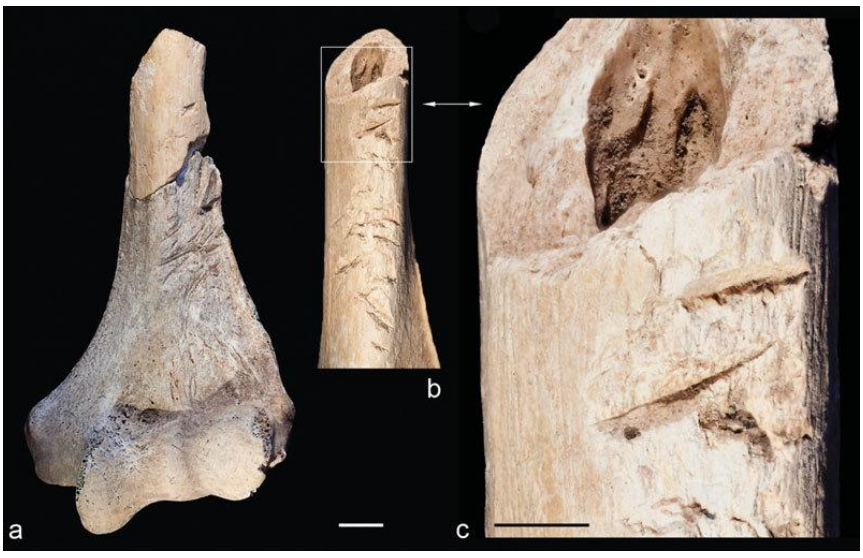

Figure 5. Chop marks on bone (Chenal *et al.* 2015).

Additional linear marks with a v-shaped cross section include *chop marks*, a mark similar in appearance to cut marks, but which result when a tool abruptly and forcefully makes contact with the bone (Figure 5). *Scrape marks*, are produced when the edge of a tool scrapes across the surface of the bone; exhibiting striations which are shallower in comparison to cut or chop marks (Potts & Shipman 1981; Binford 1984; Cook 1986; Blumenschine & Selvaggio 1988; Noe-Nygaard 1989).

2.6.1.3. Tooth marks



Figure 6. Rodent gnawing on bone (Mahomed 2018).



Figure 7. Carnivore tooth marks on bone (Mahomed 2018).

As mentioned above, linear marks with a u-shaped cross section are frequently a result of an animal chewing on a bone, with the teeth producing marks which are frequently more abrasive than linear marks with a V cross section as the teeth edges are less sharp and do not move smoothly across the bone surface (Fernández-Jalvo & Andrews 2016) (Figure 7). Linear marks produced by the incisors, predominantly by

rodent gnawing, is characterised by a distinctive pattern of furrowing upon the surface of the bone from incisor tracks, and are identified by a parallel series of shallow, broad grooves (Bunn 1981; Johnson 1985; Cook 1986; Fernández-Jalvo & Andrews 2016) (Figure 6). The superimposition of linear marks by rodent incisor gnawing may appear to be branched, however, all rodent incisor marks are unbranched, with its length varying from long to short and shorter marks being deeper (Johnson 1985; Fernández-Jalvo & Andrews 2016). Linear marks produced by the canines, premolars and molars, predominantly by carnivores, are distinguished by: a u-shaped cross section which lacks any internal striations, display smooth contours which are single and unbranched (Haglund *et al.* 1988; Fernández-Jalvo & Andrews 2016). Gnawing and surface tunnel damage share a common characteristic in that the damage possessed a u-shaped cross section with micro striations, however the defining characteristic of gnawing is the parallel set of damage marks, while surface tunnel damage is a singular damage mark. This research was intended to highlight that the parallel series of damage marks by insects share characteristics with gnawing and therefore may be identified as gnawing.

2.6.1.4. Root etching



Figure 8. Root etching on bone (Pokines 2018).

Linear marks produced by plants are a result of dissolution on the bone surface by chemicals associated with the plant's growing root tips (Fernández-Jalvo & Andrews

2016). These marks possess a u-shaped cross section with contours which are smoothly concave, with the marks seldom being straight for more than a few millimetres (Lyman 1994; White & Folkens 2005; Fernández-Jalvo & Andrews 2016) (Figure 8). Undoubtedly the most significant feature of root etched bone are its abundant branched nature, which may appear incorrectly identified as the bone surface being corroded or cracked (Behrensmeyer 1978; Lyman 1994; White & Folkens 2005; Fernández-Jalvo & Andrews 2016).

2.6.2. Trampling marks

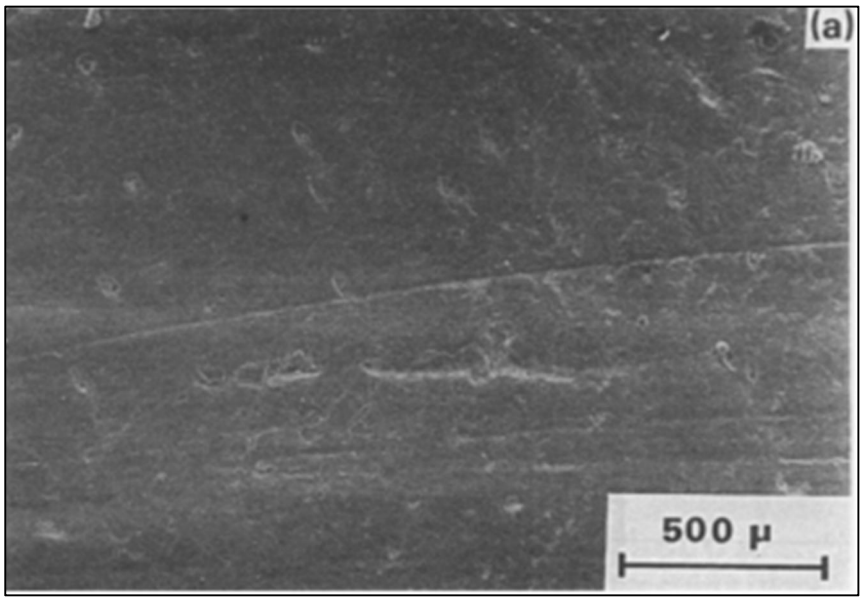

Figure 9. Trampling marks on bone (Olsen & Shipman 1988).

In contrast, trampling marks are formed as a result of the long bone rotating around its axis as a result of trampling, therefore, trampling marks are primarily oriented transversely to the long axis of the diaphysis and rarely reach 4 cm in length (Andrew & Cook 1985; Behrensmeyer *et al* 1986; Olsen & Shipman 1988; Domínguez-Rodrigo *et al*. 2009; Fernández-Jalvo & Andrews 2016) (Figure 9). A common aspect of cut and trample marks, and linear marks with a v-shaped cross section in general, is a lack of secondary branching (Fernández-Jalvo & Andrews 2016).

2.6.3. Pitting and perforations



Figure 10. Tooth pitting on bone (Mahomed 2018).

Pits are characterised as superficial marks on the bone surface which do not possess a consistent morphology (Fernández-Jalvo & Andrews 2016). Perforations are characterised as marks which penetrate into the underlying cancellous bone and can be distinguished as cone shaped or square bottomed perforations, and between a regular or irregular cross sectional profile (White & Folkens 2005; Fernández-Jalvo & Andrews 2016) (Figure 10). A common feature of pits and perforations which distinguishes them from linear marks are their lengths being less than four times their breadth (Fernández-Jalvo & Andrews 2016). The most frequent source of pits and perforations on bone are a result of carnivores chewing, or gripping, which produces characteristically cone shaped perforations on the bone (Haglund *et al.* 1988; Blumenschine 1995; Selvaggio & Wilder 2001; Fernández-Jalvo & Andrews 2016).

Overall, this study aims to contribute to the fairly limited literature on invertebrate damage to bone. The invertebrates which were utilised for the controlled lab based experiments are all forensically important modifiers of tissue, however, their damaging effect on bone, and the aspect of their anatomy which is responsible for the damage, their mouthparts, are understudied. From an archaeological perspective, the process of the invertebrates damaging the bone falls under the concept of taphonomy. It is important to note that other processes might produce characteristics similar to invertebrate damage. Due to time constraints this study documented invertebrate damage under experimental conditions, but looked to published literature to detect other damage with similar or overlapping features.

Chapter 3: Materials and Methods

This chapter comprises the methodology utilised for this study and consists of five sections. The first three sections encompass the pre-experiment, experimental and analytical protocol. The fourth section provides a list of invertebrates used, the tank identification number, along with their initial and final numbers. The final section describes the damage to the bone by utilising the terminology of Parkinson (2012).

3.1. Pre-experiment protocol

In an effort to replicate the post mortem impact by select invertebrates on bone, long bones of chicken (*n* = 10 tibiotarsus ['drumsticks']), and lamb (*n* = 10 femora ['shanks']), were chosen for their hard and soft bone characteristics (Appendix A; Appendix B). These bones are also commonly found in the archaeological record. Half of the sample size (*n* = 5) of each bone type was roasted on a wood burning grill, to simulate food roasting. All roasted samples were approximately less than 5 cm from the burning wood. The lamb femora took approximately 45 minutes to an hour to roast, while the chicken tibiotarsus took approximately 30 to 45 minutes. No artificial fire lighters were used to avoid chemical contamination of the bone. The other half of each bone type (*n* = 5) were left raw. Following the roasting, the entire sample (*n* = 20) was de-fleshed by hand to ensure that no damage was accidently inflicted on the bone that may be mistaken for insect damage. The bone samples were then photographed with an iPhone 7 12 Megapixal camera and the bones analysed for any damage, of which there was none.

Twenty tanks were set up. This preparation involved washing each of them with water and lining them with a litre of substrate (coconut/palm peat) which was moist to the touch. One of the tanks was used as a control tank and was set up without any insects and one of each bone sample type (chicken raw and roasted and lamb raw and roasted) to eliminate the possibility that factors other than insects altered or changed the bone. The control ran for a month. For the duration of each experiment, all tanks were kept within a laboratory on the third floor of the Oppenheimer Life Sciences building (North facing) at the University of the Witwatersrand. The process was repeated twice for reliability in (March/April and October/November 2019.

3.2. Experiment protocol

The bone samples were exposed to the three families of beetle (Family Dermestidae, Trogidae and Tenebrionidae) and two families of fly (Family Calliphoridae and Phoridae). Each bone sample was placed in a separate tank and labelled ‘raw’ or ‘roasted’ and given an accession number, represented roman numerals i - v. The first experiment, named experiment 1, ran for a month, from March 2019 to April 2019 with 2-3 visits weekly being conducted to record any modifications observed and to provide food (corned beef, cat food or apples) and water for the insects. Initial and final insect numbers were recorded. At the end of the month, the bones were removed, placed in individually marked packets and frozen in a chest freezer for a week to exterminate any remaining insects on the bone that may cause further damage. The experimentation and analysis was then repeated from October 2019 to November 2019 and named experiment 2. Covid-19 and the national lock down imposed on South Africa by the national government prevented a third laboratory trial scheduled for March / April 2020.

3.3. Analytical protocol

After freezing, each bone sample was air dried, in the shade within a well ventilated laboratory, and then photographed with an iPhone 7 camera and analysed with a Dino Lite USB microscope (1.3MPix, 90x digital zoom) and Dino Capture 2.0 software to identify any damage caused by the insects. The damage type, discussed below, and dimensions of the damage were recorded in a Microsoft Excel spreadsheet for statistical analysis. The dimensions, in millimetres (mm), of the damage was obtained using a Zeiss Stereo Discovery V12 microscope.

3.4. List of invertebrates used

Each family and species of invertebrates was placed in its own tank with the bone samples.

3.4.1. Experiment 1

Table 1: List of beetles and flies used including initial and final numbers and identified tank used.

Order Coleoptera (Beetles)					
Family	**Species**	**Initial no.**	**Final no.**	**Tank id chicken**	**Tank id lamb**
Dermestidae	*Dermestes maculatus* (de Geer, 1774)	11	11	6	2
	Dermestes maculatus larvae (de Geer, 1774)	4	>100	6	2
Tenebrionidae	*Anomalipus elephas* (Fåhraeus, 1870)	6	6	9	1
	Zophobas morio larvae (Fabricius, 1776)	15	14	10	3
Trogidae	*Omorgus (Afromorgus) melancholicus* (Fåhraeus, 1857)	15	15	5	4
	Omorgus (Afromorgus) squalidus (Olivier, 1789)	2	2	5	4
Order Diptera (Flies)					
Family	**Species**	**Initial no.**	**Final no.**	**Tank id chicken**	**Tank id lamb**
Calliphoridae	*Calliphora vomitoria*	8	7	0	3
Phoridae	*Megaselia scalaris*	8	7	32	4

3.4.2. Experiment 2

Table 2: List of beetles and flies used including initial and final numbers and identified tank used.

Order Coleoptera (Beetles)					
Family	**Species**	**Initial no.**	**Final no.**	**Tank id chicken**	**Tank id lamb**
Dermestidae	*Dermestes maculatus* (de Geer, 1774)	0	3	8	3
	Dermestes maculatus larvae (de Geer, 1774)	32	14	8	3
Tenebrionidae	*Anomalipus elephas* (Fåhraeus, 1870)	0	0	6	1
	Zophobas morio larvae (Fabricius, 1776)	16	8	7	2
Trogidae	*Omorgus (Afromorgus) melancholicus* (Fåhraeus, 1857)	10	9	9	4
	Omorgus (Afromorgus) squalidus (Olivier, 1789)	2	2	9	4
Order Diptera (Flies)					
Family	**Species**	**Initial no.**	**Final no.**	**Tank id chicken**	**Tank id lamb**
Calliphoridae	*Calliphora vomitoria*	>50	>50	10	5
Phoridae	*Megaselia scalaris*	>50	>50	10	5

The beetles used were provided by the authors supervisor, Dr. James du G. Harrison. The flies used were collected by using the defleshed meat from the bone samples as bait within a tank.

3.5. Damage identification

Terminology to describe the damage by invertebrates to bone in this study follows that of Parkinson (2012).

Bore holes = Deep semi-circular holes which may or may not have a discernible bottom that penetrate through cortical or cancellous bone, and into the medullary cavity.

Destruction = Described as the obliteration of bone, complete destruction of cancellous bone or articular facets, removal of cortical bone which results in the abrading of the associated surface area.

Discolouration = Staining of the periosteal surface.

Gnawing = Clusters of sub-parallel or parallel striations located in close proximity to an edge, or clusters of irregularly oriented striations which cover a large surface area.

Surface pits

Class 1: Highly variable in shape, however, frequently semi-circular to elliptical shallow depressions with a u-shaped profile that have striations emanating from around the depressions outer circumference.

Class 2: Semi-circular shallow depressions with randomly oriented, often intersecting, striations appearing over the complete feature.

Class 3: Irregular-shaped depressions with complex profiles which are not associated with striations.

Surface tunnels = Shallow furrows with a u-shaped profile excavated across the surface of a bone. Bore holes may appear at either one or both ends of the furrow. Primarily occurring as a single furrow, however, occasionally as a complex of interconnected furrows.

3.6. Summary

A sample of 10 chicken drumsticks (half roasted and half raw) and 10 lamb shanks (half roasted and half raw) were defleshed by hand and placed in tanks with moist-to-the-touch coconut/palm peat and a chosen invertebrate, three families of beetle (Family Dermestidae, Trogidae and Tenebrionidae) and two families of fly (Family Calliphoridae and Phoridae), for the experimental period of a month. An identical control tank was set up without any insects. These bones were chosen for their hard and soft bone characteristics, and their common presence within the archaeological record, in an effort to replicate the post mortem processes by invertebrates on bone. A Dino Lite USB microscope was used to identify insect damage, a Zeiss stereo Discovery.V12 microscope was used to obtain dimensions of the damage and terminology used by Parkinson (2012), including bore holes, destruction, discolouration, gnawing, surface pits and surface tunnels, was used to describe the damage, all of which was recorded in a Microsoft Excel spreadsheet.

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Chapter 4: Results

This chapter comprises the results obtained from both experiments and consists of four sections**.** The first section briefly discusses the control. The results of experiment 1 are then reported, with this section comprising the identification of damage by the beetles and flies. Following this, the result of experiment 2 are reported. The results of both experiments are then compared.

4.1. Control

After a macroscopic and microscopic analysis of the control bone samples, no form of damage was identified, therefore, any form of damage identified in the non-control bones are regarded as a result of invertebrate activity that they were exposed to during the experiments.

4.2. Experiment 1 damage identification

Following the same analytical procedure of the control for experiment 1, the damage produced by each beetle species was identified. A total of four damage types were identified; bore holes, surface destruction, gnawing and surface tunnels.

4.3. *Dermestes maculatus* (de Geer, 1774) larvae and adults

Both adults and larvae were placed in the same tank, which would make the damage indistinguishable between the two. However, at closer inspection, a significant number of larvae were found at the location of, or close proximity to, the identified damage (Figure 11; Figure 12). Based on this evidence, the identified damage could be attributed to the larvae more so than the adults.

Upon completion of the experiment, it was observed that the remaining flesh on both chicken and lamb, raw and roasted, bone samples were consumed by the dermestid beetles and larvae, a common activity of this species (Figure 11; Figure 12).



Figure 11. Larvae found at and in close proximity to damage on chicken bone sample.



Figure 12. Larvae found at and in close proximity to damage on lamb bone sample.

4.3.1. Bore holes

This damage type was present on both raw and roasted chicken bones and none on the raw and roasted lamb bones (Table 3). All bore hole damage was identified at the articular facet of the chicken bone samples (Figure 13) (Table 3). The mean measurement of the bore holes were 3.19 mm and 3.11 mm for the x and y axes respectively (Table 3). Unlike Parkinson's (2012) description of bore holes, the observed bore hole damage was more circular (Figure 14; Figure 15; Figure 16).

Table 3: Summary of bore hole damage by *Dermestes maculatus* larvae and adults.

Bone indentification	**Bone type**	**Damage location**	**x axis measurement**	**y axis measurement**
Raw ii	Chicken	Articular facet	4.26 mm	3.67 mm
Raw ii	Chicken	Articular facet	3.52 mm	3.38 mm
Raw ii	Chicken	Articular facet	1.98 mm	1.94 mm
Roasted ii	Chicken	Articular facet	3.01 mm	3.43 mm
Mean			3.19 mm	3.11 mm



Figure 13. Macro view of bore hole damage on chicken raw ii.

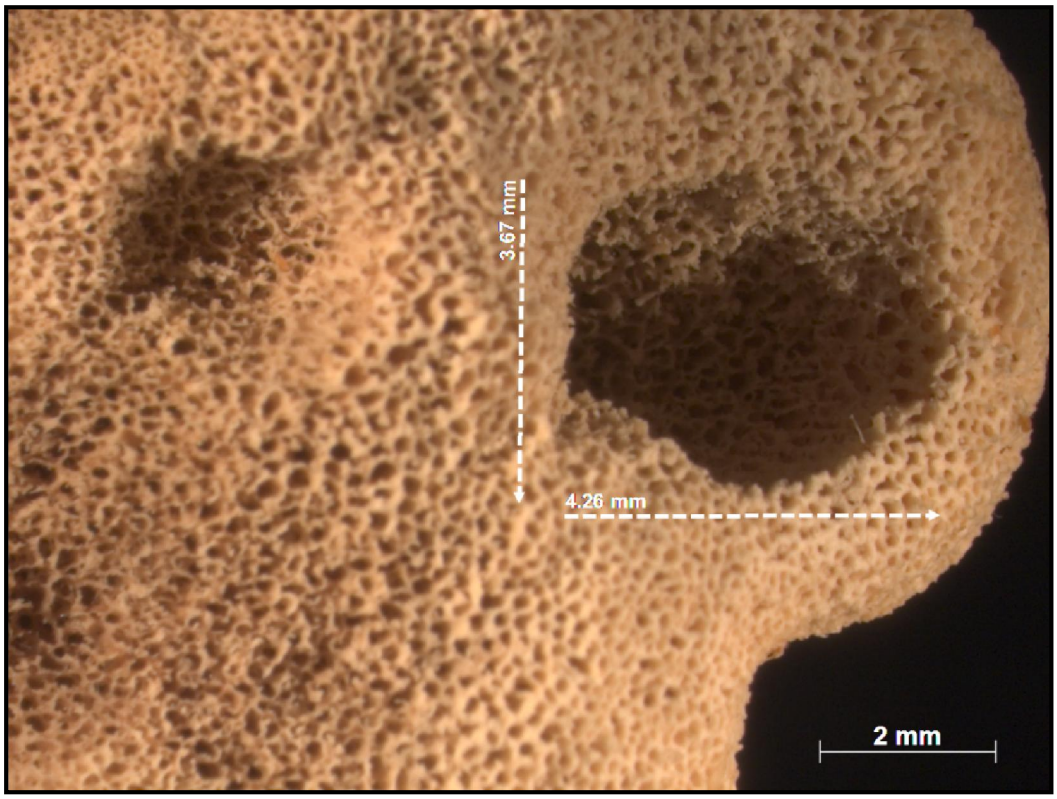

Figure 14. Micro view of bore hole on articular facet of chicken raw ii.

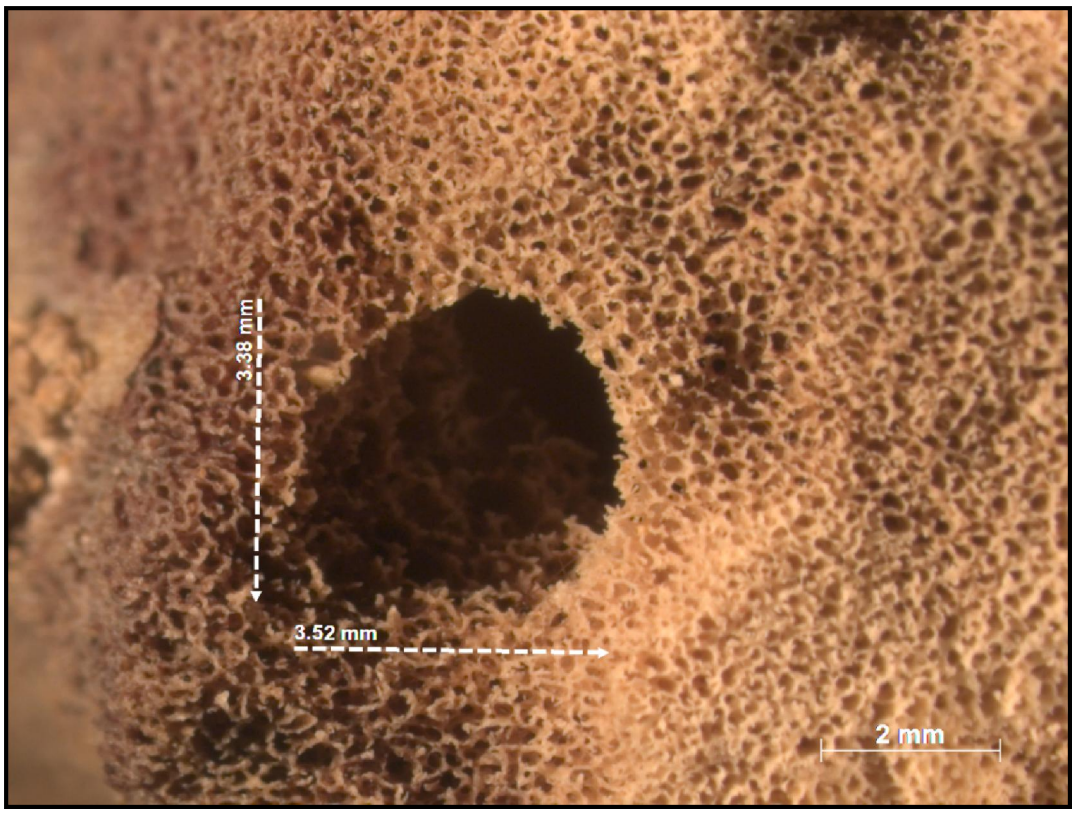

Figure 15. Micro view of second bore hole on articular facet of chicken raw ii.

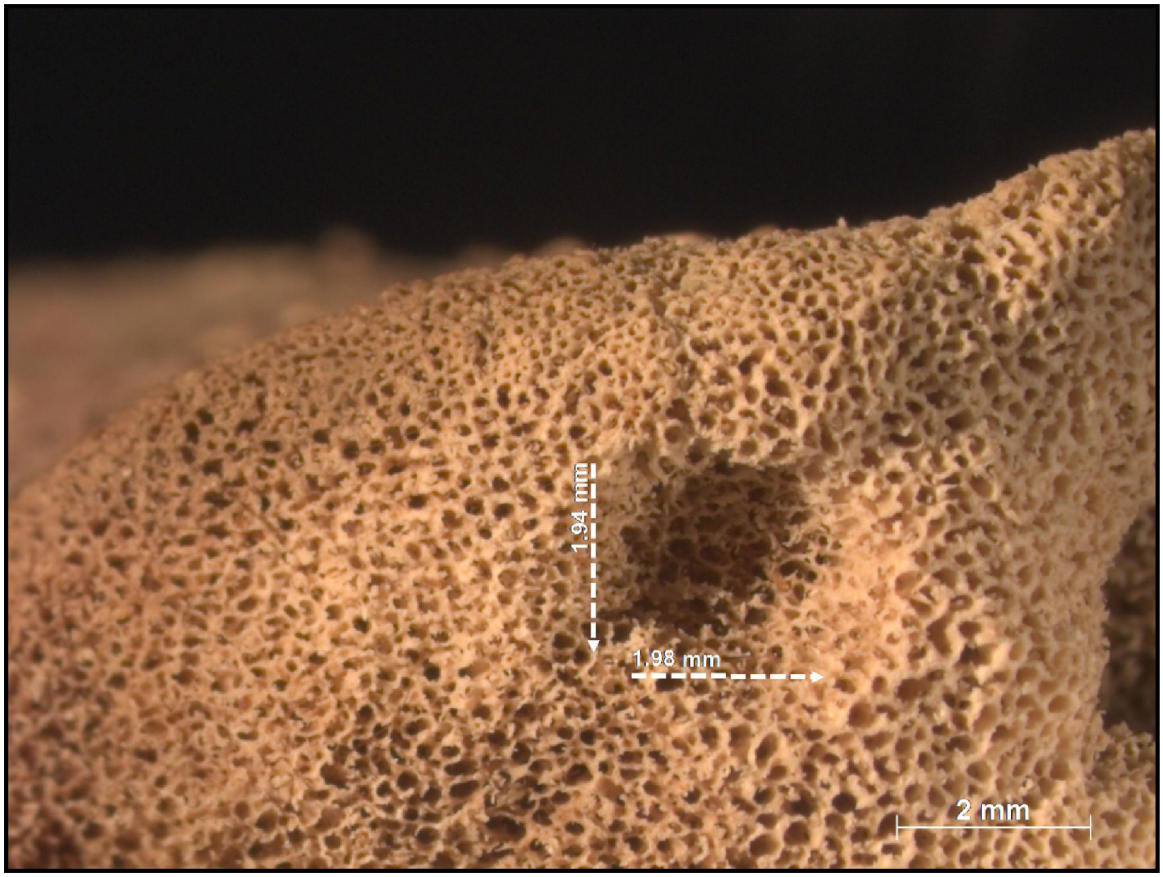

Figure 16. Micro view of third bore hole on articular facet of chicken raw ii.

4.3.2. Destruction

Both raw and roasted chicken bones displayed destruction as the fibulae were broken (Table 4). Destruction was also identifed on the articular facet of lamb roasted iii bone(s) (Figure 17; Figure 18). A microscopic analysis of the destruction displayed evidence of the damage by *Dermestes maculatus* mouth parts (Figure 19). The table below summarises the location and approximate percentage of the damage observed on the bone sample as a whole (Table 4).

Table 4. Summary of destruction damage by *Dermestes maculatus* larvae and adults.

Bone indentification	**Bone type**	**Damage location**	**~ % of bone damaged**
Raw ii	Chicken	Fibula	< 5 %
Roasted ii	Chicken	Fibula	< 5 %
Roasted iii	Lamb	Articular facet	< 20%



Figure 17. Destruction located at articular facet of lamb roasted iii.

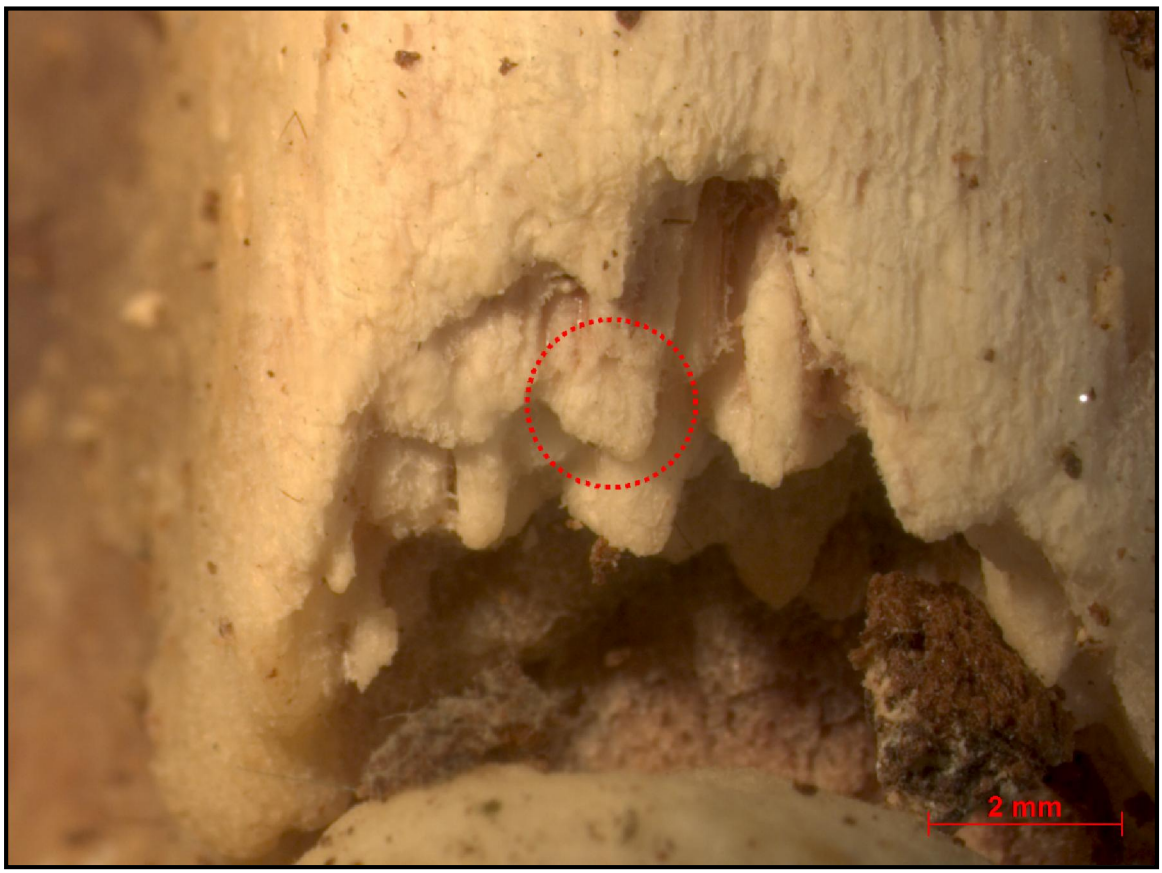

Figure 18. Destruction located at articular facet of lamb roasted iii.

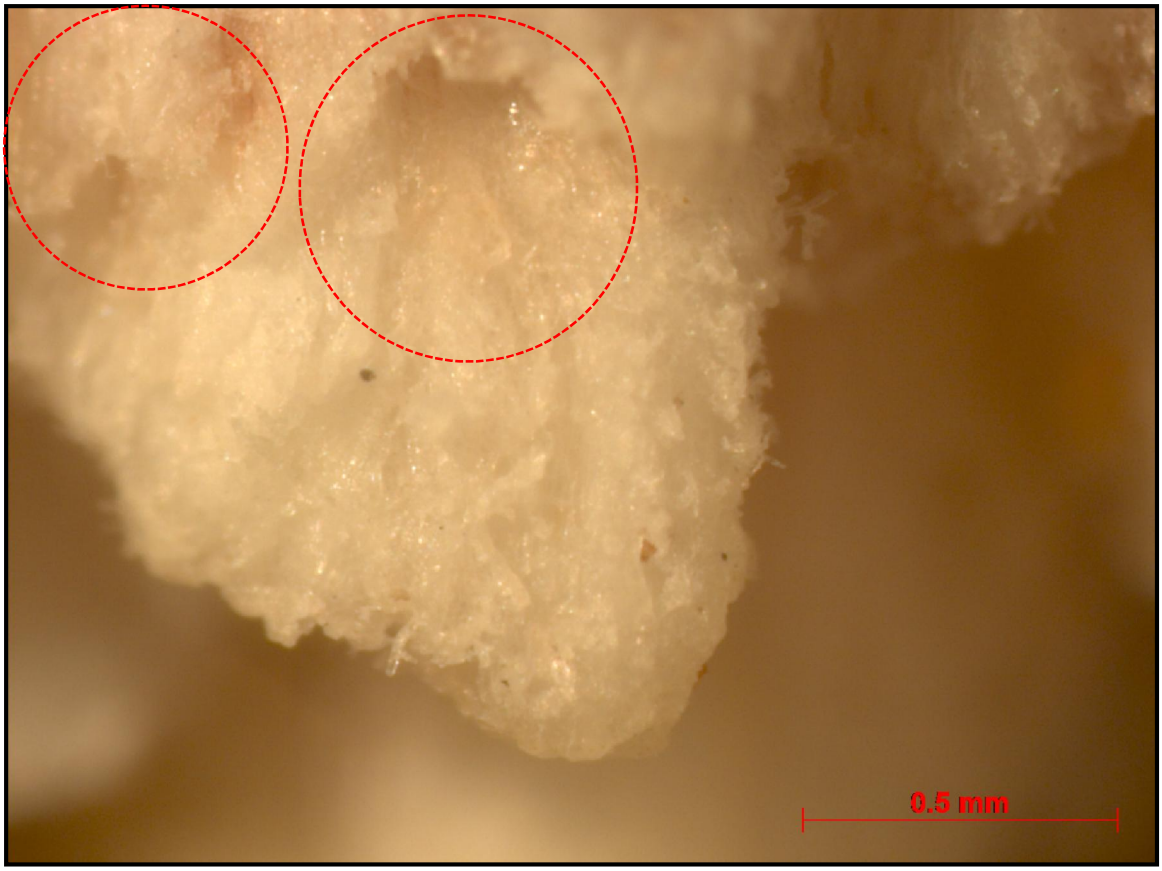

Figure 19. Zoomed view of circled area in Figure 8, with evidence of *Dermestes maculatus* adult and larvae mouth activity.

4.3.3. Gnawing

This form of damage was identified on chicken raw ii bones (Table 5). The damage was found in close proximity to the articular facet and measured 6.08 mm and 4.68 mm, with a mean length of 5.38 mm (Figure 20) (Table 5).

Table 5. Summary of gnaw damage by *Dermestes maculatus* larvae and adults.

Bone identification	**Bone type**	**Damage location**	**Damage length**	$\bar{x}$
Raw ii	Chicken	Close proximity to articular facet	6.08 mm and 4.68 mm	5.38 mm

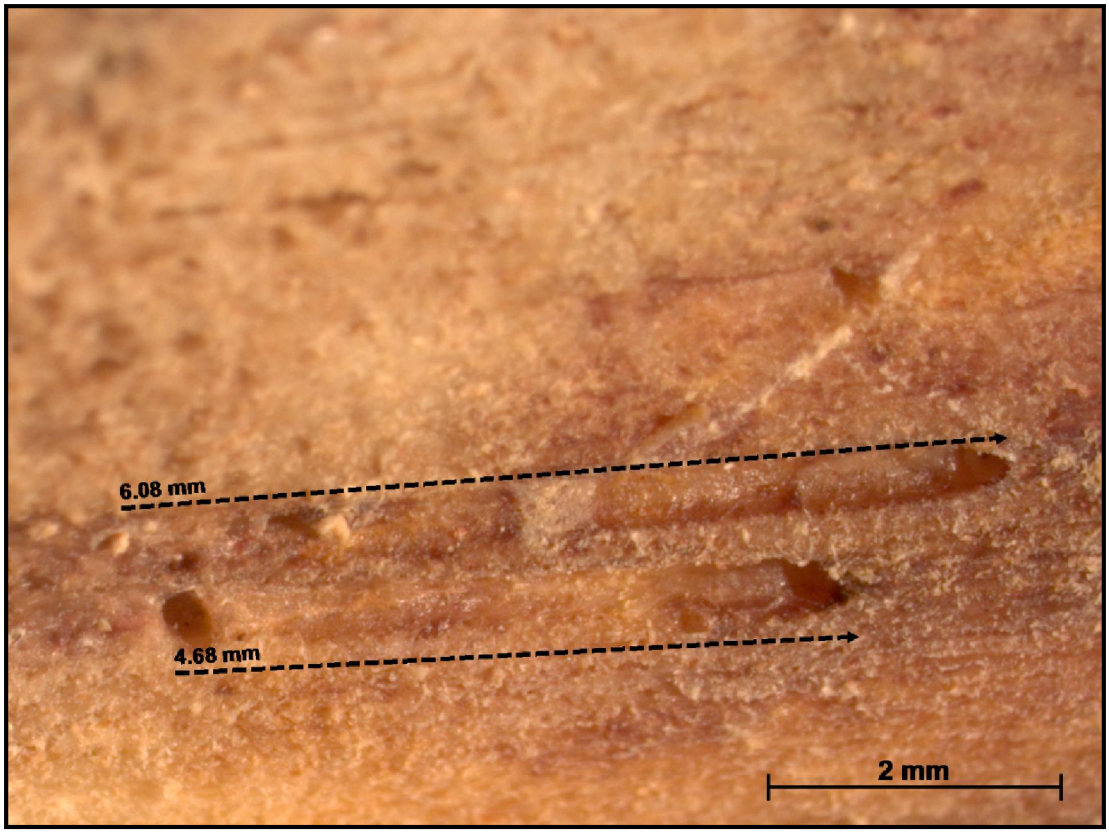

Figure 20. Gnawing on chicken raw ii.

4.3.4. Surface tunnels

This form of damage was identified on chicken raw ii and chicken roasted ii bones (Table 6). The damage was found on the bone shaft, with measurements of 4.89 mm and 7.31 mm and a mean of 6.1 mm (Figure 22; Figure 23) (Table 6). After close observation, micro striations were found within the surface tunnels, providing evidence of the damage by *Dermestes maculatus* mouth parts (Figure 21).

Table 6. Summary of surface tunnel damage by *Dermestes maculatus* larvae and adults.

Bone identification	**Bone type**	**Damage location**	**Damage length**
Raw ii	Chicken	Shaft	4.89 mm
Roasted ii	Chicken	Shaft	7.31 mm
Mean			6.1 mm

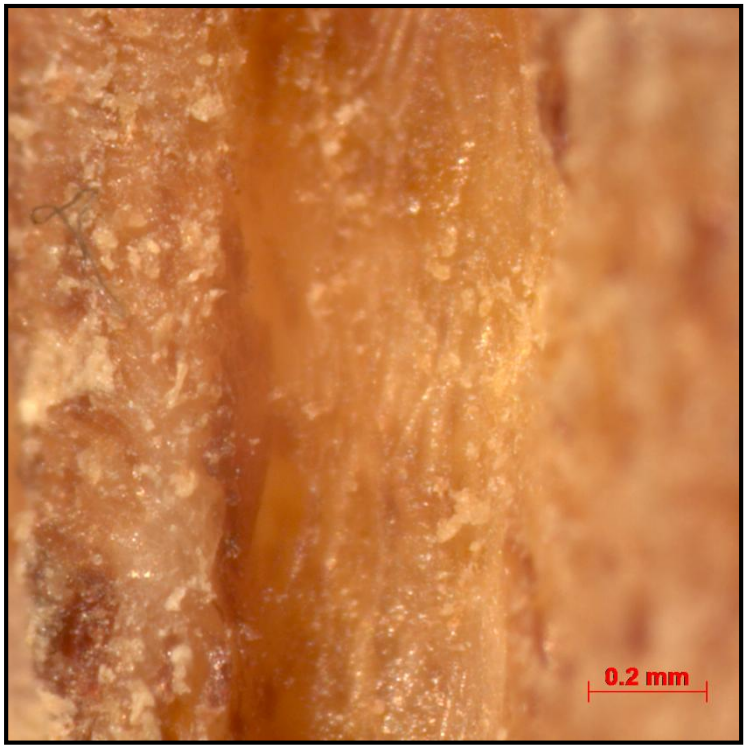

Figure 21. Micro striations observed in surface tunnel.



Figure 22. Surface tunnel damage by *Dermestes maculatus* adults and larvae on chicken raw ii.

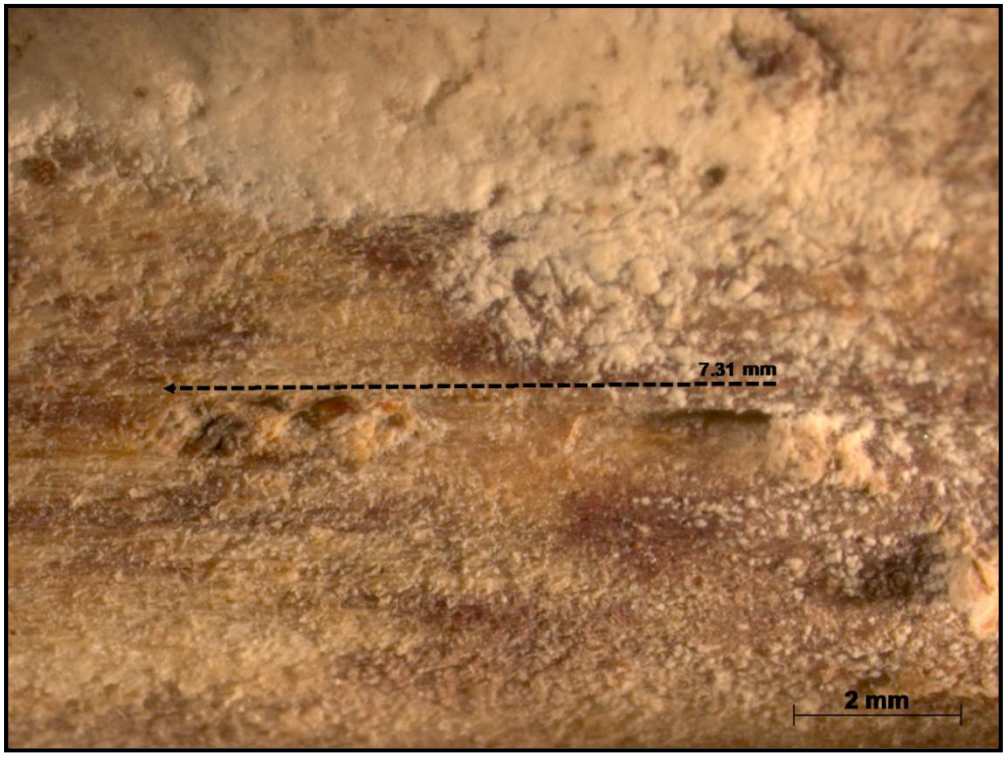

Figure 23. Surface tunnel damage by *Dermestes maculatus* adults and larvae on chicken raw ii.

4.4. *Anomalipus elephas* (Fåhraeus, 1870) and *Zophobas morio* larvae (Fabricius, 1776)

Upon completion of the experiment, it was observed that the remaining flesh on both chicken and lamb, raw and roasted, bone samples was still present and had dried and produced a white mould.

4.4.1. Destruction

This form of damage by *Anomalipus elephas* and *Zophobas morio* larvae was only identified on lamb roasted i bone (Figure 24). Less than 20% of the bone sample was damaged, with the damage only being observed at the articular facet (Figure 24).

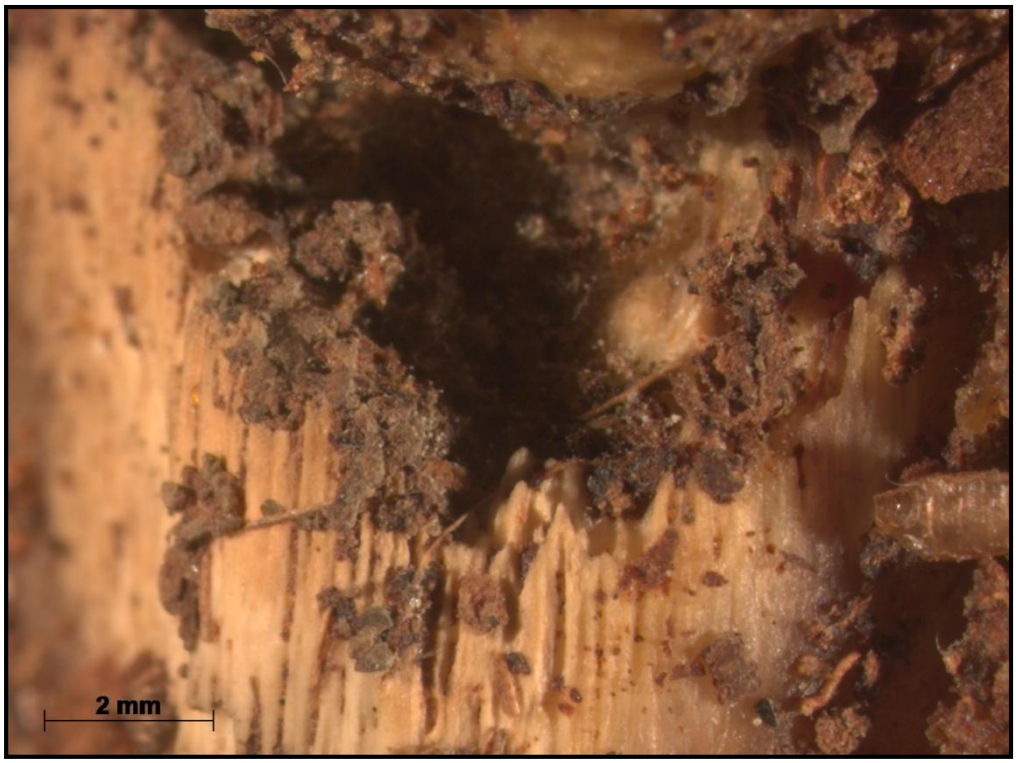

Figure 24. Destruction located at articular facet of lamb roasted iii.

4.5. *Omorgus (Afromorgus) melancholicus* (Fåhraeus, 1857) and *Omorgus (Afromorgus) squalidus* (Olivier, 1789)

After a microscopic and macroscopic analysis of all the bones exposed to *Omorgus (Afromorgus) melancholicus* and *Omorgus (Afromorgus) squalidus*, no form of damage could be identified. Additionally, upon completion of the experiment, it was observed that the remaining flesh on both chicken and lamb, raw and roasted, bone samples was still present and had dried and produced a white mould.

4.6. Fly damage

Neither *Calliphora vomitoria* (Linnaeus, 1758) nor *Megaselia scalaris* (Loew, 1866) were shown to have damaged the bone samples in any way. Similar to the bone samples exposed to the *Omorgus (Afromorgus) melancholicus* and *Omorgus (Afromorgus) squalidus*, remaining flesh on both raw and roasted chicken and lamb bone samples was present and had dried and produced a white mould.

4.7. Summary of damage identification for experiment 1

A total of four damage types were identified on the chicken bone samples; bore holes, surface destruction, gnawing and surface tunnels (Table 7). Of the 10 chicken bone samples, the damage was only observed on raw ii and roasted ii (Table 7).

Table 7. Damage identification on raw and roasted chicken bones, experiment 1.

	Damage identification					
Bone identification	**Bore holes**	**Destruction**	**Discolouration**	**Gnawing**	**Surface pits**	**Surface tunnels**
Raw i	-	-	-	-	-	-
Raw ii	x	x	-	x	-	x
Raw iii	-	-	-	-	-	-
Raw iv	-	-	-	-	-	-
Raw v	-	-	-	-	-	-
Roasted i	-	-	-	-	-	-
Roasted ii	x	x	-	-	-	x
Roasted iii	-	-	-	-	-	-
Roasted iv	-	-	-	-	-	-
Roasted v	-	-	-	-	-	-

Destruction was the only damage type found on the lamb bone samples (Table 8). Out of the 10 lamb bone samples, roasted i and iii exhibited damage (Table 8).

Table 8. Damage identification on raw and roasted lamb bones, experiment 1.

	Damage identification					
Bone identification	**Bore holes**	**Destruction**	**Discolouration**	**Gnawing**	**Surface pits**	**Surface tunnels**
Raw i	-	-	-	-	-	-
Raw ii	-	-	-	-	-	-
Raw iii	-	-	-	-	-	-
Raw iv	-	-	-	-	-	-
Raw v	-	-	-	-	-	-
Roasted i	-	x	-	-	-	-
Roasted ii	-	-	-	-	-	-
Roasted iii	-	x	-	-	-	-
Roasted iv	-	-	-	-	-	-
Roasted v	-	-	-	-	-	-

4.8. Experiment 2 damage identification

After a macroscopic and microscopic analysis of the bone samples in experiment 2, the damage produced by each beetle species was identified. A total of three damage types were identified on the bones exposed to Tenebrionidae larvae only; destruction, gnawing and surface tunnels.

4.9. *Dermestes maculatus* larvae and adults

After a microscopic and macroscopic analysis of all the bones exposed to *Dermestes maculatus* larvae and adults, no form of bone damage could be identified. The remaining flesh on both chicken and lamb, raw and roasted, bone samples was partially consumed by the dermestid beetles and larvae.

4.10. *Omorgus (Afromorgus) melancholicus* and *Omorgus (Afromorgus) squalidus*

After a microscopic and macroscopic analysis of all the bones exposed to *Omorgus (Afromorgus) melancholicus* and *Omorgus (Afromorgus) squalidus*, no form of damage could be identified. The flesh on both chicken and lamb, raw and roasted, bone samples was still present and had dried and produced a white mould.

4.11. *Anomalipus elephas* and *Zophobas morio* larvae

The flesh on both chicken and lamb, raw and roasted, bone samples was partially consumed by the tenebrionid larvae.

4.11.1. Destruction

Chicken roasted ii was the only bone sample to display destruction, which was identified in close proximity to the articular facet (Figure 25) (Table 9). Less than 5% of the bone sample displayed destruction damage (Table 9).

Table 9. Summary of destruction damage by *Zophobas morio* larvae.

Bone indentification	Bone type	Damage location	~ % of bone damaged
Roasted ii	Chicken	Close proximity to articular facet	< 5%



Figure 25. circled area displaying destruction by *Zophobas morio* larvae.

4.11.2. Gnawing

Two sets of this form of damage were identified on chicken raw ii bones only (Table 10). The first set of gnawing was observed on the shaft and measured 7.02 mm and 6.88 mm, with a mean of 6.95 mm (Figure 26) (Table 10). The second set of gnawing was found in close proximity to the articular facet and measured 8.32 mm and 7.75 mm, with a mean of 8.04 mm (Figure 27) (Table 10).

Table 10. Summary of gnaw damage by *Zophobas morio* larvae.

Bone identification	**Bone type**	**Damage location**	**Damage length**	$\bar{x}$
Raw ii	Chicken	Shaft	7.02 mm and 6.88 mm	6.95 mm
Raw ii	Chicken	Close proximity to articular facet	8.32 mm and 7.75 mm	8.04 mm
Mean			7.5 mm	

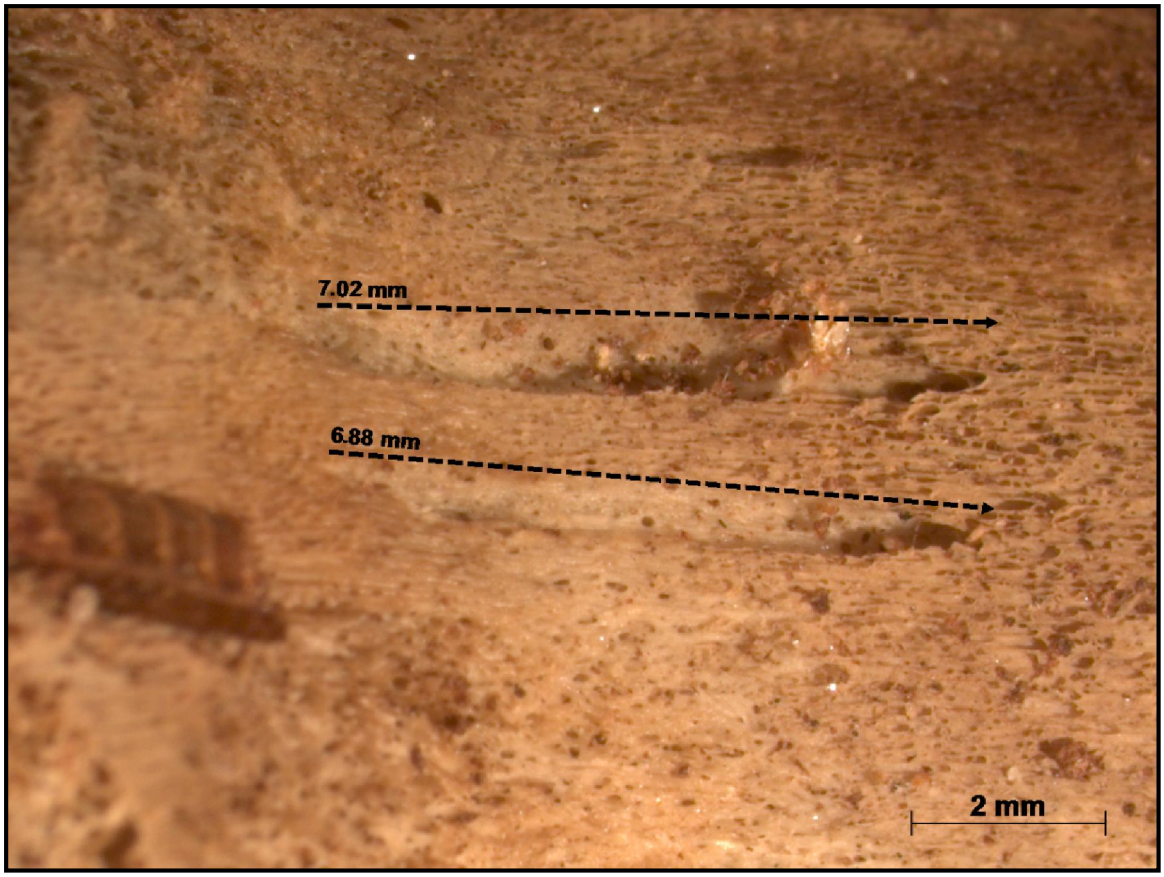

Figure 26. Gnawing by *Zophobas morio larvae* on chicken raw ii.

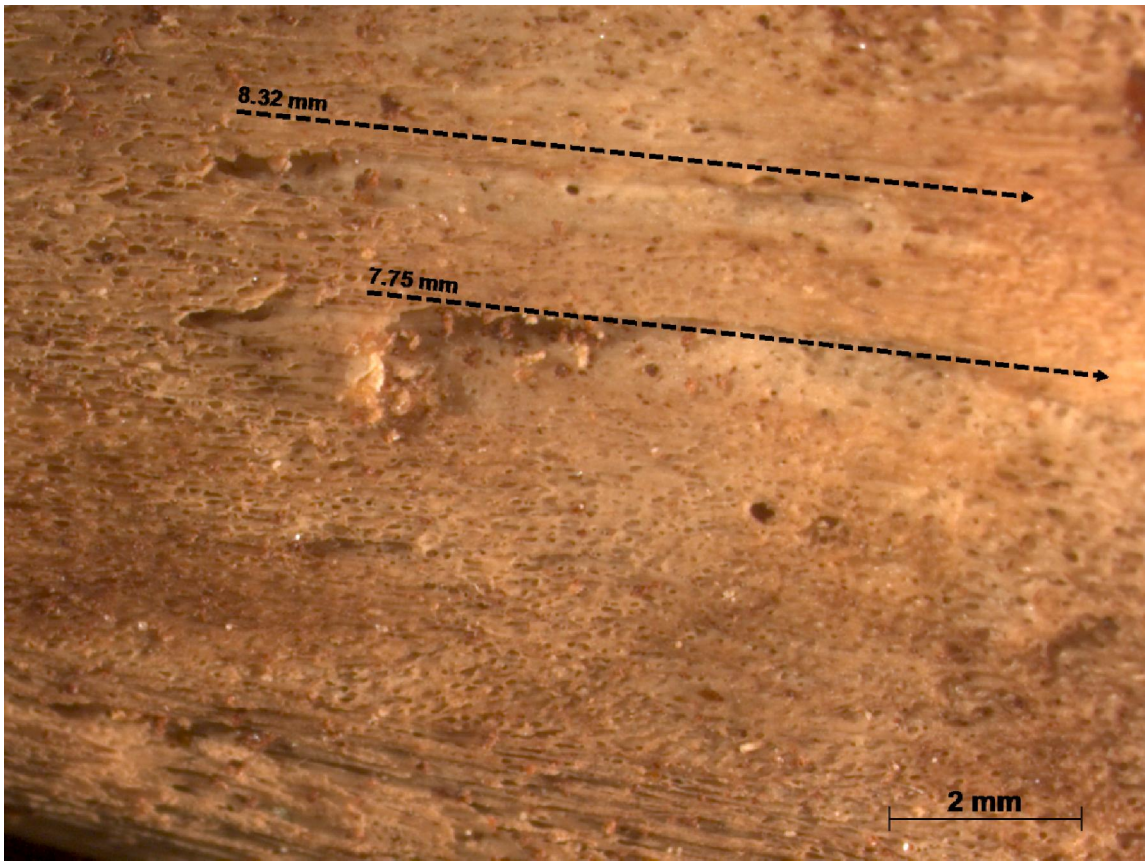

Figure 27. Gnawing by *Zophobas morio larvae* on chicken raw ii.

During the analysis of the bones exposed to *Dermestes maculatus* larvae and adults, *Anomalipus elephas*, *Omorgus (Afromorgus) melancholicus* and *Omorgus (Afromorgus) squalidus*, no form of damage was identified.

4.12. Fly damage

After a macroscopic and microscopic analysis of the bone samples exposed to both families of flies in experiment 2 neither *Calliphora vomitoria* nor *Megaselia scalaris* were shown to have damaged the bone samples in anyway.

4.13. Summary of damage identification for experiment 2

A total of two damage types were identified on the chicken bone samples; surface destruction and gnawing (Table 11). Of the 10 chicken bone samples, the damage was only observed on raw ii and roasted ii (Table 11). No form of damage could be identified on the lamb bone samples

Table 11. Damage identification on raw and roasted chicken bones.

	Damage identification					
Bone identification	**Bore holes**	**Destruction**	**Discolouration**	**Gnawing**	**Surface pits**	**Surface tunnels**
Raw i	-	-	-	-	-	-
Raw ii	-	-	-	x	-	-
Raw iii	-	-	-	-	-	-
Raw iv	-	-	-	-	-	-
Raw v	-	-	-	-	-	-
Roasted i	-	-	-	-	-	-
Roasted ii	-	x	-	-	-	-
Roasted iii	-	-	-	-	-	-
Roasted iv	-	-	-	-	-	-
Roasted v	-	-	-	-	-	-

4.14. Number of bones exposed to and affected by insects

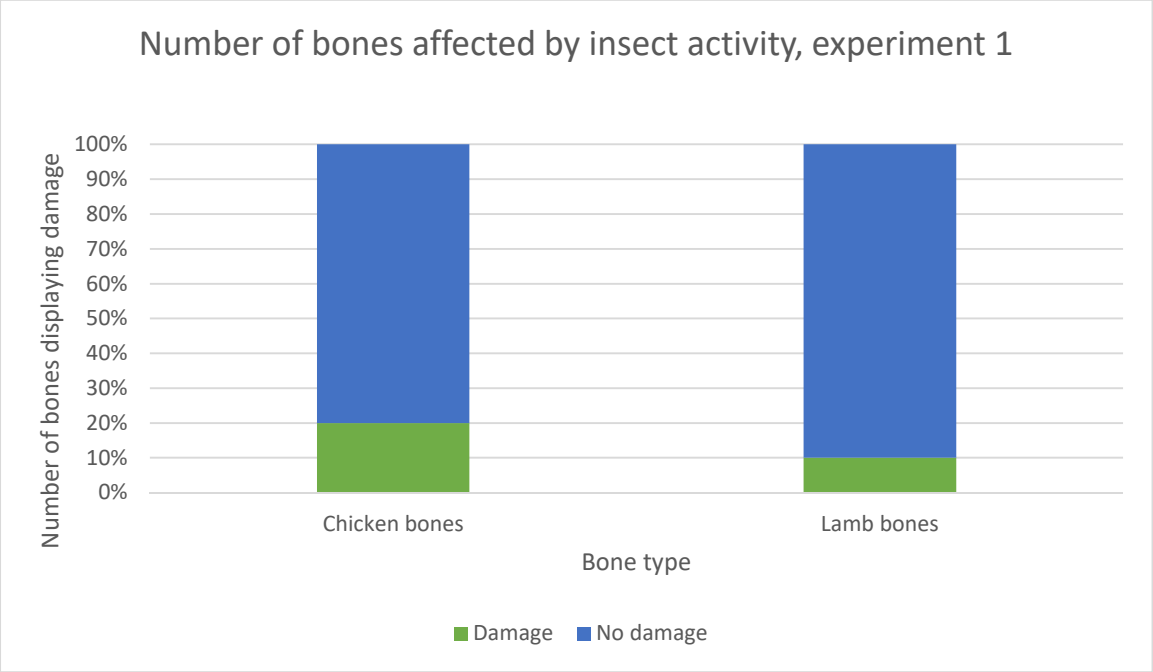

Figure 28. Number of bones affected by insect activity in experiment 1.

From the 10 chicken bone samples exposed to insects in experiment 1, 20% of the bones, two in total, exhibited damage (Figure 28). With regards to the lamb bone samples, one out of the 10 bone samples exhibited damage, equating 10% of the sample (Figure 28).

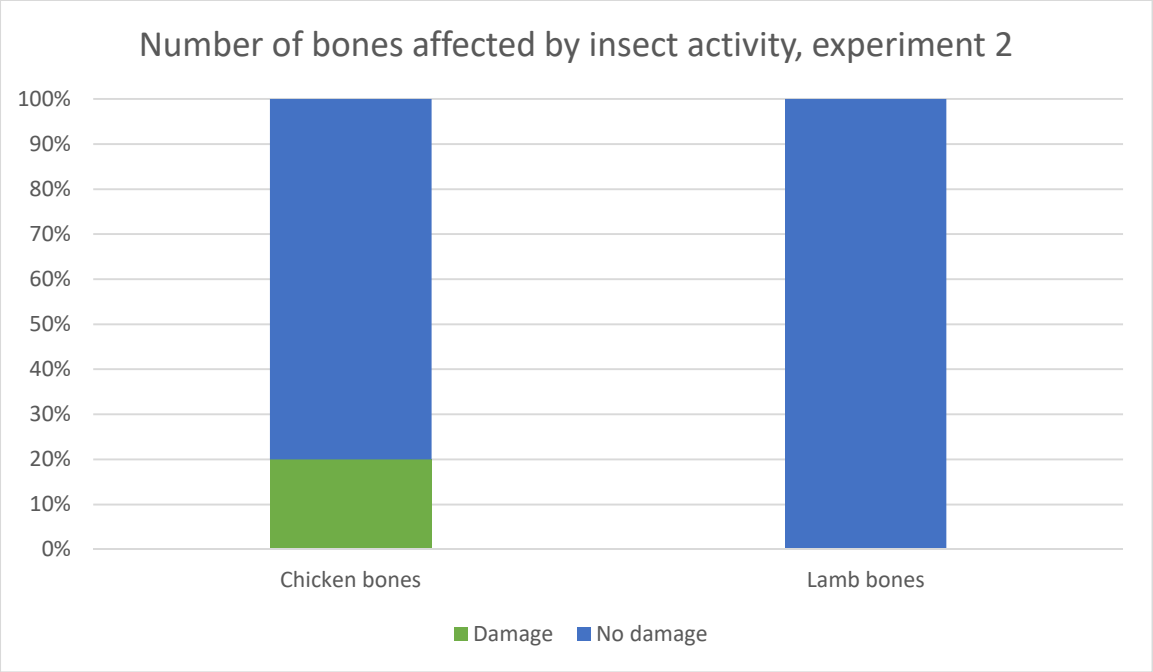

Figure 29. Number of bones affected by insect activity in experiment 2.

Of the 10 chicken bone samples exposed to insects in experiment 2, 20% of the bones, two in total, exhibited damage (Figure 29). With the lamb bone samples, no damage could be identified (Figure 29).

4.15. Bone type and its likelihood of being damaged

To test whether there was a significant difference between the samples, Fisher's exact tests were conducted. These were used to test the statistical significance of the number of bones that were exposed to insects and affected by insect activity, and the number of bones that were raw and roasted and affected by insect activity.

4.15.1. Experiment 1

The Fisher's exact test statistic value is 1. The result is not significant at $p < .05$ (Table 12). The evidence suggests that in experiment 1, avian and mammalian bones are equally likely to be damaged.

Table 12. Fisher's exact test of bone type and its damage, experiment 1.

Results			
	Damage	No damage	Marginal row totals
Chicken bones	2	8	10
Lamb bones	2	8	10
Marginal column totals	4	16	20 (Grand total)

4.15.2. Experiment 2

The Fisher's exact test statistic value is 0.4737. The result is not significant at $p < .05$ (Table 13). The evidence suggests that in experiment 2, avian and mammalian bones are equally likely to be damaged.

Table 13. Fisher's exact test of bone type and its damage, experiment 2.

Results			
	Damage	No damage	Marginal row totals
Chicken bones	2	8	10
Lamb bones	0	10	10
Marginal column totals	2	18	20 (Grand total)

4.16. Raw versus roasted bone samples

Tests were also conducted to assess whether any significant difference exists between raw and roasted bone. For chicken bones, the Fisher exact test statistic value is 1. The result is not significant at $p < .05$ (Table 14). The evidence suggests that in experiment 1, raw and roasted chicken bones are equally likely to be damaged.

Table 14. Fisher's exact test of damage on raw and roasted chicken bone, experiment 1.

Results			
	Damage	No damage	Marginal row totals
Raw	1	4	5
Roasted	1	4	5
Marginal column totals	2	8	10 (Grand total)

For lamb bone, the Fisher's exact test statistic value is 0.4444. The result is not significant at $p < .05$ (Table 15). The evidence suggests that in experiment 1, raw and roasted lamb bones are equally likely to be damaged.

Table 15. Fisher's exact test of damage on raw and roasted lamb bone, experiment 1.

Results			
	Damage	No damage	Marginal row totals
Raw	2	3	5
Roasted	0	5	5
Marginal column totals	2	8	10 (Grand total)

The Fisher's exact test statistic value is 1. The result is not significant at $p < .05$ (Table 16). The evidence suggests that in experiment 2, raw and roasted chicken bones are equally likely to be damaged.

Table 16. Fisher's exact test of damage on raw and roasted chicken bone, experiment 2.

Results			
	Damage	No damage	Marginal row totals
Raw	1	4	5
Roasted	1	4	5
Marginal column totals	2	8	10 (Grand total)

The Fisher's exact test statistic value is 1. The result is not significant at $p < .05$ (Table 17). The evidence suggests that in experiment 2, raw and roasted lamb bones are equally likely to be damaged.

Table 17. Fisher's exact test of damage on raw and roasted lamb bone, experiment 2.

Results			
	Damage	No damage	Marginal row totals
Raw	0	5	5
Roasted	0	5	5
Marginal column totals	0	10	10 (Grand total)

4.17. Part of bones most affected by insects

4.17.1. Experiment 1

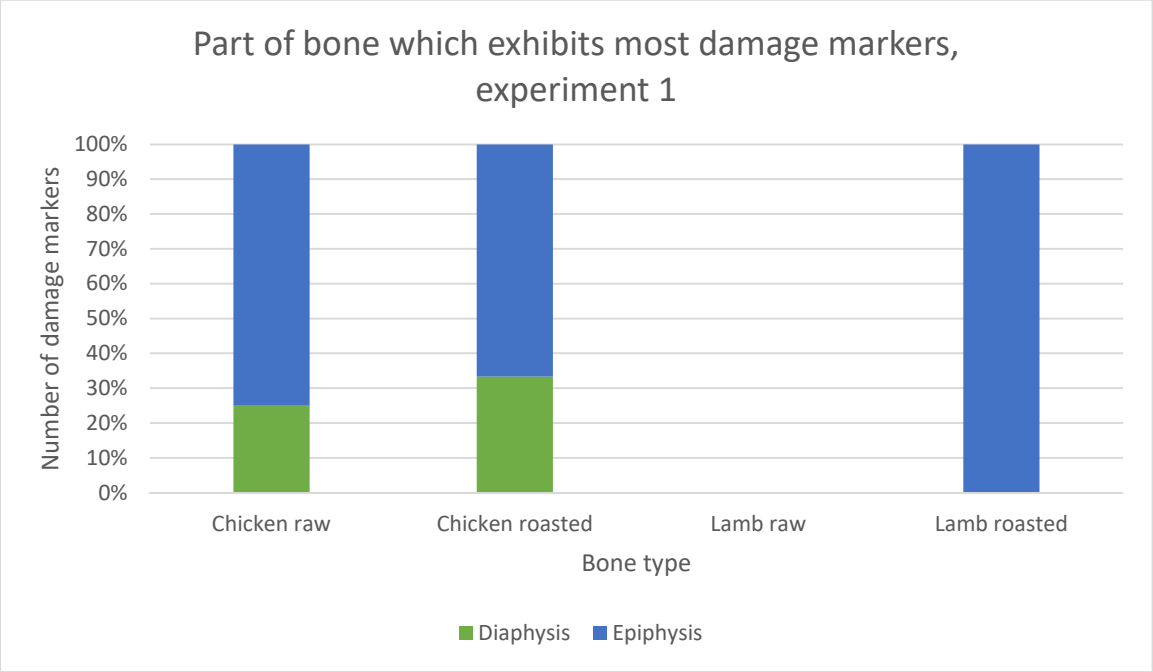

Figure 30. Part of bone which exhibits most damage in experiment 1.

Each bone sample was divided into two areas, diaphysis and epiphysis, to asses which element displayed the most damage markers (Figure 30). With the raw chicken bone samples, 75% of damage appeared on the epiphysis and 25% on the diaphysis (Figure 30). For the roasted chicken samples, approximately 67% of damaged was found on the epiphysis and 33% on the diaphysis (Figure 30). No damage was identified on raw lamb samples, while the roasted lamb samples only displayed damage at the epiphysis (Figure 30).

4.17.2. Experiment 2

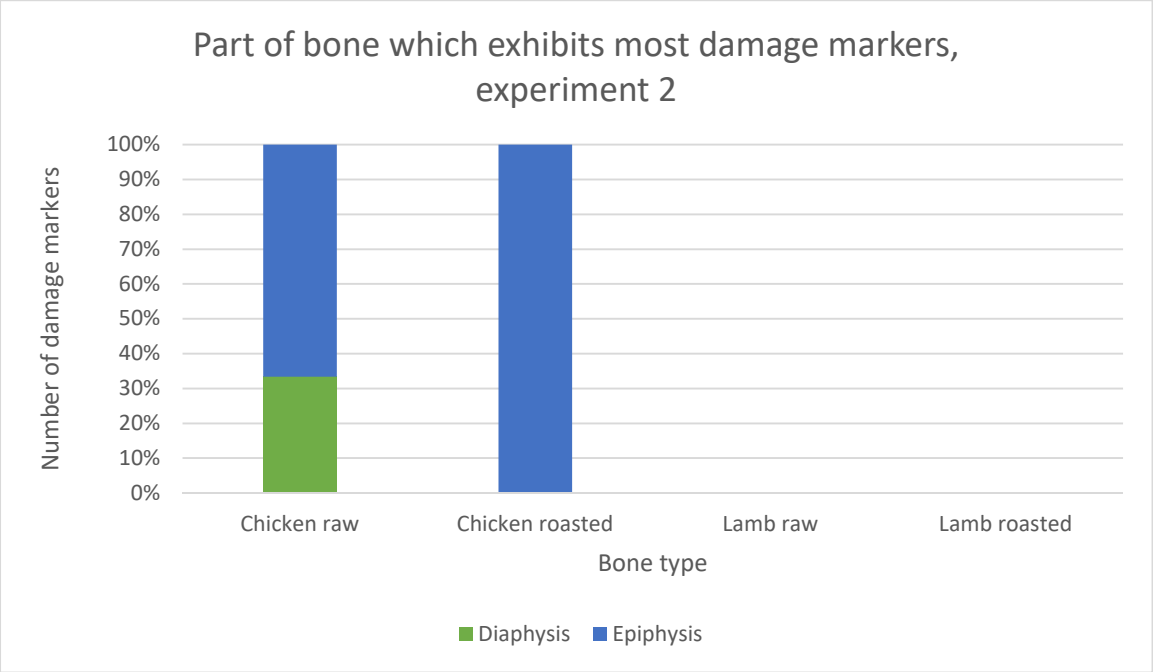

Figure 31. Part of bone which exhibits most damage in experiment 2.

For the raw chicken bone samples, approximately 67% of the damage was found at the epiphysis, and 33% on the diaphysis, while all damage on the roasted chicken samples were found at the epiphysis (Figure 31). No damage was identified on the raw and roasted lamb bone samples in experiment 2 (Figure 31).

4.18. Comparison of experiment 1 and 2

Following the macro and microscopic analysis of the bone samples, the results were compared (Table 18). In experiment 1, Dermestid adults and larvae produced bore hole, destruction, gnawing and surface tunnel damage, while no damage could be identified in experiment 2 (Table 18). Tenebrionidae adults and larvae produced destruction damage in both experiments and gnawing damage in experiment 2 only (Table 18). No form of damage was identified on the bone samples exposed to Trogid beetles in both experiments (Table 18). No form of damage could be identified on the bone samples exposed to Calliphorid and Phorid flies in both experiments.

Table 18. Summary of identified damage by dermestid adult and larvae, Tenebrionidae adult and larvae and trogid adult beetles.

	Dermestidae		**Tenebrionidae**		**Trogidae**	
	Experiment 1	**Experiment 2**	**Experiment 1**	**Experiment 2**	**Experiment 1**	**Experiment 2**
Bore hole	x	-	-	-	-	-
Destruction	x	-	x	x	-	-
Discolouration	-	-	-	-	-	-
Gnawing	x	-	-	x	-	-
Surface pits	-	-	-	-	-	-
Surface tunnels	x	-	-	-	-	-

Chapter 5: Discussion

This chapter comprises a discussion of the results of the previous chapter and consists of four sections: bone density, comparison of invertebrate damage with other forms of damage, body decomposition and a summary of the chapter.

Avian and mammalian bones are commonly found in the archaeological record, such as evidence of domestic chicken, *Gallus gallus domesticus* (Linnaeus 1758), dating to 2590 ± 30 BP in Northern Ethiopia and domestic sheep, *Ovis aries* (Linnaeus 1758), in northern Botswana, dated to 2020 ± 40 BP, Blombos Cave, dated to 1960 ± 50 BP, and Spoegrivier in Namaqualand, dated to 2105 ± 65 BP (Henshilwood 1996; Robbins *et al.* 2005; Robbins *et al.* 2008; Ramsey 2009; Woldekiros & D'Andrea 2017; Coutu *et al.* 2021). Results from this dissertations experiments have shown that invertebrates are capable of inflicting damage on bone, with the Fisher exact test on the bone type most affected suggesting that both avian and mammalian bones are equally likely to be damaged in both experiment 1 and 2 (Table 16; Table 17). Moreover, the results have shown that the epiphysis, a less dense skeletal element, was most affected by invertebrates for both chicken and lamb bones.

5.1. Bone density

In taphonomy, density refers to a ratio of a bone's mass to volume (Lyman 1984). Lyman (1984) and Pokines & Symes (2013) describe how less dense skeletal elements comprised more blood, grease and marrow, making it structurally weaker but more nutritious than skeletal elements of greater density. As a result, less dense skeletal elements, such as the epiphyses of long bones, are more susceptible to gnawing and destruction by carnivores than elements of greater density (Pokines & Symes 2013).

Results from the authors' experiments show that the epiphysis displayed the highest frequency of damage markers. The epiphysis comprises primarily of cancellous, or spongy, bone surrounded by a thin layer of cortical bone (White & Folkens 2005). Cancellous bone is the porous network which fills the interior of bone, with the interstices of this network being filled with marrow (White & Folkens 2005; Houck & Siegel 2010; Christensen & Passalacqua 2018). In comparison to the diaphysis, the epiphysis allowed for a less demanding method of accessing the nutrient rich marrow

within the bone, which consequently resulted in the damage observed on the bone samples. The authors' research has shown that less dense skeletal elements are more susceptible to damage by invertebrates.

Bore hole damage by dermestid larvae and adults were only found at the articular facets of chicken (Raw and Roasted ii). Chicken (Raw ii) displayed a high concentration of bore hole damage, with three bore holes found in close proximity to each other. Two of the three bore holes penetrated through cortical bone to cancellous, while the third bore hole penetrated through cortical and cancellous bone into the medullary cavity. Upon analysis of the medullary cavity, no marrow remained. Similar to the bore hole damage on the chicken bone sample, surface destruction on lamb (roasted iii) was identified at the articular facet

Backwell *et al*. (2012) describes bore holes as semi-circular holes, between 3.41 and 4.20 mm in length and 2.83 and 2.64 mm in width, which penetrate through to the medullary cavity (Figure 34; Figure 35). Bore hole damage from the authors experiments displayed similar dimensions, with the length ranging between 1.98 and 4.26 mm and the width ranging between 1.94 and 3.67 mm. The defleshing of bone samples left few traces of meat for the invertebrates to consume, and in the case of the Dermestes larvae and adults, all trace remains were consumed. The next viable source of nutrition would be the connective tissue of an articular facet and the marrow of the medullary cavity, which can be confirmed by the aforementioned being consumed which produced the bore hole damage and surface destruction on the bone samples. Backwell *et al*. (2012) notes that termites favoured fresh thin cortical and spongy bone with meat and marrow, an aspect which appears to be shared with the damage inducing invertebrates of the author's research.

Gnawing and surface tunnel damage share a common characteristic in that the damage possessed a u-shaped cross section with micro striations, providing evidence of Dermestes larvae and adult mouth activity. This demonstrates that the mouth parts of Dermestes larvae and adults are capable of inflicting linear damage on a chicken tibiotarsus or an equivalent bone sample. In contrast to the sum and extent of bore hole and destruction damage by Dermestes larvae and adults, gnawing and surface tunnels, while present, were less frequent. Whereas articular facets, the location of bore hole and destruction damage, provided nutrition in the form of connective tissue,

and in the case of the chicken tibiotarsus marrow, gnawing and surface tunnels, more than likely, did not provide sufficient nutrition and was abandoned, resulting in the low occurrence of these forms of damage.

After the analysis of all the bones exposed to *Dermestes maculatus* larvae and adults in experiment 2, no form of bone damage could be identified. This was an unexpected result, as experiment 1 showed Dermestes larvae and adults were capable of producing substantial damage. The decline in population of experiment 2 suggests that the invertebrates were unable to acquire sufficient nutrition from feeding on remaining flesh and articular facets to increase the population, which would have in turn resulted in more feeding and, as experiment 1 has shown, damage from said feeding.

Experiment 1 produced the most promising results with bore hole, destruction, gnawing and surface tunnel damage, in contrast to experiment 2 which produced no damage results. The lack of damage and decrease in population suggests that the feeding activity of this species was significantly less frequent in experiment 2 as the invertebrates were not able to acquire the required nutrition to maintain and grow the population, in comparison to experiment 1. Based on experiment 1's results, dermestids do indeed inflict damage on bone.

Similar to the destruction damage by Dermestes adults and larvae, *Anomalipus elephas* and *Zophobas morio* larvae produced destruction damage at the articular facet of the lamb (roasted i) bone sample. Backwell *et al.* (2012) describes destruction as the macroscopically visible obliteration of bone and the etched appearance as removal of the outer lamellae, exposing the underlying structure of bone (Figure 32; Figure 33). Both of these damage types were found in the authors' research as well and were collectively identified as destruction. The defleshing and roasting of the bone sample left few traces of meat which had not been consumed by *Anomalipus elephas* and *Zophobas morio* larvae. The destruction damage at the articular facet indicates that, much like the Dermestes adults and larvae, connective tissue was consumed as a source of nutrition.

After analysing all the bones exposed to *Zophobas morio* larvae, gnawing, surface destruction and surface tunnel damage were identified. Similar to the gnawing by Dermestes, one set of the gnawing was identified in close proximity to an articular

facet. Further comparison of the gnawing by the two species showed that the *Zophobas morio* larvae produced less uniform and more abrasive gnaw damage that had a slighter longer mean length and was slightly further apart from each other. This species displayed the most consistent damage from both experiments, with destruction damage being identified, both of which had an abrasive nature.

As mentioned in a previous chapter, the Family Trogid are generally drawn to dry remains and are found during the later decay stages. The experimental bone samples used were not in an advanced stage of decay, which may be why no damage was identified for *Omorgus (Afromorgus) melancholicus* and *Omorgus (Afromorgus) squalidus* in both experiments. No damage could be identified on the bone samples exposed to *Calliphora vomitoria* and *Megaselia scalaris* in both experiments.



Figure 32. Destruction damage by termites on sheep humeri after six months, scale bar = 1 mm (Backwell *et al*. 2012).



Figure 33. Destruction damage by termites on sheep humeri after 12 months, scale bar = 1 mm (Backwell *et al*. 2012).



Figure 34. Bore hole damage by termites on sheep humeri after six months (Backwell *et al*. 2012).



Figure 35. Bore hole damage by termites on sheep humeri after six months, scale bar = 1 mm (Backwell *et al*. 2012).

Parkinson (2012) conducted experiments to determine if *Periplaneta americana* (Linnaeus, 1758), commonly known as cockroaches, and *Dermestes maculatus* were capable of inflicting damage to bone. Parkinson (2012) identified five modification types by *Dermestes maculatus*, which includes; bore holes, destruction, gnawing and surface tunnels (Figure 36 - 42). The final modification type was surface pits, and these were further divided into

Class 1, highly variable in shape, however, generally semi-circular to elliptical shallow depressions with a u-shaped profile that have striations emanating from the depressions outer circumference.

Class 2, semi-circular shallow depressions with randomly orientated, often intersecting, striations appearing over the entire feature.

Class 3, irregular-shaped depressions with complex profiles not associated with striations (Parkinson 2012). Parkinson (2012) identified three modification types by *Periplaneta americana*, including; destruction, discolouration and gnawing (Figure 33-37). The results here are consistent with that of Parkinson (2012), as bore holes, destruction, gnawing and surface tunnels were identified.

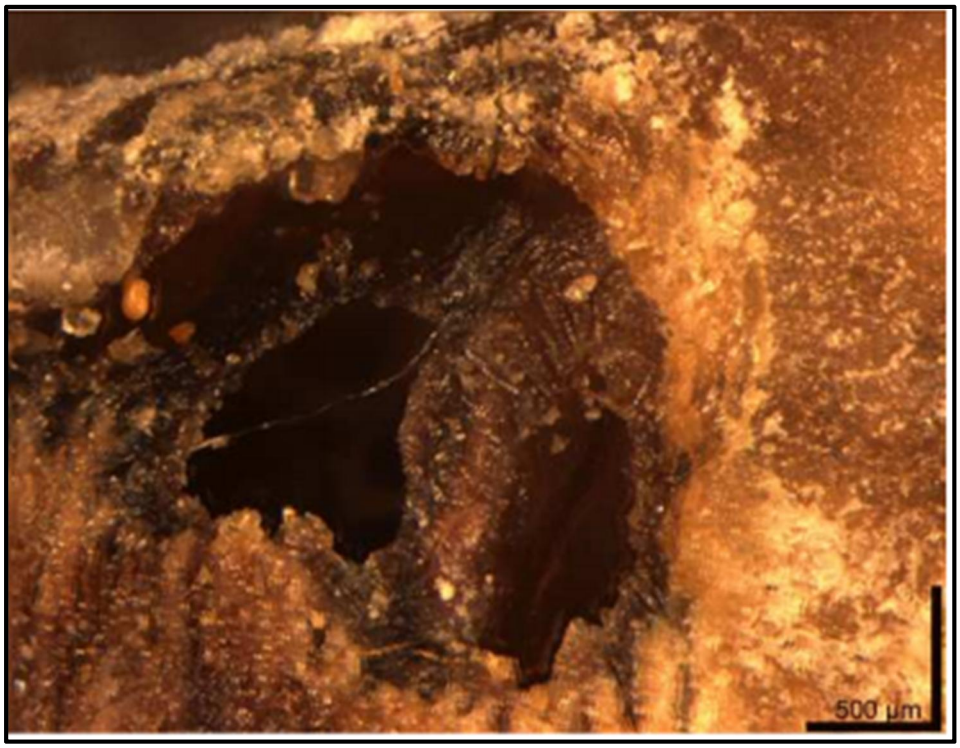

Figure 36. Dermestid bore hole on experimental bone sample (Parkinson 2012).

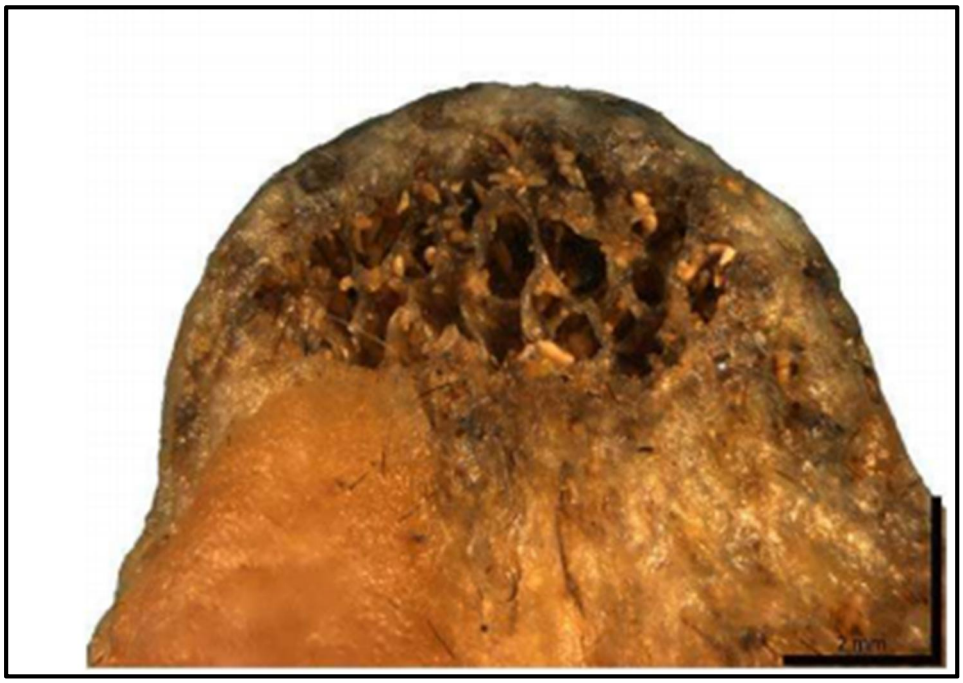

Figure 37. Dermestid destruction on experimental bone sample (Parkinson 2012).



Figure 38. Dermestid gnawing (Parkinson 2012).

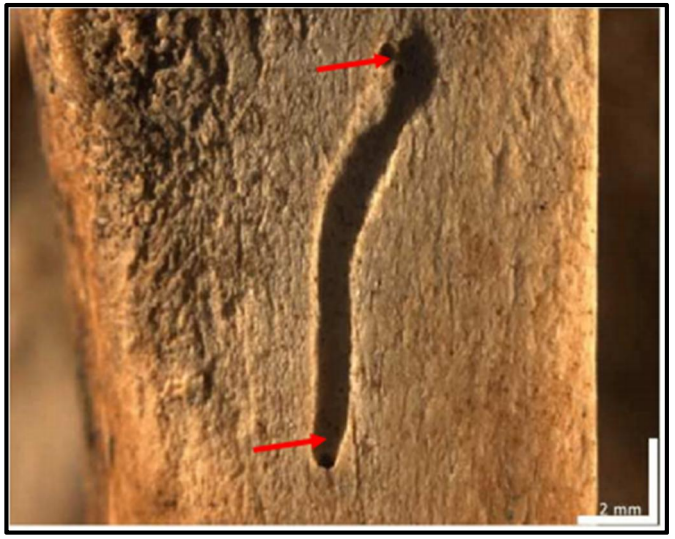

Figure 39. Surface tunnel by Dermestidae (Parkinson 2012).



Figure 40. Class 1 pit by Dermestidae (Parkinson 2012) .



Figure 41. Class 2 pit by Dermestidae (Parkinson 2012).



Figure 42. Class 3 pit by Dermestidae (Parkinson 2012).



Figure 43. Discolouration by *P. americana* (Parkinson 2012).

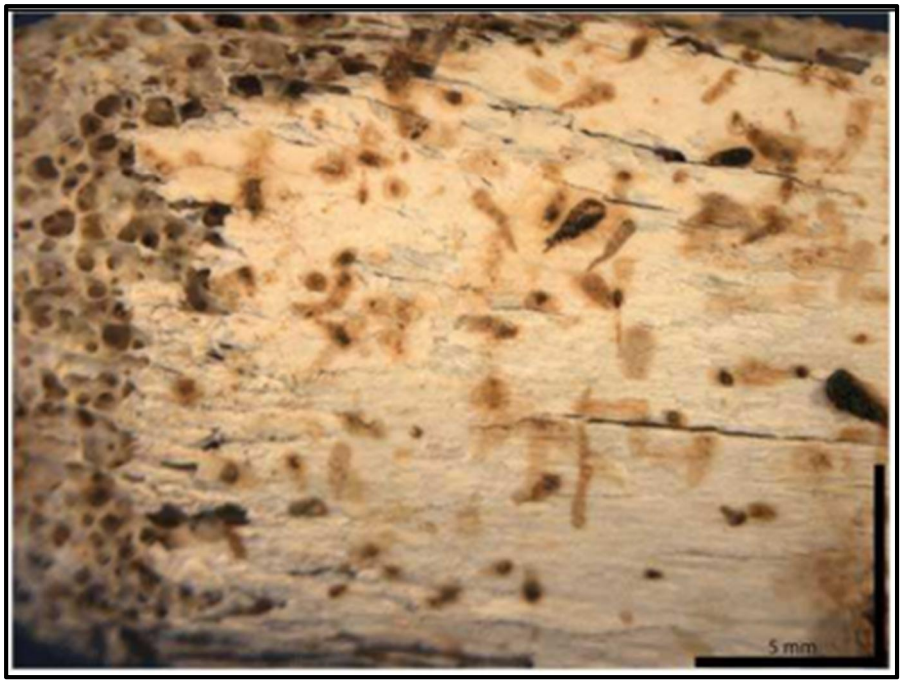

Figure 44. Discolouration by *P. americana* (Parkinson 2012).



Figure 45. Destruction by *P. americana* (Parkinson 2012).



Figure 46. Destruction by *P. americana* (Parkinson 2012).



Figure 47. Gnawing by *P. americana* (Parkinson 2012).

Dirks *et al*. (2015) highlight the presence of invertebrate activity on hominin fossils from the Dinaledi Chamber. This included; microscopic removal of the bone surface and multiple evenly spaced parallel striations which are associated with smooth based pits (Dirks *et al.* 2015). A controlled experiment was conducted to compare the observed features on the Dinaledi chamber bones with results from the experiment showing that invertebrates were able to produce a comparable set of modification to those observed on the Dinaledi chamber specimens (Dirks *et al.* 2015). A comparison of the Dinaledi bone samples with the authors experimental bone samples showed similarities as removal of the bone surface was observed by *Zophobas morio* larvae, in addition to the parallel striations being comparable with gnawing observed by *Dermestes maculatus* larvae and adults.

5.2. Comparison of invertebrate damage with other forms of damage

In taphonomy, equifinality is defined as achieving an identical final state from different initial conditions and methods (Lyman 2004). Various processes may produce similar results to the damage on bone caused by invertebrates, therefore, taphonomic literature is used to eliminate processes which do not exhibit similarities with invertebrate damage.

5.2.1. Cut marks

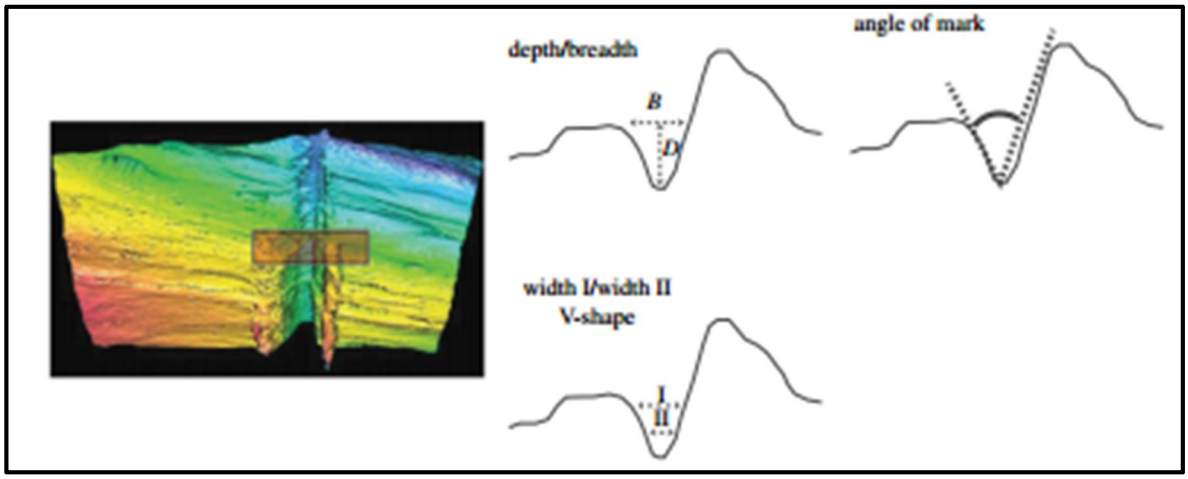

Figure 48. Stone tool cut mark morphology on bone (Braun *et al.* 2016).

After a comparison of the damage by invertebrates on the experimental bone samples, it is evident that there are no similarities with cut marks. The main distinguishing characteristics of cut marks are the v- shaped cross section and the mark being greater than 4 cm. Linear marks observed on the experiment bone samples all possessed u-shaped cross sections and were not greater than 1 cm. Braun *et al.* (2016) conducted cut mark experiments on epiphyseal, near epiphyseal and diaphyseal fragments using stone tools. Three dimensional images of the cut marks morphology were captured using a Nanovea ST400 white-light non-contact confocal profilometer (Braun *et al.* 2016) (Figure 48). A comparable characteristic with Braun *et al.* (2016) and the experiments on insect damage are the frequency of damage marks in relation to a specific part of the bone, with both experiments show more damage marks at the epiphysis or near epiphysis than the diaphysis. This relates to bone density, with the epiphysis allowed for a less demanding method of accessing the nutrient rich marrow within the bone.

5.2.2. Trampling

After a comparison of the damage by invertebrates on the experimental bone samples, it is evident that there are no similarities with trampling marks. The main distinguishing features of trampling marks are the v-shaped cross section, linear marks observed on the experiment bone samples all possessed u-shaped cross sections. Andrews & Cook (1985) utilized the death of a juvenile cow to examine the post mortem effects of an assemblage which was undisturbed by humans and marginally used by badgers, domestic dogs and red foxes (Andrews & Cook 1985). Six types of damage were identified by Andrews & Cook (1985), none of which were comparable with the authors' results, these included; multiple fine oblique striations, troughs, superficial irregular marks, v-shaped incisions, grooves with multiple parallel, internal striations and scrapes composed of multiple striations. (Figure 49-54).

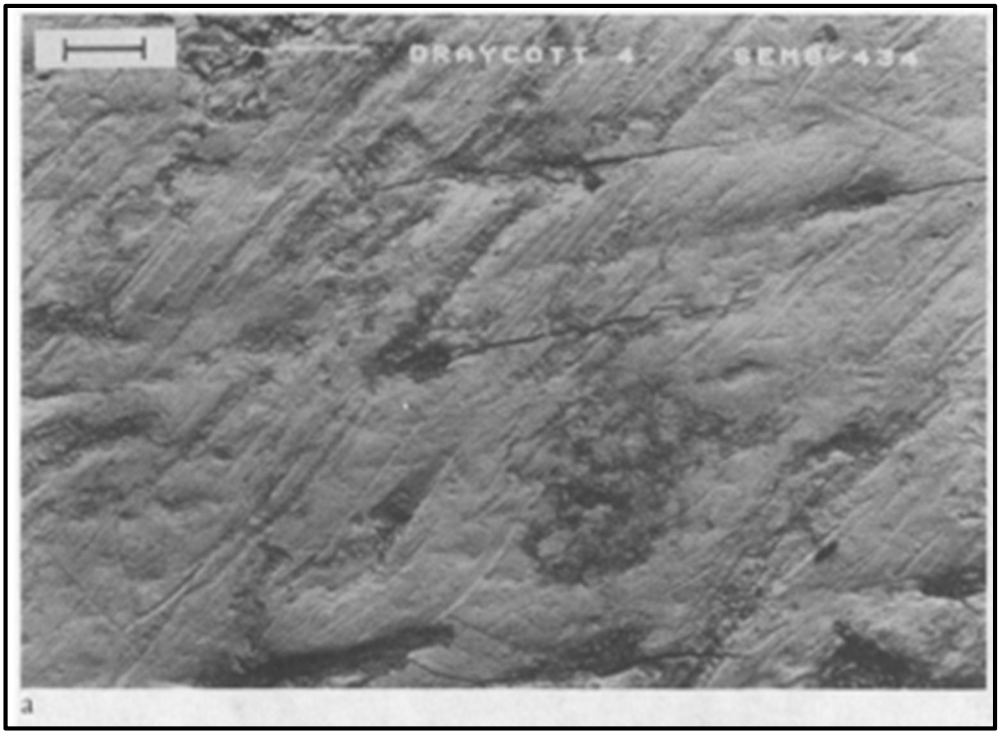

Figure 49. Multiple fine oblique striations from trampling on bone from a juvenile cow (Andrews & Cook 1985).

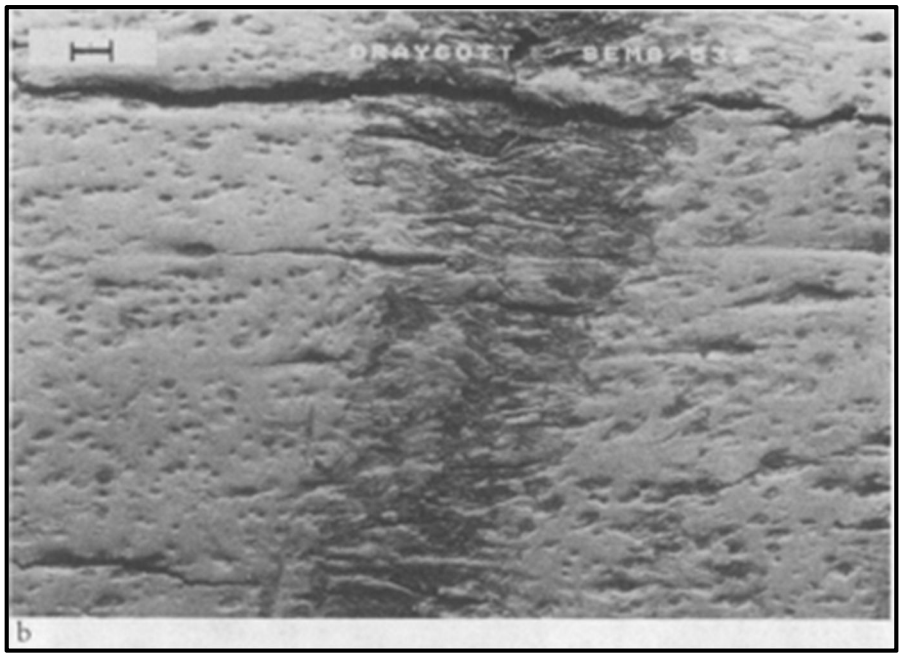

Figure 50. Troughs from trampling on bone from a juvenile cow (Andrews & Cook 1985).

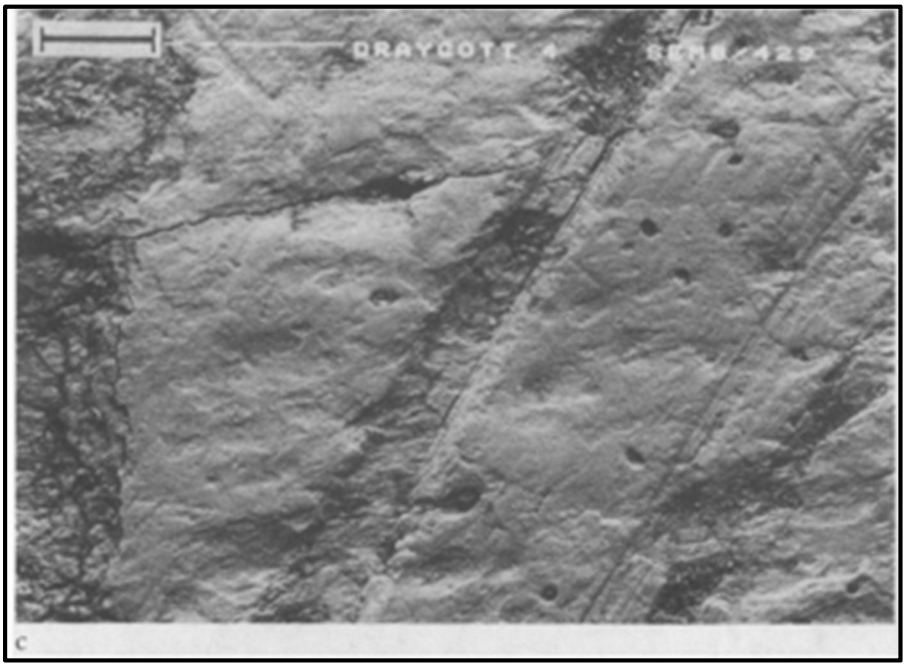

Figure 51. Superficial irregular marks from trampling on bone from a juvenile cow (Andrews & Cook 1985).



Figure 52. v-shaped incisions (Andrews & Cook 1985).

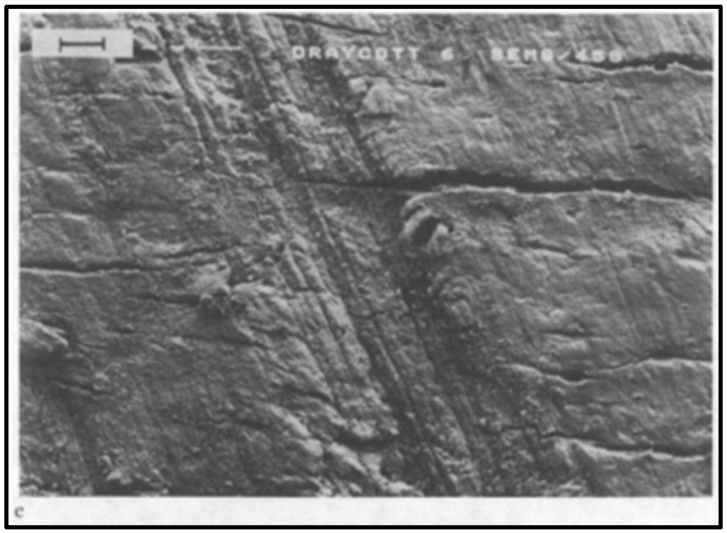

Figure 53. Grooves with multiple, parallel striations

(Andrews Cook 1985)

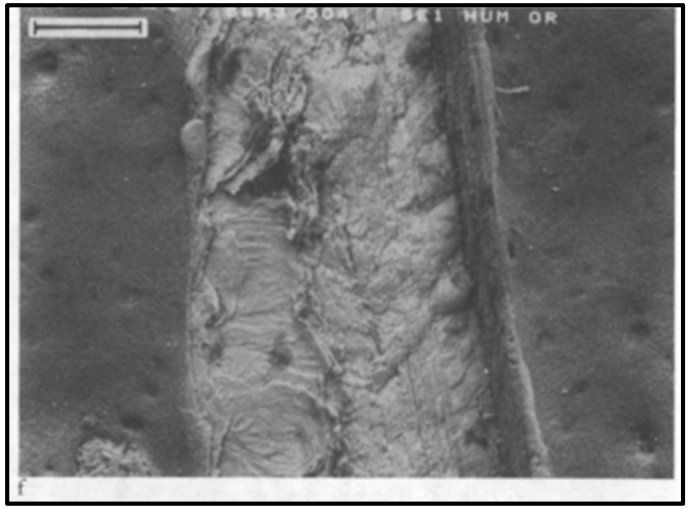

Figure 54. Scrapes composed of multiple striations (Andrews & Cook 1985).

Domínguez-Rodrigo *et al*. (2009) conducted experiments for distinguishing trampling from cut marks. Bone samples were trampled in five different sediments at different time intervals (Domínguez-Rodrigo *et al*. 2009). Results from the experiment showed that the trampling mark possessed an irregular winding shape with microabrasions found in close proximity (Domínguez-Rodrigo *et al*. 2009) (Figure 55). Further analysis of the trampling marks showed internal striations which followed the trajectory of the trampling mark, in addition to a shoulder striation which was shallower than the main trampling mark (Domínguez-Rodrigo *et al*. 2009) (Figure 56; Figure 57).

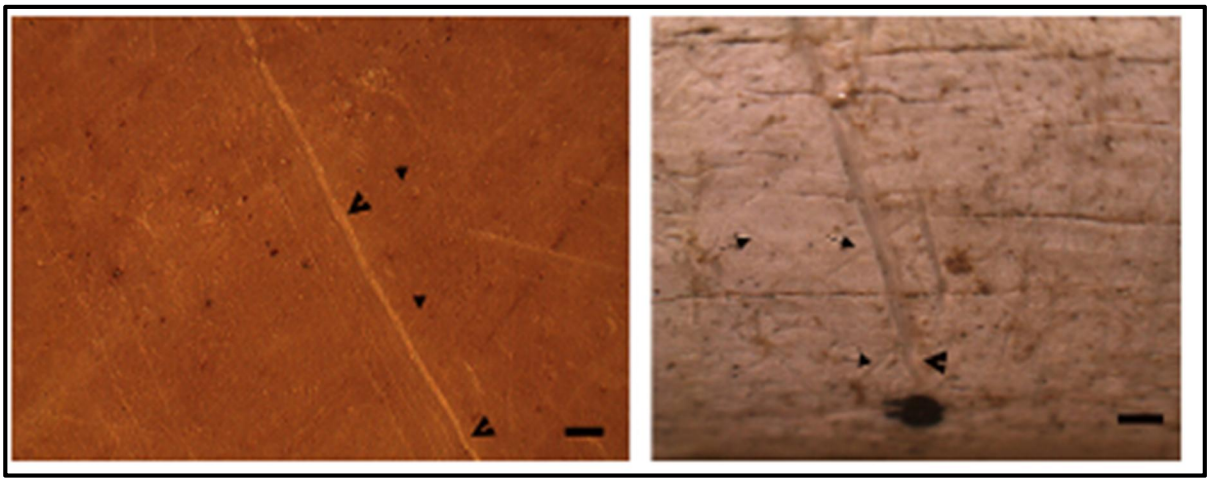

Figure 55. Microabrasions found close to the main trampling mark (Domínguez-Rodrigo *et al*. 2009).

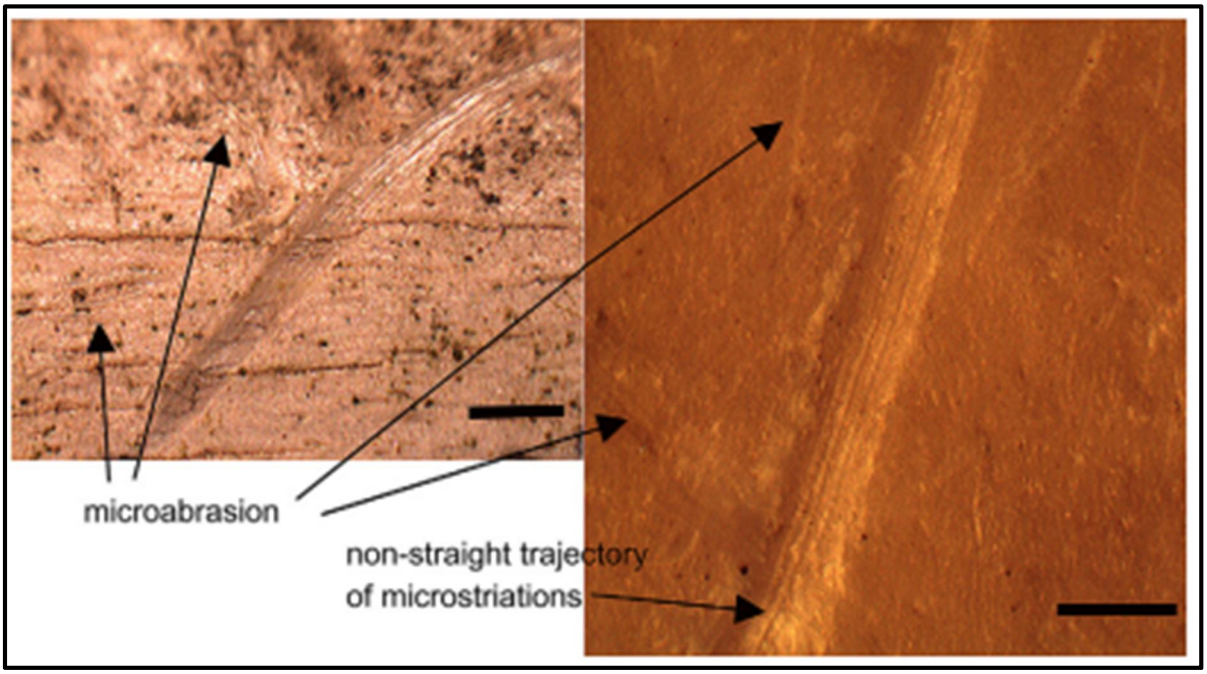

Figure 56. Microabrasions and internal striations (Domínguez-Rodrigo *et al*. 2009).

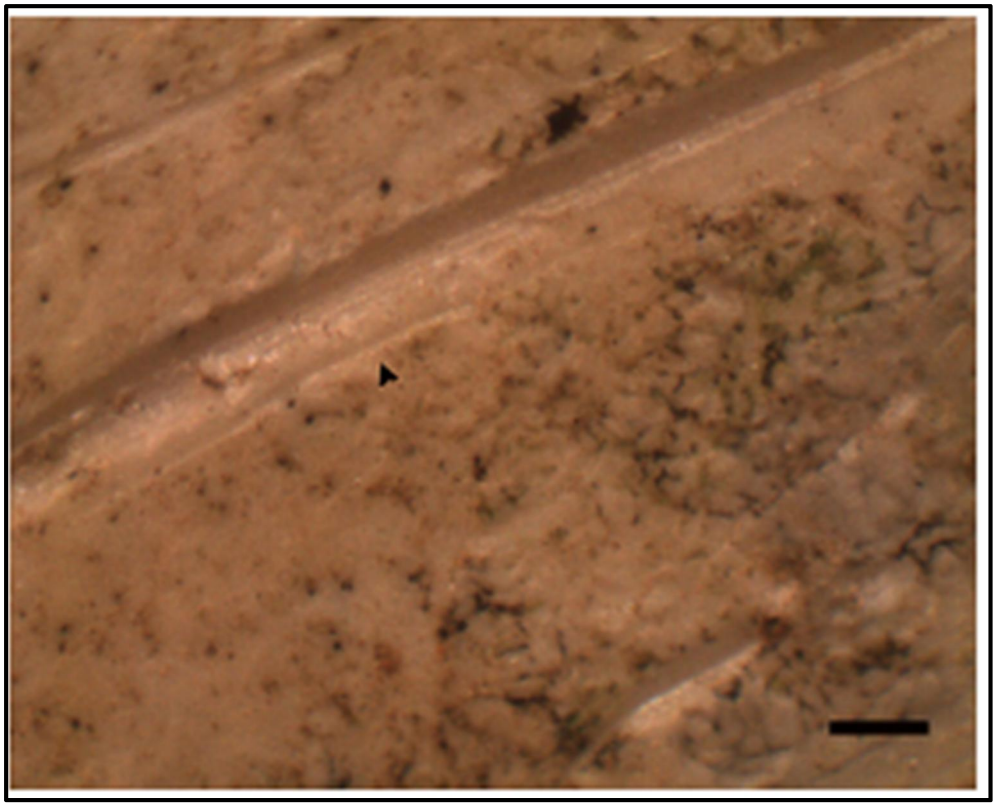

Figure 57. Shoulder striation (Domínguez-Rodrigo *et al*. 2009).

A comparison of Domínguez-Rodrigo *et al*. (2009) with the authors experimental bone samples showed no similarities with trampling marks. The main attributes identified by Domínguez-Rodrigo *et al*. (2009) are the microabrasions found close to the main damage mark, internal striations which follow the trajectory of the damage mark and a shallow shoulder striation. Linear damage marks from the authors experiments did not possess microabrasions found close to the main damage mark. Whereas microstriations were found in my experiments, they were randomly orientated and did not follow the damage marks trajectory. Lastly, the linear marks from the authors' experiments did not possess a shoulder striation.

5.2.3. Rodent Gnawing

Mahomed (2018) analysed the human skeletal remains from the 1854 Historic Cave siege, from which gnaw marks comprised 8% of surface damage. The gnaw marks had the distinctive parallel series of shallow, broad grooves, a result furrowing upon the surface of the bone from incisor tracks (Figure 58). The main distinguishing features of rodent gnawing are the distinctive furrowing pattern of a parallel series of broad, shallow grooves. Whereas the experimental bones do exhibit linear damage with a u-shaped cross section, none of the identified damage possess the distinctive furrowing pattern of rodent incisors.

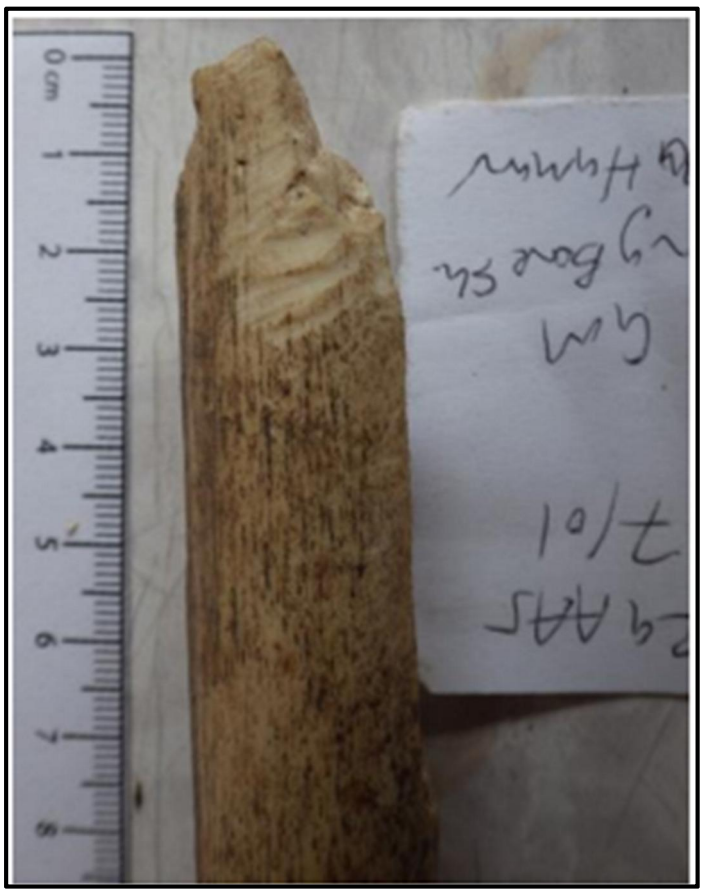

Figure 58. Rodent gnawing on human long bone (Mahomed 2018).

5.2.4. Carnivore tooth marks

The human skeletal remains from the 1854 Historic Cave siege displayed extensive surface damage by carnivores, with 92% of surface damage being attributed to the teeth of carnivores (Mahomed 2018). Of the 92% of surface damage, 46% consisted of scoring which are linear marks with a smooth contoured u-shaped cross section which lacks any internal striations (Mahomed 2018). The remaining 46% comprised pitting and perforations (Mahomed 2018) (Figure 59-61).

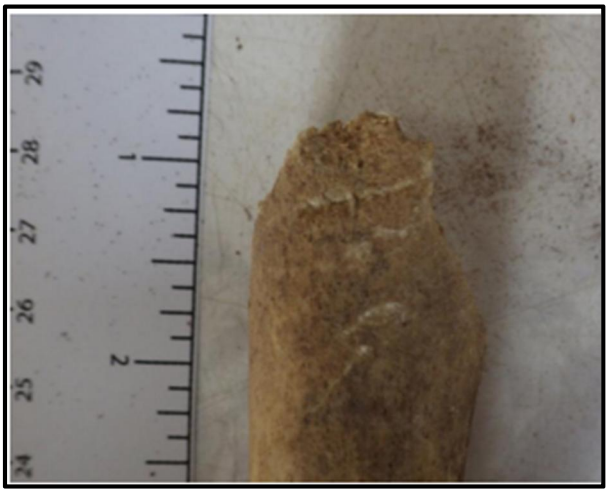

Figure 59. Linear carnivore tooth marks on human long bone (Mahomed 2018).



Figure 60. Carnivore tooth pit on human long bone (Mahomed 2018).

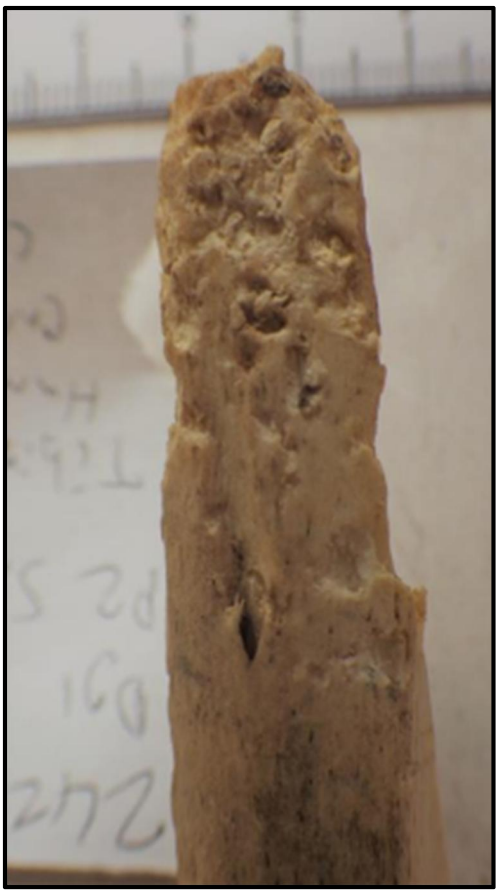

Figure 61. Carnivore tooth pitting on human long bone (Mahomed 2018).

By comparing the damage of invertebrates on the experimental bone samples, it is evident that there are no similarities with carnivore tooth marks. The main distinguishing features of carnivore tooth marks are the u-shaped cross section with smooth contours. Whereas the experimental bones do exhibit linear damage with a u-shaped cross section, the identified damage by invertebrates possess internal microstriations.

By comparing the damage of invertebrates on the experimental bone samples, it is evident that there are, in theory, similarities with pitting and perforations by carnivores on the chicken bones which exhibit bore holes. However, pitting and perforations by carnivores display a higher occurrence and are found in close proximity to, and occasionally, superimposed on each other in comparison to the damage observed in the authors' experiments which were less frequent and more spaced out between each other.

Arilla *et al*. (2020) note that small carnivores, such as the red fox, *Vulpes vulpes* (Linnaeus, 1758), genet, *Viverra genetta* (Linnaeus, 1758) and badger, *Taxidea taxus* (Schreber, 1777), may inflict damage on bone. Damage identified as a result of small carnivore damage include; pitting, furrowing, tooth marks associated with crenulated edges and scoring (Arilla *et al*. 2020) (Figure 62-65). Similar to the damage of their larger counterparts, furrowing and scoring by small carnivores were smooth contoured and u-shaped (Arilla *et al*. 2020). The authors experimental bones do exhibit linear damage with a u-shaped cross section, the identified damage by invertebrates possess internal microstriations. The most significant difference between the small carnivores induced damage and the authors invertebrate damage bone samples are the marks associated with crenulated edges, as none of the invertebrate-damaged bone samples displayed this characteristic.



Figure 62. Furrowing and pitting on ulna (Arilla *et al*. 2020).



Figure 63. Furrowing on femur (Arilla *et al*. 2020).

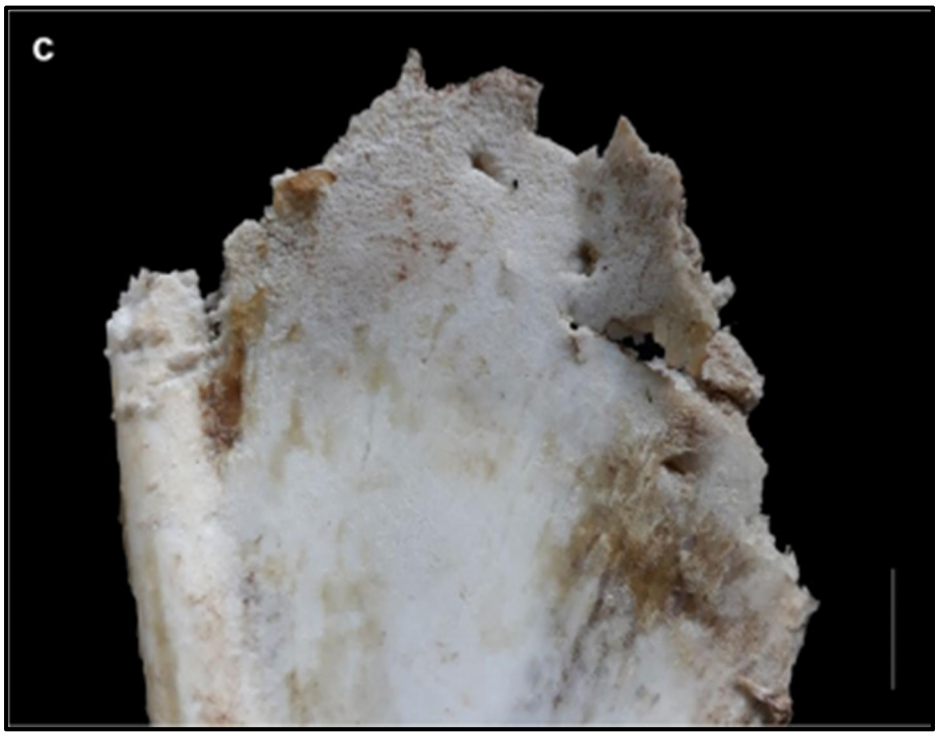

Figure 64. Tooth marks on scapula associated with crenulated edges (Arilla *et al*. 2020).



Figure 65. Pitting and scoring on scapula (Arilla *et al*. 2020).

5.2.4 Root etching

Root etching consists of a network of u-shaped shallow grooves on bone as a result of acid secretion by plants (Figures 66-68) (Binford 1981, White et al. 2012; Tjelldén et al. 2015). By comparing the damage of invertebrates on the experimental bone samples, it is evident that there are no similarities with root etching. The main distinguishing features of root etching are the branched, u-shaped cross section with smooth contours. Whereas the experimental bones do exhibit linear damage with a u-shaped cross section, the identified damage by invertebrates do not exhibit any branches.

Fisher (1995) notes that root etching may also take the form of closed spaced or isolated pits. D'Errico *et al*. (2015) identified such pits on an engraved bone fragment from Blombos Cave, measuring 100 – 200 µm (Figure 69; Figure 70). A comparison of these pits with the damage found in the authors experiments show that the bore holes range from 1.94 to 4.26 mm, displaying larger dimensions than the root etched pits.



Figure 66. Root etching on sheep mandible (Binford 1981).



Figure 67. Root etching on a human cranium from a prehistoric California site (White *et al.* 2012).



Figure 68. Root etching grooves on an Iron Age human long bone (Tjelldén *et al*. 2015).

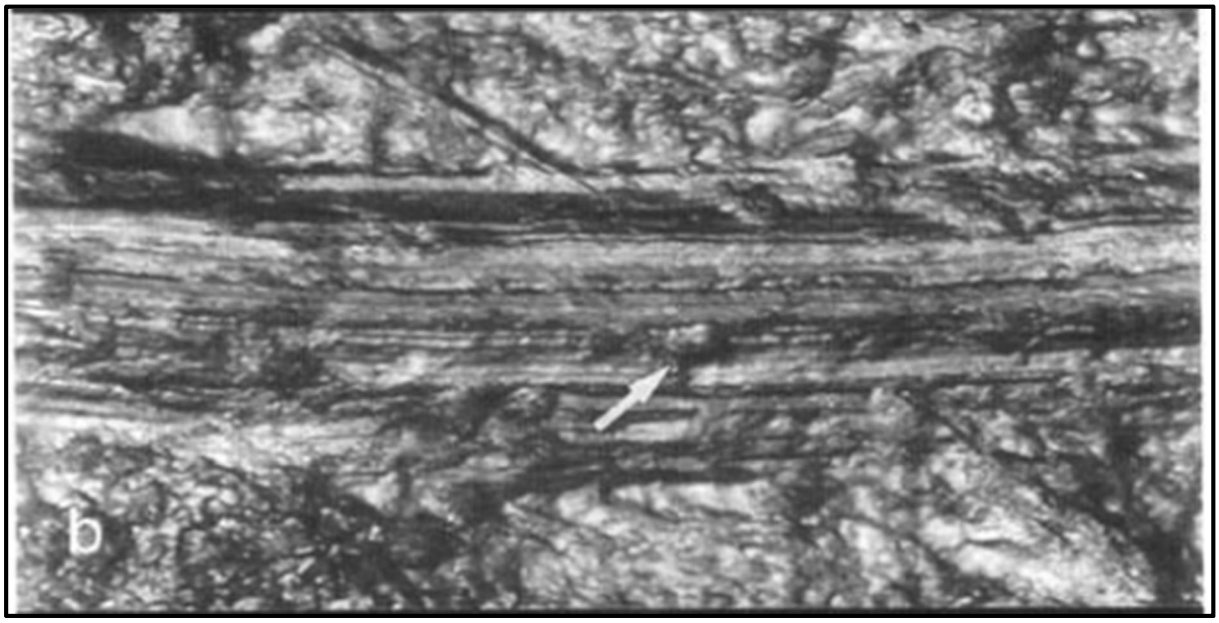

Figure 69. Pit as a result of root etching (D'Errico *et al*. 2015).

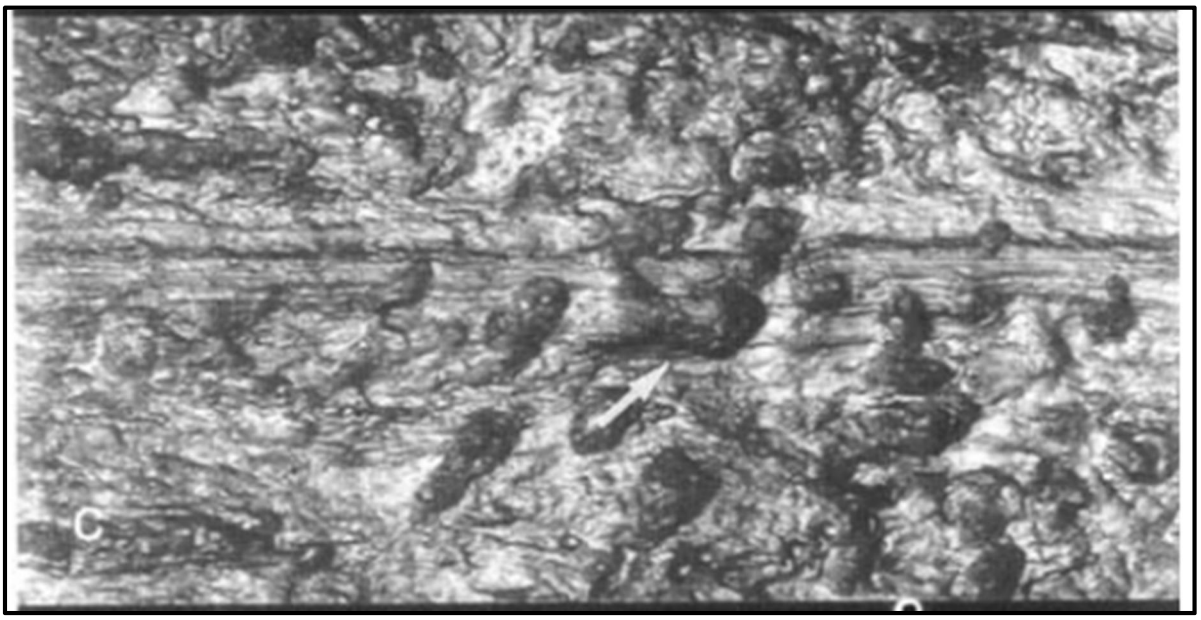

Figure 70. Pit as a result of root etching (D'Errico *et al*. 2015).

5.3. Body decomposition

Following death, the body undergoes decomposition of soft tissue. The decomposition process is driven by multiple factors, key among them are insect feeding activity (Haglund & Sorg 2002; Gennard 2012; Rivers & Dahlem 2014). Gennard (2012) describes a five stage decomposition process for open air corpses;

Stage 1: Fresh stage, begins from death to the first indication of body bloating. The invertebrates present during this stage are blowflies.

Stage 2: Bloated stage, characterised by the breakdown of the body through putrefaction. During this stage more blowflies are attracted to the corpse in addition to the possibility of rove beetles.

Stage 3: Active decay stage, advanced process of putrefaction occurs in which the corpse progressively deflates and fermentation occurs. Invertebrates attracted to the corpse during this stage are muscid flies, histerid and silphid beetles.

Stage 4: Post-decay stage, during this stage bone, cartilage, skin and some residual flesh remain. This stage is dominated by the presence of beetles and the deduction in flies populating the corpse.

Stage 5; Skeletonisation, final stage of decomposition during which bones and hair are all that remain. Gennard (2012: 35) notes that “no obvious groups of insects are associated with this stage, although beetles of the family Nitidulidae can, in some instances, be found.”

The results of the authors’ experiments have shown consistency with the decomposition process and the role of flies. Given that the experimental samples were bones, which possessed very little flesh, flies, while present, did not feed on the bone samples. More significantly, the authors’ research has shown that when present, Dermestidae and Tenebrionidae are able to inflict damage on less dense skeletal elements through their feeding activity.

5.4. Summary

Bone density is described as the ratio of a bone's mass to volume, with less dense skeletal elements comprising more blood, grease and marrow, making them more susceptible to gnawing and destruction than elements of a greater density. Results have shown that the epiphysis showed a higher frequency of damage markers over the diaphysis for both chicken and lamb bones. Experiments conducted by Backwell *et al.* (2012) show that termites favoured less dense elements as boreholes and destruction were found at the epiphyses. Parkinson (2012) conducted experiments to determine if dermestids and cockroaches were able to modify bone, with dermestids producing bore holes, destruction, gnawing and surface tunnels and surface pits and cockroaches producing destruction, discolouration and gnawing. Experiments of invertebrate damage on bone were also carried out by Dirks *et al*. (2015) which showed removal of the bone surface as well as parallel striations.

Various processes may produce similar results to the damage of invertebrates, therefore the results of the authors' experiments were compared with literature on cut marks, trampling marks, rodent gnawing, carnivore tooth marks and root etching. Results of this comparison showed that the invertebrate damage was unique from the other forms of damage.

Chapter 6: Conclusion

This study aimed to contribute to the fairly limited literature towards providing a growing understanding of invertebrate damage on bone. The invertebrates which were utilised for the controlled lab-based experiments are all forensically important modifiers of tissue, however, their damaging effect on bone, and the aspect of their anatomy which is responsible for the damage, their mouth parts, are insufficiently understood. From an archaeological perspective, the process of the invertebrates damaging the bone falls under the concept of taphonomy. It is important to note that many other processes might produce similar characterisitcs of invertebrate damaged bone, due to the limitations of this study, it is not possible to test all these processes, therefore, previous literature was utilised for a comparitive analysis to eliminate processes which do not exhibit similarities to invertebrate damage.

A sample of 10 chicken drum sticks (half roasted and half raw) and 10 lamb shanks (half roasted and half raw) were defleshed by hand and placed in tanks with moist-to-the-touch coconut/palm peat and a chosen invertebrate, three families of beetle (Family Dermestidae, Trogidae and Tenebrionidae) and two families of fly (Family Calliphoridae and Phoridae), for the experimental period of a month. An identical control tank was set up without any insects. These bones were chosen for their hard and soft bone characteristics, and their common presence within the archaeologcial record, in an effort to replicate the post mortem processes by select invertebrates on bone. A Dino Lite USB microscope was used to identify insect damage, a Zeiss stereo Discovery.V12 microscope was used to obtain dimensions of the damage and terminology used by Parkinson (2012), including bore holes, destruction, discolouration, gnawing, surface pits and surface tunnels, was used to describe the damage, all of which was recorded in a Microsoft Excel spreadsheet.

Results from experiment 1 indicated that *Dermestes maculatus* larvae and adults produced bore holes, destruction, gnawing and surface tunnel damage on the bone samples, whereas experiment 2 showed no macro or micro indicators of dermestid beetle damage. Results from experiment 1 indicated that *Anomalipus elephas* and *Zophobas morio* larvae produced destruction damage on the bone samples, whereas experiment 2 indicated that tenebrionid beetles and larvae additionally produced destruction, gnawing and surface tunnel damage. Results from experiment 1 and 2

showed that *Omorgus (Afromorgus) melancholicus* and *Omorgus (Afromorgus) squalidus* did not macroscopically or microscopically damage the bone samples. Results from experiment 1 and 2 showed that *Calliphora vomitoria* did not macroscopically or microscopically damage the bone samples. Similarly, experiment 1 and 2 showed that *Megaselia scalaris* did not macroscopically or microscopically damage the bone samples. Additionally, marks made by cutting, trampling, teeth, root etching and pitting and perforation were compared with the invertebrate damaged bones. The comparison yielded results which indicated that there were no similarities between invertebrate damage on bone and the other forms of damage.

The results of the authors' experiments have shown consistency with the decomposition process and the role of flies. Given that the experimental samples were bones, which possessed very little flesh, flies, while present, did not feed on the bone samples. More significantly, the authors' research has shown that when present, Dermestidae and Tenebrionidaeneo are able to inflict damage on less dense skeletal elements through their feeding activity.

The evidence for invertebrate damage on bone provides a significant source of knowledge and application within the field of archaeology. A comparison can be made with the invertebrate damaged bones and intentional anthropogenic modifications or pathologies to ensure that no misinterpretations are made in identifying damage of this nature, overall, assisting in differential diagnosis, functioning to distinguish between intentional and unintentional or bone alterations. Taken as a whole, this research study does not aim to provide a final conclusion to understanding invertebrate damage on bone, but rather contribute to the fairly limited literature towards providing a growing understanding of invertebrate damage on bone.

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Appendix A

Experiment 1



Figure A1. Raw i chicken bone sample.



Figure A2. Raw i chicken bone sample.



Figure A3. Raw ii chicken bone sample.



Figure A4. Raw ii chicken bone sample.



Figure A5. Raw iii chicken bone sample.



Figure A6. Raw iii chicken bone sample.



Figure A7. Raw iv chicken bone sample.



Figure A8. Raw iv chicken bone sample.



Figure A9. Raw v chicken bone sample.



Figure A10. Raw v chicken bone sample.



Figure A11. Roasted i chicken bone sample.



Figure A12. Roasted i chicken bone sample.



Figure A13. Roasted ii chicken bone sample.



Figure A14. Roasted ii chicken bone sample.



Figure A15. Roasted iii chicken bone sample.



Figure A16. Roasted iii chicken bone sample.



Figure A17. Roasted iv chicken bone sample.



Figure A18. Roasted iv chicken bone sample.



Figure A19. Roasted v chicken bone sample.



Figure A20. Roasted v chicken bone sample.

Appendix B

Experiment 1



Figure B1. Raw i lamb bone sample.



Figure B2. Raw i lamb bone sample.



Figure B3. Raw ii lamb bone sample.



Figure B4. Raw ii lamb bone sample.



Figure B5. Raw iii lamb bone sample.



Figure B6. Raw iii lamb bone sample.



Figure B7. Raw iv lamb bone sample.



Figure B8. Raw iv lamb bone sample.



Figure B9. Raw v lamb bone sample.



Figure B10. Raw v lamb bone sample.



Figure B11. Roasted i lamb bone sample.



Figure B12. Roasted i lamb bone sample.



Figure B13. Roasted ii lamb bone sample.



Figure B14. Roasted ii lamb bone sample.



Figure B15. Roasted iii lamb bone sample.



Figure B16. Roasted iii lamb bone sample.



Figure B17. Roasted iv lamb bone sample.



Figure B18. Roasted iv lamb bone sample.



Figure B19. Roasted v lamb bone sample.



Figure B20. Roasted v lamb bone sample.