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Taphonomic investigation into environmental effects on bone surface modifications.

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Abstract:

The current project investigated the extent to which taphonomic processes such as short-term exposure to the Biostratinomic effects of weathering and diagenetic effects of the soil matrix may alter or obliterate evidence of cutmarks on bones. It examined factors that may contribute towards bone degradation and therefore, cutmark degradation. There are a lack of multi-analytical methods and experimental data to support the hypothesis of the cross-linking ecological interactions and their direct damaging effect to bone, and consequent impact upon evidence of bone trauma and its identification. There is a need to understand how microenvironmental factors affect each other and how these ecological interactions may impact the longevity and survivability of the bone condition and therefore the cutmark condition. This research combines a review of existing literature with primary experimental data to determine if microenvironmental patterns can be distinguished and explore whether the changes to the different types of cutmarks could have a significance in a forensic investigation. Bladed instruments were used to inflict cutmarks upon the surface of Porcine bone; the bone specimens were deposited at a shallow depth and left on the surface of an identified hostile environment. The remains were removed bi-monthly and physical data from the cutmarks and geochemical data from the soil matrix were collected and analysed. Further observations were found regarding the effects of a hostile environment towards the cortical layer of the remains, that contradict the time frames of other studies and solidifies the hypothesis that damage to the bone surface from taphonomic modifications can occur in a shorter time frame and are local to the microenvironment. It has been found that there are previous unobserved phenomena on the remains specific to the physical appearance of the cutmarks. Specifically, there is a potential link between change in kerf width of the cutmark edge and physical changes to it as a result of the ecological interactions between the microenvironment and the cutmark on the bone found through digital and confocal microscopy. The level of activity for these changes such as the presence of macrofauna and microflora reflect upon the size and shape of the cutmark. This in turn impacts certain microscopic and scanning ‘wound-matching’ methods that have been investigated in the field of Forensic Science. It outlines that these methods should not assume that the dimensions of the cutmark accurately reflect the dimensions of the blade that was used to inflict said mark without consideration of the environment it was found in. This study has complimented and added to current research of how taphonomic changes may mimic, hide, or obliterate trauma on bone. From this the awareness of the influence from the abiotic and biotic microenvironmental effects and the associated ecological interactions will increase as a result of its contribution.

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Chapter 1 - Introduction:

Taphonomy is best defined as the study of the processes that affect plant and animal remains around the time of, and after, death. The application of Taphonomy in forensic investigations has progressively increased in the past twenty years. Modern taphonomic analysis as opposed to its original palaeontological form Efremov (1940), is adapted to forensic and/or archaeological applications (Bonnichsen and Sorg 1989; Haglund and Sorg 2001; Pokines and Symes 2013). A growing number of experiments and investigations have arguably established the common changes as a result of taphonomy to decomposing remains; specifically, how the post-depositional changes occur as a result of complex environmental factors at are part of a delicate ecosystem (White and Folkens 2005; Carter and Tibbett 2008; Nawrocki and Latham 2013). Moreover, there has been an increase in investigations into the diagenetic effects of soil towards skeletal remains and the extent to which the surface of the bone can alter/change as a result of ecological interactions (Stogner 2016; Nikita 2016; Dent *et al.* 2003; Carter *et al.* 2010; Madgwick 2010; Pokines and Ames 2015). However, such studies lean heavily towards either very short-term decomposition i.e. from the first stage of soft-tissue decomposition to the dry stage or are towards longer lengths of depositions from years to decades post-skeletonization. There are only a few studies that specifically investigate how the bone surface can change within the first instance of post-skeletonization (Cunningham *et al.* 2011; Schultz *et al.* 2018; Fisk *et al.* 2019). Consequently, one of the aims of the current study is to investigate further into the post-depositional changes to the bone surface from taphonomic modifications as well as trauma on the bone.

The current study focuses upon incised cutmarks on bone. The tools applied were a non-serrated instrument with an edge bevel (knife like) that leaves a V-shape profile (Symes *et al.* 2010; Crowder *et al.* 2011); a serrated instrument that perforates the bone to create a superficial mark across the bone surface that leaves a square based mark (Bonte 1975; Loe and Cox 2005; Symes *et al.* 2010; Crowder *et al.* 2011) and an untouched flake (unmodified stonetool) that has a narrow cross section, steep sides with the apex of the cutmark going to be steeper on one side as opposed to the other and a possible V shape (Greenfield 2006; Juana *et al.* 2010; Otárola-Castillo *et al.* 2018).

Regarding Sharp-force Trauma in forensic investigations there has been extensive research that involves characterising trauma marks; specifically investigating class characteristics, cutmark morphology and prevalence of trauma on bone in cases of dismemberment (Bonte 1975; Andahl 1978; Symes 1992; Salfati 2000; Symes *et al.* 2002; Bamasr *et al.* 2003; Delabarde 2010). There has been little research into how the appearance and longevity of cutmarks change due to taphonomic modification, particularly in a forensic context (Calce and Rogers 2007). Therefore, this current experiment in addition to investigating how the bone

surface will change, will also investigate to what extent individual cutmarks created from different tool types will degrade in a destructive/hostile environment; and from this, which ecological interactions within the environment will cross-link with each other and impact the survivability of the bone condition.

1.1 - Aims:

1. To investigate the morphological effects of short-term deposition to sharp force trauma on bone at a microscopic level.
2. To consider the range of possible factors and causative agents responsible for such changes.
3. To investigate the effects that deposited bones exert on the soil matrix and surface microenvironment and the nature of inter-relationships between the two.

1.2 - Objectives:

- Design a mechanical means of inflicting sharp-force trauma on the bone specimens that mitigates the human error element in manually inflicting marks in trauma experiments.
- Conduct a battery of analyses of the soil matrix to understand the possible ecological interactions between the soil and the bone specimens.
- Track surface environmental changes regarding humidity, temperature, sun exposure and rainfall to see if they can link to the changes within the soil matrix as well as the surface specimens.
- Conduct a macroscopic and microscopic examination of the trauma marks and surrounding bone surface pre and post-deposition.
- Visually record the change in the mark dimensions (Kerf Width) as well as what physical changes that are exhibited and link to the type of environment the bone specimens are deposited in.
- Determine the validity of two and three-dimensional microscopy regarding the analysis of the cutmarks and the surrounding surface across the deposition period.

Chapter 2 - Background and Literature Review:

2.1 - Sharp Force Trauma:

The ability to identify sharp-force trauma on bone remains is important in a forensic investigation, yet there has been a lack of experimental investigation of the taphonomic processes that may occur to bone trauma. To date, the most sufficient/relevant literature is Calce and Rogers 2007 preliminary study into the taphonomic changes to blunt force trauma. Previous studies provide a basic understanding of the taphonomic changes that occur in bone in depositional and post-depositional environments (e.g. Karr and Outram 2012; Outram 2001; Pokines and Higgs 2015; O'Brien *et al.* 2007). Also, there has been supporting research in the investigation of trauma caused by dismemberment and what weapons are used e.g. handsaws, knives and axes (Salfati 2000; Delabarde 2010). Although rare, there have been forensic cases where such trauma and dismemberment has been inflicted as a means to conceal the body and erase proof of human interaction (Black *et al.* 2017; Porta *et al.* 2016). When attempting the difficult task of determining cause and manner of death from the investigation of skeletal remains, it is essential to understand what taphonomic agents and conditions may erase, alter or hinder the identification of such trauma (Hyma and Rao 1991).

2.2 - Biostratinomy and Bone Weathering:

The investigation of biostratinomic factors (such as butchery and weathering) is one of the most studied aspects of taphonomic histories, especially from an archaeological perspective (Lyman 1994). Biostratinomy in this context concerns the pre-burial modification of bone, specific to weathering and movement of the remains (Fernández-López and Fernandez-Jalvo 2002). Bone weathering therefore is a key investigative route, as there are several mechanisms involved that will degrade bone (and thus its trauma) in a subaerial or surface context. These mechanisms being temperature, rainfall, sun exposure and humidity are integral when investigating the effects of subaerial/surface exposure to the bone condition. There have been studies that discuss the prevalence of weathering in assemblages, and what characteristics are identified in addition to the environmental processes that control them (such as temperature, humidity, rainfall and sun exposure) (Behrensmeyer 1978; Fernandez-Jalvo and Andrews 2016; Nikita 2016; Stogner 2016). Behrensmeyer's (1978) weathering stages describe the different forms of surface alteration that is exhibited on skeletal remains; these stages largely range in years in difference, however, there have been several taphonomic studies that suggest that these stages recorded in her study actually can differ within a different environment (her data derives from southern Kenya). For example, studies in New England found signs of her 'Stage 1' weathering to occur just 24 weeks of exposure as opposed to her 0-3 years (Sorg 2011; Junod 2013). There was a study conducted in the

subtropical humid environment of central Florida and found her ‘Stage 2’ and ‘Stage 3’ weathering to occur significantly earlier i.e. within months rather than several years (Schultz *et al.* 2018). Therefore, different microenvironments certainly will influence the extent the skeletal remains are weathered and therefore when signs of these ‘weathering stages’ will be observed; hence why the stages are acknowledged but not inherently followed in this thesis.

2.3 - Soil Geochemistry:

Preliminary reading for determining what geochemical and petrological analyses have been previously conducted in research that investigates the diagenetic effects to bone preservation in a buried environment. There are several abiotic and biotic factors present in a burial environment that contribute towards the decomposition and destruction of bone (Hopkins 2008). To understand the post-mortem changes to the bone (and thus the bone trauma), one needs to investigate several important variables ranging from the basic texture, mineralogy and water movement of the soil to the potentially dynamic microbial activity, pH and ion concentration (Pate *et al.* 1989). Chemical and Bioerosive degradation of bone includes a series of different interactions in the soil; Nord *et al.* (2005) primarily found that soil acidity in the soil environment mainly effects the macroscopic appearance on bone. However, the microorganisms present in the soil (such as exogenous bacteria) may have a major influence on organic contents and histological microstructure i.e. the microscopic appearance.

There are such factors that do not directly cause damage to the bone, however, may provide a sufficient environment for those factors that do. For example, water holding capacity and its movement has a role in the rate of dissolution of bone mineral. Especially, in the exchange of exogenous ions from the soil to the bone; exogenous contamination from groundwater can supress microbial activity as well (Hedges and Millard 1995). There are several ecological interactions that cross-link with each other, which needs to be considered. Other different studies only consider some interactions and their rippling effects, as seen in the literature.

Cross-linking extrinsic factors need to be considered in their entirety i.e. the need to understand how one factor may affect the other. This is discussed in the literature between only a few factors e.g. pH, metal ion availability (Harter 1983) and its overarching link to the soil moisture (Sharma and Raju 2013). All link to the main bio-controlled modifiers of bone in soil (Nielsen-Marsh *et al.* 2000), of which there is a considerable amount of research that investigates how specifically microorganisms degrade bone (Child 1995; Bell *et al.* 1996; Trueman and Martill 2002; Carter *et al.* 2008; Kontopoulos *et al.* 2016).

2.4 - Soil Texture & Mineralogy:

Texture is a key factor to investigate and understand, as the texture type of a soil matrix often will dictate what other effects may occur i.e. it influences other physical factors of the soil. For example, the proportions of sands and silts in soils with a lower clay content will determine the pore characteristics and therefore the water movement/regime within it. Texture affects the water holding capacity and movement of the soil; fine textured soils will retain moisture more than coarse textured soils (Krogman and Iscan 1986). Coarser texture provides an easier transmission of water due to the lack of clay content; clay has the ability to retain water due to smaller particle size.

Soil particle size and proportion therefore influences water permeability and air exchange within the soil. For example, coarse textured soils allow gases and water (moisture) to move relatively rapidly through the soil matrix i.e. this type of soil loses moisture easily, thus appears as a low moisture content (Tibbett and Carter 2008). However, if the environment is low enough in moisture and dry enough in regard to little rainfall, then desiccation is promoted. Thus, in turn, it can actually inhibit decomposition in more extreme settings such as hot dry (Egypt) or cold dry (Siberia) environments.

2.5 - Soil Moisture:

As discussed above the moisture content of the soil is a very influential factor that should be considered during diagenesis studies. If soil particles are coarser (sandy soils) with less clay content, then the ability to retain moisture is reduced; so, a greater diffusion of gas and water is allowed, which promotes decomposition due to the rapid movement of ground water.

Whereas, a wetter, finer textured soil can result in decreased decomposition as the rate of oxygen exchange might be low for microbial demand, low rates of gas diffusion and retained wet conditions result in anaerobic microbial suppression (Carter 2005). Following this logic, soils with higher diffusion rates (in association with its texture class) allows for reasonable conditions for ground water movement and microbial activity; however, if the environment is too dry (low humidity or desiccated environment), then it can inhibit decomposition because the hydrolytic enzymes associated with the cycling of carbon are retarded (Surabian 2012). This is an example of how moisture is dynamic an influential factor, in this case specific to an indicator of Ground Water Movement (GWM) and potential microbial activity within a texture class.

Matric potential is something that should also be considered, it essentially is the soil water potential, i.e. it’s the potential that is derived from the surface tension of water menisci between

soil particles (Carter *et al.* 2009). It was concluded in a study above that the moisture content of the soil can modify/influence the relationship between cadaver decomposition, soil microorganisms and temperature. It's understood overall that it's not a closed system, water is being added through rainfall, lost through evaporation and drainage; there are external factors at play to be considered in soil hydrology.

2.6 - Soil Organic Content:

The amount of organic matter levels can influence and be influenced by other factors in the soil matrix. Regarding texture, soils with a higher clay content usually have higher organic matter content due to the slower decomposition of it; it depends on the bonds between the surface of clay particles and the organic matter and the potential for aggregate formation (FAO 2018). Macroaggregates physically protect organic matter molecules from mineralization through stabilizing them with soil microsites, protecting them from processes such as microbial attack (ontl *et al.* 2015). Therefore, soils with a lower clay proportion lack the ability to protect organic matter molecules via macroaggregate production i.e. their exposure is greater to degradative factors. Therefore, sandy soils will typically have a low amount of organic carbon, which sharply declines with depth, and the surface soil (0-0.15m) is the principal reservoir off this carbon concentration (Carlye 1993).

Poor organic content is contributed by extremes in pH of the soil, the acidity of a soil can hinder the growing conditions as well as inhibit microorganism activity (expect for acidophiles) (FAO 2018). The reasons behind why the organic content is low in a soil matrix highlights how it's a hostile/destructive environment for remains i.e. the organic content of the bone is susceptible to degradation from biological activity, greater movement of water etc. It's stated in (Manifold 2012) that the more corrosive/destructive soils are characterised by a low pH, high exchangeable acidity and a low organic content.

2.7 - Porosity (Bulk and Particle Density):

Understanding the porosity and therefore the density of the soil matrix is key to determine the hostility of an environment towards skeletal remains, as certain levels of porosity and density correlate with other key variables and can contribute towards a degradative environment for the bone specimens.

It's been stated previously what factors may be influenced by or may influence these joined variables such as water holding capacity, movement and organic content. The greater the bulk density, the smaller the pore volume; and there is a reduction in available water holding capacity, thus plant growth can be hindered. Essentially soils with a lower organic content

often will have higher relative bulk densities and lower porosity values (and vice versa) (Chaudhari *et al.* 2013).

Bulk density itself is inversely proportional to porosity, meaning high bulk density is an indicator of a lower soil porosity and soil (Silva 2011). Sandy soils have a higher bulk density as the total pore space in sands is less than silt or clay soils. The particles in silt/clay soils are finer, so, a large number of small particles can fit in a volume of soil, so they have a greater amount of inter-granular space between them. Sandy soils have larger particles and since fewer large particles can occupy the same volume of soil, there are fewer pores and thus a relatively lower porosity (Azlan *et al.* 2012; NRCS 2019)

Although, a sandier based soil may have a relatively lower porosity, this does not mean it cannot facilitate a more destructive environment, especially for susceptible remains. Due to the nature of the sand particles being coarser, they have less surface area to which hygroscopic water can attach, allowing better fluid movement and interconnection between the pores i.e. higher permeability as opposed to Clayey soils (Gartell 1992; Ball 2001; Bruand *et al.* 2006). It was stated above about how soil particle size affects water permeability and that sandy soils will have a higher permeability compared to more clayey soils. This supports the above point that density and porosity are influential factors as it's known that a soil matrix with greater water movement in combination with other contributing factors can create a hostile environment that will degrade bone.

2.8 - Soil Acidity (pH):

The relationship between the H+ ion concentration within the soil water and the calcium phosphate composition in bone is well established; an increase of the H+ ion concentration forces the reaction to the right, meaning hydroxyapatite will dissolve more in conditions with more [H+]; whereas in more alkaline i.e. lower [H+] it is increasingly stable (Nielsen-Marsh *et al.* 2000). Acidity of a soil is certainly an influential factor in bone degradation and cross links with other factors e.g. flow of water. When the flow rate is high in an acidic environment there is constant replenishment of the H+ ions in the immediate soil solution, meaning any increases in flow rate may increase the dissolution of the mineral component of the bone (Symes and Pokines 2012). Therefore, there is a lower solubility of bone mineral in alkaline systems with a pH greater than 7.5 and a higher solubility in acidic systems with a pH lower than 6. Alkaline soils are controlled mostly by the amount of soluble calcite in the ground, whereas acidic systems are controlled more by the amount of CO2 ions in the soil (Rowell 1994).

Brothwell (1981) described the difference between certain types of soil and bone-surface preservation e.g. in extreme pH soils that may be very chalky or decalcified the bones will be

damaged, whereas more clay type soils with a higher pH they can be preserved. Essentially demineralization of the bone is expected to occur in very acidic soils, whereas calcium carbonate deposition can occur in extreme alkaline soils (Brickley and Ferlini 2007). Differential damage can occur in alkaline and acidic conditions, in alkaline conditions the organic collagen hydrolyses and facilitates microbial attack; results the hydroxyapatite becoming brittle (Smith 2003). Whereas acidic soils on the other hand produce more extensive macroscopic damage such as thinning or windowing of the cortical bone as the rate of mineral dissolution is faster than the damage facilitated by alkaline soils (Nikita 2016). The acidic soils breaks down both the inorganic hydroxyapatite component of the bone and the organic collagen component; thus thinning the bone cortex (Polkines and Baker 2013). Pokines and Symes (2013) discussed the gross morphological effects of acidic soil erosion, commonly the smooth surface texture is lost as well as defined features; the loss is common at the epiphyses of the long bones where the cortical bone is the thinnest and may be destroyed entirely throughout the process. A supporting study from Casallas and Moore (2012) found that after 8-10 years in soil with a pH ranging from 4.2-4.5, there was near complete mineral dissolution.

2.9 - Major and Trace Elements in Soil Sediments:

The exchange of exogenous and endogenous ions between the soil matrix and the bones depend on the ion levels in the soil matrix and whether any leaching is likely to occur; inclusion of exogenous ions found in the bone apatite are indicators of diagenetic change as there is a certain level ion reactivity in bone apatite which makes it a good absorbent for different ionic species. Presence/absence of these can lead to a change in bone condition (and therefore can have a tandem effect on bone trauma condition) (Nielsen-Marsh *et al.* 2000). It's chosen to be investigated as it's certainly an influential factor especially with others, it's been found that some exogenous ions in the soil can suppress microbe activity and decreased their bio-erosive effects. These ions are lined to water saturation levels i.e. water holding capacity limits in the soil as well as ground water movement. Therefore, it's key in mineral dissolution, specifically concerning Ca^2+ and PO4^3- ions; there are combinations/conditions that are and are not favourable for bone preservation. For example, limited GWM (soils with a larger amount of fine clay particles) and high concentration of calcium and phosphate ions means a high survivability, whereas, increased GWM (soils with larger amount of coarse sand particles) and low concentration of calcium and phosphate ion means a low survivability.

Regarding the ionic exchange between soil and bone, Calcium and Phosphate ions are major ions of inorganic hydroxyapatite and they can affect preservation based on leaching. Calcium can be leached from the bone in a highly acidic environment, there are a high a number of hydrogen ions in the soil and the calcium leaches out to create an equilibrium between the ion

ratio in the bone to the ratio in the soil (Baxter 2004). Phosphate ions from the bone can be precipitated by the Fe and Al ions interacting in acidic soils; the ions in the soil remove the phosphate ions from the bone essentially (Siegel and Saukko 2012). Specifically, the ions react with dissolved iron and aluminium ions and precipitate as ferric iron and aluminium phosphates (Perk 2006). It's key to note that the Calcium could return to the hydroxyapatite if the environment were to become less acidic, however, that is unlikely, even with the slight influx that can occur during soft tissue decomposition. Ionic exchange is also considered to be linked to pH as there are certain elemental ions can that can cause degradative damage to bone in different pH levels; as the soils pH either facilitates or disables the mobility of the ions. Meaning, ionic exchange, sorption/desorption are influenced by pH (Caporale and Violante 2015)

According to Harker 1983, pH is a defining factor in metal ion availability as the amount of retained metal ions depends upon the [H+] where retention would increase with a pH from 7.5 onwards. Therefore, greater permeability and GWM in the soil also facilitates the movement and exchange of ions between bones and soil. Sharma and Raju 2013 supports this claim that it's related to WHC (retention), the moisture and therefore the movement of water in the soil.

2.10 - Microbial Activity of Soil:

It is known how microbes and their activity may be more frequent or less based on other influential factors, one of which being the texture class of the soil. To reiterate, in soils with more fine textured soils, the rate of oxygen exchange is lower because retained wet conditions and low rates of gas diffusion create a low anaerobic microbial demand i.e. anaerobic microbial suppression occurs (Carter 2005). The exogenous ions in the groundwater may also suppress microbial activity e.g. cross-linking between the bone collagen and humics in the soil may retard the degradation, however it's most likely the reaction between the soils exogenous ions and the demand for the microbes (Hedges and Millard 1995). Regarding soil acidity, it's been stated already that more alkaline soils facilitate microbial attack better resulting in histological damage, loss of organic components and biomolecular degradation (Nikita 2016). This does not ignore the potential damage to be done by microbes in acidic soils however, as microbial activity only ceases to occur once it's below approximately 4.5 pH (Water) excluding acidophilic microorganisms (Rousk *et al.* 2009). It should be noted that fungi have a greater tolerance for lower pH optima in soils than bacteria, this is most likely because their metabolism is pH regulated (Lynch 1995), meaning fungi can adapt to a larger range of pH for their survival and function. Rousk *et al.* (2009) determined that fungal growth was favoured at a low pH whereas bacterial growth was favoured at high pH in arable soil (Buckman and Brady 1969; McCauley *et al.* 2017). It was further discussed that there is a systematic pattern with

decreased bacterial growth with a lower pH irrespective of soil type, as well as the increase of fungal/bacterial growth ratio with lower pH (Rousk *et al.* 2011). This means that in a lower pH soil, the community shifts from a balance between fungi and bacteria to a more fungi dominant soil (Rousk *et al.* 2010).

2.11 - Microorganism presence – Nematode Population Activity:

Nematodes are one of the most numerous multicellular organisms in the soil in terrestrial and aquatic ecosystems; their existence and identification is complex due to the number of identifiable species compared to the larger number of unidentifiable species. They are varied and inhabit different soil environments in dissimilar amounts based on the physiological, hydrological and biochemical conditions of the soil matrix. The soil free-living nematode communities' composition, morphology, feeding guild proportion and activity are influenced by abiotic factors and nutrient availability (Pen-Mouratov *et al.* 2004).

They are quite versatile in their own environment, meaning they are a sufficient bioindicator for microenvironmental changes in the local soil matrix, these changes being associated with specific ecological processes (Bongers and Bongers 1998). The extent to which their significant population changes throughout the seasons has been studied in multiple environments, however, a typical pattern can be seen. This pattern being the total number of nematodes is highest in the Autumn period and decreases during the Winter and Summer period. The reasons are mostly linked to moisture where they favour a wetter environment as opposed to a drier one; the populations are lower in the winter due to the lower temperature and organic content, whereas the populations are lower in the summer months due to the lack of moisture and higher temperature (Pinochet and Cisneros 1986; Bilgrami and Gaugler 2004; Brmež *et al.* 2004). This pattern is not followed exact among every soil environment, of course it depends simply on the soil matrix being the appropriate temperature, moisture level and level of nutrients.

There has been limited work done specific to a systematic description of nematode community responses to vertebrate decomposition; according to the present studies, macrofaunal communities associated with decomposition of vertebrate are restricted to cataloguing taxa of nematodes as well as determining if their taxa differ based on the remains body section (Szelecz *et al.* 2018; Keenan *et al.* 2018). There are a specific lack of studies of how these communities have changed in a short period of time at different intervals in response to vertebrae decomposition; this aspect of the study hopes to achieve this. However, the accuracy of the identification will only be specific to the feeding guild rather than the explicit species due to the limited time during this study.

2.12 - Diagenetic Bio-erosive Activity of Macroarthropods on Bone Condition:

From Chapter 3.5 of Undergraduate Thesis (Gent 2018 unpublished) Verbatim:

Bioerosive effects of arthropods on bone have been investigated previously by Jean-Bernard Huchet in 'Approche ichnologique et taphonomique des altérations ostéolytiques dues aux insectes en contexte archéologique' (Huchet 2014). Where non-human biological agents such as arthropod orders are said to be involved in the taphonomy of bone degradation. From taking an ichnological approach i.e. investigating the traces produced by organisms to study the taphonomy of bone degradation (Mángano and Buatois 2011). Specific details about the taphonomic history of a bone specimen can reveal the identity of a biotic agent. Huchet also investigates various osteolytic lesions enacted by insect activity such as perforations, local bone deficiencies, erosion of cortical and trabecular layer etc. The behaviour of the insect activity has been explored further, where different species will exploit skeletal remains in different circumstances i.e. how termites will exploit exposed and buried bones, the *Dermestes* genus will feed primarily on sub-aerially exposed desiccated carcasses (Huchet *et al.* 2013). This is very useful information to keep in mind in the possible case of insect activity, whether this activity will or will not impact the taphonomy of the bone surface and the trauma on said surface can't be assumed. However, it has been highlighted by other authors that insects can be taphonomic modifiers for bones, therefore they could potentially be modifiers of bone trauma (Paik 2000; Fejfar and Kaiser 2005; Britt *et al.* 2008). Taphonomic overprinting may occur as a result of their movement and be shown as 'trace morphs' under the terms V-shaped linear and branching grooves (Bader *et al.* 2009). These examples of shallow linear traces on the bone surface (depending on their dimensions) may partially affect the kerf morphology of the trauma mark. However, the possible Bioerosive effects of insects cannot be assumed in this investigation without direct observation of one of the primary orders of insects that (known as taphonomic agents) being active (Huchet *et al.* 2013).

2.13 - Techniques Used to Analyse and Characterise Cutmarks on Bone:

Over the last ten years there has been a larger increase of methods that can be used to investigate the appearance, structure and dimensions of cutmarks inflicted upon bone. The foundation for this has been from a ranged interest in interpreting the cutmarks in an archaeological context such as butchery practices (Bello *et al.* 2009; Mate-Gonzalez *et al.* 2017) or in a forensic context such as looking at 'stab marks' on rib bones or evidence of dismemberment at the epiphyses of long bones (Puentes and Cardoso 2013; Porta *et al.* 2016). The more advanced three-dimensional methods have the ability to identify the variation of the cutmarks based on the tool-edge characteristics through the techniques being able to reconstruct the surface features accurately.

The research aim will influence what information is to be recovered from analysing the cutmark, for example Puentes and Cardoso (2013) aimed to investigate further into the effect that a knifes blade angle has on the intra and inter-individual variation in human costal cartilage. This of course requires a method that has the ability to investigate a tool classes striation pattern observed in the kerf wall and floor of a cutmark, here they created casts and processed them using an Olympus stereomicroscope. Two-dimensional microscopy has been very useful in being able to obtain data regarding classification of the cutmark as well as observing the topography of the surface and the mark morphology in a range of research areas (Greenfield 2006; Kooi and Fairgrieve 2012; Porta *et al.* 2016; Orlikoff *et al.* 2018). However, three-dimensional microscopy can offer additional information that 2D microscopy (optical and SEM) cannot; as stated in (Moretti *et al.* 2015) which directly observed cross sections of cutmarks, as well as involving certain calculations relevant to the micromorphology of the cutmark. Controversially, it has been discussed that there should be higher classification errors in samples analysed by 2D rather than 3D. In this study, it was actually established that although the 3D methods have a higher accuracy for identification and classification, the 2D methods match classification rates generated by 3D methods (Courtenay *et al.* 2018).

Analysis has been further advanced where micro-computed tomography needs to be utilized in an investigation (Thali *et al.* 2003; Pounder and Sim 2011), Rutty *et al.* 2013 explored the role of this in forensic investigations to establish that this technique provides greater spatial resolutions and can overcome limitations that occur with more image-based methods such as optical microscopy. Further than this, using this technique allows you to overcome more simple optical restraints, one being the limited depth of field within two-dimensional microscopy or in three-dimensional microscopy where there are optical obscurities.

Aside from 3D optical microscopy and Micro-CT scanning of a cutmark, there has been explorations into laser scanning, confocal microscopy and micro-photogrammetry; this has been assessed in Mate-Gonzalez *et al.* (2017), where they compared the resolution and the quantitative recording ability of the techniques. In summary, they found that overall they produced statistically similar results with small differences between them that are negligible; of course, this should be noted as they are different techniques by source, however, have produced ‘statistically indistinguishable results’.

In summary, there is a large variety in techniques to analyse the structure, appearance and dimensions of cutmarks on bone. The choice of technique will depend on the researcher’s resources i.e. what equipment is available at their disposal, the desired obtainable information and limitations of the sample. The pertaining literature suggests that although there is a large amount of advanced techniques that can offer a wide disposal of useful information; the more

basic two- or three-dimensional optical methods are still as accurate when it comes to determining base features such as tool classification and dimension measurements.

2.14 – Forensic Relevance and Epistemological Outline of Taphonomy:

Taphonomy is a wide-reaching subject integrated into multiple fields and applied to a variety of investigations rooted in paleontology, geology, archaeology, anthropology and forensic science. Since it's origin with Efremov (1940), the area of study accepted under the term comprises post-mortem processes, of which there are two lines of approach outlined by Quinney (2000). The first of these is 'neotaphonomy' or actualistic taphonomy, which largely involves experimention applied to scenarios/situations generally in the recent past through an hypothetico-deductive analogous comparison i.e. the method of inferring the nature of past events by analogy with observable processes and actions in the present (Rudwick 1976). The second is palaeotaphonomy, this approach retrieves key information regarding the content of depositional sites, their formation processes and relative context through using techniques such as temperospatial patterning, skeletal part representation and identifying breakage patterns in skeletal remains. Nawrocki (1995) identified importantly three classes of taphonomic processes and variables. There are: 1) Environmental factors which involve the biotic/abiotic factors of both the environment and the remains of interest. 2) The individual i.e. the intrinsic traits that can influence the decomposition process such as age, weight, and sex. 3) Cultural and behavioural factors, such as the type of burial and the circumstances of death, as both can reveal specific aspects about that individual and the society, they were a part of, whether modern or ancient. These broad taphonomic processes can be investigated from either of the above approaches. Forensic taphonomic research can have all three taphonomic 'classes' investigated within both approaches; experiment-based investigations can fall within actualistic taphonomy whereas the case-based single study reports can be considered to be paleotaphonomic in nature.

Nawrocki (1996) identifies geotaphonomy and biotaphonomy as two main subfields of taphonomy that have gained acceptance in the past decade, both of which have been applied within forensic taphonomy. The former investigates the effects of the assailant and the remains on the surrounding geological/sedimentological environment, whereas the latter examines modifications to the remains themselves. Like forensic taphonomic investigations, these two broad subfields can follow both the actualistic and the paleotaphonomic approach; both biotaphonomy and geotaphonomy link together to allow an investigation into the factors that could have affected the remains by understanding the specific microenvironment of the recovery scene. Taphonomic theories over time have greatly developed and improved themselves through interacting with new fields and exploring them within the realms of the

investigation. For example, the neotaphonomic approach became greatly popular within anthropological and archaeological studies between the 1980s-1990's and from this valuable modern analogue and experimental field projects were developed (Fernández-Jalvo and Andrews 2016). They showed how certain taphonomic modifications changed through time and space via techniques such as photographing, mapping, and measuring the dispersal patterns of remains. In addition, environmental parameters could be measured (melding bio and geo-taphonomy) to support these patterns and as well as conduct various long-term monitoring experiments to compare to the past to give further context. These actualistic monitoring studies ranged between the study of large and small animal remains (most of are the former), where investigating them can reveal crucial environmental details; thus reveal the patterns that can explain the temporal or spatial context of some of the bone assemblages (Madgwick and Broderick 2016; Wescott 2018).

Once the field of forensics was added to taphonomy, it definitely expected to have a large impact on the broader field, due to its nature it required more rigorous, analytical and highly meticulous experiments that could be sufficiently classed as 'forensic evidence'. In addition, Quinney outlined (Black and Ferguson 2011) that there are few taphonomic studies that are sufficient enough to come under as 'forensic evidence' meaning the key discoveries outlined within them, might not have been approached in the highest of standards; and that in general there are a lot of unstandardized protocols. More traditional taphonomic approaches may not be seen as sufficient also as they focus more on the application of uniformitarian assumptions in order to understand the decomposition processes (Lyman 1994). Whereas this newer 'subclass' of taphonomy i.e. forensic taphonomy is based less on assumptions and more on utilized knowledge of the contemporary world as well as understanding what occurs between the process and product of the experiment (Pobiner and Braun 2005). Fortunately, Haglund and Sorgs 1997 and 2002 volumes together offer a comprehensive introduction ti the area of forensic taphonomy establishing the necessary literature and research for their time; although there has been a plethora of literature since , they are still considered essential to understand the origin of this subfield and how it should fit within the realms of taphonomy in general. Haglund and Sorg (2002) emphasise the importance of the synonymous relationship that forensic science has with taphonomy; both subjects and professions can learn from each other and work together. They outline the need to be able to distinguish between damage on a bone caused by rodent-gnawing from damage that resulted from an assault on the individual, as well as the physical relationship they could have with each other i.e. how one may remove the history of the other (such as taphonomic overprinting) (Haglund and Sorg 2002).

As outlined above, the one shared aspect between the experimental sides of forensic science and taphonomy that should always be considered is actualism. The experiments and

researched conducted by forensic scientists and experimental taphonomists can learn from their different analyses and improve upon themselves; this has carried on into what Forensic Taphonomy is known and is appreciated as now. Forensic Taphonomy as a discipline does have an odd place in the applications to the medicolegal standard as it's questioned whether it reaches the standards to have a solid place in the courtroom (Tibbett and Carter 2009). To reach such a standard might appear impractical, even though methods and hypotheses are improving by considering a larger array of extraneous factors and variables that need to be understood to further understand the ecosystem of the cadaver and the surrounding environment (Dirkmaat et al 2008; Dirkmaat and Cabo 2016).

Lastly, Quinney (2000) outlines one of the larger issues in taphonomy, that as there is one physical past, there may be multiple agents that have produced it, therefore, our interpretation of those agents or lack of awareness of them in an experiment, might affect our reconstructive ability of these traces. Overall, these issues are currently acknowledged, and continue to be explored. Whether this gold standard is reached in the near future is unknown, however, it can be said that the area of Forensic Taphonomy as a discipline, is attempting to take advantage of these more actualistic (i.e. neotaphonomic) approaches, with consideration of the past paleotaphonomic approaches to learn from each other and improve.

2.15 - The Biomechanics of Bone and Skeletal Trauma:

The biomechanical properties of a bone i.e. the strength, elastic modulus, hardness, and conductivity that result from its anatomical structure and composition will influence how it will fracture (Kimmerle and Barabar 2008). Bone itself is a composite structure that has viscoelastic properties that are transversely isotropic, meaning it's a material which has a single material direction and whose response in the plane orthogonal to this direction is isotropic i.e. the lines of resistance are aligned in a single plane (Dong and Guo 2004; Black and Ferguson 2011; Popov et al 2019). The composite structure of bone can be identified as a mix of hydrated organic matrix that is composed of collagen (organic) and hydroxyapatite (mineral). The biomechanical properties of bone are influenced by this specific structure; the collagen is pliant and is reinforced by stiff mineral particles i.e. the brittleness of the mineral is compensated for by the viscoelasticity of the collagen (Sasaki 2012).

Regarding structural resistance, bone has been found to be more resistant to compressive forces than to tension, meaning failure typically occurs more so when tension is applied. When applied forces do not align with the bone structure (e.g. they go against the lines of resistance) then 'osseous deformations' (such as plastic deformation) can be created as a result of the bone not being able to distribute/dissipate the energy efficiently (Davidson et al 2011; Kemp 2016). This is influenced by the bones ability to absorb the energy (explained through youngs

modulus of elasticity); when the bone is exposed to the specific force, it can only be competent for so much of it (Carter et al 1980; Currey et al 2004; Currey et al 2006). Meaning, if the applied force exceeds the point of structural competency, the structure will fail and ultimately create permanent change to the bone structure and fracturing. If the bone can sufficiently absorb the applied energy and is competent, the bone should return to its original shape so long as the yield point isn't reached where plastic deformation occurs or it exceeds the yield point and fails (Symes et al 2013; Hart et al 2017).

In context, these forces may cause injury and fractures to the individual, it's known that there are many important factors that can influence injury and failure in addition to bone composition, such as shape and thickness of the bone as well as the type of tissue (trabecular or compact bone) (Kimmerle and Barabar 2008). It is known that trabecular bone allows for maximum strength for body weight load and regular physical activities, which is based on its crisscross-like structure (Currey 2002; Barak et al 2008; Waugh and Grant 2018). However, compact bone (aka cortical bone) is actually stiffer with a higher resistance to stress and a lower resistance to strain, whereas trabecular bone, with its more porous structure, has low resistance to stress and a high resistance to strain (Hart et al 2017). Stress being the applied load per cross-sectional area, and strain being the change in length per initial length (Cole and van der Meulen 2011). Repeated stress and/or strain can result in a fracture (Schmitt 2007). Regarding applied forces, bone can handle compression better than tension, specifically cortical/compact bone reflects this, whereas trabecular bone can be less predictable and more volatile mostly due to its less organised/arranged perforated connective structure (Kieser et al 2013; Hart et al 2017).

Tension and compression forces are two of the five major applied forces according to (Smith 2017), the rest being torsion, bending and shearing; in most compression injuries actually, force is applied through bending or shearing also, as there have been various reports on the intricacies between them. For example, a shearing force is technically a bending force that is applied when the bone is immobilised and can occur in deeply penetrating or sharp force injuries. Whereas a torsion injury can occur as the result of twisting a bone and can be seen as a result of beating or torture via a stroking weapon. Bending forces that result in fracture rarely occur without another force being present such as tension or shearing (Ortner and Putschar 1981). Understanding the biomechanical processes behind how different fractures and injuries are created are necessary to understand the injury itself. Bone fractures can be relatively predictable as the bone itself can only respond to forces dictated in a certain manner, hence why a forensic anthropologist can gain a lot of information about the trauma mechanism from these fracture patterns (Kimmerle and Baraybar 2008). The injuries of interest are ones caused by weapons specifically, of which there is a large difference between blunt force trauma (BFT) injuries and sharp force trauma (SFT) injuries; BFT injuries are those sustained

from low-energy impacts over a large surface area from a broad instrument, whereas, SFT injuries are a mix of low- and high-energy forces applied dynamically over a narrow focus by an instrument with a sharp edge/point (Byers 2017). They can range individually based on the circumstances e.g. BFT injuries can either be low-load or high-load based on whether it was a small implement used such as a hammer or a larger force such as an explosive blast (Kimmerle and Baraybar 2008). SFT injuries will differ among themselves based on how the sharp-edge/pointed instrument is used, i.e. whether or not the force is applied in a vector perpendicular to the contact area (vertically) with a light or heavy instrument (weight will change the potential for fracturing here) or if it was inflicted across parallel to the surface with enough pressure to produce and injury (e.g. serrated implement) (Black and Ferguson 2011). The former is more likely to create osseous deformations than the latter due to the applied force involved, and the potential propagation of force applied across the bone surface will be greater than if it was drawn across i.e. hacking as opposed to sawing should cause more underlying structural damage or exceed the structural competency more if enough force is applied dynamically. Overall, there are a variety of investigated extrinsic factors that can influence the nature of the applied force and the resulting injury ranging from the velocity, weight, distance and weapon characteristics; all of which can be reflected upon the injury and interpreted by a forensic anthropologist.

2.16 - Concluding Point:

Overall, there is a plethora of literature that establishes these individual factors have been investigated regarding their influence in the preservation of bone during and before deposition. However, there is a lack of multi-analytical approaches to investigating these factors as a whole, especially from a forensic viewpoint and the compounding effects on the bone surface survivability and longevity (and therefore the trauma survivability and longevity).

Chapter 3 – Method:

3.1 - Approach:

This research project uses porcine (*Sus scrofa domesticus*) bone remains, which are a suitable experimental proxy for human remains (Tsukamoto and Pape 2008). However, those available were juvenile remains only (average weight is 75kg), therefore, this will have certain implications regarding the analysis. The table below is a summary and outline of the methods considered, further elaboration of the steps approached, and phases are delineated after.

Phase	Procedure	Materials	Tools	Procedure Outline
1	Bone Collection	50 Bone Specimens (Ribs and Longbones)	30L Cooler for transportation	Go to Soutars Fine Meats (Butchery Source) and collect pre-arranged number of defleshed, fresh bone specimens. Mixture of Long bones and Ribs from five different pigs of the same herd, and similar age/weight.
	Cutmark Infliction	50 Bone Specimens (Ribs and Longbones).	Constructed (with weights) Cutmark Infliction Device (CID). Three chosen blades of choice (cleaver, hacksaw, untouched flake).	Inflict three cutmarks on each bone for each off the three chosen tools. Cutmarks will be spread evenly across the bone specimen for ease and accuracy of infliction. Cutmarks should be inflicted preferably within the same time period as each other to avoid as much variation as possible. Cleaver tool will be attached to CID at a specific height and weight. Hacksaw and untouched flake will be augmented individually (if attachment to the CID isn't possible) to deliver the same number of strokes in the same direction under the same weight.

Phase	Procedure	Materials	Tools	Procedure Outline
2	Maceration	50 Bone Specimens (Ribs and Longbones).	Beaker bath Scalpel Tweezers Appropriate PPE and biohazard protection	Set the water bath to 37.5 degrees (chosen optimal temperature for bacterial growth) Bath can only fit a limited number of bones, so macerate in batches. Macerate for two days fully, and after the first batch is done, during the maceration of the second batch, conduct the next phase for the first batch (further explanation below in section 3.2.2). After maceration is complete, remove the specimens carefully, soft tissue should peel off relatively easily and dispose in the biohazard bin. Remove enough to make the cutmarks visible enough for the scanning in the next phase. Pat dry with blue roll, leave in the fume cupboard shortly and then conduct the next stage.
3	Scanning of the Cutmarks	Batch ready Bone Specimens (Ribs and Longbones)	VHX5000 Keyence Microscope Appropriate PPE and biohazard protection	Once the specimens are relatively dry (not fully dried out), start scanning the cutmarks using the Keyence microscope. Photograph the cutmarks to the best resolution possible (at the time) ready for appropriate length and width measurements of each cutmark (procedure is described further below). Scanning and measuring will be conducted within the same day the batch has finished with maceration to avoid as much variation as possible.
	Moulding of the Cutmarks	Scanned ready Bone Specimens (Ribs and Longbones)	Hydrophilic Vinyl Polysiloxane Impression Cartridges Dental Gun Dispenser Mixing tips	Once specimens have had the cutmarks scanned and measured, they will be ready to be moulded. The impression materials are fast acting so for ease and to save time mould several cutmarks in one go of the same type i.e. lay the bones with the cleaver cutmarks facing up first, shoot the material in the cutmark and the surrounding area and wait to dry. After

			Oral Tips	that, turn them over so the next cutmark type (Serrated or Stonetool) can be moulded appropriately. Moulds once dry will be removed carefully, wiped with IMS and blue roll, then stored in sterilin tubes. Further information on this procedure is below. This is planned to be repeated and a part of Phase 5.
Phase	**Procedure**	**Materials**	**Tools**	**Procedure Outline**
4	Experiment Set-up, Deposition and Sampling	50 Bone Specimens prepared ready for deposition (Ribs and Longbones)	30L Cooler for transportation Excavation equipment Garden wire Ground pins Bamboo Chicken wire Barrier poles Labels for bones Sampling bags Plant corer.	Using the barrier poles, ground pins and garden wire, outline the burial and surface plot for the experiment, making sure there are separate grids individually for the pigs and for the 'Exhumation Event' i.e. the number of months that the specimens will stay deposited for before being removed and examined. Make sure each bone has its laminated label attached, and this with garden wire is secured to the ground or to the nearest barrier pole. Chicken wire will be added around the plot or over the surface lightly to avoid scavenger activity, however, avoid restricting the specimens from plant growth or general exposure. Samples the soil using the plant corers and store in the sampling bags with an appropriate label both for the topsoil and burial layer of the burial plot. Further information is discussed below.

Phase	Procedure	Materials	Tools	Procedure Outline
5	Environmental & Soil Analysis	Collected cored samples from the burial plot	SEE TABLE 2 FOR OUTLINE OF SOIL TESTS	SEE TABLE 2 FOR OUTLINE OF SOIL TESTS
	Cutmark Measurements & Observations	Photographs of cutmarks on the Keyence	Keyence VHX5000	Prior to the first 'Exhumation Event' i.e. EE2, this stage will just consist of measuring the length and width of the pre-deposition cutmarks for the bone specimens. Phase 5 is repeated after each exhumation event once the specimens have been cleaned and then to be photographed using the Keyence VHX5000 prior to measurement of the post-deposition cutmarks. Following the measurement of the post-deposition cutmarks, physical changes will be chosen to be observed and tallied to indicate the level of change or degradation that a cutmark has gone through during deposition. Following this, cutmarks will have their moulds created again to be compared to the pre-deposition cutmarks. Further information is discussed below
6	Exhumation and Removal of Bone Specimens	50 Exhumed Bone Specimens (Ribs and Longbones) for that time period	Starting from EE2 - 2mm large sieve 55µm small sieve 30L Cooler for transportation	Once specimens are removed from the deposition areas, they are transported in the 30L cooler in sample bags specifically to the laboratory. They are then photographed, cleaned carefully and then pat dried ready for the repeat of Phase 5 i.e. Environmental & Soil Analysis and Cutmark Measurements & Observations.

Phase	Procedure	Materials	Tools	Procedure Outline
7	Data aggregation and Statistical Analysis	Sample data from the soil tests Quantitative and qualitative results from Cutmark measurements and observations.	Computer with SPSS Statistical Software Package and Microsoft Office Software	This will involve a comparison of the physical and chemical changes of the soil as well as any measurable and observational physical changes to the cutmarks during the deposition periods. When appropriate, the data will have their normality and statistical significance determined to further outline any possible patterns across the experiment timeline. Further information on this is below.

Table 1: This is a summary materials table that outlines the procedures involved across the methods of this study. It is only an outline of the rationale, further details on the steps involved in the method approach as well as the specific phases is stated further below (Section 3.1.1 – 3.5.5).

3.1.1 - Step 1: Construction of Cutmark Infliction Device (CID) and Individual Tool Attachments:

The CID (aka 'The Inflictor') is a basic counterbalance mechanical manual contraption which has a bevelled blade attached to an adjustable frame, of which a specific height, length and weight can be chosen and be consistent. A quick release mechanism and wide base ensures a stable release and repetitive infliction of a (chop) cutmark

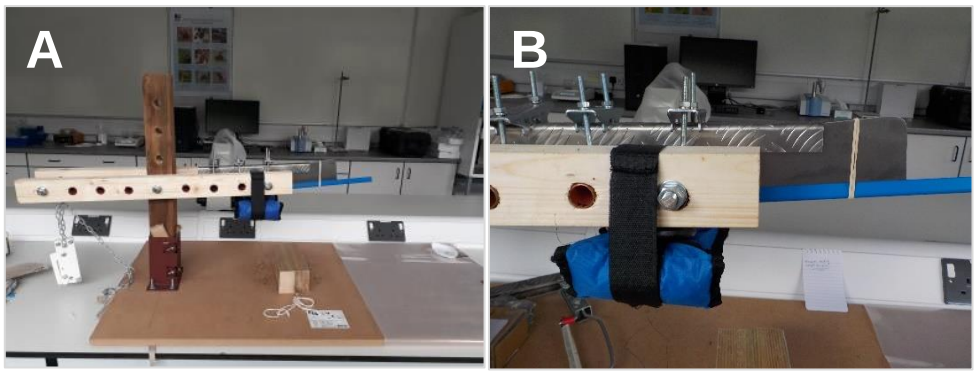


Figure 1 (A-B): Full and close view of the Cutmark Infliction Device in its entirety. Specific measurements and calculations can be found in Appendix Section C.

The overall additional mass that was chosen was 4.5kg (approximately); the mass of the bar, cleaver blade, U-bar and screws were used with other measurements were used to calculate the velocity of the blade. The velocity of the infliction was calculated and designed not to change as long as the weights didn't change, nor did the height of the arm. This specific mass was chosen as the minimum needed to sufficiently create a cutmark on the bone surface suitable for analysis. The calculated velocity itself is not necessarily meant to be the representative velocity inflicted by an average human; as in the context of hacking/dismemberment, one would attempt to achieve to segment the bone fully. This is not the aim or extent of damage that is being investigated, this mass is chosen to ensure consistency and the velocity is calculated to outline this is the minimum amount needed to successfully inflict trauma achievable by human action on the bone surface of these bone types and size.

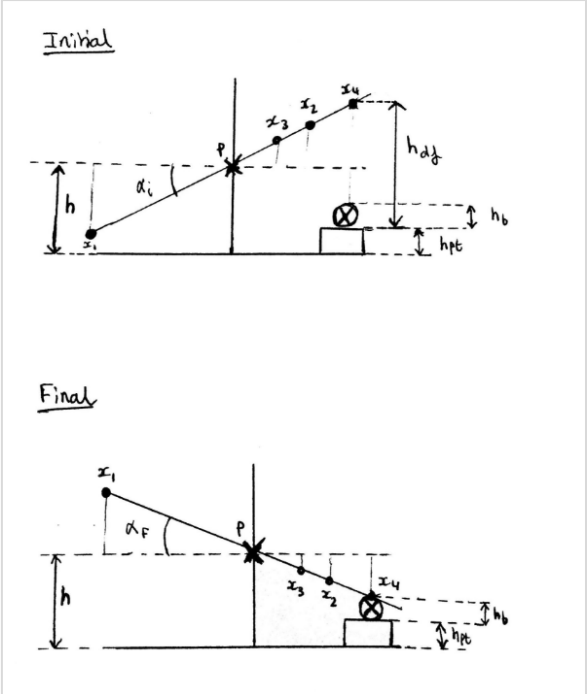


Figure 2: This is a rough base drawing for the velocity model based on the structure of the inflictor at its 'initial' stance i.e. when the release mechanism is connected to the base board and its 'final' stance when the inflictor has been released.

The figure above is not to scale and is only to show the theory behind the velocity model. The Velocity for when the middle of the cleaver inflicted upon a rib bone is calculated to be 2.339 (+/- 0.055) m/s and for a long bone it's calculated to be 2.131 (+/- 0.058) m/s. Moment of inertia is calculated to be = 0.04610599503 g cm^2. The error values for the velocity are based on the varied heights of the bone types. However, they don't appear to create a significant difference. The Key and the relevant equations for this velocity model can be found in Appendix Section C.

Lack of funds and restrictions of time made it difficult to construct unique attachments for the hacksaw and stonetool blades. So, for the hacksaw blade and untouched flake, individual frames were made with a known weight were attached to the blade securely. Then during their use they were pushed forward/backwards the same number of times as each other (five times) without pressure being added from the user, only from the known weight.

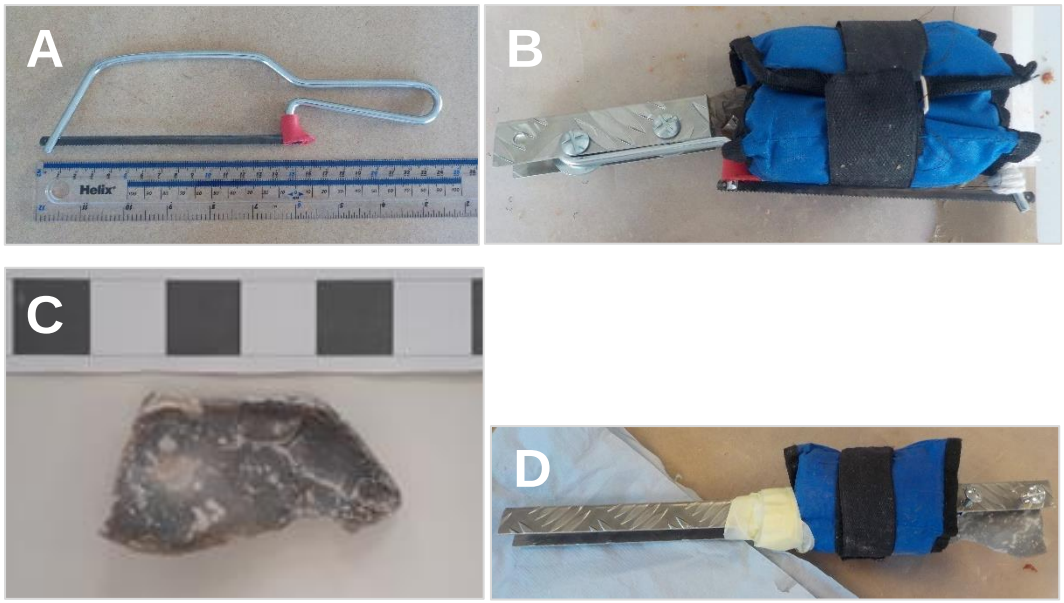


Figure 3 (A-D) - (A-B): Hacksaw and hacksaw attachment with 1kg weight attached to the blade. (C-D): Untouched flake and flake attachment with 1kg weight attached to the blade.

The CID and individual tools were cleaned and assembled at the laboratory on the day of infliction.

3.1.2 - Step 2: Collection of Bones

50 bone specimens were planned to be collected fresh on September 18th, 2018 from Soutars Fine Meats (Butchery Source), 10 bones from 5 individual pigs. Only 40 were able to be collected initially, the last 10 were collected shortly afterwards.

The 10 bones were 6 Long bones and 4 Ribs: 2 x Femora, 2 x Humeri, 2 x Radii/Ulna, 4 x Ribs.

They were briefly stored at 4 degrees in a refrigerator on the 18th, for the infliction to start on the 19th to ensure cutmarks were inflicted whilst the bones were fresh.

The pigs came from the same herd and the joints and ribs had been acquired at the same time (except for Pig 5, they were collected shortly after the 18th).

3.1.3 - Step 3: Sourcing of Moulding Materials

Hydrophilic Vinyl Polysiloxane Impression Materials with the appropriate equipment was collected ready for the impression moulding of the cutmarks to occur as soon as Phase 2 (See below) had concluded.

The impression cartridges were loaded into a dental gun dispenser. The mixing tips and oral tips were appropriately attached to the dental gun dispenser ready to be used.

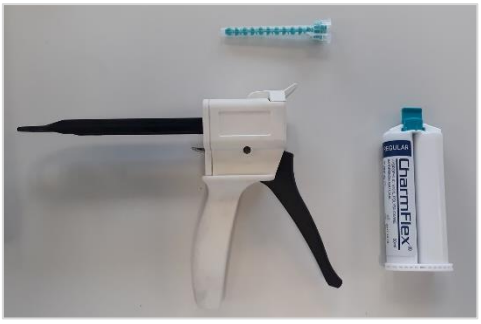


Figure 4: The dental gun dispenser and Charmflex mould mix.

There was a pilot practice to use the moulding material on the cutmarks after maceration and drying to determine whether the moulding material would dry sufficiently. The results were as expected according to Martin Smith (*Pers Comm*) for a first time try, the user needed to let the material dry longer and to use more material to avoid bubbles forming in the material and it sticking to the bone surface.

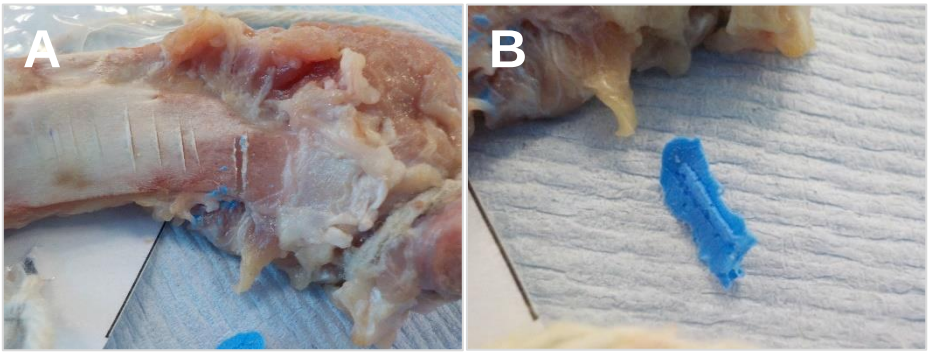


Figure 5 (A-B) – (A): Cutmark on a rib bone after moulding material has been removed. (B): Mould created from the above mentioned cutmark.

3.2 - Pre-Deposition Method:

3.2.1 - Phase 1: - Cutmark Infliction

It was decided due to time constraints that the experimenter would only be able to inflict three lots of each of the three tool marks on each of the fifty bone specimens (450 cutmarks in total). It was desired to inflict all the cutmarks within the same window of decay, to avoid bias against infliction spreading across multiple days.

Cutmarks are inflicted in a relative equal distance from each other, one at the proximal epiphysis, diaphysis, and at the distal epiphysis on each available side of the bone. For the ribs, two cutmark types had to be inflicted on the same side, however, they were made sure to be spread apart from each other equally.

Chop marks were created using a cleaver attached to the CID; whereas the hacksaw and stone tool cutmarks were created using a known weight attached to the blade with 5 strokes in the same direction repeated by the experimenter (without influence of the experimenter's downward force/weight).

3.2.2 - Phase 2: - Maceration

The intention of maceration was decided based on the requirement to accurately photograph and record the cutmarks with as little alteration to the measurements from the presence of soft tissue. Manual soft tissue removal proved difficult and time consuming (on the day) without damaging the bone. Therefore, it was decided that the remaining flesh had to be macerated carefully.

There was concern of the internal endogenous bacteria present in the bone specimens that are argued to be influential in the decomposition process. However, the soft tissue being present was arguably going to create issues in regard to recording. Therefore, the experimenter had to compromise with a method that allowed for removal of enough soft tissue to view/record the cutmarks, as well as making sure that the bones microbial life isn't sterilised (like most maceration methods result in).

After a preliminary read of different maceration methods, the one chosen for effective removal and low risk of sterilisation is macerating the bone specimens in a water bath at 37.5 degrees for approximately 48 hours. Based on the preliminary reading it is established that warm water maceration at this temperature encourages natural bacterial growth and therefore allows for encouraged decomposition of flesh to occur. Two days was deemed a sufficient amount of time as in the listed studies, the remains they used were mostly fleshed and articulated, it was logical to base the 48-hour window off this as the remains used here were mostly de-fleshed

and disarticulated, therefore, it was adapted based on the methods in the literature (Mairs *et al.* 2004; Ioana-Mihaela 2015; Silverman 2018).

The 1st batch procedure was during 24th-26th of September, the 2nd batch procedure was during the 26th-28th of September. During the 2nd batch 48-hour period, the 1st batch of specimens were processed through Phase 3. Following the 28th of September, the 2nd batch of specimens were processed through Phase 3.

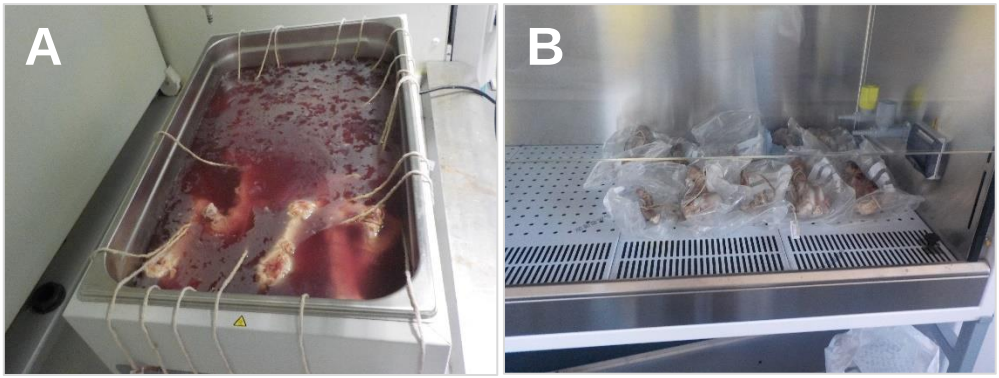


Figure 6 (A-B) – (A): Bone specimens in warm water bath of 37.5 degrees (B): Bone specimens after they were removed and pat dry in the fume cupboard.

N.B. Phase 2 & 3 were reluctant to occur straight after Phase 1 on the 19th of September, once the last 10 specimens (i.e. Pig 5) were collected and had marks inflicted upon them, then Phase 2 & 3 could occur for all 50 specimens.

3.2.3 - Phase 3: Recording the Cutmarks (Scanning and Moulding)

There are two parts of recording in this phase; the first involved the cutmarks being scanned and photographed using a Keyence VHX5000 digital microscope (DM).

It was decided before the approach that the DM was not viable for accurate 3D modelling of the cutmarks due to reflectivity issues encountered, hence the approach of moulding the cutmarks with VPS material and creating the 3D models from that was decided upon (ready for Phase 5).

Figure 7 (A-B) – (A): Keyence VHX5000 Digital Microscope used to photograph and measure the cutmarks. (B): Bone specimens after they were macerated and during the quick moulding process.

3.2.4 - Phase 4: Experiment Set-up, Deposition & Sampling:

The figure below (Figure 8) shows the 50 samples are split between the surface and burial designated areas, the surface area will support the biostratinomic investigation of any potential taphonomic modifications that might occur prior to burial whereas the burial area will support the diagenetic investigation of any potential taphonomic modifications that might occur whilst deposited. There are appropriate territory lines (red and blue grid lines) that separate the samples by Exhumation Event (i.e. how many months it stays deposited for) and Pig Number (the indiviudal pig it came from). The lack of planned specimens (originally 6 Pigs of 10 Longbones each), means the distribution isn't completely equal comparing one Exhumation Event to the other. However, more importantly it was arranged so the same number of bones removed from the burial plot at an Exhumation Event, would be the same number of bones from the surface plot at that time period i.e. it's the best that could be done with the available resources. The burial trench is measured out to be 180cm x 180cm, with the bones being a 'shallow spades depth' of approximately 24cm. They are depositied at an experiment site used by Bournemouth University at Wytch Farm, Wareham, Dorset on October 11th 2018 (EE0), to then be next exhumed at December 11th. The soil sampling here is done using the 'W' random distribution across the whole burial plot prior to the deposition of the specimens.

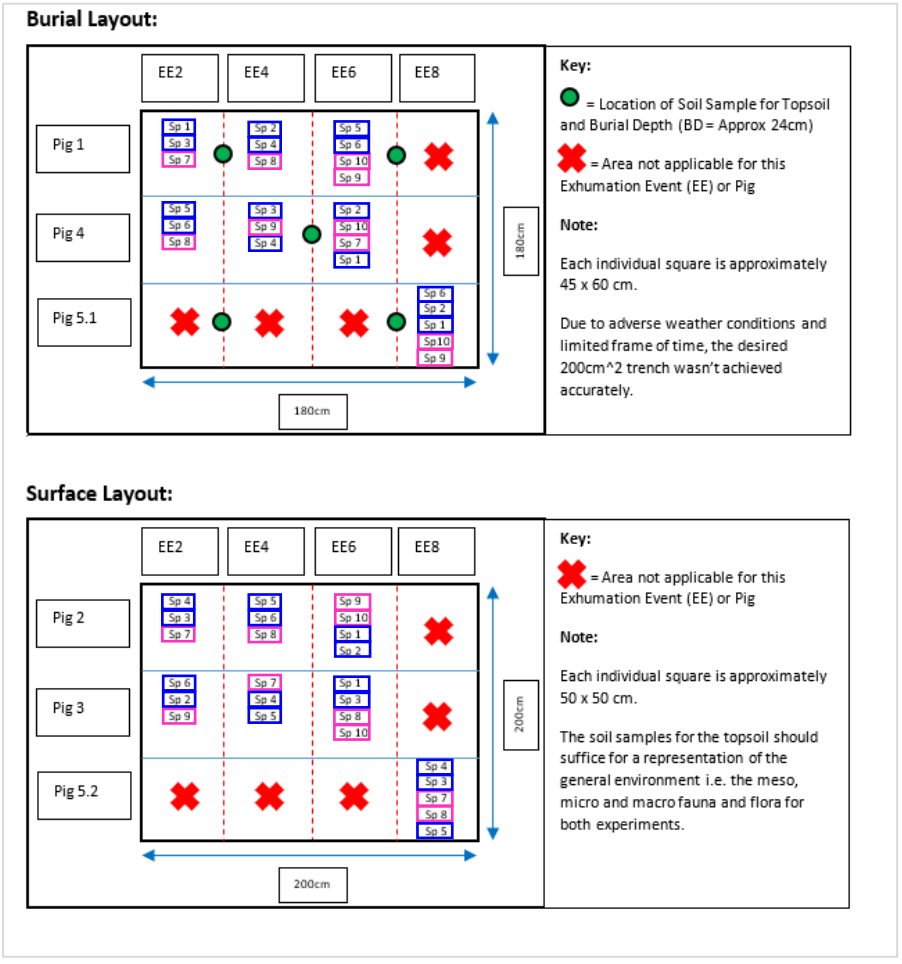


Figure 8: Basic Experiment set-up showing the distribution of the bone specimens across the surface and burial plots from a plan view (looking down on the plots). Pink rectangles are Ribs and Blue rectangles are Longbones.

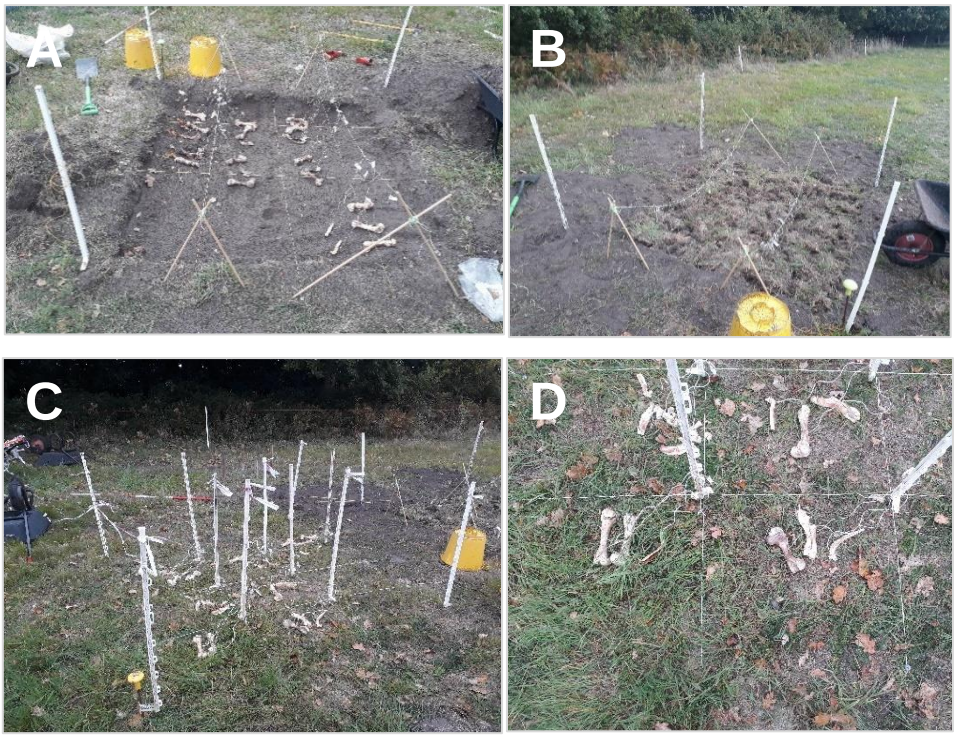


Figure 9 (A-D) - (A-B): Basic Experiment Set-up showing the distribution of the 50 bone specimens across the surface and burial plots.

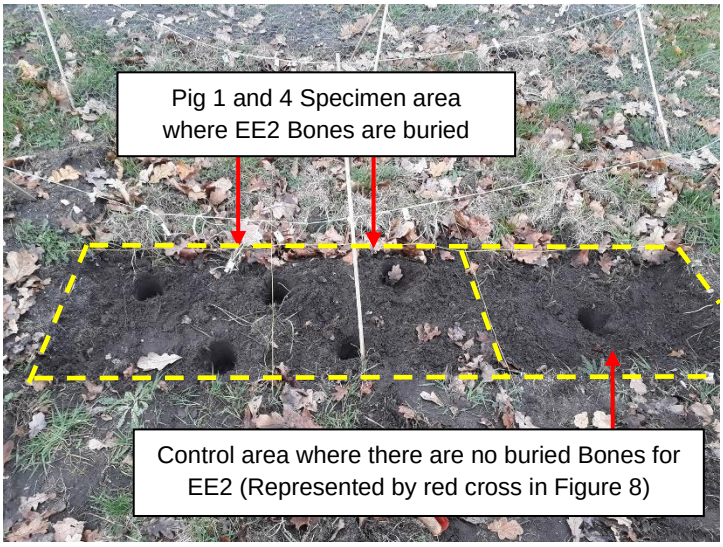


Figure 10: An example of the soil sample sampling technique used to collect the soil from the EE2 interval.

As shown in the figure above, for each 'Exhumation Event' the soil of the grids with the to be exhumed specimens will be sampled using the 'W' random sampling technique in those specific areas only. The control sample will be taken from the grid in the same territory line without the specimen to ensure it's received the same physical changes as the sections with the specimens (e.g. turning over of soil) and are the red crosses in Figure 8.

3.3 - Post-deposition Method:

3.3.1 - Phase 5: Environmental & Soil Analysis and Cutmark Measurements & Observations

As established above in the experiment layout diagram, topsoil and burial layer soils were taken at the time of deposition. These are stored at 4 degrees and will have a battery of tests conducted to create a 'Current Soil Matrix Profile' (CSMP) at the time of deposition/exhumation. Of which it will include data regarding the following biotic and abiotic factors:

- pH(lime)
- Porosity (Relative Bulk Density and Particle Density)
- Soil Texture
- Weather Conditions (Temperature, Rainfall, Humidity and Daily Sunshine %)
- Fauna & Flora
- Total Microbial Activity
- Heavy Metal Concentration
- Organic Content
- Microorganism Activity

It was determined that the soil samples had to be processed in an organised manner due to the different requirements each geochemical method had as well as different number of test repeats and amounts. So, a flow diagram was created for the benefit of the author to conduct these tests in a streamlined mode with knowing how much of each of the 'W' distribution sample bags were needed.

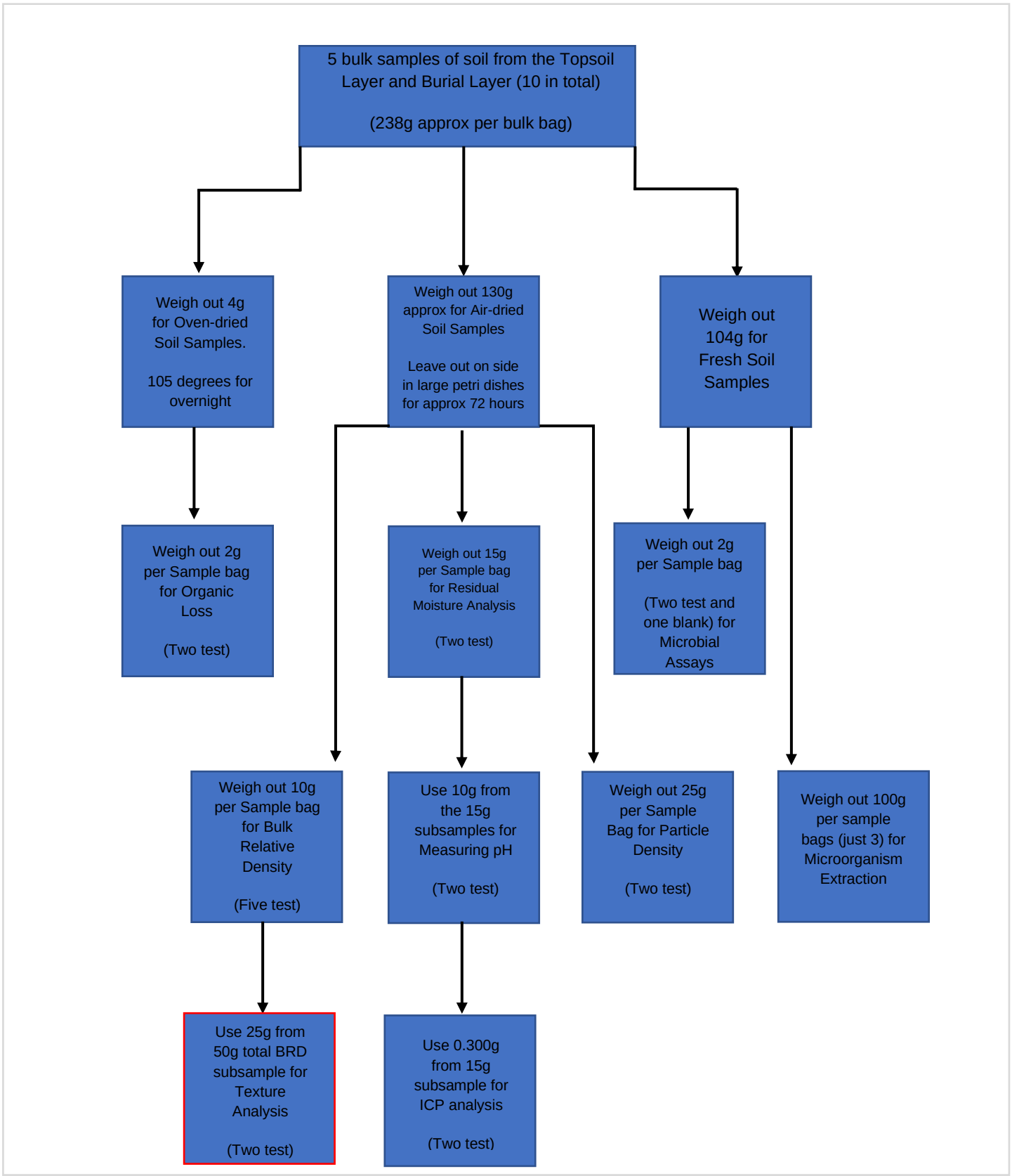


Figure 11: The Flow chart created and followed by the author to ensure the amount of soil to be used did not exceed the amount collected and so it could be followed by others easily. Texture analysis box is highlighted red as it only was done once.

Each soil test with raw data can be found in Appendix Section F with each of the CSMP's for each deposition interval, below is a table summarising each test used with the justification and the expected output (as written in each CSMP document). Further details of each method can be found in Appendix Section H – Method Guides.

Test	**Method Summary**	**Justification & Context**
Determining Organic Content of the Soil	It involves heating 2g of fine oven dry soil in a muffle furnace overnight at 450 degrees, then reweighing afterwards. In total there were 20 samples, which consisted of tests and repeats of each off the 5 burial and 5 topsoil samples taken from site. Then calculating the percentage loss of ignition based on the different weight values recorded.	This test was done to measure an estimate of the organic matter content of soils, the result output is grams of organic carbon per 100 grams of soil. It's seen as sufficient method for a rough estimation of organic matter as opposed to the wet oxidation procedure; which is time consuming, costly and also has a potential to cause environmental pollution (Salehi *et al.* 2011).
Determining Residual Moisture Content of the Soil	The fresh soil was weighed out to approximately 15g and left to air dry. After the weight becomes constant it will be reweighed as the 'dry weight'. Then using the P – Moisture equation and the weight values the moisture content of the sample can be calculated.	Moisture content of the soil matrix is influenced by the physical conditions of the soil e.g. soil particle size and proportion. It in turn can facilitate further or less damage by effecting the preservative ability of the soil towards the remains and the decomposition process
Determining Density and Porosity of Soil (Relative Bulk Density & Particle Density)	Porosity is determined through calculating the particle and bulk density of the soil, the difference between these two represents the volume of air spaces inside the soil i.e. the porosity. Bulk density is determined by weighing out soil that occupies a space of exactly 10mL (therefore its units are 10/g mL^-1); this was repeated 5 times per 10 sample bags for the topsoil and burial layers	Understanding the porosity of the soil is important as it influences the soils aeration, water transfer and storage capacity. For example, low porosity i.e. high bulk density indicates compaction of the soil either artificially or naturally. Depending on the soil texture, the soils permeability can either be

	Particle density is determined by calculating the density of 30g of soil in a 250mL flask of water with the air expelled from it essentially (therefore its units are g/mL^-1); this was repeated twice per 10 sample bags for the topsoil (5 bags) and burial layers (5 bags).	high or low i.e more waterlogged or greater at draining; this can influence what diagenetic effects will occur to the bones condition (and therefore, the bone trauma).
Test	**Method Summary**	**Justification & Context**
Determining Soil Texture	Approximately 25g of air-dried fine soil is weighed out and blended with a dispersing (anti-flocculent) agent (10mL of Sodium Hexametaphosphate) and 100mL of water to prevent the soil particles from binding/clumping together. It's poured through a 63 µm sieve in a 1L measuring cylinder on the floor, the particles are washed through till the measuring cylinder volume is made up to 1000mL. The sand grains in the sieve are washed into a pre-weighed 250mL beaker to be dried at 105 degrees for 24-36 hours. After cooled it is reweighed. The cylinder contains the clay and silt fraction, it needs to be covered and inverted (10-20 times) to suspend the soil and set down gently. After 5 hours without disturbance the first 10cm of the cylinder should be siphoned off into a Buchner flask. 25mL of this suspension will be pipetted into a pre-weighed 100mL beaker and placed in a drying oven till it's dry (approximately 12-24 hours at 105 degrees). Then it will be reweighed. After the percentage of sand and clay are calculated (further calculations for explanation are found with the method in Appendix A), then the silt fraction can be calculated from the percentage difference.	The texture of soil is defined by the relative proportion of sand, silt and clay within it. The proportion of these fractions to each other defines within this system which of the 11 classes of soil this is. This is based upon the 'Soil Survey of England & Wales Soil Texture Class Triangle' seen blow and described further in the methods in Appendix A section H. It links with other physical factors such as porosity e.g. the proportions of sands and silts in soils with a lower clay content will determine the pore characteristics, physiochemical properties and therefore the water movement/regime within it.
Determining Soil Acidity (pH Lime Potential)	Approximately 10g of air-dried fine soil is added to a 50mL beaker (this is repeated twice for each of the 5 topsoil and burial samples, therefore there will be 20pH tests to create an average). 25mL of CaCl2 solution is added, stirred and left for 15 minutes. A calibrated pH meter is be suspended in the supernatant liquid and the measurement is reported.	pH of a soil has inherently large impact on various microenvironmental patterns in the soil matrix. The concentration of hydrogen ions in solution certainly is affected by the amount of water retained in the matrix, what

		exchangeable cations are present as well as different microflora/fauna. An issue that often is considered when measuring pH is the fact when water is added to the air-dried sample, it dilutes the H+ concentration, therefore, the pH will rise. When the pH electrode is placed in the soil suspension it is in more contact with the layers of solution away from the particles than it is close too. Therefore, the recorded pH of soil water suspension is greater than what it would truly be, this is overcome by diluting the soil with CaCl2 solution, the H+ concentration is maintained by cation exchange rather than the fall of H+ ions when water is added instead. This is considered the pH Lime Potential, although the H+ ions are still diluted, the use of this chemicals allows the solution to maintain an electrolyte concentration similar to that found in the soil solution originally.
Test	**Method Summary**	**Justification & Context**
Determining Major and Trace Elements in Sediments by Nitric Acid Digestion and ICP-OES Analysis	Approximately 0.3g of fine air-dried soil is added to a 50mL centrifuge tube with HCl and HNO3, after the appropriate heating and cooling period the contents of the tube should be near dry with an additional amount of HNO3 added. Once the samples are filtered into 15mL centrifuge tubes, they can be then analysed by the ICP.	Essentially this method allows one to investigate the trace metal content of the soil sample after a series of acid digestion to the samples. It's a spectroscopic source that can be used for the determination of a wide range of major and trace elements in a single, short

	It injects a nebulized mist from the desired sample (and standards) into the centre of an argon plasma (created from ionizing a flow of gas); when it enters the plasma, the intense heat dissociates the chemical compounds. The energy from the argon plasma that is absorbed by the compound atoms, excites them and follows into ionization energy transition.The ionizing energy transitions produce spectral emissions that are characteristic of the excited elements, they're broken down into individual spectral lines by the ICPs spectrophotometer and the software translates those lines into concentrations of specific set of elements (usually given in ppm or mg/L).	integration period i.e. multielement determinations.
Test	**Method Summary**	**Justification & Context**
Determining Total Microbial Activity using Fluorescein Diacetate Hydrolysis	2g of fresh soil in a 50mL conical flask had 15mL of 60 mM potassium phosphate buffer and 0.2mL of FDA stock solution added to each sample and it's repeat i.e. test 1 and test 2. There is a blank sample from each bag which has the PB added but not the FDA, therefore 6g is taken from each sample bag.The flashs are incubated at 100 rev min^1 in an Orbital Incubator at 30 degrees for 20 minutes, the reaction is stopped when 15mL of chloroform/methanol (2:1 v/v) is added to each sample once. The contents are transferred to a 50mL centrifuge tube and centrifuged at 2000 rev min^-1 for 3 minutes. The supernatant is filtered through a Whatman, No 2 filter paper into a 30mL polypropylene tube for each sample and it's tests/blank. Transfer some of the filtrate to the cuvettes and read the absorbance at 490nm on a UV/Vis Spectophotometer. Absorbance is then used to calculate concentration based on the standard calibration curve (quadratic) made on that day.Concentration values of the samples, blanks and the associated dry matter content values are used to calculate the 'µg of Fluorescein released per gram of dry soil in 1 hour'.	This is a method complimentary to understanding the total activity of the soil microbes these being bacterial and fungal organisms.A range of bacterial and fungal exozymes and membrane bound enzymes can hydrolyse the bounds between the fluorescein and the acetate in the Fluorescein diacetate compound, FD in its liquid state is colourless, whereas fluorescein which isn't bound to acetate is a fluorescent compound.The amount of fluorescein produced after hydrolysis can be determined by measuring the absorbance of light by the sample extracts at 490nm in a spectrophotometer. Therefore, the greater the fluorescein concentration, the greater the microbial activity.

Test	Method Summary	Justification & Context
Determining Local Nematode Abundance and Population Activity	Collection of Free-living soil nematodes is conducted using a modified Baermann Funnel technique. The apparatus involves a glass funnel that is attached to a clamp stand, with 2mm gauze sieve and a layer of cheesecloth laid on top. Rubber tubing is attached to the bottom of each funnel (only two funnels could be secured at this stage) and then clamped at the end. Water is added to the level of the gauze, then a subsample of 100g of fresh soil from each sample bag is deposited there. Then water is carefully poured on top till all the soil is covered equally. This is left for 48 hours maximum; within this period any live moving Nematodes should fall to the bottom through the sieve to be collected in a 200mL glass beaker. Once the clamp is removed and the solution is collected, it's filtered through a sieve with a 63-micron aperture, according to the literature, this should be sufficient to filter out any of the smaller sediment particles as well as not allow the nematodes to fall through. The remaining liquid on the sieve is backwashed and made up in 50mL of 70% IMS solution to preserve the microorganisms. In the end there should be 50mL samples of each of the three chosen sample bags, of which 0.5mL of each of the 50mL solutions will be removed, dropped on a slide, and viewed under a Brunel optical microscope with camera attachment. This is repeated twice per 50mL sample and the number of Nematodes found will be averaged and multiplied to determine how many Nematodes there are per 100g as well as determining the feeding guild proportions.	Specific slides used for commercial identification of Nematodes were not available commercially, so non-gridded slides had to be used. Although there is no grid, a majority of the Nematodes should not be mobile, the slide is being viewed up and across and not backtracked to avoid counting and photographing the same Nematode. From this the photos will be collated and compared to reference photos of the basic feeding guilds as well as to count the abundance of each sample back.

Table 2 – Summary of initial planned geochemical soil tests to be conducted at each interval. Note not all methods are present here, just the planned ones; the information in the 'Justification & Context' column comes from the method guides and are in the CSMPs in Appendix Section F

3.3.2 - Cleaning Process & Post-cleaning Scanning:

The bone specimens were removed from the site and transported carefully to Dorset House laboratory to record further observations and to prepare the remains further. At this point any macroarthropods found on the specimens will be removed as well as any dirt on the remains.

Just to make sure any macroarthropods are not missed, the bones are placed in a 2mm large sieve above a 55µm aperture sieve to collect anything during washing (photographs of cleaning equipment can be found in Appendix Section G – Miscellaneous).

The cutmarks were scanned and photographed using the VHX5000 Keyence Digital Microscope, a 400µm scale was used with each of the photographs and the measurement software was used to measure the length of each cutmark and five width profiles (to create an average width) as shown below in the example figures.

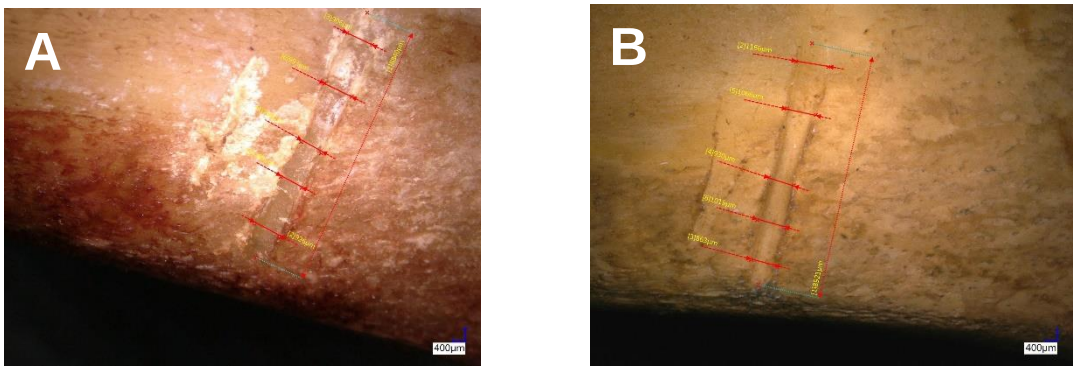


Figure 12 (A-B) - (A): Pig 1 Specimen 3 Serrated Cutmark 2 (Pre-deposition) photograph with measurements taken using the Keyence VHX5000 Digital Microscope. (B): Pig 1 Specimen 3 Serrated Cutmark 2 (Post-deposition) photograph with measurements taken using the Keyence VHX5000 Digital Microscope.

There are limitations with 2-Dimensional measurements of the cutmarks which includes keeping the bone specimen at the same position and angle when being photographed. This of course means there is an expected variation with some of the measurements if the cutmarks are in a 'difficult' position. There were situations when the cutmark itself was difficult to measure due to the texture of the bone surface shown in the below figures.

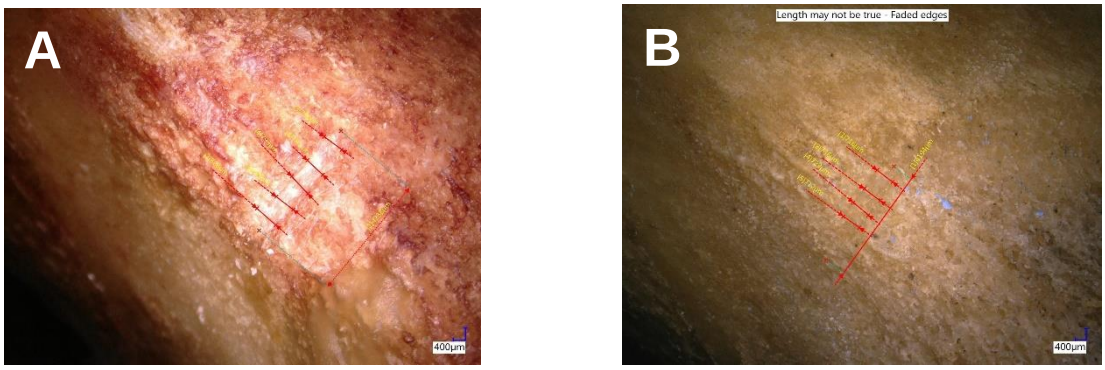


Figure 13 (A-B) - (A): Pig 2 Specimen 4 Serrated Cutmark 3 (Pre-deposition) photograph with measurements taken using the Keyence VHX5000 Digital Microscope. (B): Pig 2 Specimen 4 Serrated Cutmark 3 (Post-deposition) photograph with measurements taken using the Keyence VHX5000 Digital Microscope.

The measurements that are deemed 'appropriate' meaning measured in the same position and are deemed accurate by the author, are recorded as the cutmark length and average width in µm. These were compared to determine if there is:

- A notable difference of measurement between the months of deposition for each type of cutmark
- A notable difference of measurement between each cutmark type at each deposition stage

The photos without the measurements were investigated to note and track any physical changes to the cutmark structure (from a 2D microscopic view) that may have implications regarding the identification of:

- Cutmark Class Type (Incision, Serrated, Stone Tool)
- Cutmark Tool Type (Cleaver, Hacksaw, Untouched Flake)

The physical changes that were planned to be noted and described individually are the following:

- Edge Flaking (EF).
- Edge Disintegrating (ED).
- Edge Fading (EF2).
- Edge Fracturing (EF3).
- Staining – Green/Brown (GS or BS).
- Root Growth (Fungal or Plant) (RGF or RGG).
- Arthropod Activity (AA) – includes damage and presence.

These observable taphonomic changes are described further below in Table X which were used as a 'key' for determining the microscopic physical changes.

Observable Taphonomic Change	Descriptive criteria	Figure Appendix Reference
Edge Flaking (EF)	This is the flaking/flaring of the edge of the cutmark. It can be across either edge fully or partially. It can either be denoted as minor flaking that is at the very edge of the cutmark, or it could be extensive where it has spread further to the surrounding area to encourage cortical flaking.	Figure A-B
Edge Disintegration/Degradation (ED)	Disintegration or degradation of the cutmark edge will look like either a minor or extensive removal of the edge. The texture itself could look crumbled and without its structural integrity, with either most of the cut edge being removed or only partially.	Figure C-D
Edge Fading (EF2)	Typically, one of the edges of the cutmark will appear to be level with the surrounding surface either linearly or only partially. It is the loss of the edge detail and definition.	Figure E-F
Edge Fracturing (EF3)	Post-mortem fracturing/cracking which either appear from the cutmark edge linearly or spreading away from it. Typically, it is localized towards the tip of the cutmark.	Figure G-H
Surface Erosion (SE)	Surface erosion could either be removal of the cortical layer, a form of pitting or general surface destruction. This is specific to the area surrounding the cutmark specifically and might be identified as cortical flaking, increase in porosity or surface cracking.	Figure I-J
Kerf Erosion/Degradation (KE/D)	Areas of the kerf floor are either degraded of damaged. This could either look like a localised destruction of wear partially across the floor, or it could cover it wholly. It could be brought about through interaction with a destructive agent rather than solely wear over time.	Figure K-L
Staining – Brown or Green (BS or GS)	Staining is divided between colour, whether it is brown (or a close variation such as tan, yellowed or dark brown) or green (or a variation such as it being a lighter or darker green). Green staining (GS) denotes the interaction between the bone surface and either a algal or chlorophyll source. Brown staining (BS) denotes the interaction between the bone surface and the tannins and/or mineral content from the soil that the specimens were deposited in. The staining itself could either be spread across the whole surface including the cutmark and the surrounding area. The depth of colour depends on length of interaction and lack of exposure that might wash or remove said staining. The proportion of brown to green staining may indicate the resting orientation/position of the bone whilst the stains are forming.	Figure M-N

Observable Taphonomic Change	Descriptive criteria	Figure Appendix Reference
Root Growth – Fungal or Plant Root (RGF or RGG)	This includes any observation of the presence of roots along the surrounding surface of the cutmark or within it. This root growth may be either spread across or specific to a section of the cutmark and will often be found growing within any available cavity in the localised area it is interacting with. The roots found either will be known as 'plant roots' (RGG) where they will look thicker, larger, opaque, white, yellow or brown; or fungal roots (RGF) which will look thin, translucent and white. Typically, they will be found in areas of erosion or some level of degradation.	Figure O-P
Arthropod Activity (AA)	Arthropod Activity is specific to the observed presence of arthropods either within the cutmark or the close surrounding surface. They can either be localised to a specific area or be seen across in the available cavities. Certain arthropods will be found in areas of erosion potentially with another taphonomic agent such as plant or fungal roots.	Figure Q-R
Bone Loss (BL)	Bone loss could be specific to a cutmark that had an area partially segmented and it's fully become segmented now, or it has been removed by other means.	Figure S-T

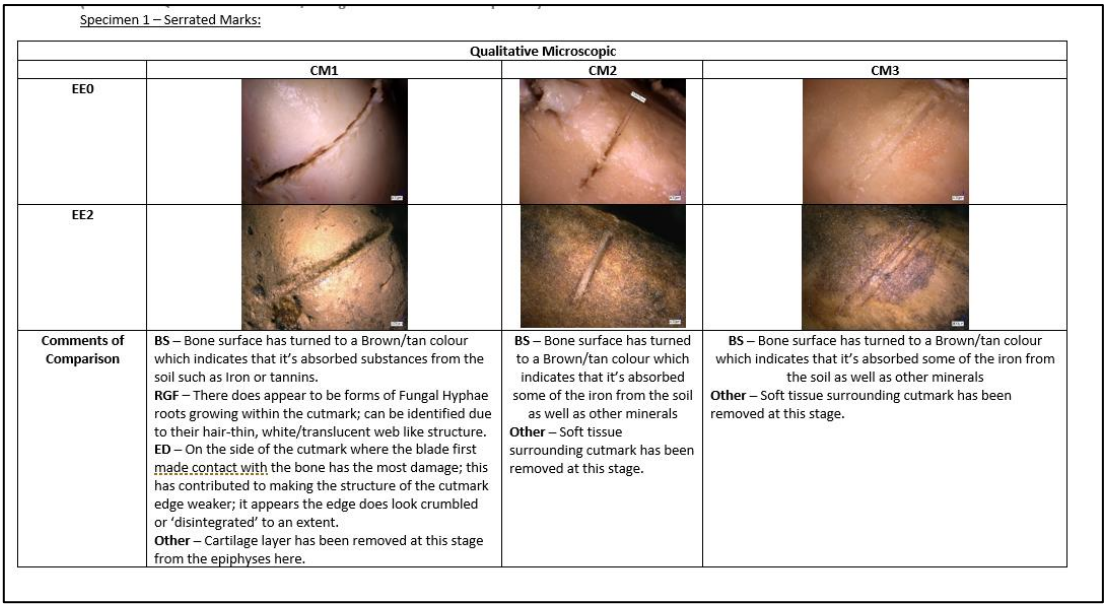
Table 3: Physical Change Key Observations to be Recorded. The referred to figures can be found in Appendix Section G; these are observed changes from this study that are used as an example of what the key is referring to.

In addition to the Microscopic Analysis, the overall macroscopic differences of the bone surface (excluding the cutmarks) were noted and the frequency of which were determined per deposition interval and state (surface or burial state); these changes reflect the latter three above as well as the following:

- Cortical Flaking
- Surface Stripping
- Fracturing/Cracking
- Surface Porosity Increase
- Fungal/Bacterial Damage/Growth

It is important to identify and investigate the relationship between the microscopic & macroscopic damage and the possible ecological interactions between the bone specimen and the environment. For example, it has been established that within the chemical environment, primarily soil acidity mainly affects the macroscopic appearance of bone, however, microorganisms have a major influence on the microscopic appearance (Nord *et al.* 2005). Hence why it is important to investigate the microscopic and the macroscopic appearance of the bone simultaneously.

The presence/absence of the physical change was noted in the 'Specimen Sheets' that can be found in Appendix Section F; an example is shown below:



Specimen 1 – Serrated Marks:

	Qualitative Microscopic		
	CM1	CM2	CM3
EE0			
EE2			
Comments of Comparison	**BS** – Bone surface has turned to a Brown/tan colour which indicates that it's absorbed substances from the soil such as Iron or tannins. **RGF** – There does appear to be forms of Fungal Hyphae roots growing within the cutmark; can be identified due to their hair-thin, white/translucent web like structure. **ED** – On the side of the cutmark where the blade first made contact with the bone has the most damage; this has contributed to making the structure of the cutmark edge weaker; it appears the edge does look crumbled or 'disintegrated' to an extent. **Other** – Cartilage layer has been removed at this stage from the epiphyses here.	**BS** – Bone surface has turned to a Brown/tan colour which indicates that it's absorbed some of the iron from the soil as well as other minerals **Other** – Soft tissue surrounding cutmark has been removed at this stage.	**BS** – Bone surface has turned to a Brown/tan colour which indicates that it's absorbed some of the iron from the soil as well as other minerals **Other** – Soft tissue surrounding cutmark has been removed at this stage.

Figure 14: Screenshot of Cutmark Comparison Sheet detailing the noted physical changes observed to the cutmarks compared to its pre-burial state.

The presence was tallied up and the absence of a physical effect was not noted. Any cutmark discounted was noted as 'N/A' and had the value of zero in the count.

4	BURIAL -CLEAVER													
5	Spec No.	Edge Degr	Edge Flak	Edge Fadi	Edge Frac	Kerf Erosi	Surface Er	Gree Stai	Brow0 Sta	Root Grov	Root Grov	Insect Act	Bone Loss	Other (O)
6	P1S1CL1	0	0	0	0	0	0	0	1	0	1	0	0	1
7	P1S1CL2	0	0	0	0	0	0	0	1	0	0	0	0	1
8	P1S1CL3	0	0	0	0	0	0	0	1	0	1	0	0	1
9	P1S3CL1	1	0	0	0	0	0	0	1	0	0	0	0	1
10	P1S3CL2	0	1	0	0	0	0	0	1	0	1	0	0	1
11	P1S3CL3	0	1	0	0	0	0	0	1	0	0	0	0	1
12	P4S5Cl1	0	0	0	0	0	0	0	1	0	0	0	0	1
13	P4S5Cl2	0	0	0	0	0	0	0	1	0	0	0	0	1
14	P4S5Cl3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
15	P4S6Cl1	1	0	0	0	0	0	0	0	0	0	0	0	1
16	P4S6Cl2	0	0	0	0	0	0	0	0	0	0	0	0	1
17	P4S6Cl3	0	1	0	0	0	0	0	0	0	0	0	0	1
18	**SUM**	**2**	**3**	**0**	**0**	**0**	**0**	**0**	**8**	**0**	**3**	**0**	**0**	**11**
19	P1S7CL1	0	1	0	1	0	0	0	1	0	0	0	0	1
20	P1S7CL2	0	1	0	0	0	0	0	1	1	0	0	0	1
21	P1S7CL3	0	1	0	0	0	0	0	1	0	0	0	0	1
22	P4S8Cl1	0	0	0	0	0	0	0	1	0	0	0	0	1
23	P4S8Cl2	0	1	0	0	0	0	0	1	0	0	0	0	1
24	P4S8Cl3	0	0	0	0	0	1	0	1	0	0	0	0	1
25	**SUM**	**0**	**4**	**0**	**1**	**0**	**1**	**0**	**6**	**1**	**0**	**0**	**0**	**6**

Figure 15: Screenshot of Cutmark Comparison Raw Tally Sheet for each specimen and noted physical change. '0' Represented change is absent, '1' represented change is present, N/A means the cutmark is discounted due to absence of that part/area of the bone or it could not be found.

All the SUM values for the long bones and ribs were separated by months and collated together, shown below:

SURFACE CLEAVER													
SUM	Edge Degr	Edge Flaki	Edge Fadi	Edge Frac	Kerf Erosi	Surface Er	Gree Stai	Brown Sta	Root Grov	Root Grov	Insect Act	Bone Loss	Other (O)
LongBones 2M	2	2	0	2	0	2	3	5	2	0	3	2	12
LongBones 4M	3	5	0	2	0	2	7	6	1	3	3	1	12
LongBones 6M	5	3	0	3	0	7	12	2	1	5	2	1	12
Ribs 2M	0	0	0	1	0	1	0	0	0	0	0	1	6
Ribs 4M	0	0	0	1	0	2	4	0	0	1	0	1	6
Ribs 6M	0	2	1	0	1	4	6	1	2	3	1	0	6

Figure 16: Screenshot of Cutmark Comparison Organised Tally Sheet for each specimen and noted physical change which has the sums of the raw tallies for the long bones and the rib bones.

From this, the 'Percentage Effected (%)' was determined by dividing the total sum of the cutmarks that had shown a physical change by the total sum of cutmarks that could have shown a physical change. For example, the number of cutmarks available for the longbones would be 12 and it would be 6 for the rib bones as for each Exhumation Event there are Four longbones and Two rib bones with Three cutmarks of a singular type each. Note, for every 'N/A', it reduced the total number of cutmarks that could have shown a physical change e.g. If one N/A is present, then the total number is reduced from 12 to 11.

Surface Cleaver										
% Affected	Loss of	Kerf Er	Surface	Green S	Brown S	Root Gr	Root Gr	Insect A	Bone L	Other
LongBones 2M	12.5	0	16.67	25	41.67	16.67	0	25	16.67	100
LongBones 4M	20.83	0	16.67	58.3	50	8.33	25	25	8.33	100
LongBones 6M	22.92	0	58.3	100	16.67	8.33	41.67	16.67	8.33	100
Ribs 2M	2.08	0	16.67	0	0	0	0	0	0	100
Ribs 4M	4.17	0	33.33	66.67	0	0	16.67	0	16.67	100
Ribs 6M	12.5	16.67	66.67	100	16.67	33.33	50	16.67	0	100

Figure 17: Screenshot of Cutmark Comparison Organised Percentage Sheet for each specimen and noted physical change which has 'percentage affected' amounts for how many of the total cutmarks within that group exhibited a certain physical change.

These can be viewed in Appendix Section E under 'Physical Change to Cutmark Observation'.

3.3.3 - Phase 6: Exhumation and Removal of Bone Specimens

There is a compromise for the number of bones removed to establish an accurate profile of what alterations may/may not have occurred during deposition. Three bones per pig per exhumation event will be removed from the burial and surface experiment areas. Although a larger number would create a larger statistical base, this has been deemed sufficient, so enough bones will remain for the desired duration.

After removal of the chosen bone specimens and appropriate soil samples, **Phase 5** will be repeated in regard to relevant cutmark measuring and soil analysis.

3.3.4 - Phase 7: Data aggregation and Statistical Analysis:

Data aggregation will be conducted automatically after soil analyses and cutmark measurements are completed. Statistical analysis will take place after the desired 8-month timeline, once all the data is gathered correctly and aggregated sufficiently.

Phases 3, 5 & 6 is repeated every 2 months for 8 months in total.

The quantitative analysis involved here will be tracking the physical changes in the cutmarks and determining if the difference is significant. As well as comparing the environmental variable results with each other.

The qualitative opinions will be based on the results of the soil analyses i.e. the microenvironmental patterns will be determined based on these analyses and therefore will provide reason and justification for what qualitative changes may be observed during each removal/exhumation event.

3.3.5 - Addition to Phase 5:

In addition to Phase 5; creating 3D Digital Models were explored during the analysis of the six-month deposited specimens. Due to logistics and time restraints, this was unable to be planned prior to the experiment and was arranged during.

Prior to the data collection, a minimum pilot amount of cutmarks was be chosen to be transported and scanned using the SENSOFAR Confocal Microscope at the University of Bordeaux. Time was limited over there, therefore, the smallest number of cutmarks were chosen to be scanned, that is three cutmarks of each cutmark type of each deposition interval and type were chosen; only 56 were able to be chosen at this time.

Once the bone specimen was mounted correctly, and the settings adjusted accordingly to best fit bone surface (i.e. correct light and brightness), then a preliminary scan occurred. This was to focus the microscope to the area of interest; only a portion of the cutmark was chosen, as their large size in complete dimensions would have hindered the speed of scanning beyond the limited time window.

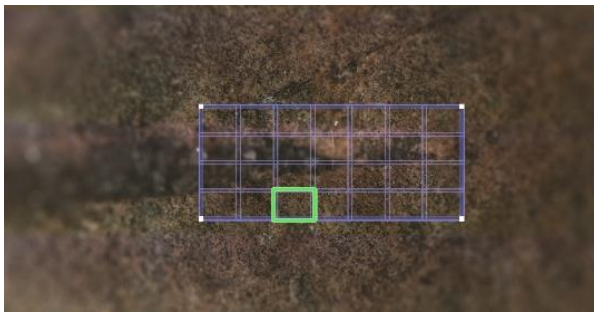


Figure 18: This is the result of the preliminary scan and the grid that overlays the area of interest of the cutmark; the cutmark is Pig 1 Specimen 2 Stonetool Cutmark 1.

This would allow the user to determine which part of the cutmark needed to be scanned; the green outline indicates which area the microscope is currently focused on.

Once the area was chosen, and settings adjusted, the 'Focus Variation' settings were to be chosen. In this case Focus Variation was chosen to reduce the amount of time needed to scan, as opposed to using the 'Confocal Scanning' setting.

The settings required an upper and lower boundary for depth to be chosen, this was chosen based on the focus of the image; the lower boundary required to be set at just beyond a clear view of the lowest point of the cutmark, the upper boundary required to be set at just beyond a clear view of the highest point of the cutmark. Therefore, the microscope lens had a height range to scan in; as focus variation creates a 3D model based on several layers of still photographs taken at different depths.

Once this was done, the cutmark could be scanned; the larger the chosen area, the greater number of ‘Field of Views’ (FOVs) needed to be scanned.

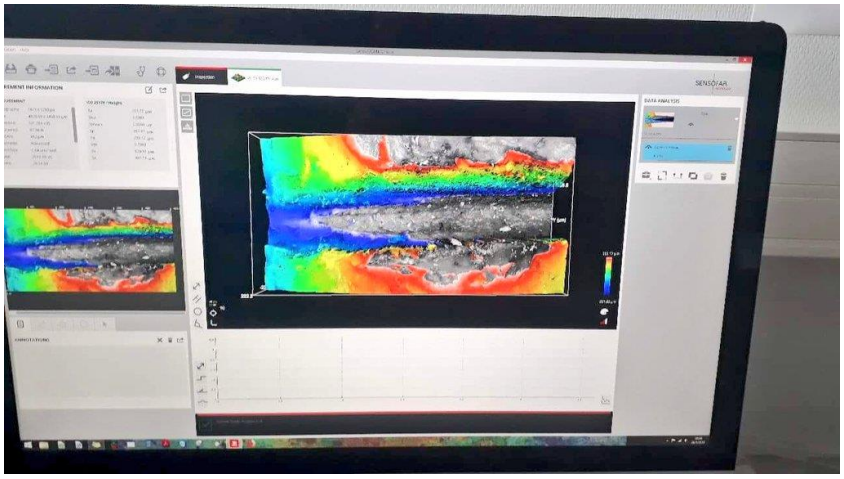


Figure 19: This is the complete scan shown in the SENSOFar software that can be saved as a (.plux) file and then opened in another software to visualise and manipulate the data.

Once the scan had completed, the software gave an example view of what the 3D model looks like before saving it onto the database. Another software (SENSOMap) was needed to manipulate and edit the model, to ensure it was presented correctly.

Once the file was uploaded to SENSOMAP, it was edited by filling in the Non-Measured Points, levelled, removal of artefacts and then converted into the 3D model; which then was adjusted according to scale to create what is below.

Several views were saved, and the entire process from the initial file to the SENSOMap software to the editing stage has been saved in a PDF for each cutmark; the 3D Images can be found in Appendix Section G.

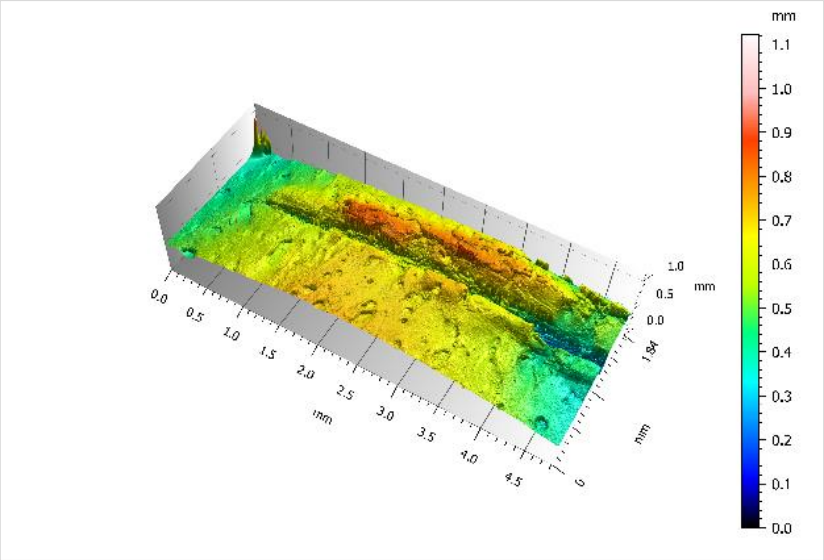


Figure 20: This is the complete 3D model that was created using the SENSOMap software, this is just one point of view, each cutmark had three point of views photographed from the 3D model to showcase the overall structure. The cutmark itself is Pig 2 Specimen 3 Cleaver Cutmark 2.

The aim of this is to gain a closer look on the bone surface surrounding the cutmark as well as have a clearer view of the cutmarks edge structure and appearance that the 2D photos may have not revealed. Therefore, the models will be compared visually to each other to determine if a certain level of degradation can be seen across the deposition intervals (Two to Six Months).

Chapter 4 – Experiment Results:

4.1 - Temporal Soil Matrix Profiles - Environmental Variables:

4.1.1 - Soil Texture & Mineralogy:

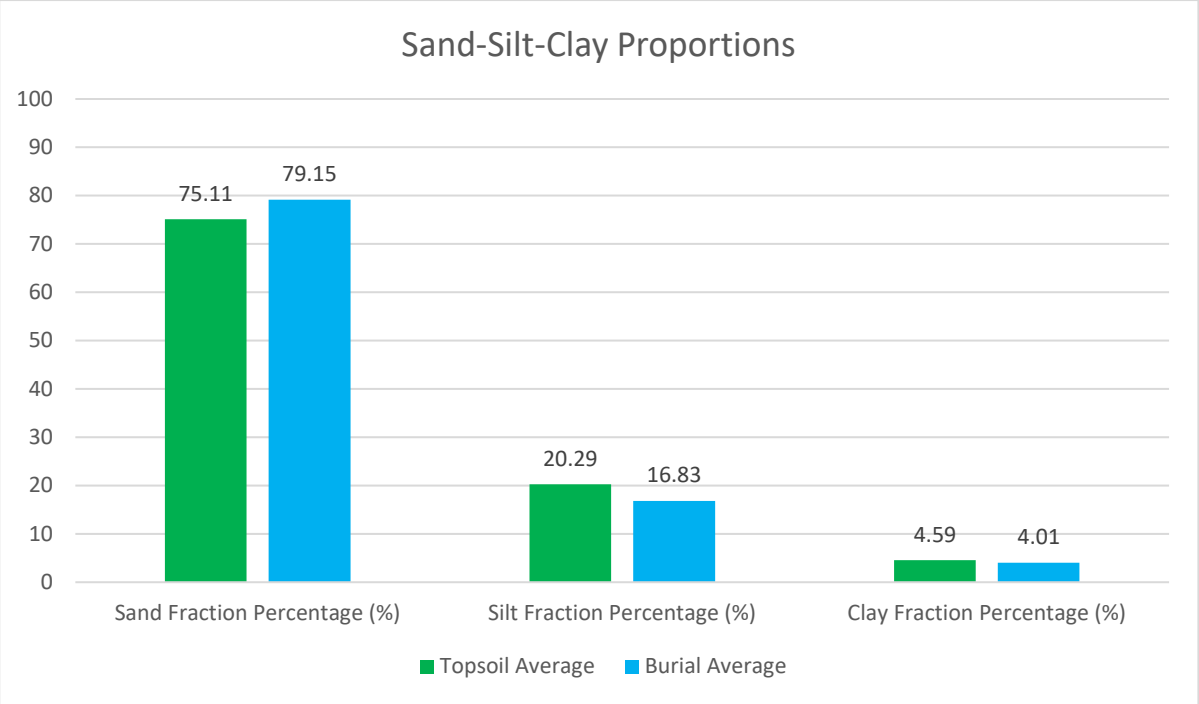


Figure 21 – This is the Sand-Silt-Clay Proportions percentage data for the Wytch Farm Experiment Site.

According to the Soil Survey of England & Wales Soil texture Class Triangle (described further in Appendix Section H – SOILMAN3). The fractions for topsoil and burial layer fall between Loamy Sand and Sandy Loam with the majority once averaged being closer to Sandy Loam. The largest fraction is Sand at 75%-79%, second being Silt (16%-20%) and third being Clay (4%-4.5%).

4.1.2 - Soil Residual Moisture Content:

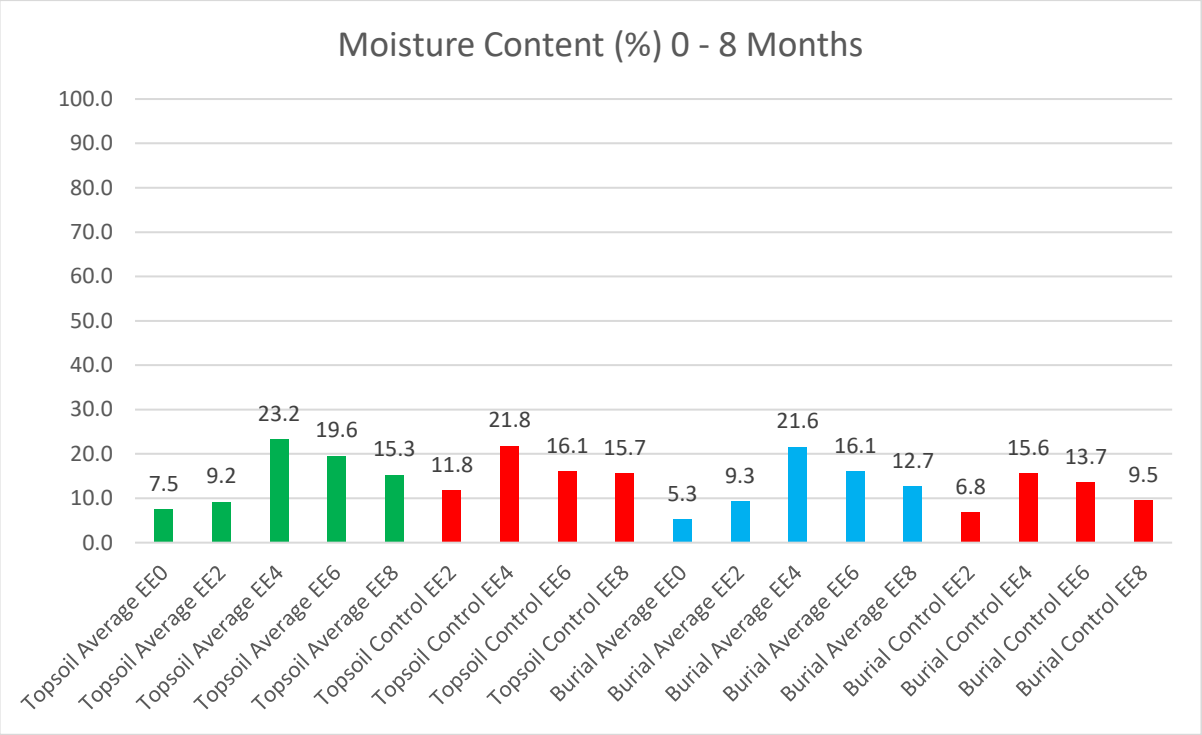


Figure 22 – This is the Moisture Content (%) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019.

This figure above show an exponential increase from the original EE0 interval up to the EE4 interval with the controls showing the same trend. The trends here closely follow changes in the weather whereby, rainfall didn't increase significantly nor did humidity. However, the METoffice snowfall data suggests there was a sudden spike in snowfall the weeks prior EE4, therefore, it's possible that this could have been the cause of this increase. The moisture levels by the EE6 interval have decreased moderately for both the specimen areas and the controls, this could be attributed to the increase in temperature and little rainfall that had occurred between the four and six-month period. Following this is another moderate decrease by the eight-month interval possibly for the same reasons; regardless of specific values, both the burial and topsoil samples follow the same trend, which could indicate that this is part of a regular cycle rather than the impact of the skeletal remains. Statistical analysis revealed that these changes in moisture across the deposition intervals are significant in nature ($P<0.01$) for both the topsoil and burial layer (greater detail on what tests were used and more information can be found in Appendix Section D). A paired t-test revealed that there is no significant difference between the topsoil moisture of the main group and the control group, however, there is a significant difference for the burial main and control group according to the test. Meaning, there is a potential that the skeletal remains may have had an effect on the moisture content, however, it's unlikely as the controls follow the same pattern as the main group, just with minorly lower values.

Interestingly, after comparing all the main variables, it appears there are significant correlations between moisture content and microbial activity for the topsoil (+0.713**), and between moisture and pH for the topsoil (-0.492*) and burial layers (-0.416*). Further information of these results can be found in Appendix Section D.

The implications of these correlations will be discussed further in Chapter 5, however it should be noted now that there are certainly anomalies to be outlined as well as the logical correlations (according to the literature).

The biggest anomaly is the supposed correlation between Moisture and pH, a logical correlation is a positive one, with an increase in moisture, means an increase in pH as increased dilution in the soil reduces the acidity of it. The opposite appears here, the graph below reveals further information on this.

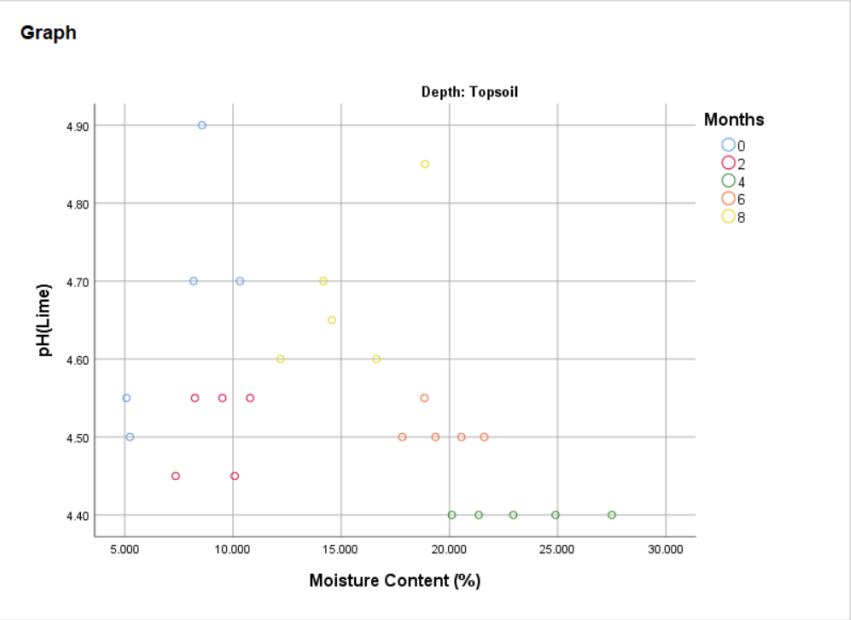


Figure 23 – This graph visualises the relationship between Moisture Content (%) and pH(Lime) over the eight-month deposition period for the topsoil layer. The Correlation Coeffcient here is -0.492 with a significance of 0.012 (P<0.05).

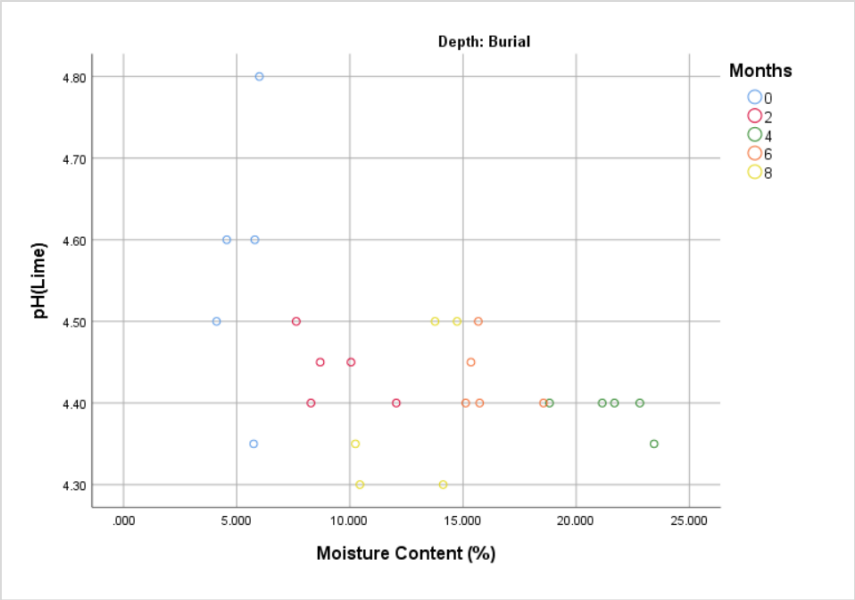


Figure 24 – This graph visualises the relationship between Moisture Content (%) and pH(Lime) over the eight-month deposition period for the burial layer. The Correlation Coeffcient here is -0.416 with a significance of 0.038 (P<0.05).

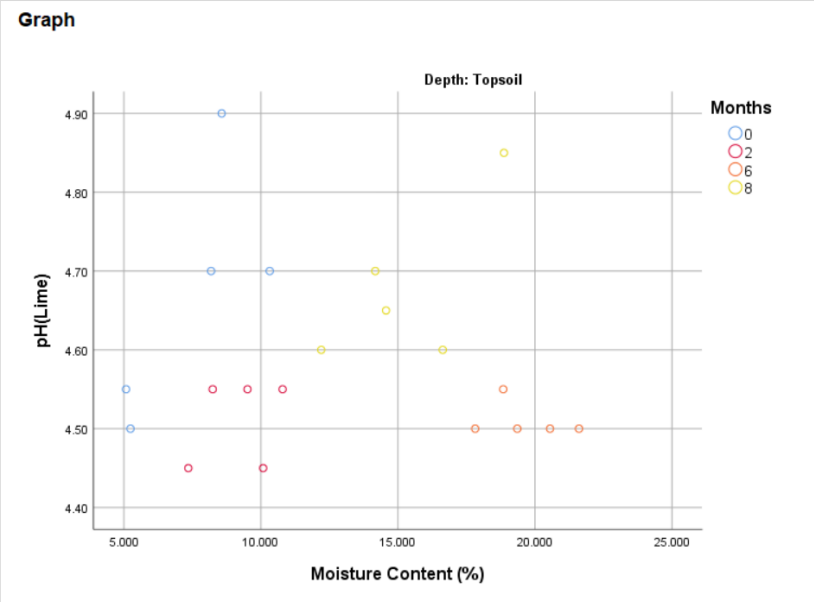


Figure 25– This graph visualises the relationship between Moisture Content (%) and pH (Lime) over the eight-month deposition period for the Topsoil layer (without the 4-month data). The Correlation Coeffcient here is -0.043 with a significance of 0.858 (P>0.05).

The data points from the four-month set for Moisture content are relatively high compared to the rest, and the pH data points aren't as varied as the rest (majority are one value). If the

four-month data points for Moisture content and pH are removed, then the correlation distribution completely changes which is reflected in the graph below.

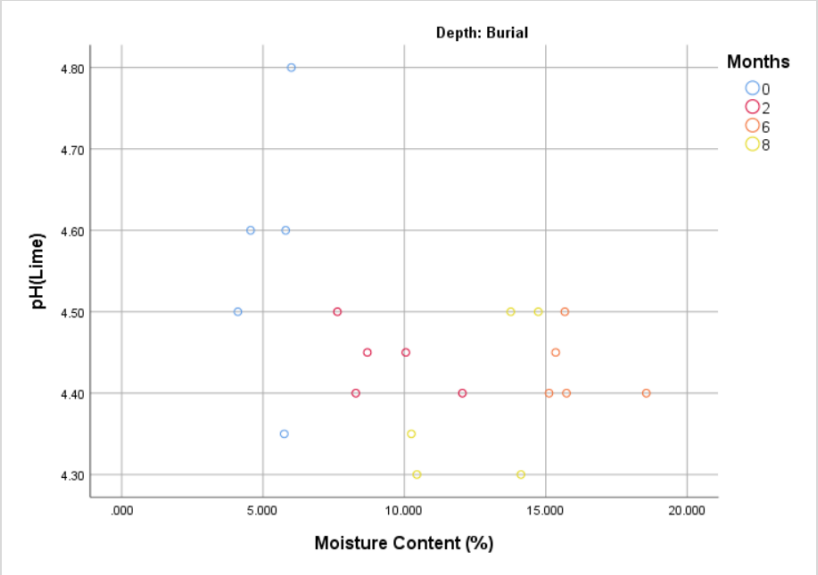


Figure 26 – This graph visualises the relationship between Moisture Content (%) and pH (Lime) over the eight-month deposition period for the Burial layer (without the 4-month data). The Correlation Coeffcient here is -0.343 with a significance of 0.139 (P>0.05).

Once this is done, and the non-parametric correlation test is was ran again, the correlation value changes to a non-significant figure. Meaning for both burial and topsoil layers, there is no correlation between moisture and pH.

4.1.3 - Soil Organic Content:

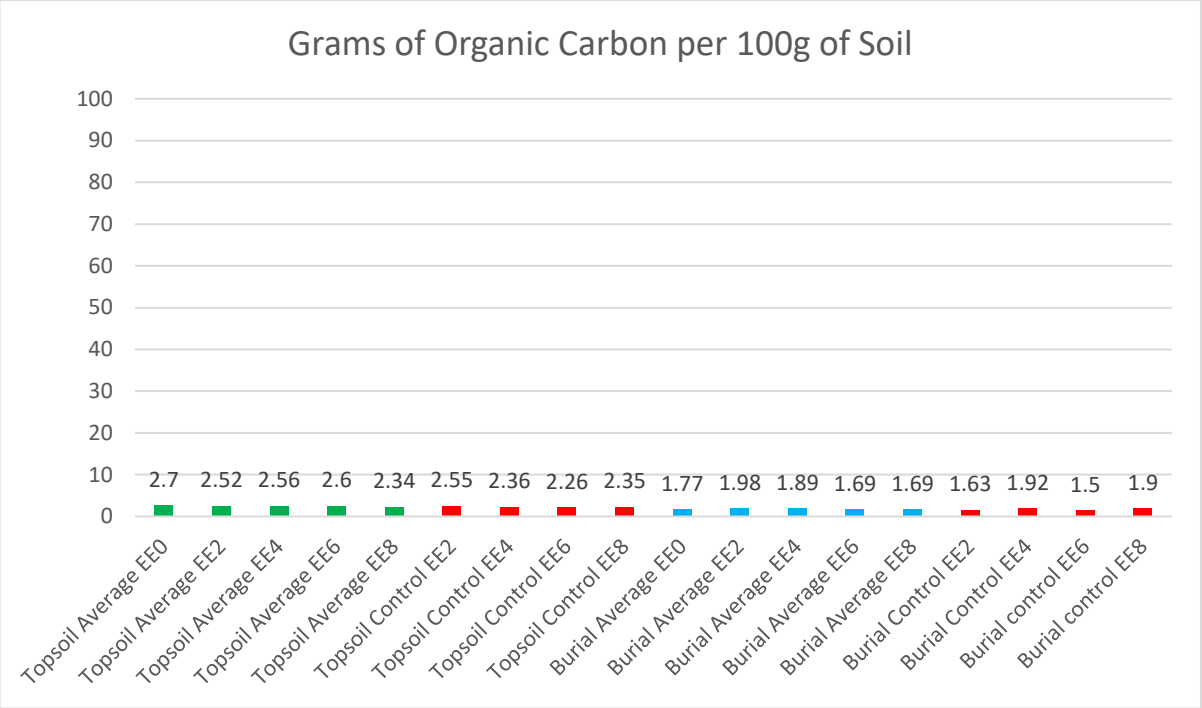


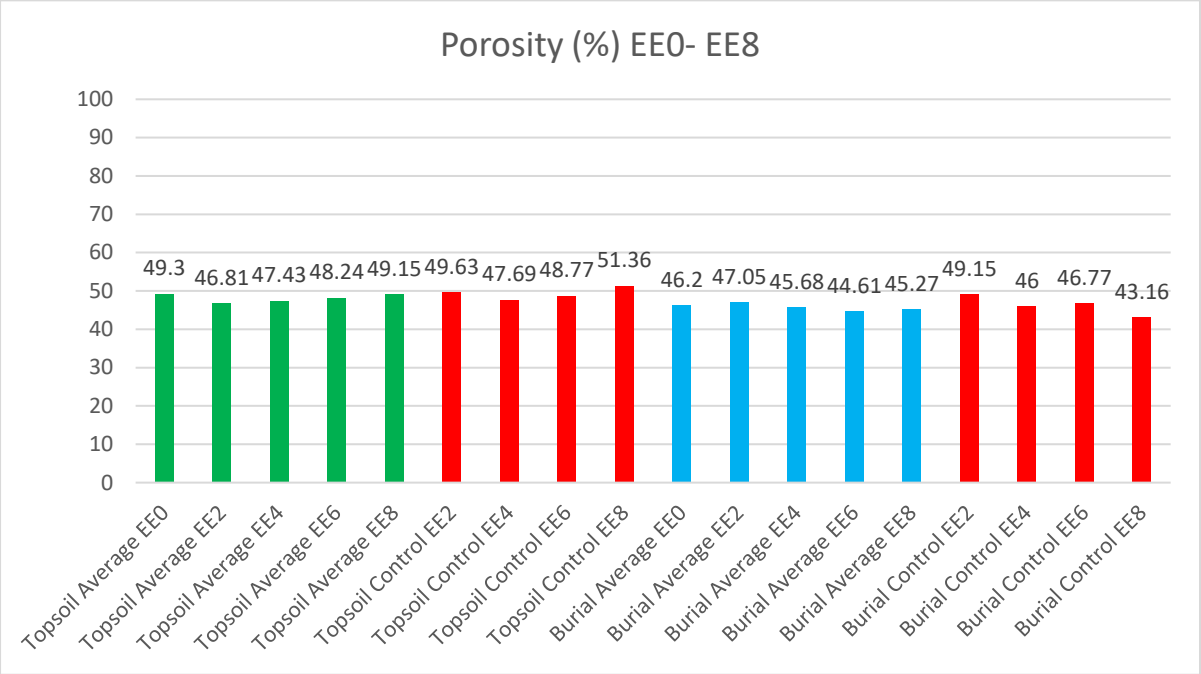
Figure 27 – This is the Organic Content (g) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019.

The figure above shows little variation for both burial and topsoil specimen areas, the only real difference between them is that the burial layer has less grams of organic carbon per 100g of soil. By the eight-month period for both specimen areas they don't return to the original values. Statistical analysis revealed that these changes in organic content across the deposition intervals are not significant in nature (P>0.05) for both the topsoil and burial layer (greater detail on what tests were used and more information can be found in Appendix Section D).

These fluctuations are unlikely to be the result of the skeletal remains. As the controls compared to the main samples using a paired t-test establishes that there is no significant difference between the sample groups.

Once most of the variables were collated and compared to determine if they correlated with each other, it revealed there is a significant correlation between Organic Content and Microbial Activity for the Topsoil sample group (+0.566*).

4.1.4 - Porosity (Bulk and Particle Density):



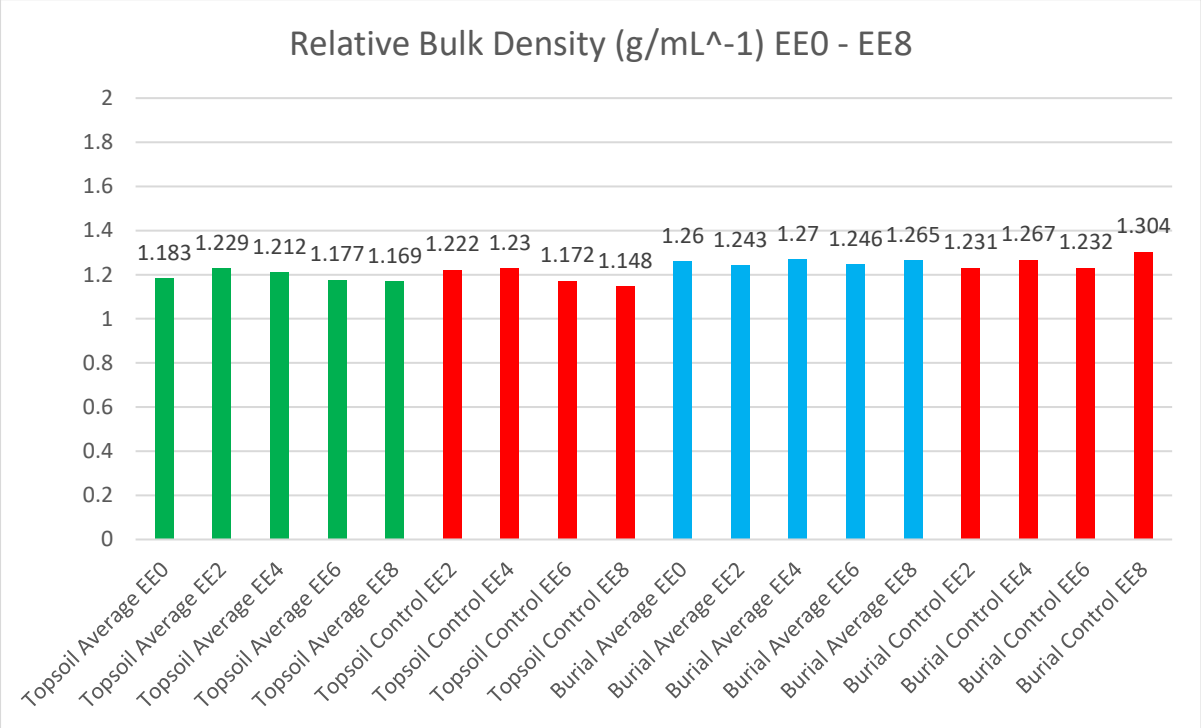


Figure 28 (A-B)- (A): This is the Porosity (%) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019. (B): This is the Relative Bulk Density (g/mL^-1) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019.

According to the figure above, the relative bulk density and therefore porosity haven't appeared to have changed drastically as a result of the bone specimens nor overturning upon first impression. Interestingly, at the two-month interval for both topsoil and burial layers, the relative bulk density and porosity values are very close to each other, this is most likely the result of the soil being disturbed and homogenising, therefore, they appear as similar densities. This is followed by a slow reversal indicating an equilibrium attempting to be reached over the rest of the periods; most likely as a result of compaction and the soil settling. The expected pattern is the density of the burial layer will be moderately higher than the topsoil layer, which is reflected above with the porosity values which are moderately lower for the burial specimen group than the topsoil group. Statistical analysis revealed that these changes in Porosity and Relative Bulk Density across the deposition intervals are significant in nature ($P<0.05$ For Porosity and $P<0.01$ for Relative Bulk Density) for both the topsoil and burial layer (greater detail on what tests were used and more information can be found in Appendix Section D). The bone specimens most likely did not affect the change in values, these were influenced by the action of the soil overturning, and the values returning to their originals is the action of compaction for the burial layer and settling for the topsoil layer (this is discussed in Chapter 5 further). A paired T-test was conducted and revealed that there is no significant difference between the control groups for the burial and topsoil layer for porosity and relative bulk density. So, it's unlikely that the bone specimen's presence has contributed towards the changes.

Once most of the variables were collated and compared to determine if they correlated with each other, it revealed there is a significant correlation between Porosity and Relative Bulk Density for the topsoil (-0.758**) and burial sample group (-0.486*). There is another anomalous correlation that appears to be between the Relative Bulk Density and Microbial Activity of the burial layer. There appears to be a strong significant correlation (+0.520**) between them both, of which is reflected in this graph below.

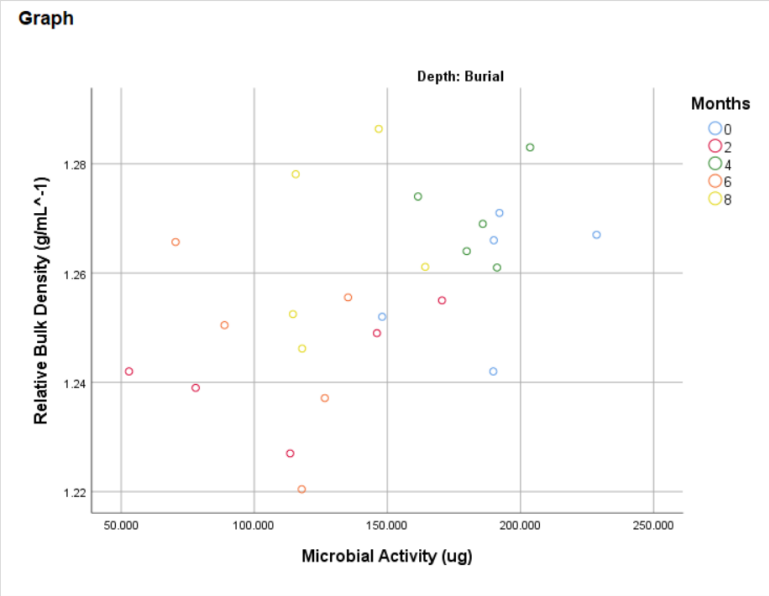


Figure 29 – This graph visualises the relationship between Relative Bulk Density (g/mL^-1) and Microbial Activity (µg) over the eight-month deposition period for the Burial layer.

This is not an issue of there being odd spikes within the month data sets, therefore this correlation appears legitimate. It is an anomaly, as a typical correlation between these factors (if present) should be a negative correlation, with an increase in microbial activity being the result of a decrease in bulk density, as there is greater gas diffusion and oxygen content. If this was the case, then the porosity values would strongly (positively) correlate with the microbial activity data. The figures below shows that that is the opposite case here, therefore, in this experiment, these values have got the same distribution, but are not the result of a direct relationship with each other.

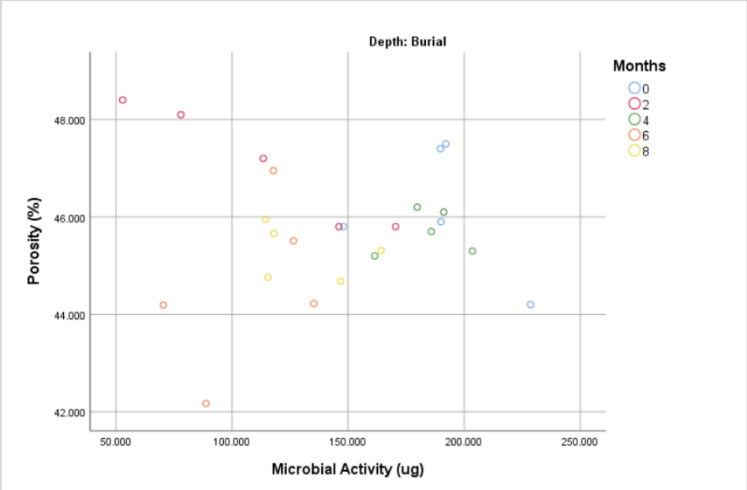


Figure 30 – This graph visualises the relationship between Porosity (%) and Microbial Activity (µg) over the eight-month deposition period for the Burial layer. The Correlation Coeffcient here is -0.011 with a significance of 0.959 (P>0.05).

4.1.5 - Soil Acidity (pH):

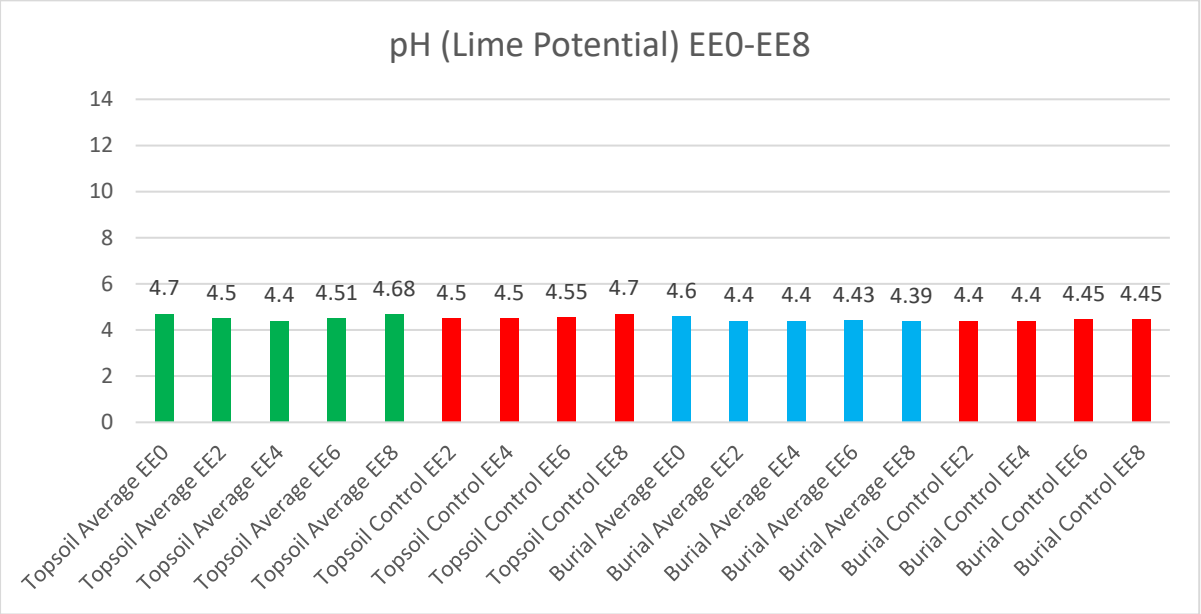


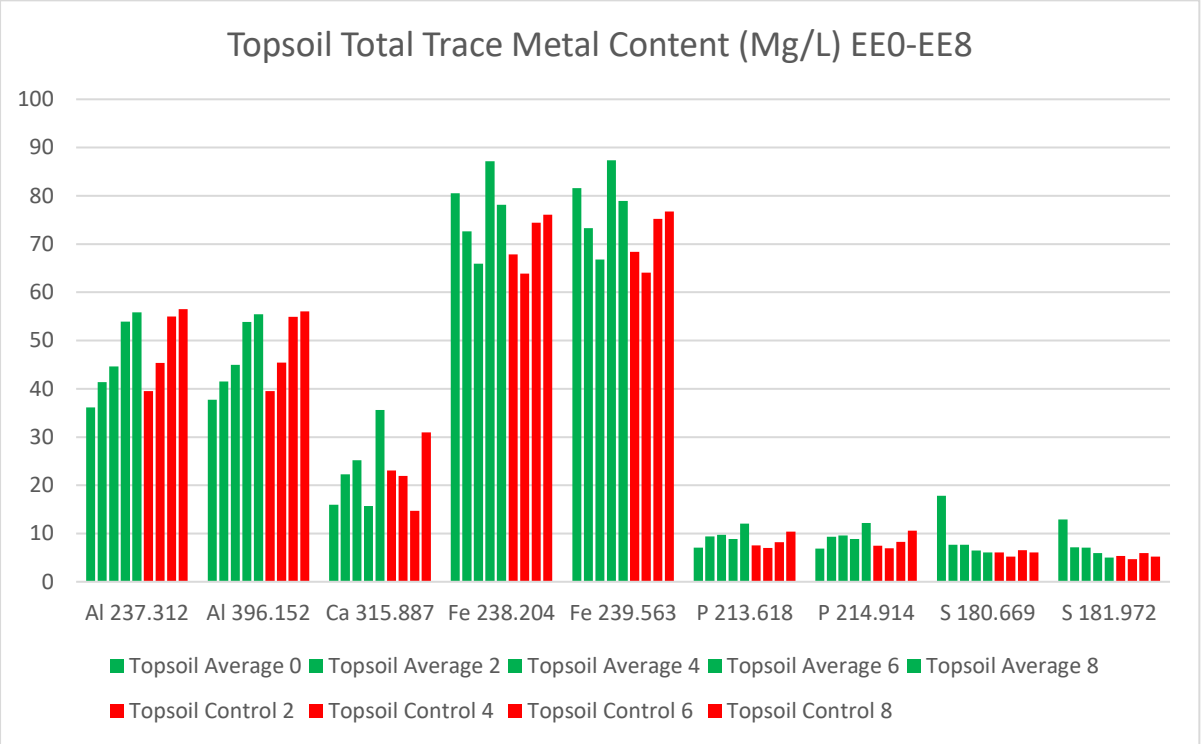
Figure 31 – This is the pH (Lime) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019.

As expected, the pH levels have experienced a minor influx, not major nor a permanent change to the soil matrix. The changes haven't exceeded a decrease greater than 0.3 in the pH scale, these changes may be seasonal, or potentially be the result of decomposing remains; it'll be explained further in Chapter 5.

Despite these appearing to be a minor influx, statistical analysis revealed that these changes in pH (Lime Potential) across the deposition intervals are significant in nature ($P<0.01$) for both the topsoil and burial layer (greater detail on what tests were used and more information can be found in Appendix Section D). A paired T-test for the topsoil results revealed that there is no significant difference between the control group and the main group. A Wilcoxon Signed Rank test for the burial results revealed there is no significant difference between the control group and the main group.

Interestingly there is a relatively strong correlation between pH and Porosity of the topsoil layer (+0.501*) that is significant. This essentially means, when the porosity has been increasing, so has the pH, and vice versa with decreases. It could be the result of the amount of water flowing within the pore spaces and thus affecting the acidity of the soil through dilution (this is discussed in further detail in the Extended Analysis in Appendix Section A. It was also found that pH correlated strongly with moisture (negatively) for both topsoil and burial layers. These were seen as anomalies in the dataset, which has been explained above.

4.1.6 - Major and Trace Elements in Soil Sediments:



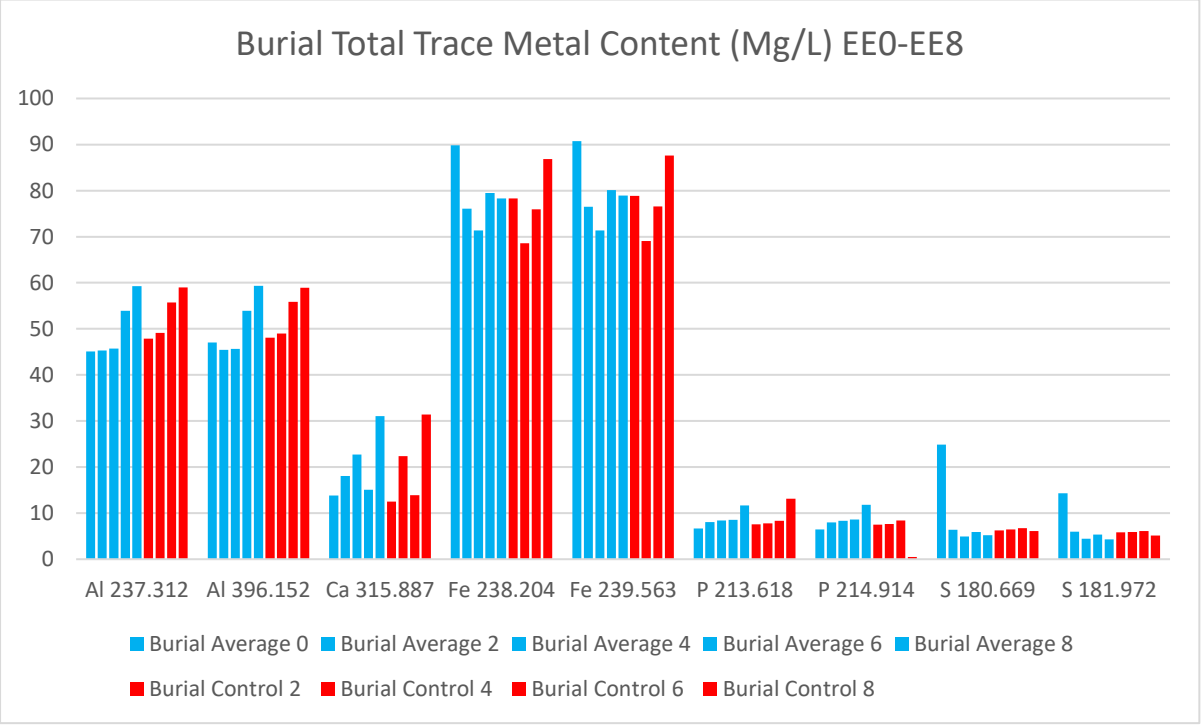


Figure 32 (A-B) – (A): This is the Topsoil Trace Metal Content (Mg/L) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019. (B): This is the Burial Trace Metal Content (Mg/L) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019.

The above figures show an intriguing trend among the 'leaching-specific' metal ions across the deposition intervals. This being an increase in calcium, phosphorus and aluminium, and a

fluctuating decrease in iron and sulphur. The increase in calcium and phosphorus and decrease in iron are of interest mostly based on their relationship between skeletal remains and the soil matrix. It's written that a change in these ion amounts within the soil matrix can indicate whether the bones specifically are leaching out these elements into the soil as a product of decomposition.

Statistical analysis revealed that these changes in Metal Ion Content in the specimen area across the deposition intervals are significant in nature ($P<0.01$) for both the topsoil and burial layer (greater detail on what tests were used and more information can be found in Appendix Section D).

Unlike other variables, these changes are most likely the result of the direct interaction between the soil matrix and the bone specimens due to their larger difference in values and the nature of the investigated ions. The controls appear to follow the same distribution and have similar values to the main group, this could be based on the proximity of the control area to the bone specimens. This was rectified for the six- and eight-month data sets as soil samples were collected from a further distance (1.5m) of where the bones were buried (with permission from another researchers plot), with soil being taken at similar depths (for topsoil and burial) on the same collection day for April and June.

It was found that there was no significant difference between the control group and the main group for the metal ion results, however, the new controls especially for Calcium and Phosphorus brings it into question. It's not appropriate to run these through statistical analysis as the zero, two and four-months would be from the same plot, and the six and eight months are from a nearby plot. However, basic comparison shows that the eight-month results for Calcium and Phosphorus are undeniably different in amount supporting the above hypothesis.

Sample	Al 237.312	Al 396.152	Ca 315.887	Fe 238.204	Fe 239.563	P 213.618	P 214.914	S 180.669	S 181.972
Topsoil Average 6	53.93615	53.8866	15.67882	87.18165	87.3845	8.85867	8.87799	6.504039	5.949196
Topsoil Control 6*2	47.4319	48.07215	11.11385	81.62945	81.0589	8.082385	8.07107	6.07806	5.7318
Topsoil Average 8	55.84893	55.42782	35.636	78.15623	78.92683	12.03853	12.19551	6.060256	5.035648
Topsoil Control 8*2	54.32625	55.3809	8.429245	77.54925	77.3752	8.825895	8.801385	4.92367	4.58515

Sample	Al 237.312	Al 396.152	Ca 315.887	Fe 238.204	Fe 239.563	P 213.618	P 214.914	S 180.669	S 181.972
Burial Average 6	53.92021	53.90456	15.09908	79.45742	80.07596	8.532889	8.583674	5.8829	5.325395
Burial Control 6*2	54.83615	55.7212	13.42145	74.63455	74.0708	8.61991	8.6022	4.488022	4.31808
Burial Average 8	59.25947	59.30438	31.06283	78.28939	78.9062	11.67504	11.83365	5.210301	4.331315
Burial Control 8*2	60.76655	62.8541	16.4929	101.6297	100.5213	7.691585	7.75151	4.41342	3.9455

Table 4 – This is the Topsoil Trace Metal Content (Mg/L) data for the 'new' six and eight-month controls.

Table 5 – This is the Burial Trace Metal Content (Mg/L) data for the 'new' six and eight-month controls.

The data in the table above establishes that the new controls for eight months differ especially for the key variables that are investigated for leaching from skeletal remains. The six-month results are an anomaly among the rest of the data, as they suddenly revert back to close to the original values from October (EE0); which is odd as its unlikely that there is a sudden change in ions against the trend, which then reverts again by eight-months. However, what is key is by the end of the experiment, when comparing the new controls to the main results, it shows that the changes to the ion content is happening in the area where the bone specimens have been deposited. The key difference here is the comparison of Calcium and Phosphorus specifically, these are the elements likely to be leached from the skeletal remains into the soil; the new controls may contribute to the hypothesis that these ion changes in the ground at due to the presence of the bone specimens, and that the original controls are too close to the specimen area. The hypotheses of why these changes in accordance with the controls is explained further in Chapter 5.

During the experimental investigation, there was a plethora of micro-mollusks and macroarthropods that were found (Arachnids, Isopods, Coleopterans etc) within the porous areas of the bone specimens, within the roots and on the surface of the bone. However, it's hypothesised that their purpose on the specimens may not have been an obligate dependency, rather it's a dependency on the structure of the bone (much like using a log or inside of a branch) as well as a good source of nutrients. Further information regarding their identification is below can be found in Appendix Section A.

Although, a majority of the organisms found on the specimens weren't osteophagic by nature, it was hypothesised that they were consuming the decomposing vegetation and fungi that was growing on the bone specimens (photographic evidence can be seen in Section 4.2 below). To argue against the null hypothesis that the organisms were only just being active there and were picked up by chance. It was considered that the roots growing on the bone specimens (plant root and mycorrhizal fungal hyphae roots growing) were more nutritious than the surrounding vegetation due to their direct attachment to the bone.

Samples	Al 237.312	Al 396.152	Ca 315.887	Fe 238.204	Fe 239.563	P 213.618	P 214.914	S 180.669	S 181.972
Burial Root Sample 1.1	8.21487	8.27227	31.5384	13.9615	13.7693	13.5985	13.6248	5.82862	4.90253
Burial Root Sample 1.2	8.48661	8.50384	34.0468	12.0882	11.9882	13.6395	13.6289	6.34263	5.3155
Average	**8.35074**	**8.388055**	**32.7926**	**13.02485**	**12.87875**	**13.619**	**13.62685**	**6.085625**	**5.109015**
Burial Root Control 1.1	8.81902	8.81651	25.8603	9.91689	9.83624	5.2564	5.29643	3.73183	3.02295
Burial Root Control 1.2	9.62326	9.61913	23.6292	10.4547	10.4345	7.84379	7.97331	3.77691	3.09339
Average	**9.22114**	**9.21782**	**24.74475**	**10.1858**	**10.13537**	**6.550095**	**6.63487**	**3.75437**	**3.05817**
Surface Root Sample 1.1	8.22341	8.20933	51.4253	6.87731	6.84611	12.4617	12.5465	6.42987	5.05856
Surface Root Sample 1.2	3.31701	3.29658	49.9264	4.55864	4.5433	14.2351	14.5206	5.84789	4.54699
Average	**5.77021**	**5.752955**	**50.67585**	**5.717975**	**5.694705**	**13.3484**	**13.53355**	**6.13888**	**4.802775**
Surface Root Control 1.1	6.54512	6.53578	28.8434	8.13896	8.18073	5.08963	5.16779	3.96269	3.19622

Samples	Al 237.312	Al 396.152	Ca 315.887	Fe 238.204	Fe 239.563	P 213.618	P 214.914	S 180.669	S 181.972
Surface Root Control 1.2	7.43861	7.43436	26.0121	9.26169	9.28426	9.17175	9.2752	3.81535	3.10236
Average	**6.991865**	**6.98507**	**27.42775**	**8.700325**	**8.732495**	**7.13069**	**7.221495**	**3.88902**	**3.14929**

Table 6 – This is the Trace Metal Content (Mg/L) data for the digested roots found on the surface and buried bones from the six-month deposition group.

The data in the table above are the trace metal ion results from the digested roots collected from the six-month surface burial bone specimens, as well as the surface and burial layers for controls. A further investigation is needed into this phenomenon with a greater sample size, different bone types, different deposition intervals etc. However, this appears to support the initial hypothesis, as in both the burial and surface root samples they have higher amounts of Calcium and Phosphorus specifically, compared to their controls. This is logical as the roots would be absorbing these nutrients specifically from the bone specimens, and therefore, theoretically will make them a better source to consume for the macroarthropods. The importance of this is discussed further in Chapter 5.

4.1.7 - Total Microbial Activity of Soil:

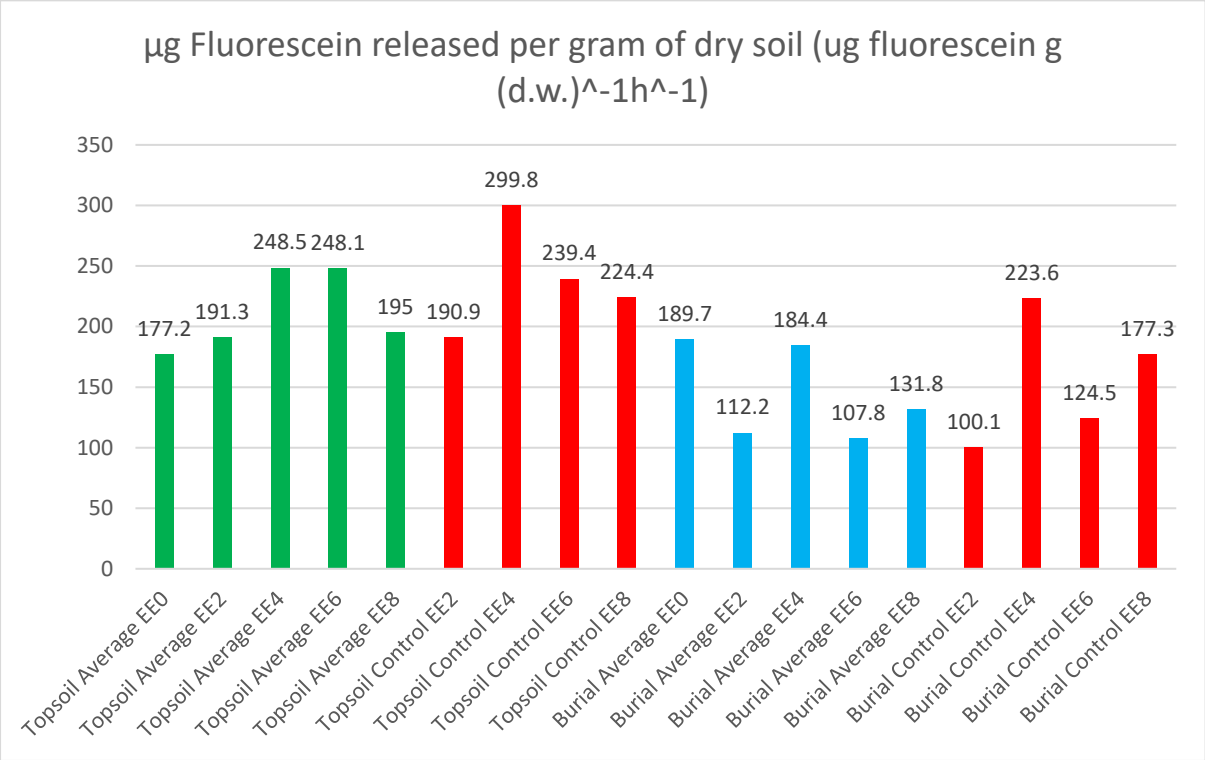
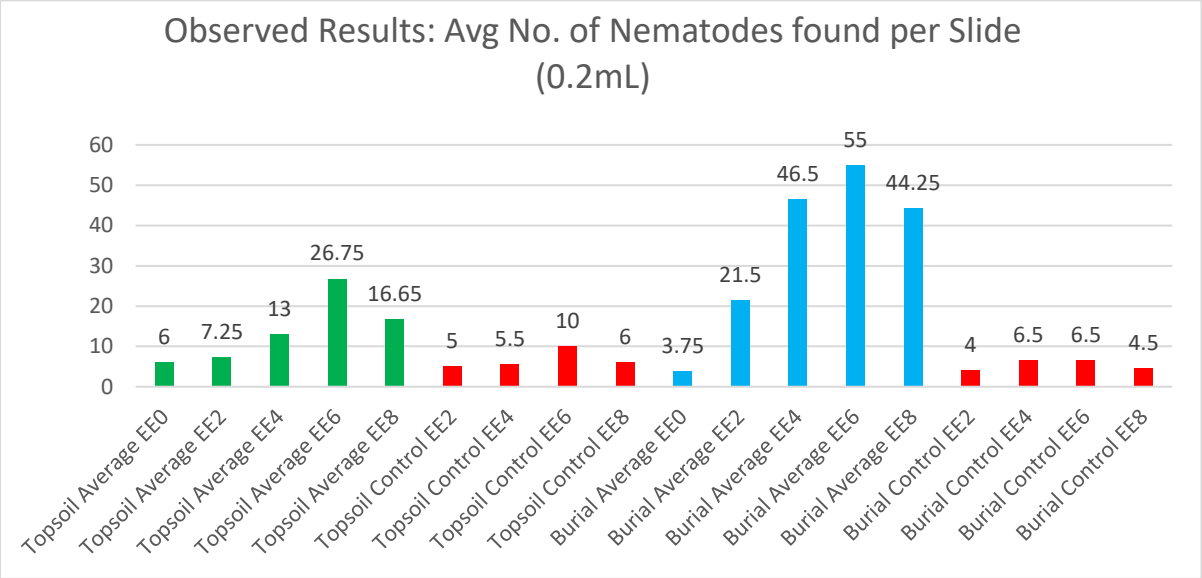


Figure 33 – This is the Total Microbial Activity (µg) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019.

The microbial fluorescein diacetate assays reflect the total microbial (bacterial and fungal) activity in the soil matrix efficiently and is useful as an indicator of the changes to their population in the environment. The data in the figure above for the topsoil sample group reflects a more logical distribution for changes across the year, however, the burial sample group is sporadic in nature. It's possible the trend here is most likely of the influence of the buried bone specimens as well as the increased release of nutrients and increased amount of bacteriophagic and fungivore microorganisms (Nematodes) (shown below). Statistical analysis revealed that these changes in Microbial Activity across the deposition intervals are significant in nature ($P<0.05$ for Topsoil and $P<0.01$ for Burial) for both the topsoil and burial layer (greater detail on what tests were used and more information can be found in Appendix Section D). A paired T-test revealed that there is no significant difference between the control groups and the main group for burial and topsoil layers. However, the new controls for the six-month and eight-month deposition interval brings this into question and is further discussed in the discussion.

It was found that there are significant correlations between microbial activity and organic content and moisture for the topsoil. As well as a significant but anomalous correlation between microbial activity and relative bulk density. The correlations found for the topsoil explain the significant changes across the deposition periods as it's been noted that an increasing amount of organic content and moisture can influence microbial activity (this is discussed further in Chapter 5).

4.1.8 - Microorganism and Macroarthropod Presence in Soil:



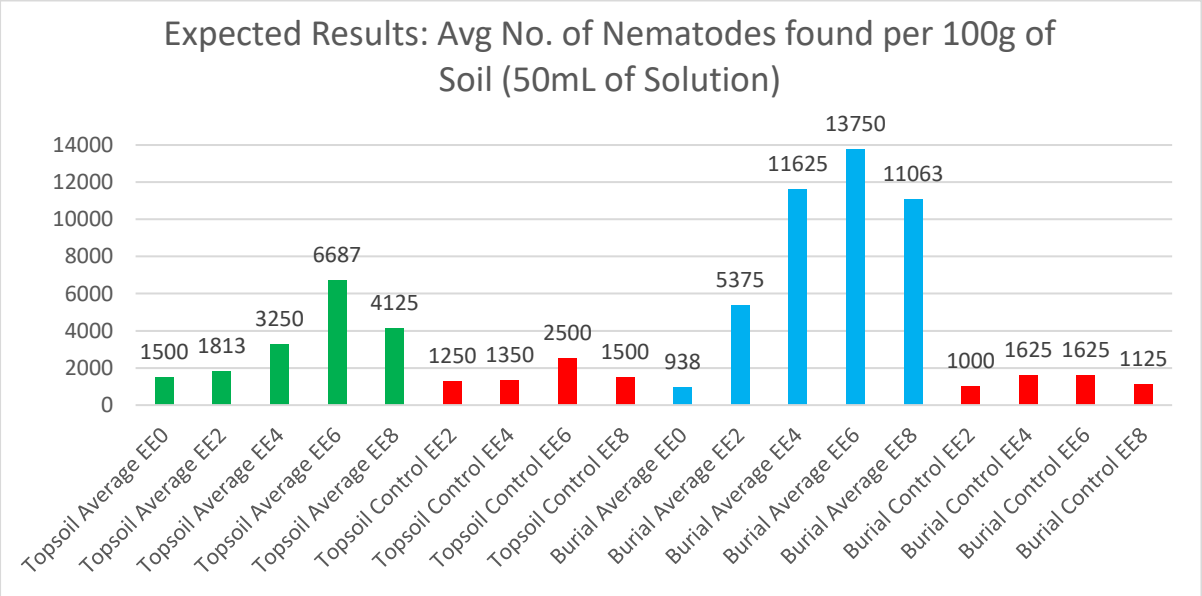


Figure 34 (A-B) – (A): This is the Observed Average Number of Nematodes (Per 0.2mL) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019. (B): This is the Expected Average Number of Nematodes (Per 100g) data for the total eight-month deposition experiment at Wytch farm from October 2018 – June 2019.

Despite the associated complications with the quantification method of the Nematodes, the table above shows a clear trend regarding the specimen areas and the control values. This being an increase in their abundance in the proximity of the specimen and a change in the feeding guild proportions. A possible relationship between the increase in nutrients in the soil from the bone specimens, variable microbial populations and these Nematodes is present and is discussed in Chapter 5.

Statistical Analysis was not conducted on these results, due to the fact that the method of quantification is considered questionable and there were problems that were encountered when running such a small sample size through the SPSS software. Despite this, there is a clear trend that can be seen here which there is a large increase in abundance in the specimen areas with little variation in the control groups for both the observed and expected results.

4.1.9 - Climate Zone and Weather Conditions:

According to the MET-Office the United Kingdom is known to have a Temperate Climate, specifically a 'Maritime Climate' where the temperature overall is quite moderate with the possibilities of hot summer days and cold winter nights (MetOffice 2012). Temperate climates are classified with an average monthly temperature above 10 degrees in their warmest months and above -3 degrees in their colder months (Spaargaren and Deckers 2005; Pratolongo *et al.* 2019). The METOffice temperature data for the Hurn station representing the Experiment Site weather conditions reflects this classification i.e. it's within the 'typical' range for what is considered to be a temperate climate. Although, the weather station is based at Hurn and not in Wareham where the experiment site is, the average temperatures for the bi-monthly periods are very close (Climate-Data 2019). Skeletal remains deposited in a temperate climate with four seasons of varying weather poses an interesting debate on whether it is a particularly destructive environment or not compared to an arid desert or a snowy terrestrial forest. It is difficult to suggest which is the more destructive environment towards skeletal remains, as there are certain microenvironmental factors that may be more influential (stated in Chapter 3). (Further information on the weather conditions of the experiment site are in Appendix Section A – Extended Analysis).

4.2 - Macroscopic Changes:

4.2.1 - Qualitative Changes Two Months:

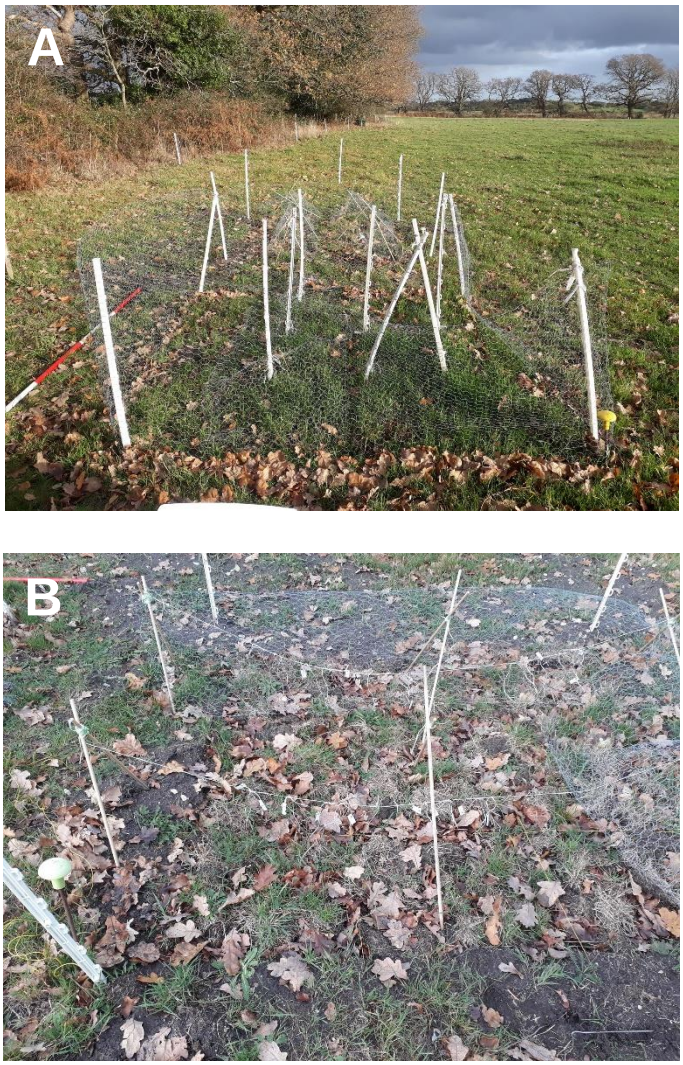


Figure 35 (A-B): shows the experiment site at the two-month interval.

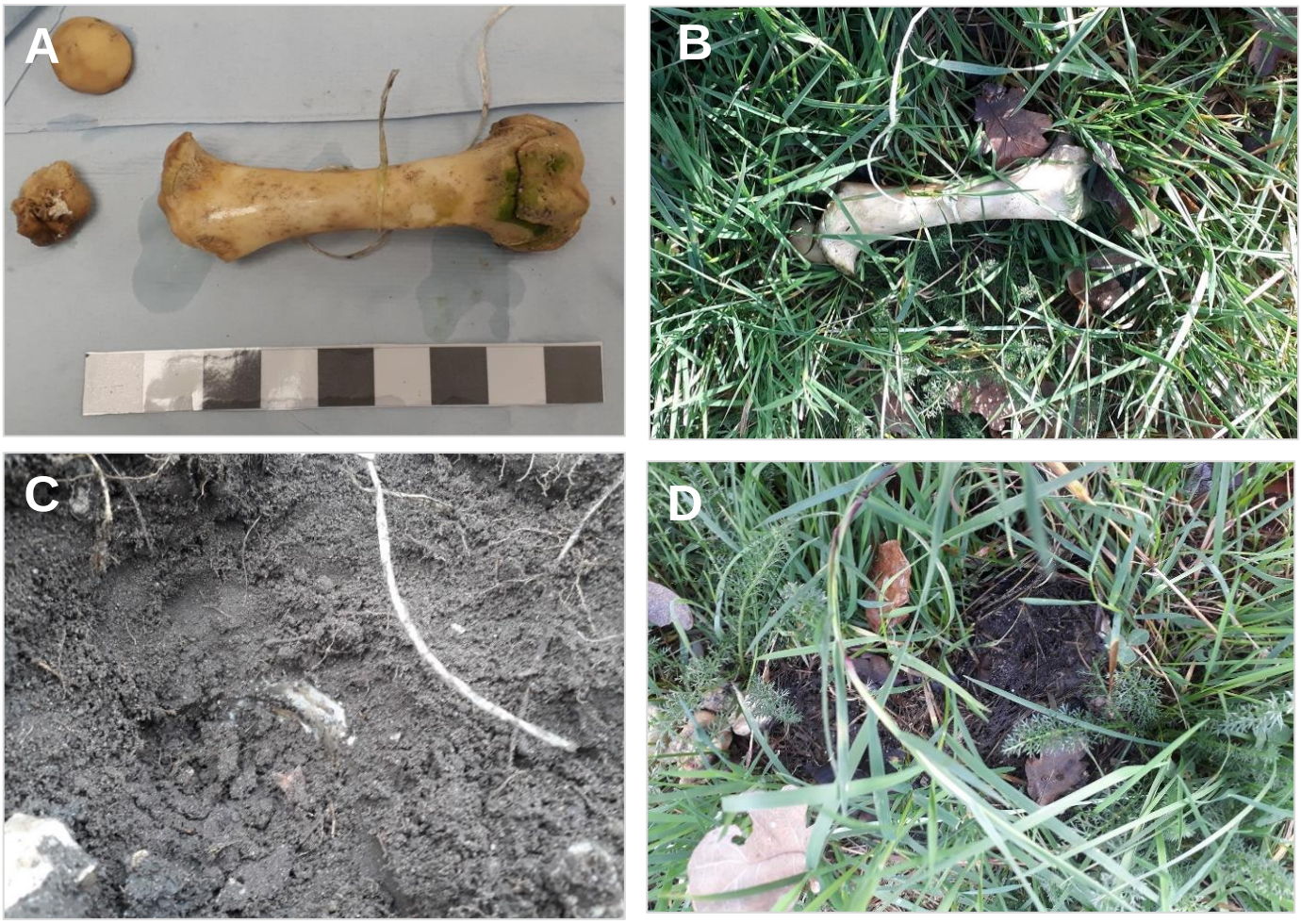


Figure 36 (A-D): Shows femora from the two-month specimen at the lab and in situ, and what the soil looked like underneath a buried bone and a surface one.

The above figures show that there had been slight grass growth for the surface specimen area and the turf for the burial specimen area had settled without the grass perishing. The surface specimens were still visible and had shown interesting interactions as a result of being in contact with the ryegrass. There is minor green staining most likely from algal growth or could be chlorophyll staining. The surface specimens have perished the grass it lies upon showing signs of arthropod activity in the contacting soil in the form of eggs. During the removal of the buried specimens, it was noted in the areas the soil was in contact with the bone specimen, there was some form of fungal growth left in the soil.

Figure 37 (A-B): Bone specimens from the two-month surface deposition area showing evidence of arthropod activity.

Among the earlier specimens there were several macroarthropods collected from the surface specimens and few from the burial specimens. Those found on the bones and in the bags, were contained in during transfer were collected and stored in sterilin tubes with 70% IMS. There is the potential that there is some surface modification from the arthropod activity that has been seen in Huchet (2014).

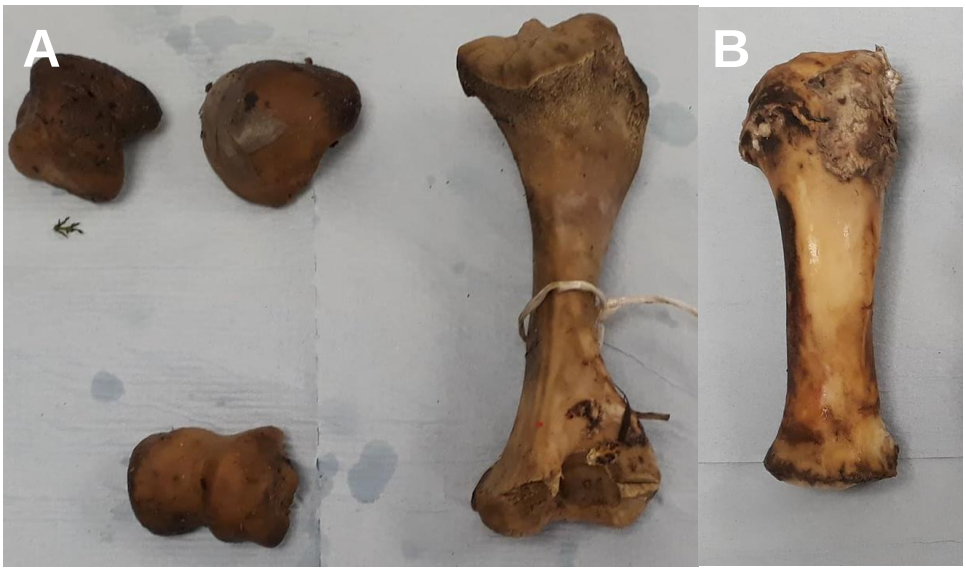
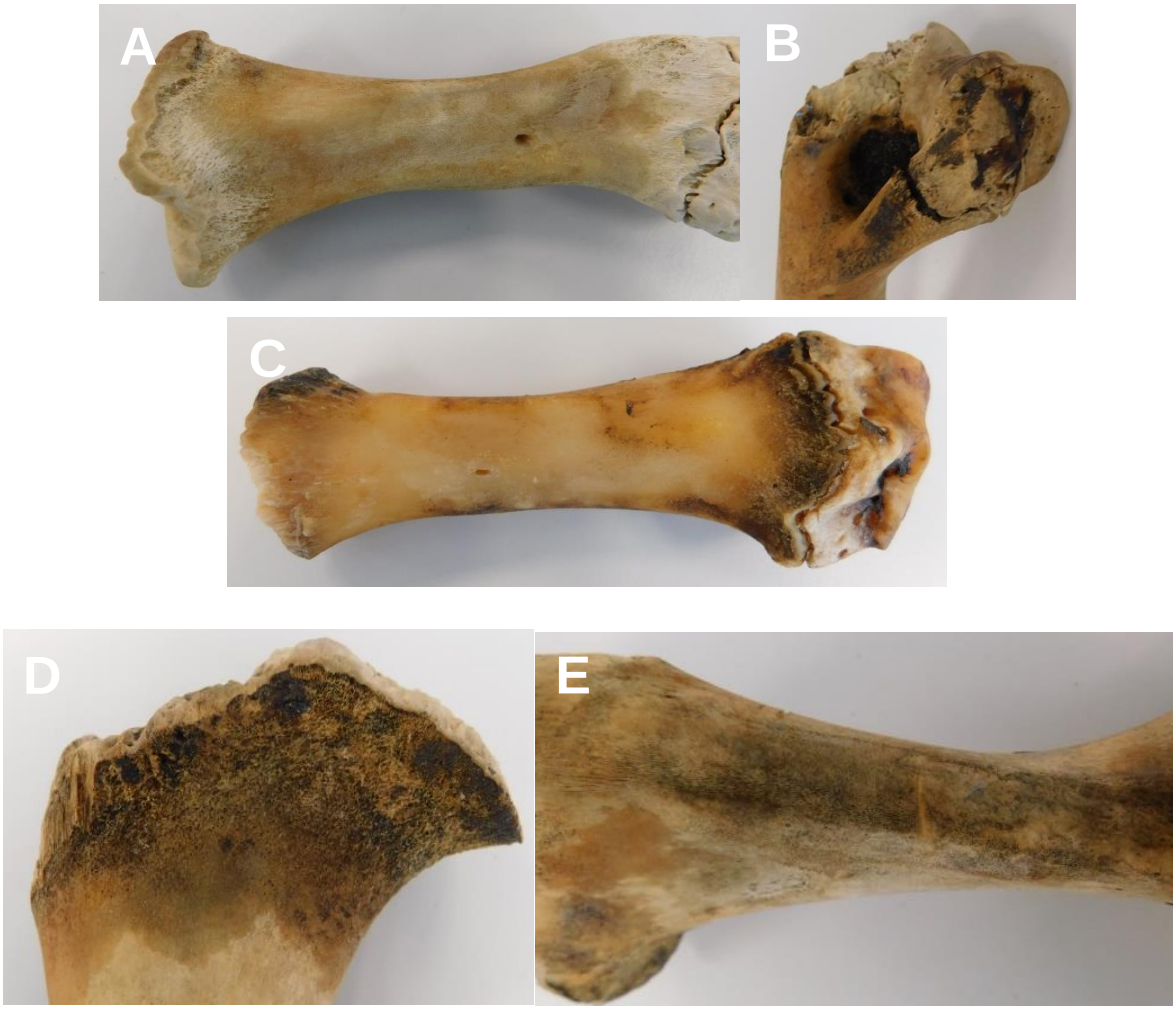


Figure 38 (A-B): Bone specimens from the two-month burial deposition area showing small amounts of cartilage and soft tissue present in small areas.

The majority of the cartilage and soft tissue has decomposed fully by this two-month interval there are a few specimens however where it was still present (figure 38 (A-B). This was promptly removed after photographing them to ensure there would not be further potential microbial activity.



Based on the above figures, it's key to note that the surface texture on some of the specimens

Figure 39 (A-E): Bone specimens from the two-month burial deposition area. Some are showing they have retained grease still as well as attached epiphyses.

can be mistaken for modification via weathering, however, as established in Chapter 5, these cavities are present as part of juvenile remains as a sign of active growth. They do not appear to have been affected much or show signs of soil erosion or consumption by arthropod activity. However, those cavities that are exposed will facilitate damage further by allowing the introduction of acidic soil water, abrasive grains, macroarthropods, roots and more; thus, it has certain implications for the four-month deposits. However, the implications of what has occurred at this stage as well as the difference between this one and the next intervals, is discussed in Chapter 5). Overall, for the two-month specimens, aside from minor organic staining, majority removal of soft tissue & cartilage, arthropod activity, and minor surface stripping. There are little macroscopic changes that have occurred and that are deemed notable for this stage.

4.2.2 - Qualitative Changes Four Months:

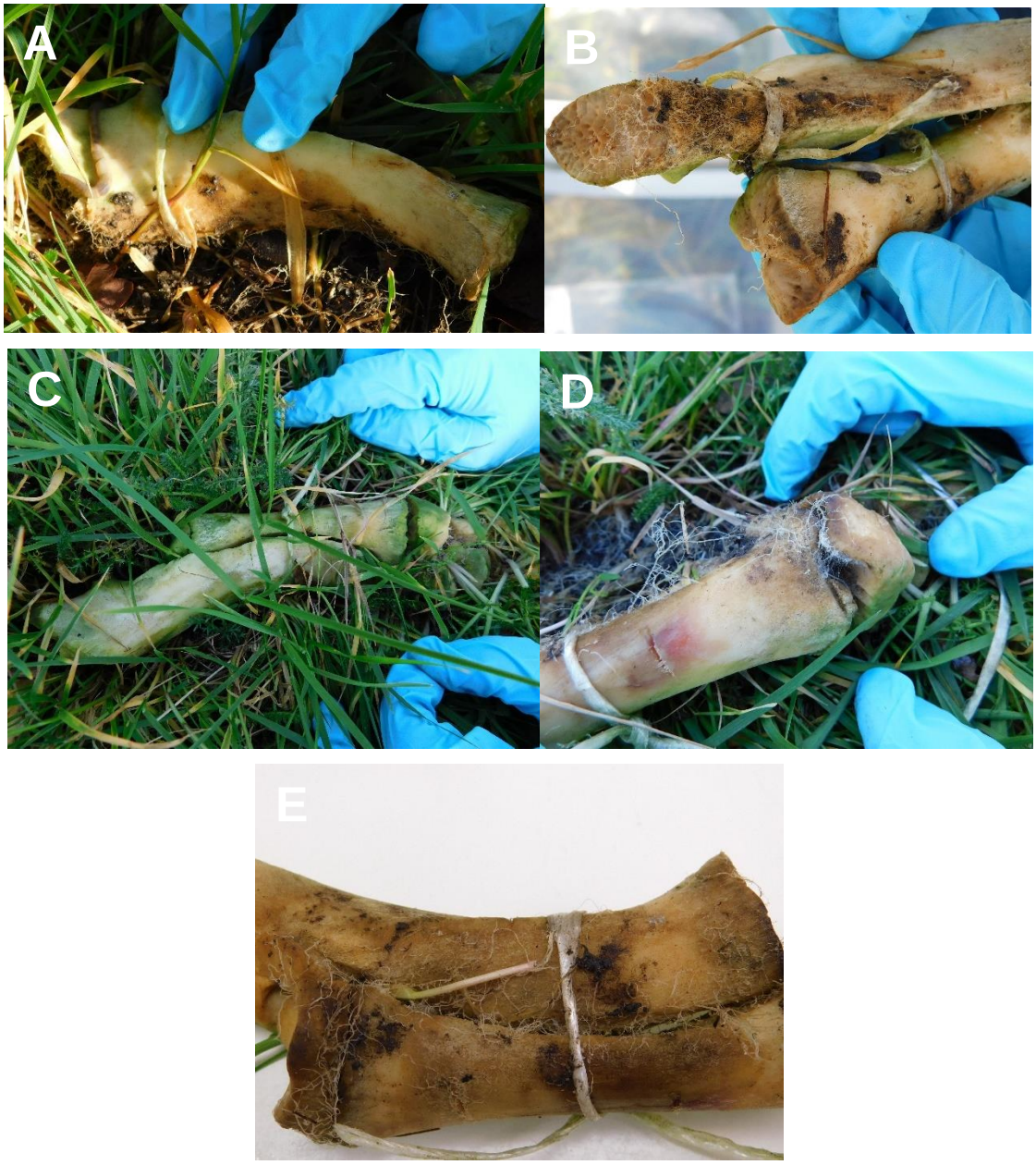


Figure 40 (A-E): Bone specimens from the four-month surface deposition area; (E): Pig 3 Specimen 5.

The above figures show that upon arrival at the site, the surface specimens have shown signs of root activity between the grass and the soil side of the specimens. Where the surface flora has perished underneath the specimens, roots from the surface have taken hold of the specimens facing down. It was later noted during the cleaning process that several of the specimens had shown this root growth. Fungal hyphae root growth was seen on several of the specimens, especially between the areas of the epiphyseal joints.

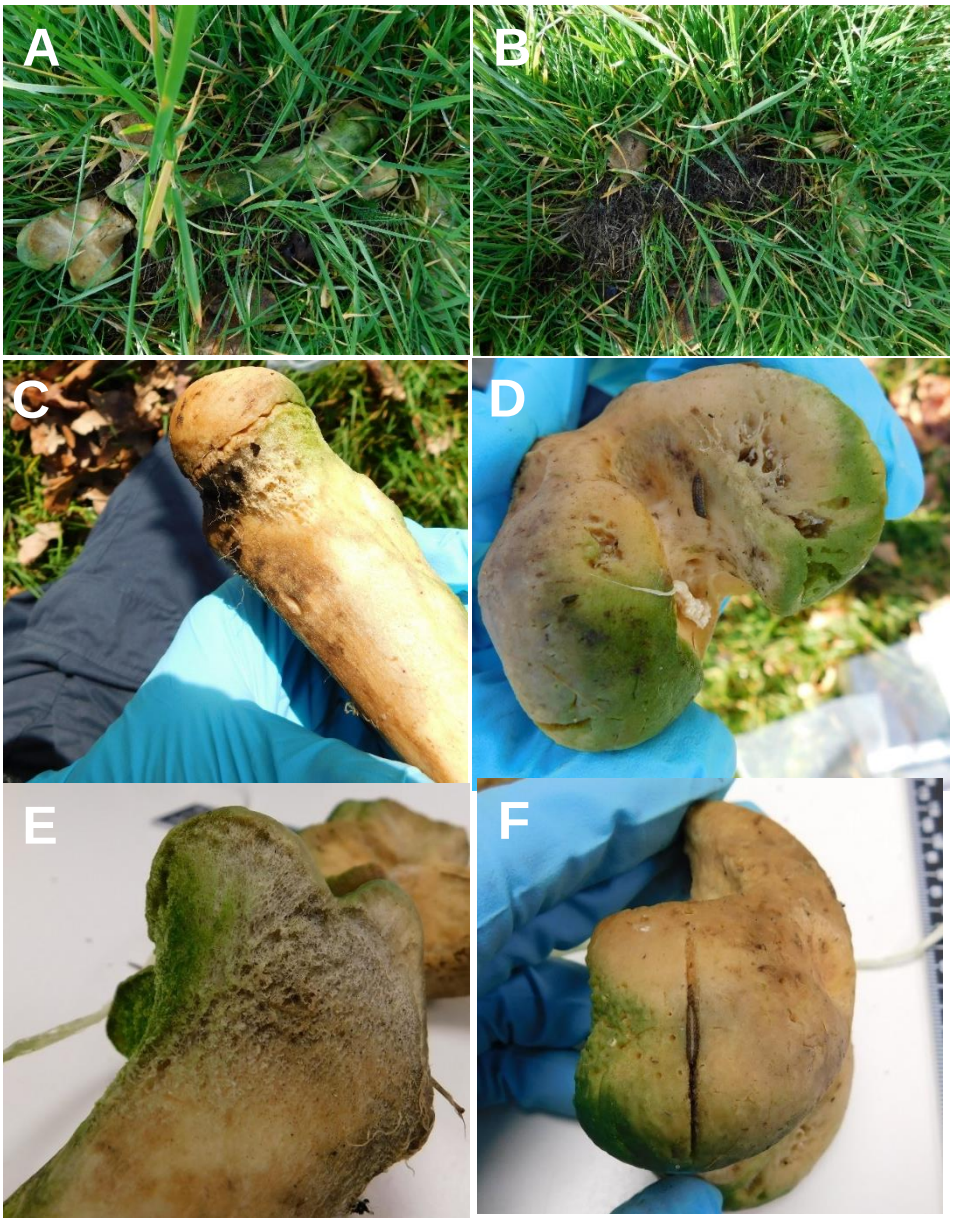


Figure 41 (A-F): Pig 3 Specimen 4 from the four-month surface deposition area.

It appears the surrounding grass grew around the specimens covering them to an extent, organic algal staining appeared on several of the specimens; interestingly arthropod activity was prolific still on the surface specimens; they were especially found in the available cavities.

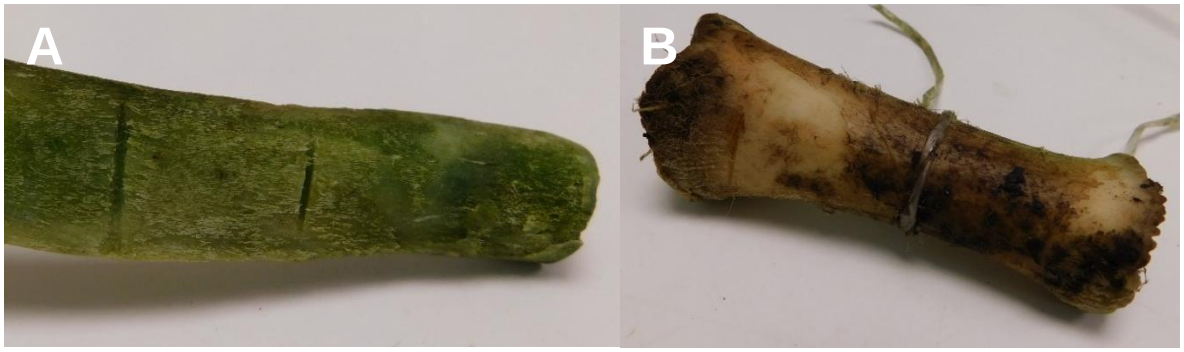


Figure 42 (A-B) – (A): Pig 3 Specimen 7 from the four-month surface deposition area. (B): Pig 2 Specimen 6 from the four-month surface deposition area.

Figure 42 (A-B) shows how on a number of the surface specimens it was noted before drying the specimens, surface flaking/stripping was appearing on a number of them. This and the surface differences between the soil side and grass of the specimens are visualised better on a majority of specimens after the roots, arthropods, and dirt was removed, and after a careful drying process.

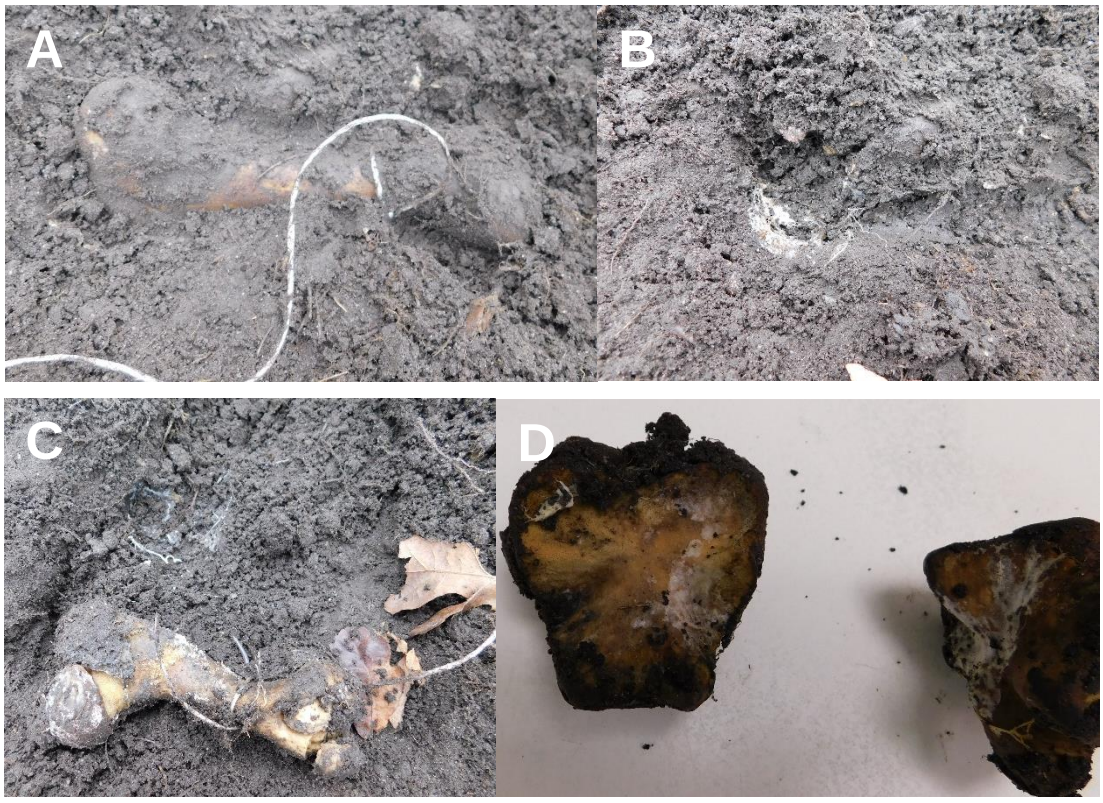


Figure 43 (A-D): Bone Specimens from the four-month burial deposition area; (D) – Pig 1 Specimen 2.

As depicted by the above figures, the soil was much wetter and viscous than the previous burial visit, upon a first glance of the burial specimens, not much had been different compared

to the two-month interval. However, once the specimens were being removed, there was a notable increase of fungal growth closer to the ends of the epiphyses. This was only seen on approximately half the specimens.

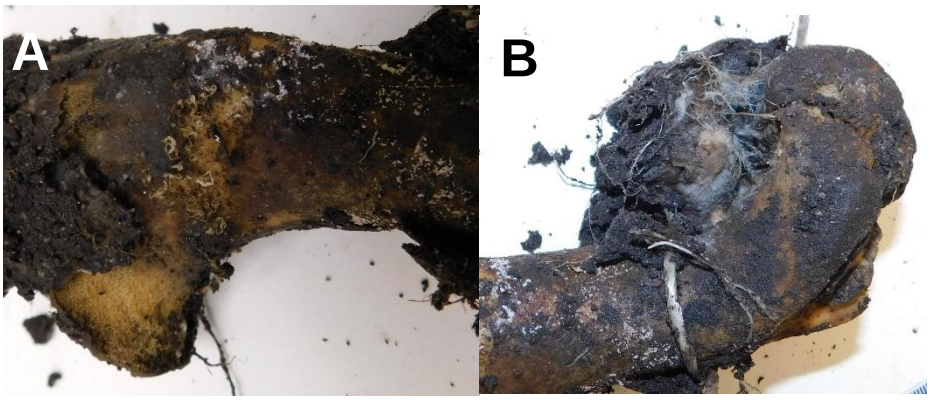


Figure 44 (A-B): Pig 1 Specimen 4 from the four-month burial deposition area

As shown above, plant root activity as well as fungal hyphae root activity was found on a few of the soil specimens, however, it was difficult to record carefully during the exhumation process. As well as fungal hyphae route growth was found on.

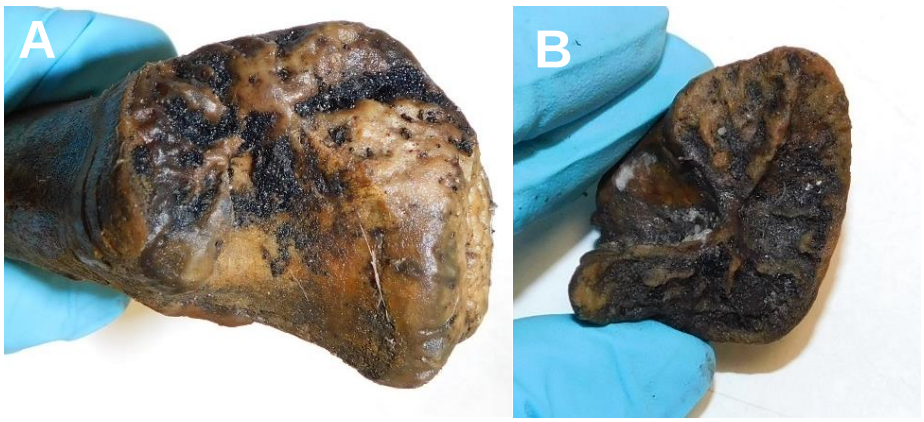


Figure 45 (A-B): Pig 1 Specimen 2 from the four-month burial deposition area

There were collections of small black mite-like arthropods were found on two of the specimens, much like a couple of specimens from the two-month specimens (Figure 45 (A-B).

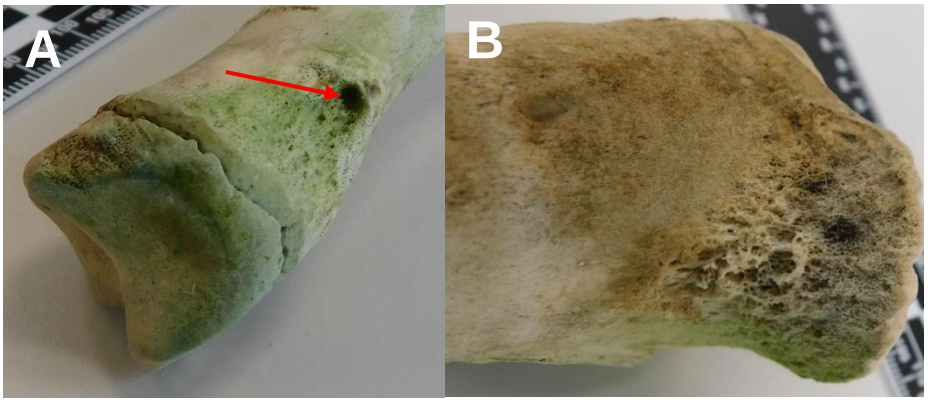


Figure 46 (A-B) – (A): Pig 3 Specimen 5 from the four-month surface deposition area. (B): Pig 3 Specimen 4 from the four-month surface deposition area.

The above figures are exampling that surface changes to the specimens were best observed once the dirt was removed and they were dried carefully (wetness and moisture obscured detailed photographs). The careful drying was in an oven at 45 degrees for 3 days until the author was assured there was not any moisture or risk of further microbial growth.

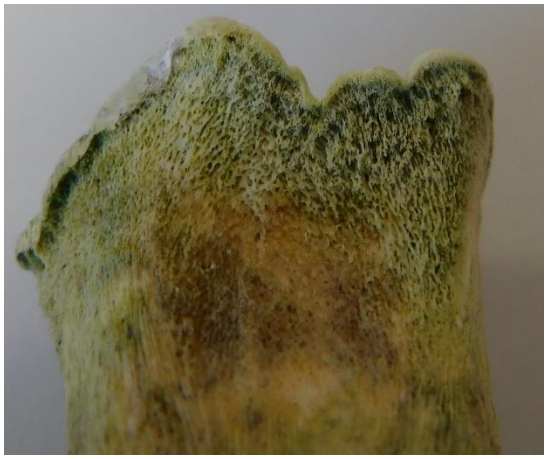


Figure 47: Pig 2 Specimen 5 from the four-month surface deposition area.

It appears that some moderate changes to the porous area of the bone can be seen in a greater volume potentially on the grass side of the surface specimens, however, texture like this could be a form of bone deformity that the pig may have had (Figure 47).

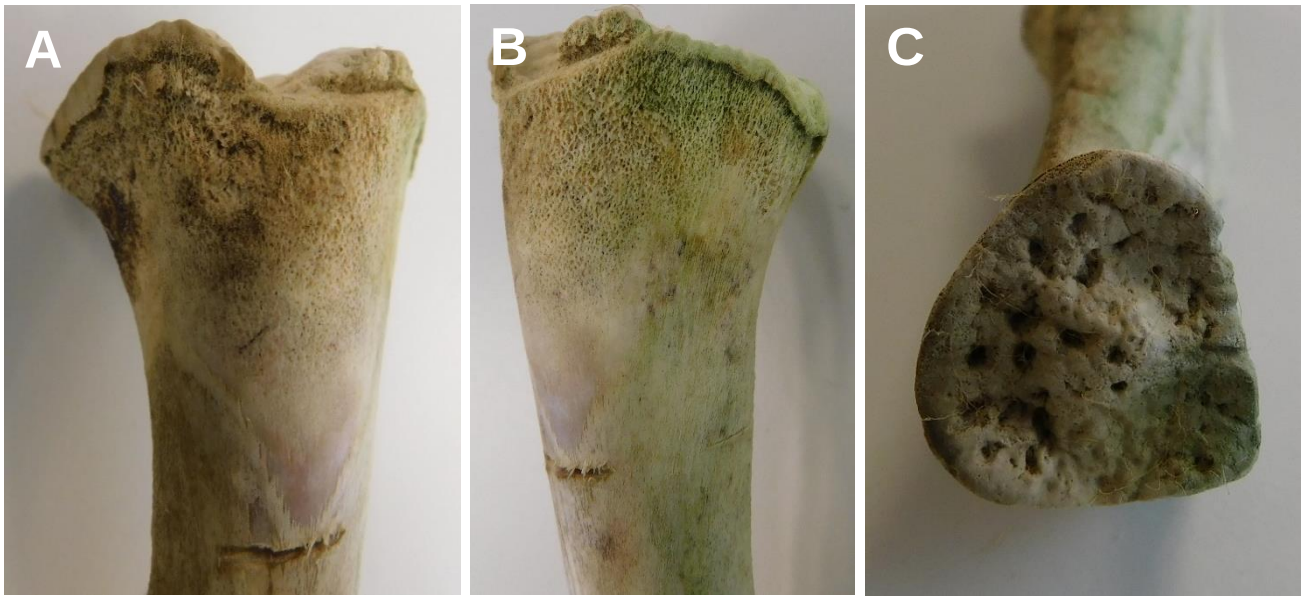


Figure 48 (A-C): Pig 3 Specimen 5 from the four-month surface deposition area, showing pseudo-weathering marks (term explained in Section 5.2.3).

There does appear to be a degree of difference between the cavity size objectively between the soil side and grass side of the specimens when it comes to these marks. Contact with the soil surface could allow for a closer contact with acidic soil water and root activity. Although, it is shown that the larger overall texture on the grass side of the specimens is more porous, the soil side in the cases of possible root activity and arthropod activity have more localised larger modifications to the surface.

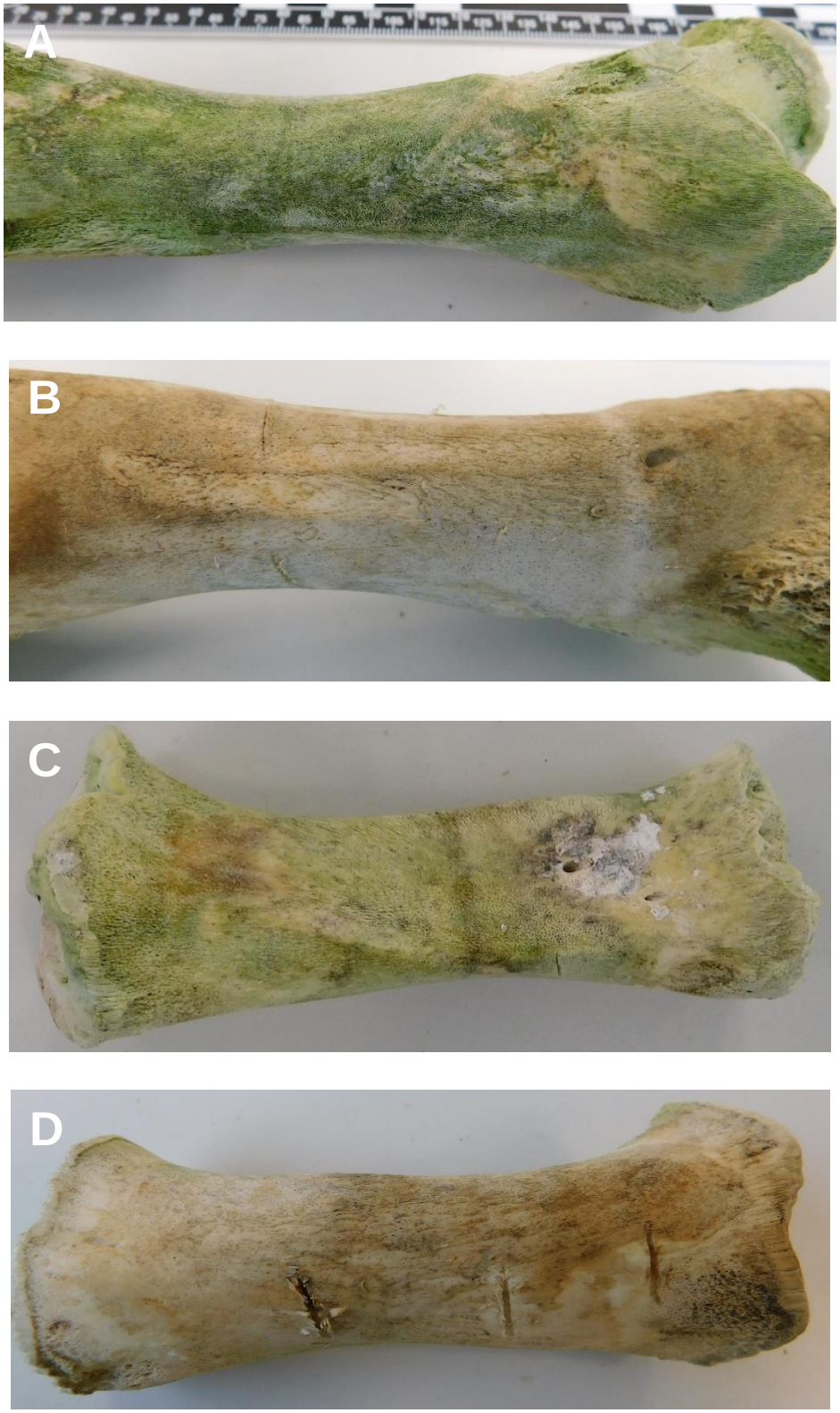


Figure 49 (A-D) – (A-B): Pig 3 Specimen 4 from the four-month surface deposition area. (C-D): Pig 2 Specimen 5 from the four-month surface deposition area.

A difference should be noted in the long bones between the soil side of the surface specimens and the grass side of them. The grass side appears to be more porous with more prolific set of cavities compared to the soil side. It should be noted that these cavities themselves for

juvenile bone are mostly pre-existing as evidence of active growth; what's key to note here is that the surface layers of the bone have been stripped away to reveal this texture. This trend is seen with several of the specimens at this stage compared to the two-month samples. It is argued it could be the result of exposure to the weather or a form of dehydration of the bone surface, revealing the cavities more.

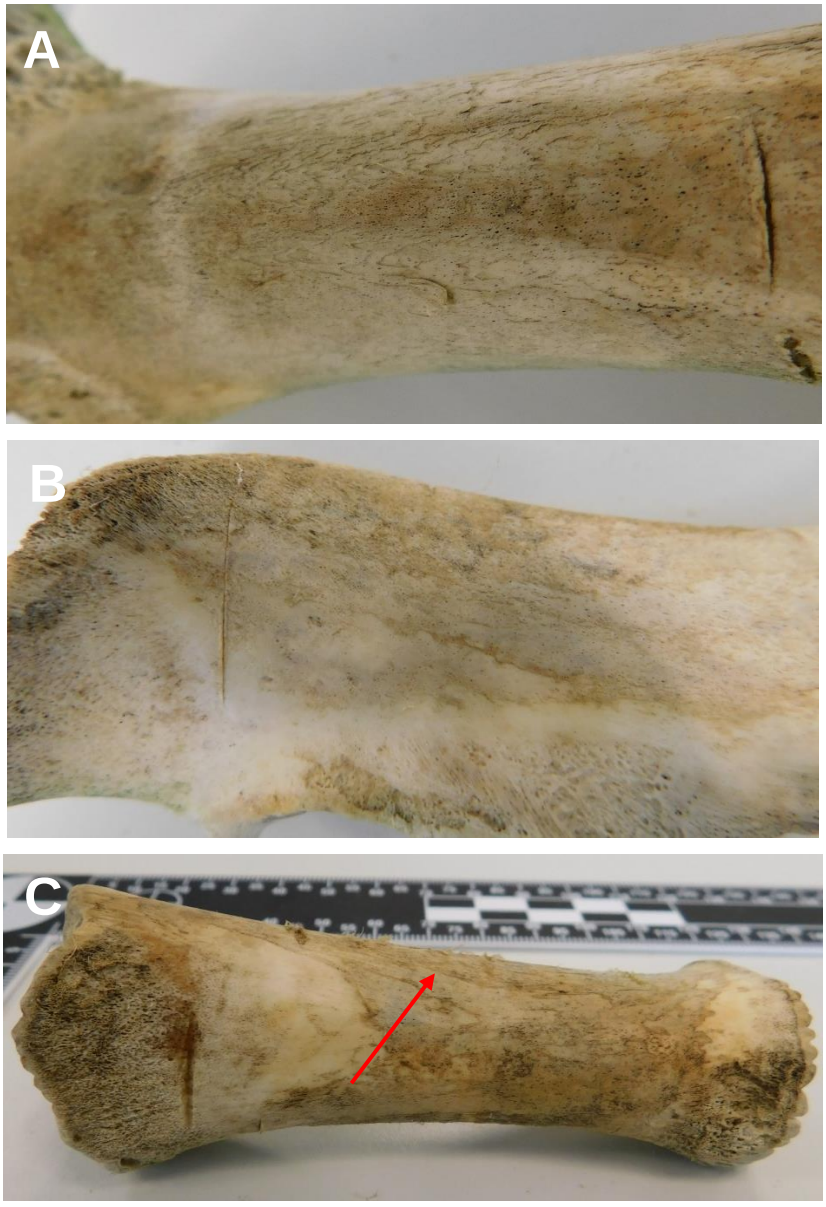


Figure 50 (A-C) – (A): Pig 3 Specimen 4 from the four-month surface deposition area. (B-C): Pig 2 Specimen 6 from the four-month surface deposition area.

On the soil side of the surface specimens there is a form of cortical flaking that is being exhibited, this is more obvious than the specimens deposited for two-months, also it is found on the burial specimens. This indicates exposure to the soil is most likely the instigator for this kind of surface modification (Figure 50 (A-C)).

Figure 51 (A-D) – (A-B): Pig 3 Specimen 7 from the four-month surface deposition area. (C-D): Pig 2 Specimen 8 from the four-month surface deposition area.

The difference appears to be not as large when it comes to the rib bones, where there is the notable difference in texture between the grass side and soil side, however, this is most likely due to the structure of the rib i.e. the longitude ridges on the 'posterior' side whether it's facing the grass or the soil (Figure 51 (A-D)).

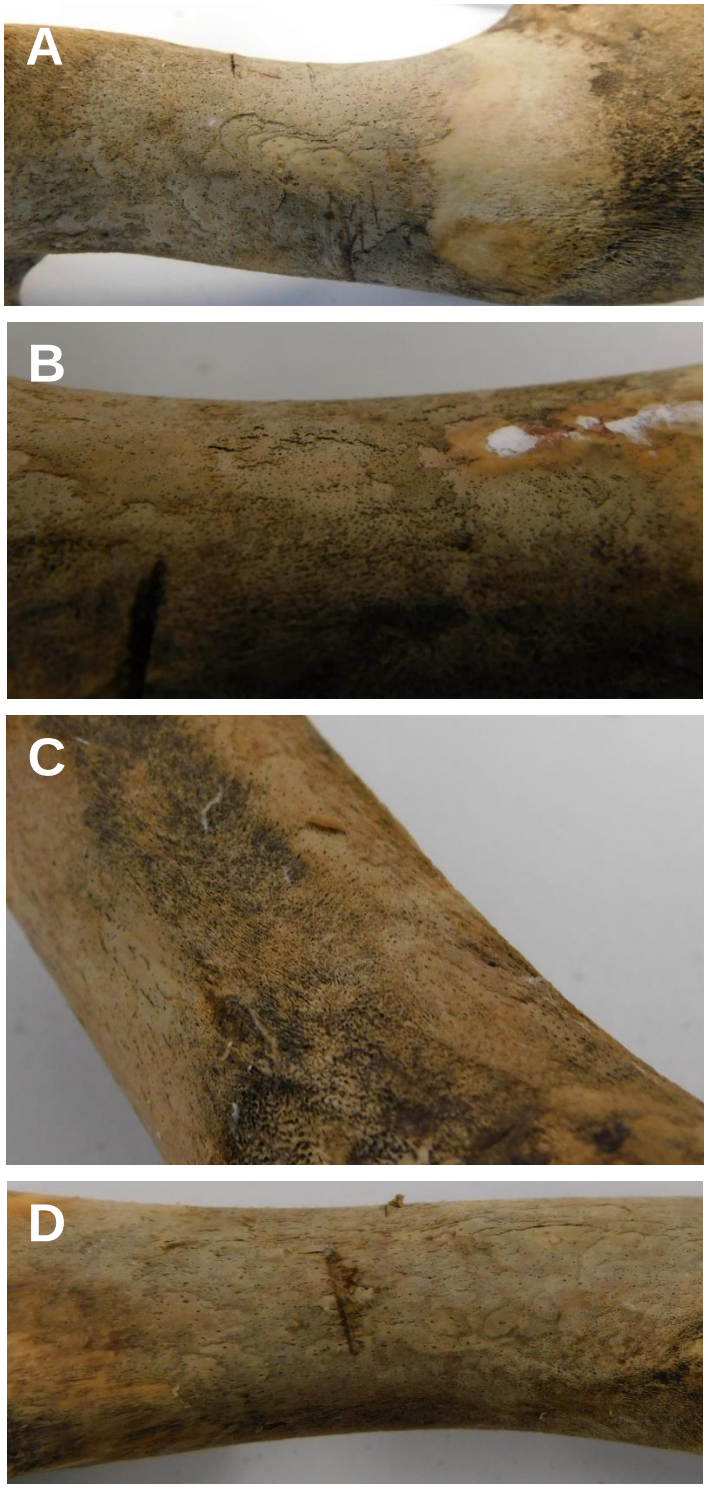


Figure 52 (A-D) – (A-B): Pig 1 Specimen 4 from the four-month burial deposition area. (C): Pig 1 Specimen 4 from the four-month burial deposition area. (D): Pig 4 Specimen 4 from the four-month burial deposition area.

The above figures are examples of the fact that the majority of the buried specimens exhibited some form of cortical flaking; similar to that of the effects found on the soil side of the surface specimens, in some cases it appears more obvious and harsher.

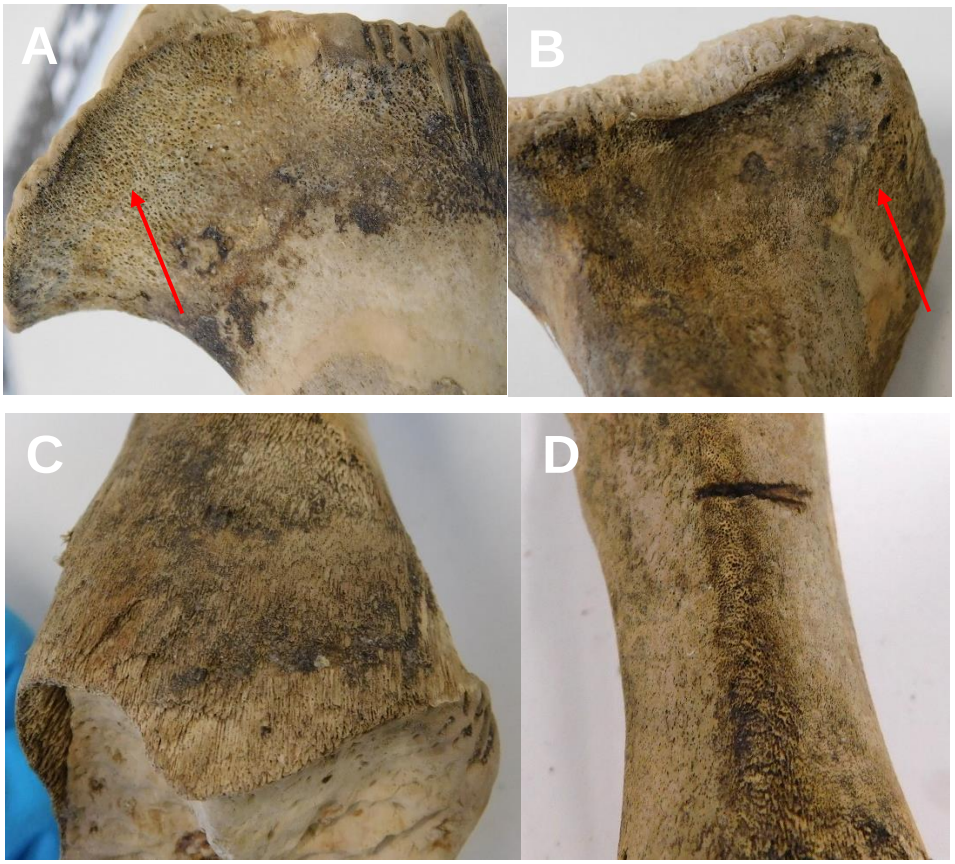


Figure 53 (A-D) – (A-C): Pig 1 Specimen 4 from the four-month burial deposition area. (D): Pig 4 Specimen 4 from the four-month burial deposition area.

As depicted in the above, the surface porosity overall of the soil specimens has increased it appears; again, these cavities are most likely the main texture of juvenile bones as active growth sites, however they appeared to have been shown clearer or enhanced in a way.

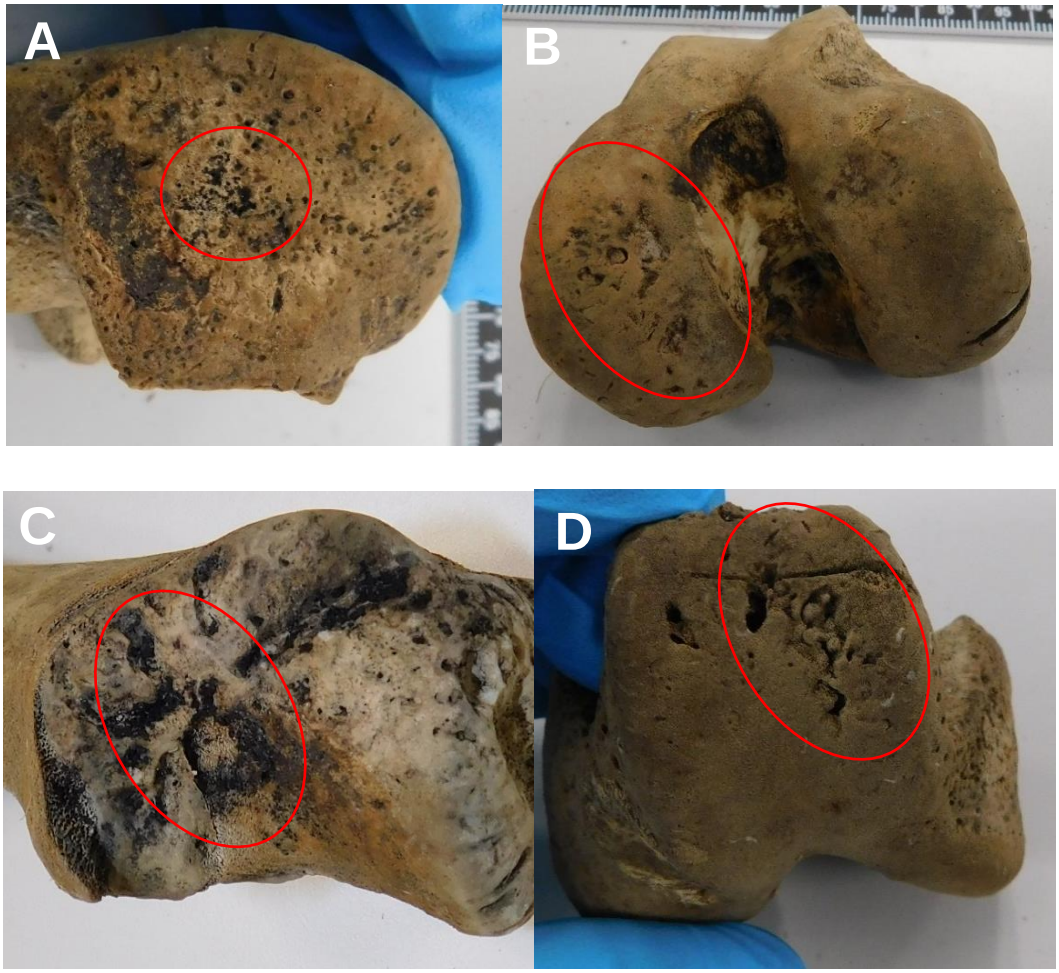


Figure 54 (A-D) – (A): Pig 1 Specimen 2 from the four-month burial deposition area. (B): Pig 1 Specimen 2 from the four-month burial deposition area. (C): Pig 1 Specimen 2 from the four-month burial deposition area (D): Pig 4 Specimen 4 from the four-month burial deposition area.

It appears that this porous structure facilitated further damaged by allowing roots to attach and possibly arthropods to be active, especially in the available cavities (Figure 54 (A-D)).

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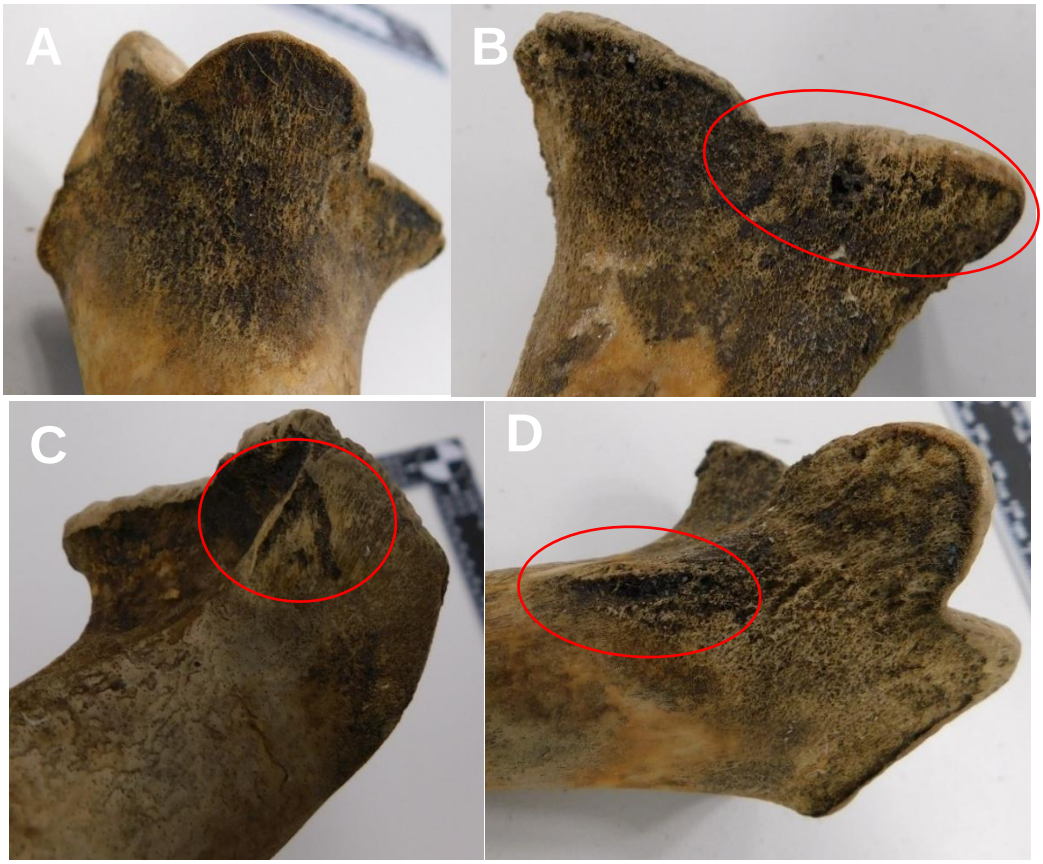


Figure 55 (A-D) – (A): Pig 1 Specimen 2 from the four-month burial deposition area. (B): Pig 4 Specimen 4 from the four-month burial deposition area. (C): Pig 4 specimen 3 from the four-month burial deposition area. (D): Pig 4 Specimen 4 from the four-month burial deposition area.

Near the epiphyses where the pseudo-weathering marks are, with some of the surface specimens, there appears to be a form of extended degradation for these areas (Figure 55 (A-D)).

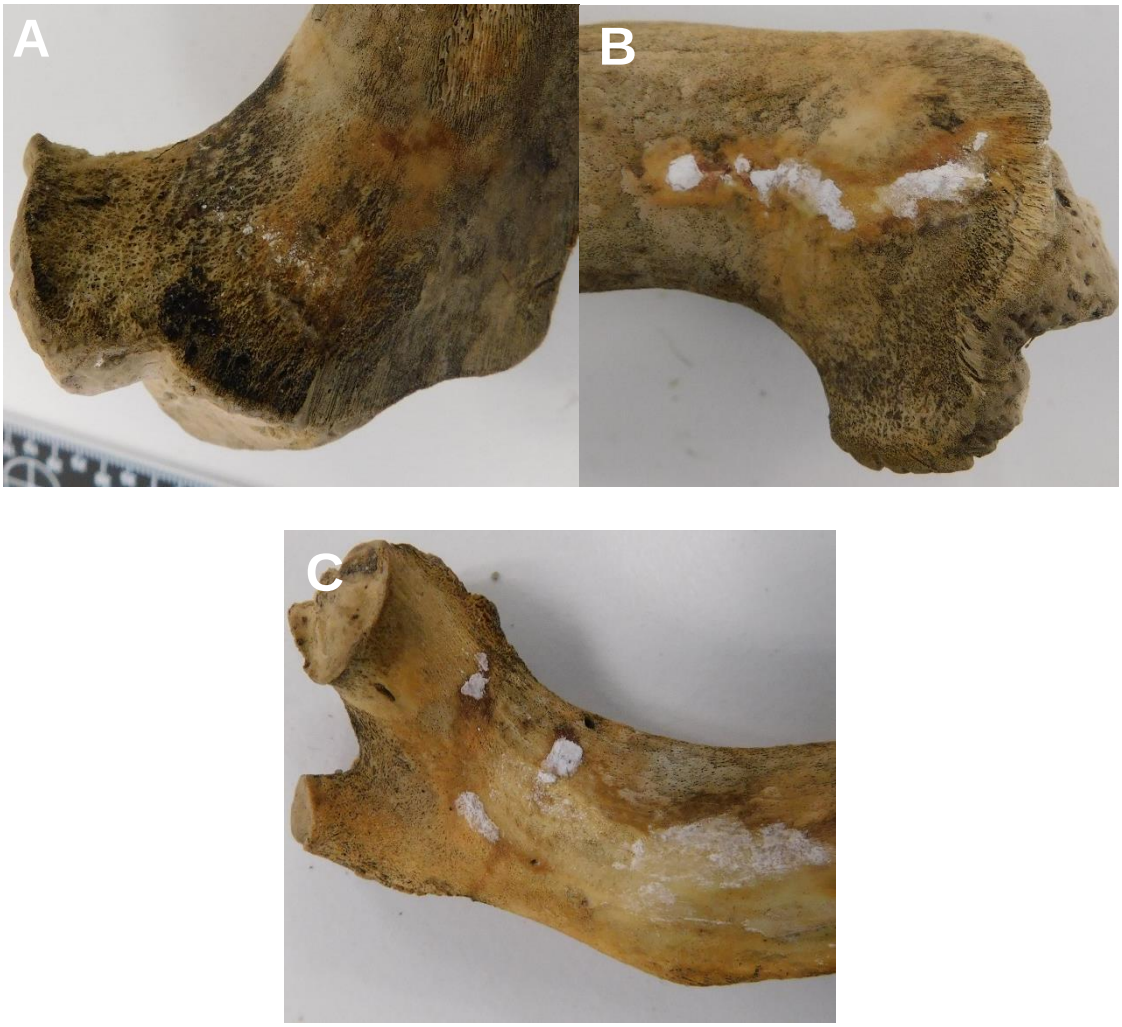


Figure 56 (A-C) – (A-B): Pig 1 Specimen 4 from the four-month burial deposition area. (C): Pig 4 Specimen 9 from the four-month burial deposition area.

The above figures show that there are also areas of some of the specimens with possible fungal damage done to the specimens; it is not likely that any major or notable damage has occurred to the bone surface.

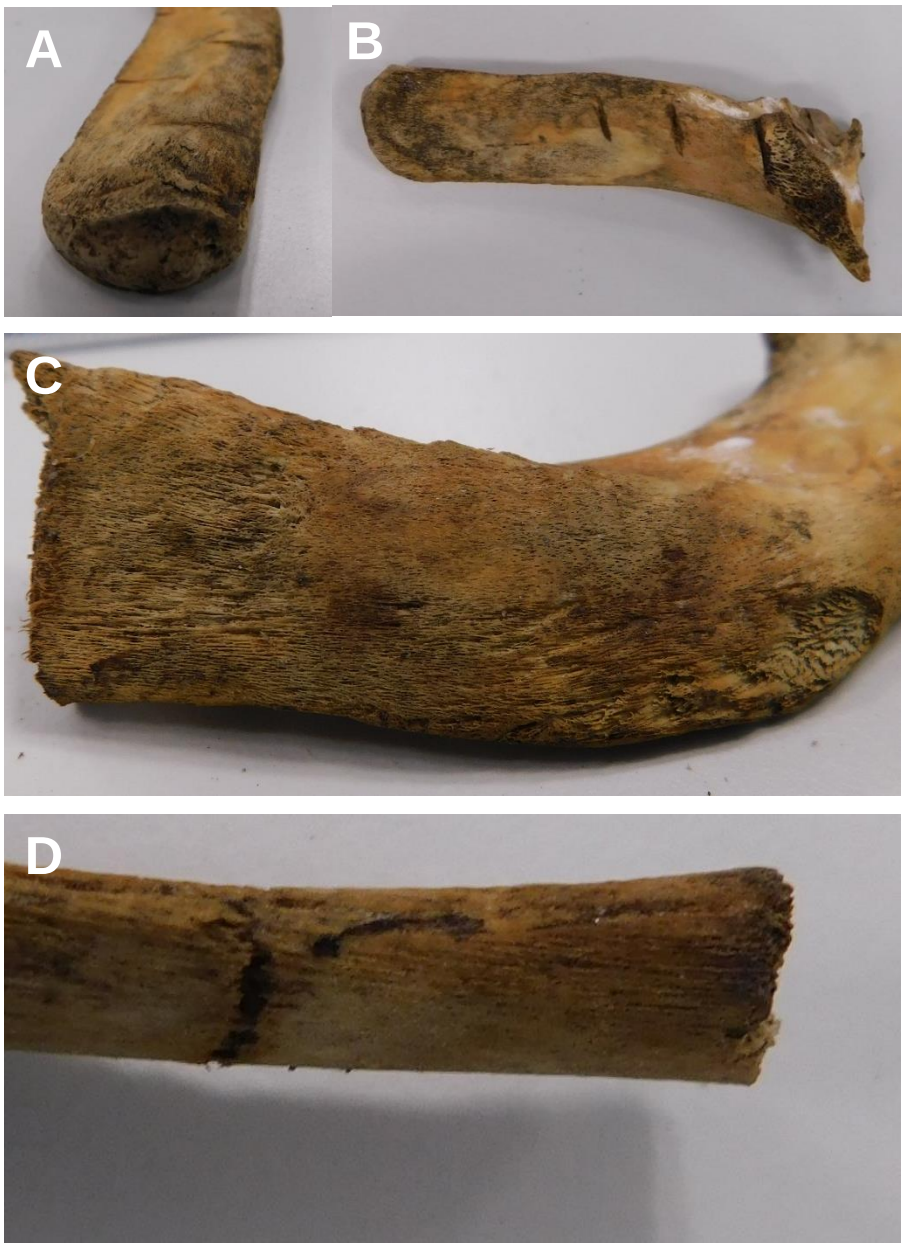


Figure 57 (A-D) – (A-B): Pig 1 Specimen 8 from the four-month burial deposition area. (C-D): Pig 4 Specimen 9 from the four-month burial deposition area.

It appears the ribs for the buried specimens compared to the surface ones repeat a similar pattern where it is received similar modification/damage to the long bones, but not as extensive. However, between the buried and surface specimens, the buried rib bones appear to show a slightly greater amount of flaking as opposed to this surface stripping/reveal of longitudinal ridge texture of the rib bone that is obvious on the surface specimens. Especially the sternal ends of the bones where the pseudo-weathering marks are typically found on juvenile rib bones i.e. the cavities possibly have worsened. This all could be a mixture of grains getting in the cavities and the addition of acidic soil water helps erode and therefore widen the cavities to an extent. There are some interesting cracks/fractures that have occurred on a specimen whose cutmarks were deep enough to fracture through partially/fully (P4S9).

Figure 58: Pig 4 Specimen 3 from the four-month burial deposition area showing an example of longitudinal cracking/fracturing that has appeared on only a couple of specimens.

4.2.3 - Qualitative Changes Six Months:

Figure 59: Surface specimen area at the six-month interval has flourished further to a point where the bone specimens left on the surface cannot be seen anymore.

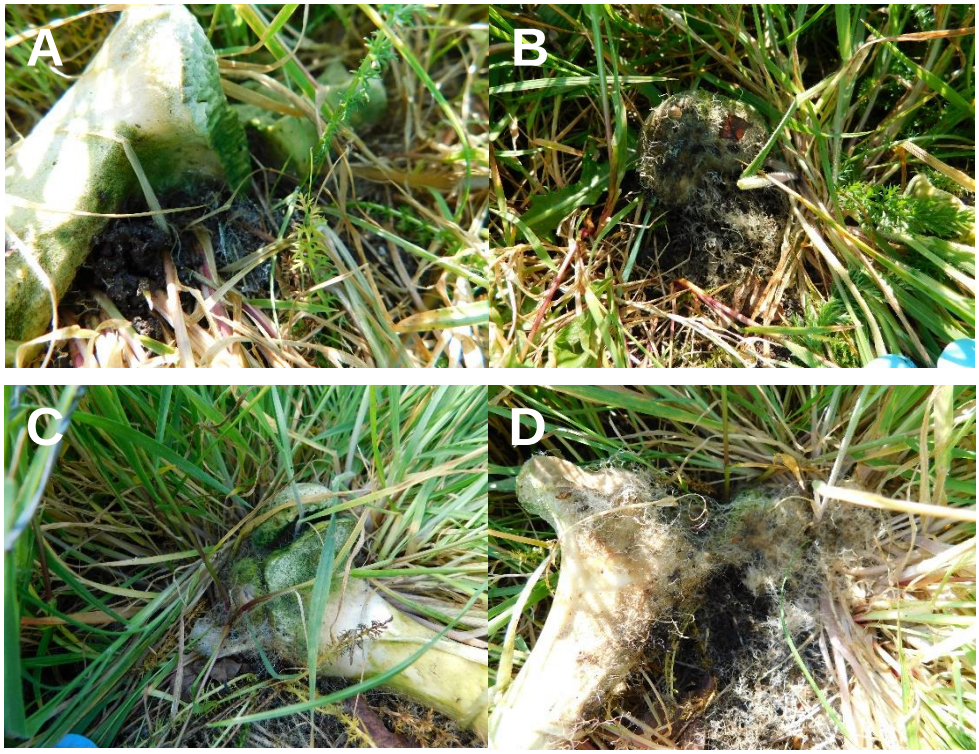


Figure 60 (A-D): Bone specimens from the six-month surface specimen area with heavy root activity growth.

The above figures depict there has been a large increase in root and arthropod activity regarding the surface specimens. Specifically, the roots activity seen previously at the 4-month interval has intensified at this point between the soil side of the specimens and the surface area. Both grass roots and white fungal hyphae roots are visible to the naked eye and have accumulated in a larger amount between the diaphyseal-epiphyseal fusion point.

Figure 61 (A-B): Bone specimens from the six-month surface specimen area.

Figure 61 (A-B) show that upon an initial inspection there doesn't appear to be any larvae present, however there was a small accumulation of woodlice seen within the roots attached to the specimens, compared to their 4-month counterparts, the organic staining has increased dramatically as well as the inorganic staining on the soil side.

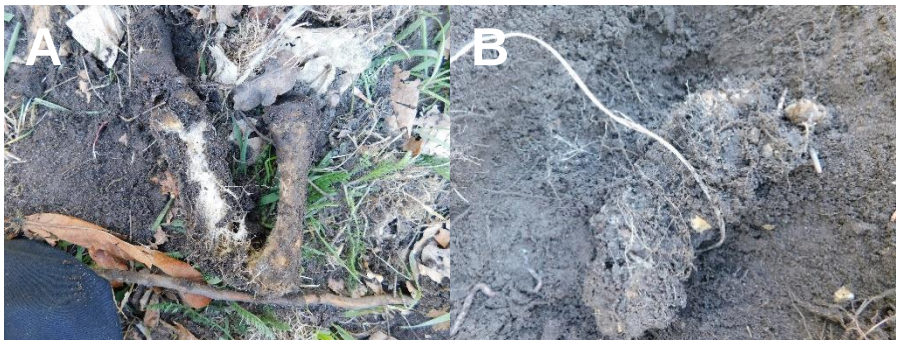


Figure 62 (A-B): Bone specimens covered in root masses from the six-month burial specimen area.

For the buried specimens, unlike the previous exhumations, there is notable activity (Figure 62 (A-B)). This being a larger increase in root activity that actually made them difficult to remove from the soil. It appears the roots (rye grass) have wrapped specifically more around the buried remains as opposed to the surrounding matrix.

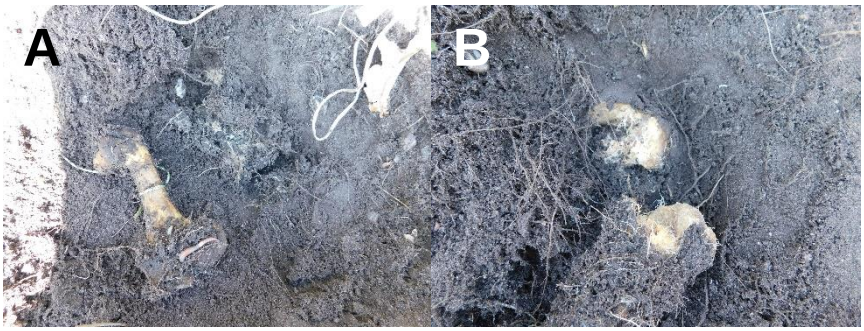


Figure 63 (A-B): Bone specimens covered in root masses from the six-month burial specimen area.

Unfortunately, there were not any arthropod activity recorded with the buried remains in situ, however it was noted that there was an interesting activity of multiple worms and Gastropods

within the soil attached to one of the specimens. Including with the grass root activity, there were small amounts of fungal root activity that could be seen in the epiphyseal areas of some of the specimens (Figure 63 (A-B)).

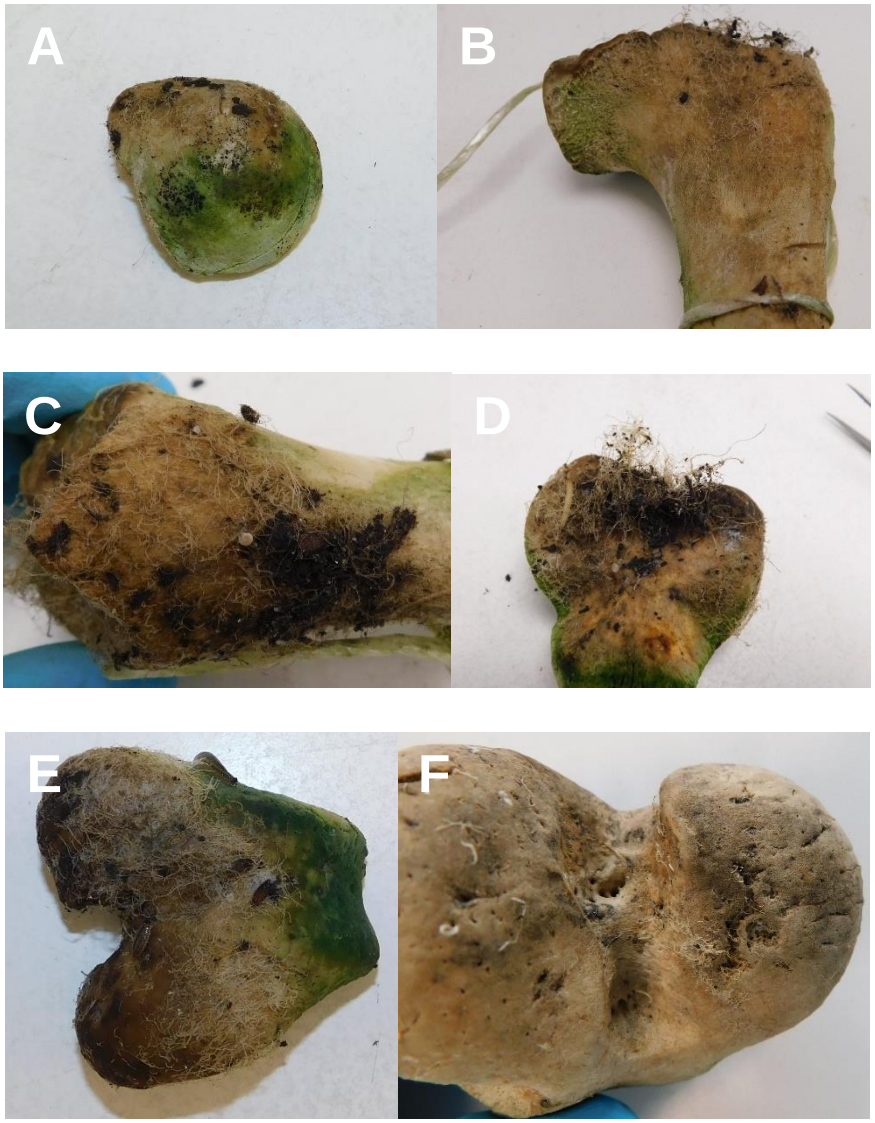


Figure 64 (A-F) – (A-B): Pig 3 Specimen 1 from the six-month surface specimen area. (C) – Pig 2 Specimen 1 from the six-month surface specimen area. (D-F): Pig 3 Specimen 3 from the six-month surface specimen area.

It appears the root activity is seen clearly as well as there being clusters of arthropod activity, possible mites. The activity of some of the arthropods found are associated with the areas where roots have accumulated largely among the surface and buried specimens (Figure 64 (A-F)).

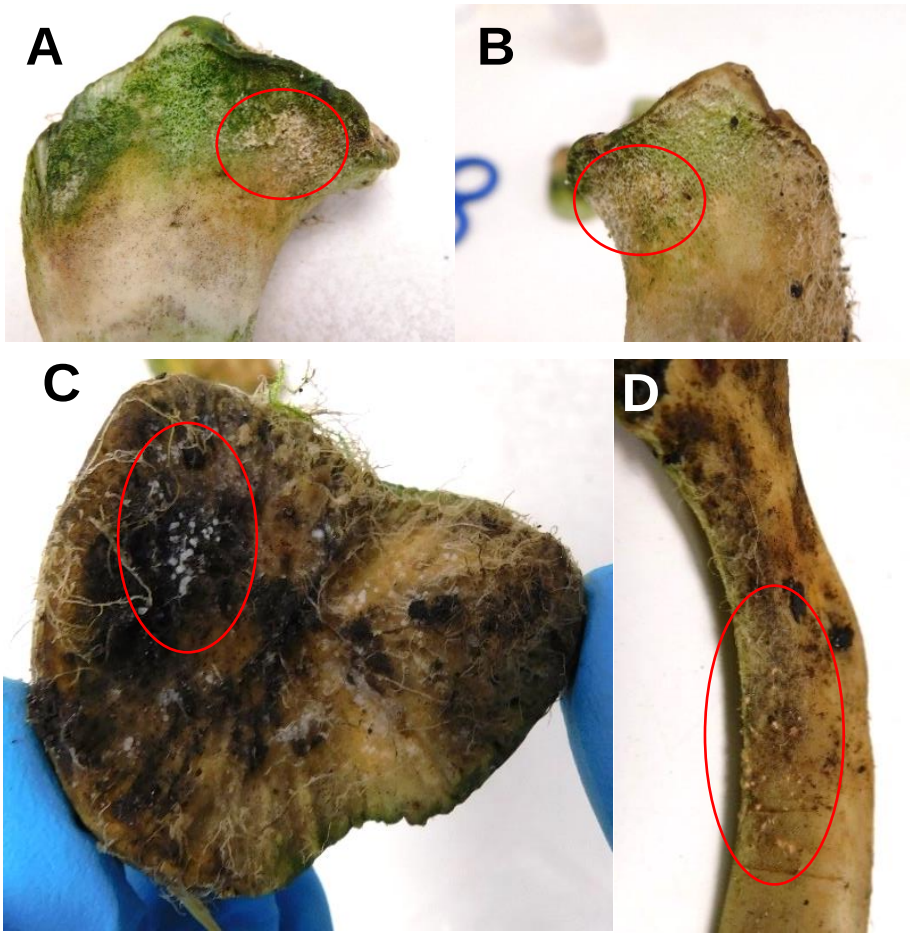


Figure 65 (A-D) – (A-B): Pig 3 Specimen 1 from the six-month surface specimen area. (C) – Pig 2 Specimen 1 from the six-month surface specimen area. (C-D): Pig 2 Specimen 10 from the six-month surface specimen area.

More than before, there also appears to be an interesting accumulation of fungal activity, orange/pink and white possible spores (Figure 65 (A-D)).

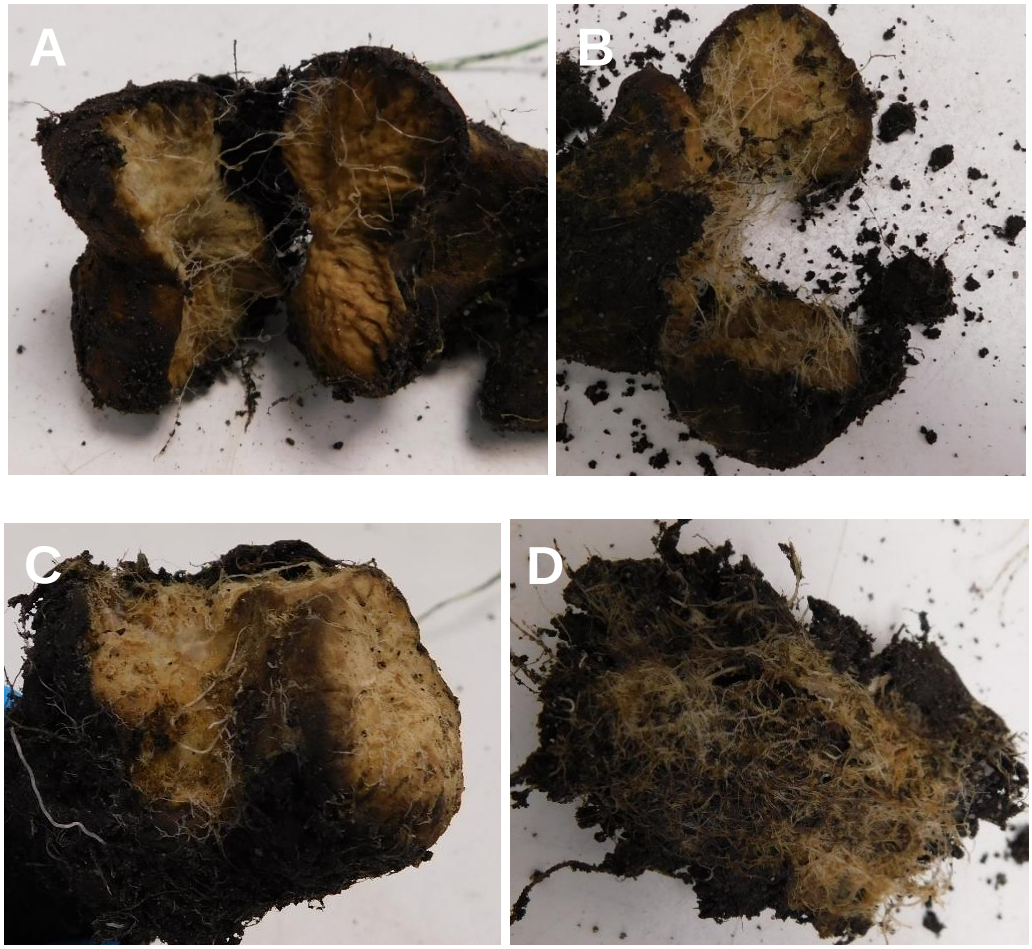


Figure 66 (A-D) – (A-B): Pig 4 Specimen 2 from the six-month surface specimen area. (C-D): Pig 4 Specimen 1 from the six-month surface specimen area.

The long bones specifically have accumulated a larger amount of plant and fungal root activity compared to their two- and four-month counterparts. Roots and Fungal Hyphae roots can be seen among the specimens before and after cleaning, they have especially accumulated in the diaphyseal-epiphyseal fusion areas and the surrounding soil (Figure 66 (A-D)).

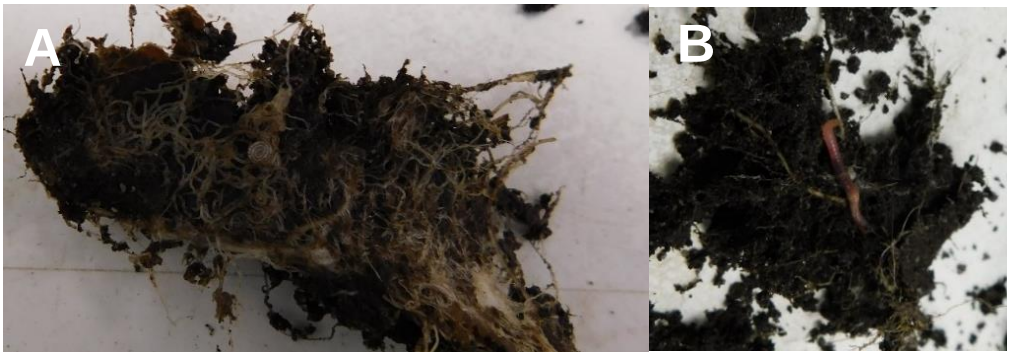


Figure 67 (A-B): Pig 4 Specimen 1 from the six-month surface specimen area.

It is clear in the above figures that there is are signs of macroarthropod and macrofauna activity, however, there usually isn't as much as the surface specimens.

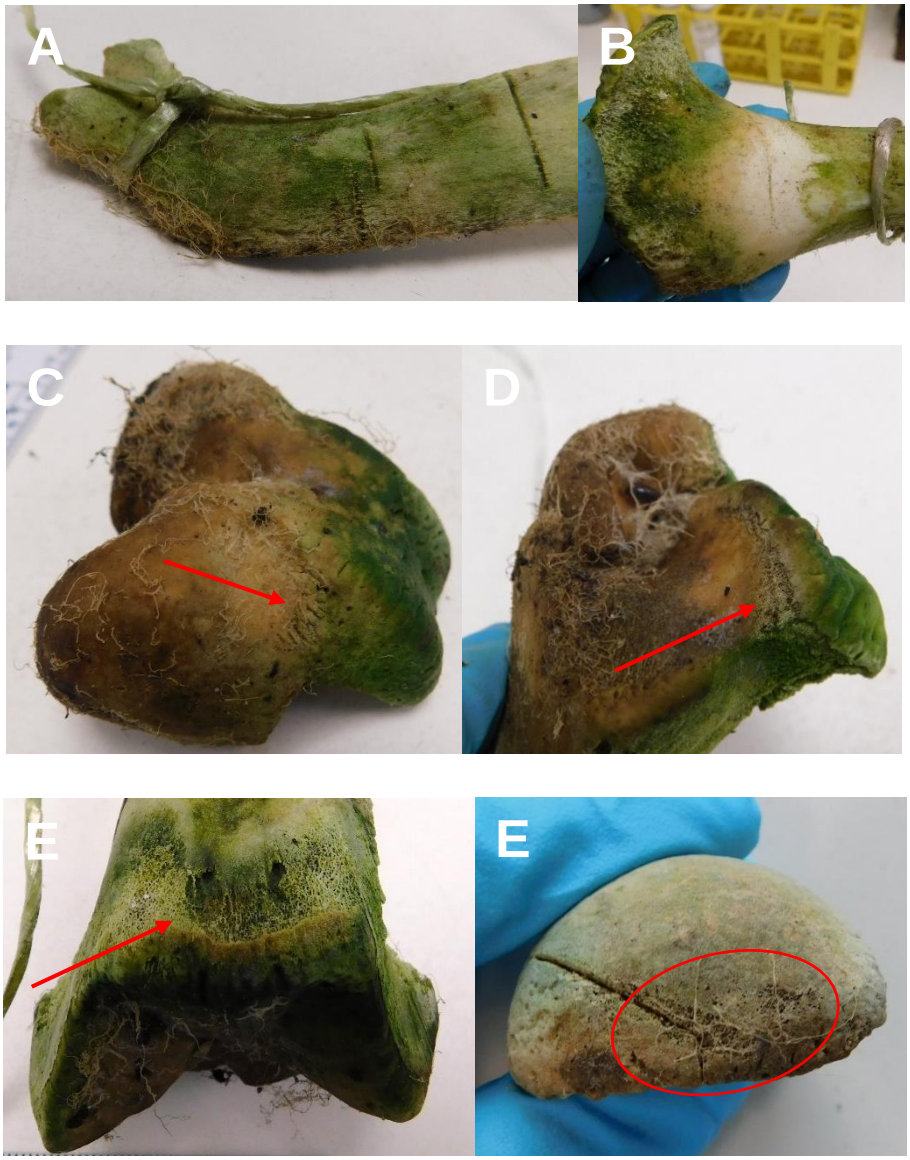


Figure 68 (A-F) – (A): Pig 3 Specimen 8. (B): Pig 2 Specimen 1(C-E): Pig 3 Specimen 1 from the six-month surface specimen area. (F): Pig 2 Specimen 2 from the six-month surface specimen.

It's shown in the above figures that on several of the surface specimens, there are different forms of irregular damage that can be noted where it's specific areas of surface erosion. This can be seen especially of areas there the root activity is prevalent. For example, root etching can be seen with figure (p2s1) and there appears to be some damage left by the roots seen with figure (p3s3). There is a possibility that some of the irregular damage could be from osteophagic arthropod activity with small bore like holes nearer the epiphyses where the 'pseudo-weathering' marks are (P3s3).

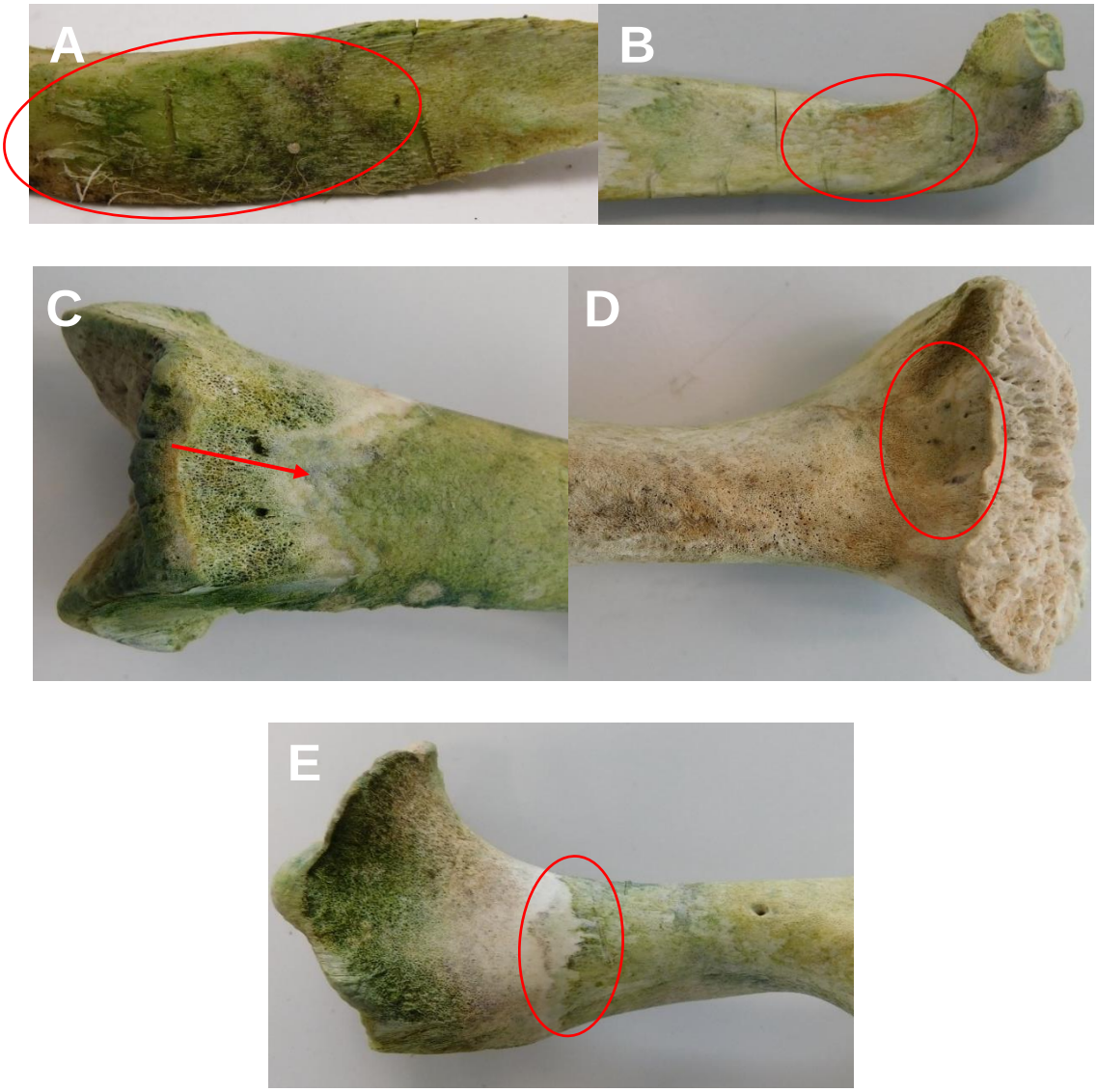


Figure 69 (A-E) – (A): Pig 2 Specimen 10. (B): Pig 3 Specimen 10 (C-E): Pig 3 Specimen 1 from the six-month surface specimen area. (F): Pig 2 Specimen 2 from the six-month surface specimen.

At this point in time it appears there is a larger increase in surface stripping for the surface specimens; this is where the cortical surface of the specimens are flaking back. Also, on the soil side of the surface specimens, an increase of cortical flaking and surface porosity is visible compared to its previous counterparts. Overall, an increase in surface degradation is notable where the more porous areas have become more worn (p3s3); as stated before, this could be the result of increased exposure to the weather, and possibly microorganisms.

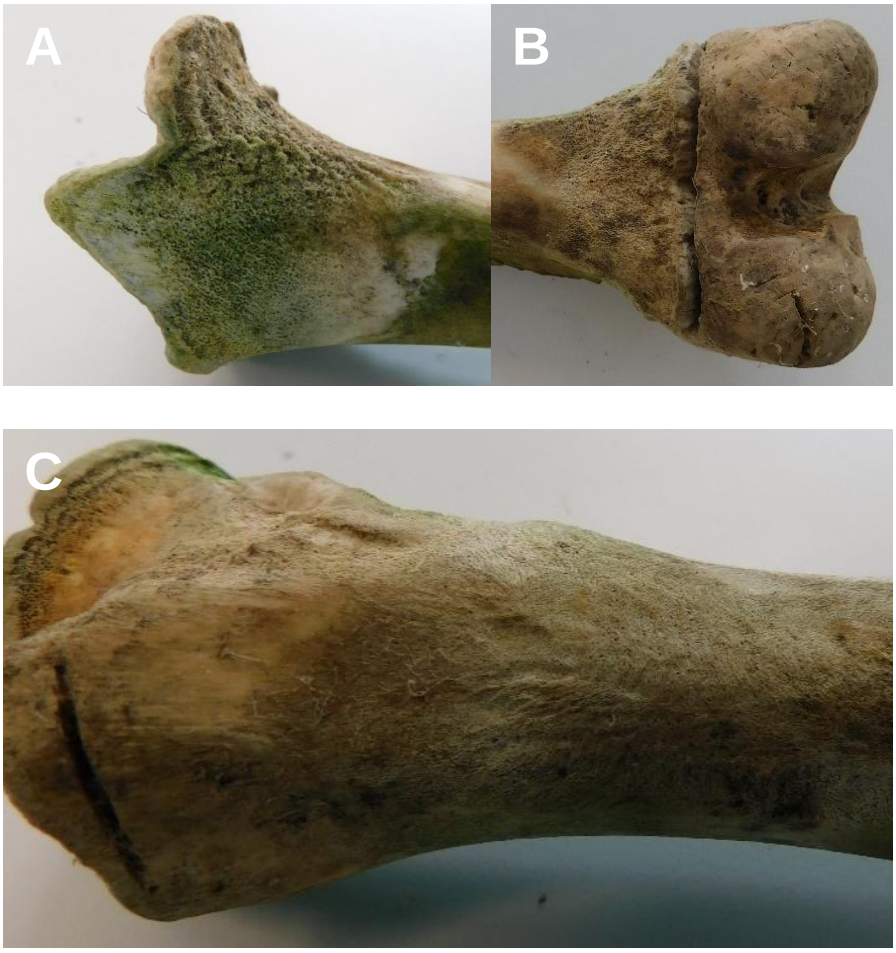


Figure 70 (A-C): Pig 3 Specimen 3 from the six-month surface specimen area.

Figure 70 (A-C) shows the potential difference there is between the cavity size objectively between the soil side and the grass side of the specimens; the reason for this could be a closer proximity or interaction with the roots, arthropod activity and acidic soil water potentially. The texture for juvenile bones is porous to an extent, however, there definitely is a visible difference across the deposition intervals that can be seen across the specimens. The soil side especially on some specimens are exhibiting a change in surface texture, where it looks like channels or fissures are being formed, especially in those areas where the roots have attached (P3S3*).

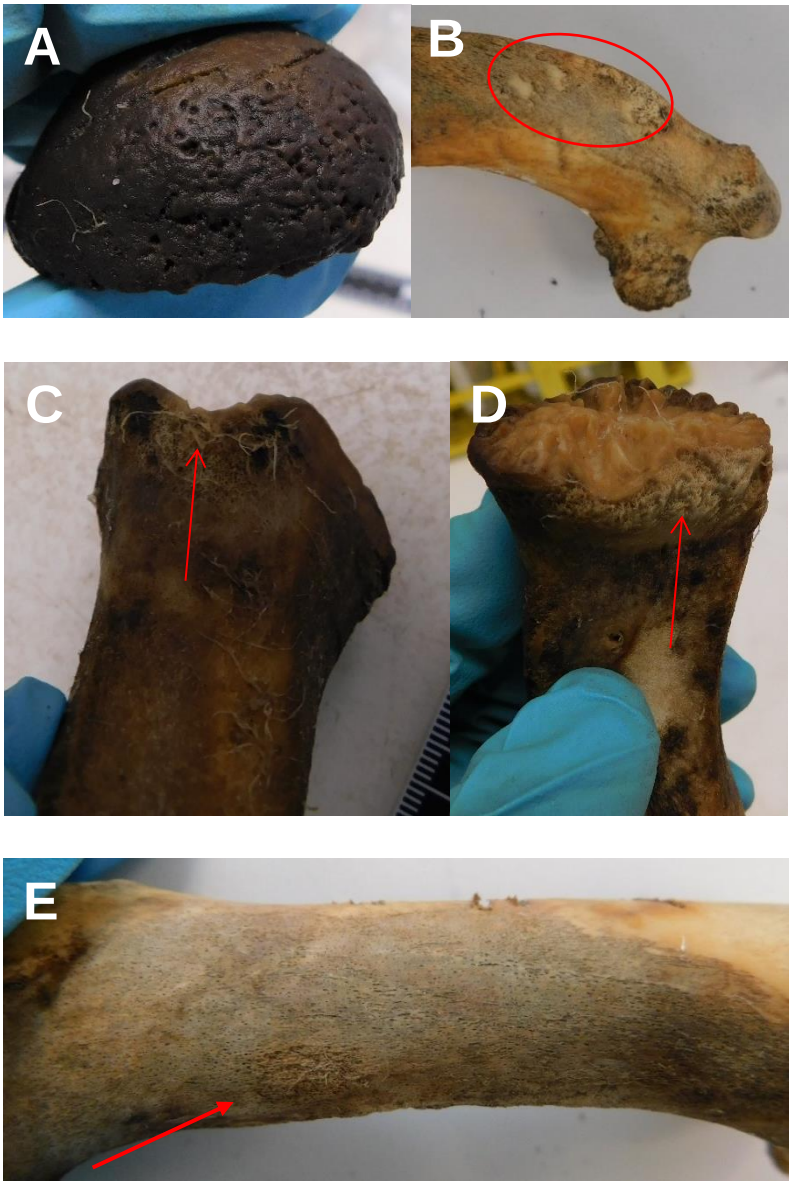


Figure 71 (A-E) – (A): Pig 4 Specimen 2 from the six-month burial specimen area. (B): Pig 1 Specimen 9 from six-month burial specimen area. (C): Pig 1 Specimen 6 from the six-month burial specimen area. (D): Pig 1 Specimen 5 from the six-month burial specimen area. (E): Pig 1 Specimen 6 from the six-month burial specimen area.

Figure 71(A) is an example of notable pitting has been found in some of the areas where roots have accumulated most, it's questionable whether the roots have caused this pitting or channelling or whether it's just unorthodox morphology of this specimen specifically (P4S2). On some of the buried specimens, there are different forms of irregular damage that can be noted where it is specific areas of surface erosion. This can be seen especially of areas there the root activity is prevalent and are possibly the result of arthropod activity also (P1s6).

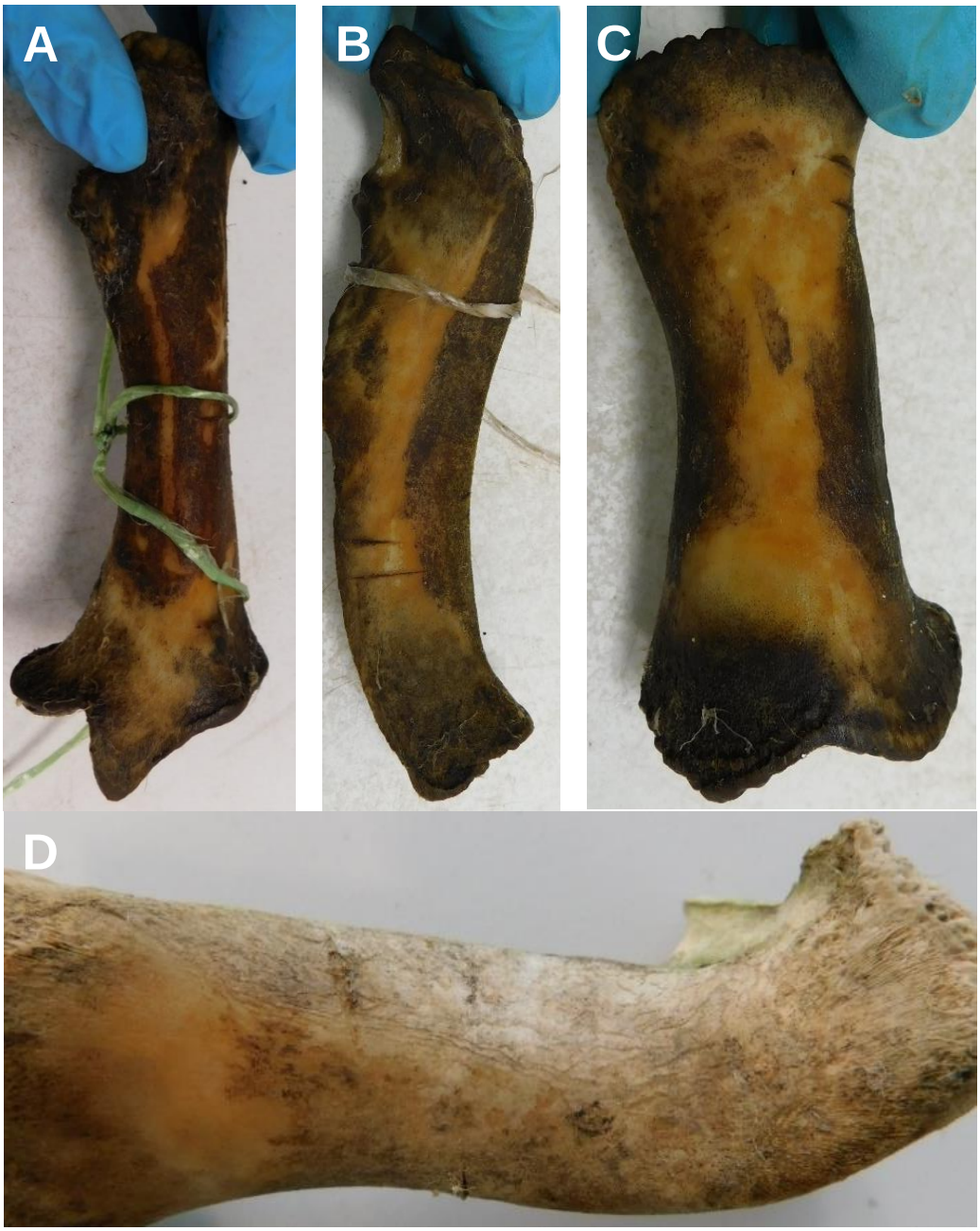


Figure 72 (A-D) – (A): Pig 4 Specimen 1 from the six-month burial specimen area. (B): Pig 1 Specimen 6 from six-month burial specimen area. (C): Pig 1 Specimen 5 from the six-month burial specimen area. (D): Pig 2 Specimen 2 from the six-month burial specimen area.

There are certain specimens with a notable amount of surface cortical flaking can be seen on a number of specimens, revealing the underlying layer; this can be attributed to the areas where most of the roots accumulated. When the soil was removed, it was very clear to see where the flaking has occurred (figure 72 (A-D)).

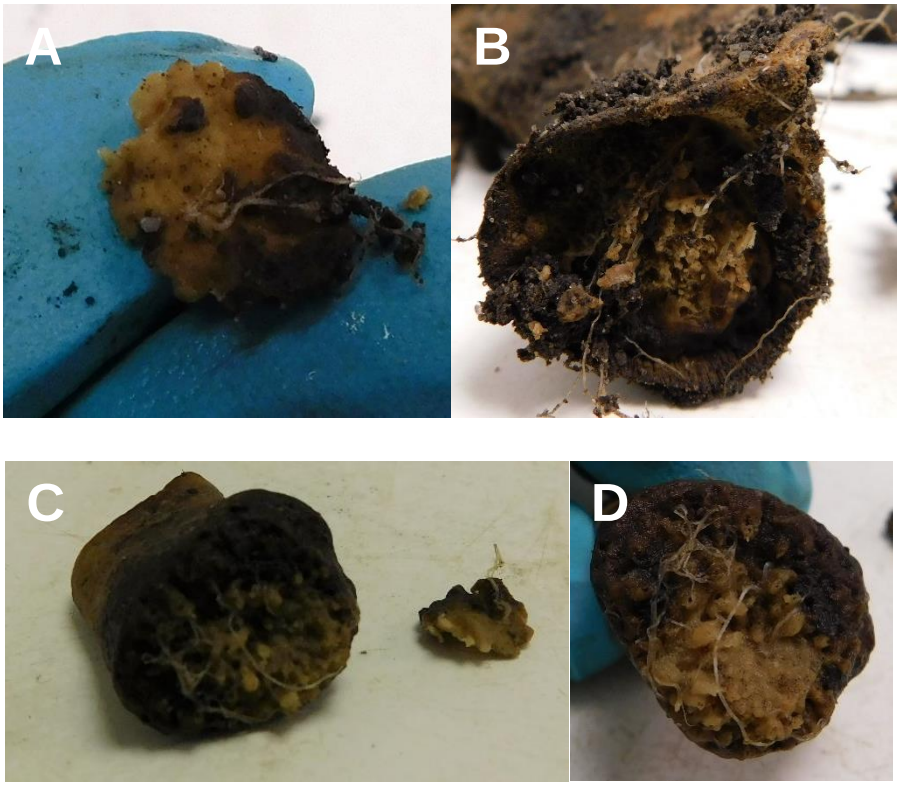


Figure 73 (A-D): Pig 1 Specimen 5 from the six-month burial specimen area.

Figure 73 (A-D) depicts a singular specimen where there was a peculiar amount of bone loss at one of the epiphyseal ends of the bone specimens, this is more intense than what has been seen previously.

4.2.4 - Qualitative Changes Eight Months:

Figure 74 (A-B): Surface specimen area at the eight-month interval where the vegetation has grown rapidly since the six-month interval, this is reflected by the amount of vegetation that can be seen growing on the specimens which has been seen since the four-month interval.

Figure 75: Surface specimen area where the grass has grown over the specimens at the eight-month interval.

At this point for the surface bone specimens, they cannot be seen at all without further inspection, similar but more advanced than at the four-month stage.

Figure 76 (A-F) – (A-D): Bone specimens from the surface specimen area showing forms of root activity and arthropod activity from the eight-month interval. (E): Pig Specimen 3 eight-month surface specimen group. (F): Pig 5 Specimen 4 from the eight-month surface specimen group.

There is a large increase in flora and macroarthropod activity surrounding the specimens and, on the specimens, (like previous intervals). Larger roots are found growing on the surface of the specimens and through the epiphyseal joints; as well as a variety of arthropods can be seen being active in these areas (Figure 76 (A-F).

Figure 77: Bone specimens from the surface specimen area showing forms of potential arthropod activity from the eight-month interval

Above is an example of other activities that were deemed interesting (upon further inspection), such as eggs being found attached to part of the epiphyses of one of the specimens.

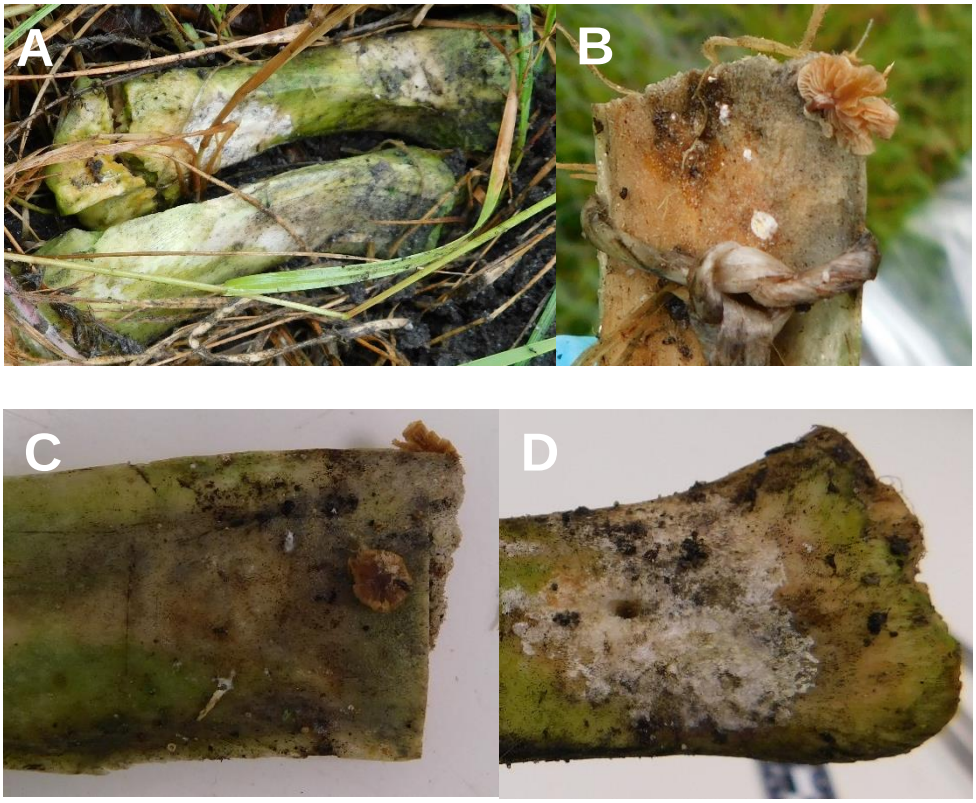


Figure 78 (A-D): Bone specimens from the surface specimen area showing forms of potential fungal activity and adipocere from the eight-month interval. (C): Pig 5 Specimen 8 from the eight-month surface specimen area. (D): Pig 5 Specimen 3 from the eight-month surface specimen area.

There are some specimens (similar to previous intervals) have a collection of what could be adipocere near the foramens on some of the specimens. As well as some form of fungal growth on the specimens (Figure 78 (A-D)).

Figure 79: Burial specimen area topsoil layer from the eight-month interval.

Although the surface above the turf was quite wet, underneath the soil itself was moderately dry (Figure 79).

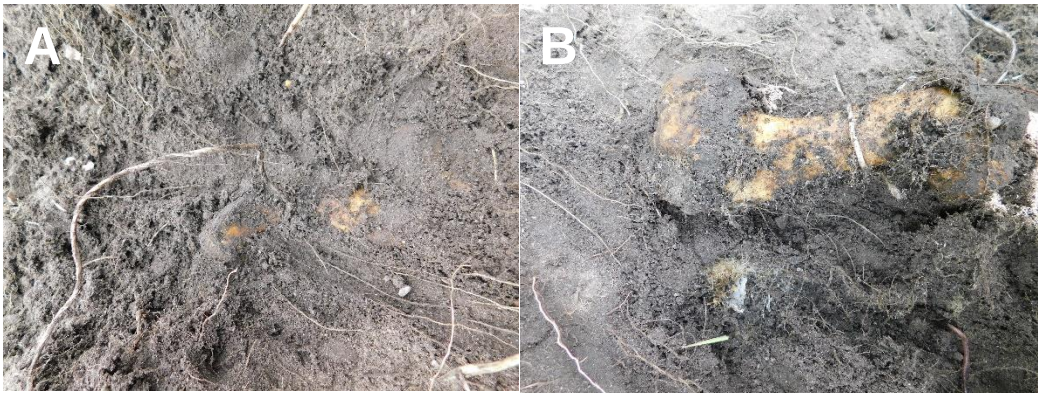


Figure 80 (A-B): Bone specimens from the burial specimen covered in roots from the eight-month interval.

Figure 80 (A-B) shows that directly above where the specimens were buried, there appeared to be a greater mass of roots growing as well as an ant's nest. Much like the six-month burial interval, the bones were essentially covered in soil and a mass of roots which made it tough to remove.

Figure 81: Plant root and fungal root activity underneath the bone specimens from the burial specimen area from the eight-month interval.

The above figures show that the roots themselves, appear to have a form of mycorrhiza fungal growing on them and on the specimens themselves, upon closer inspection.

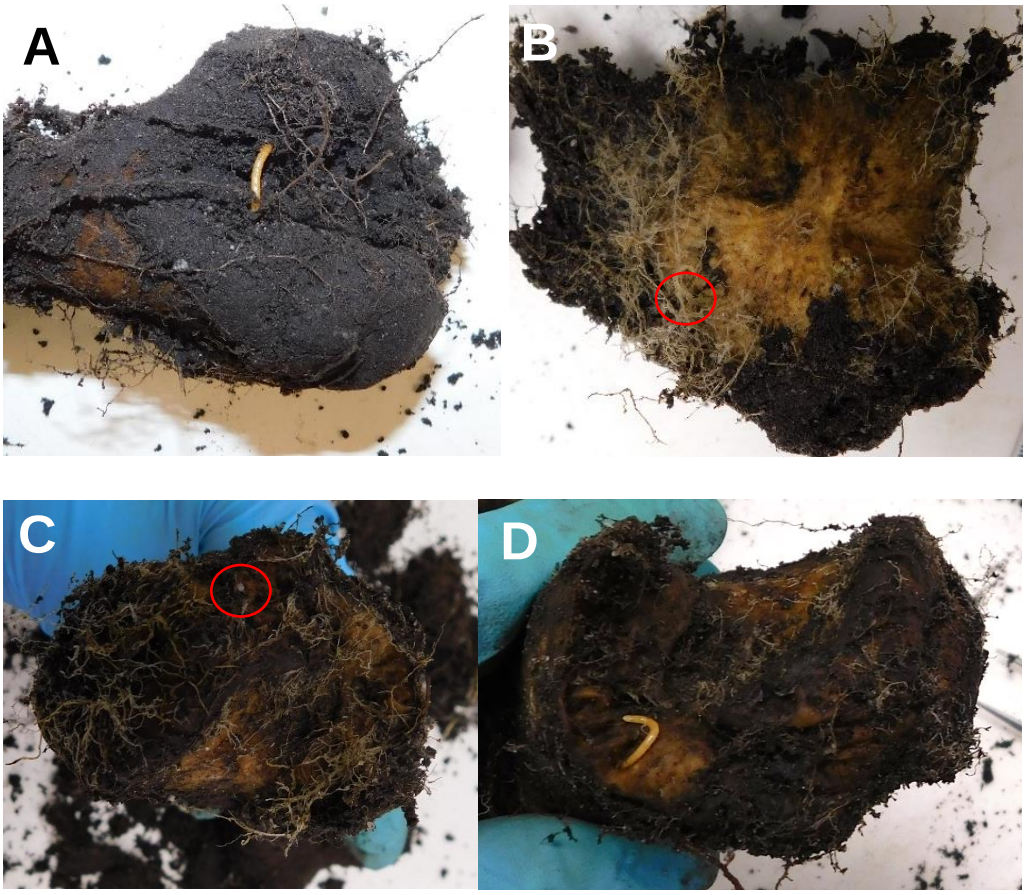


Figure 82 (A-D) – (A-B): Pig 5 Specimen 6 from the eight-month burial specimen area. (C-D): Pig 5 Specimen 1 from the eight-month burial specimen area.

There were a few macroarthropods that were collected with the burial specimens; however, they were within the roots with the bone specimens and were difficult to photograph during the exhumation. They were collected in the same sample bags as the specimens they were on specifically, to be observed later in the laboratory (Figure 82 (A-D)).

Figure 83: Pig 5 Specimen 4 from the eight-month surface specimen area.

The above figure shows an example of one of the surface specimens appearing lighter than previous deposition intervals; green staining can still be seen; however, it is not as dark and

vibrant as previously. This could be due to the increase in temperature or possibly the moisture from the turf and recent rain may have washed the specimens.

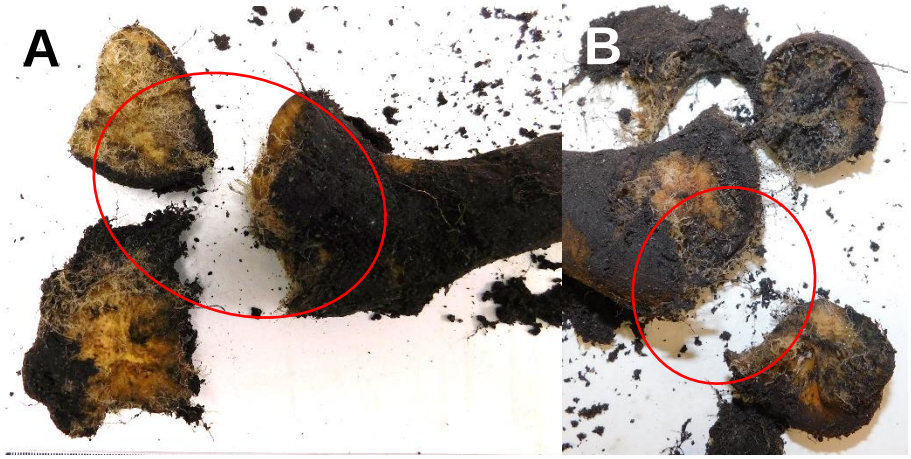


Figure 84 (A-B) – (A): Pig 5 Specimen 4 from the eight-month burial specimen area. (B) Pig 5 Specimen 1 from the eight-month burial specimen area.

The long bones typically have the larger amount of macro and microflora activity compared to the rib bones and to the previous deposition intervals for this set. Plant and fungal roots especially have been growing within the diaphyseal-epiphyseal fusion areas among the long bone specimens (Figure 84 (A-B)).

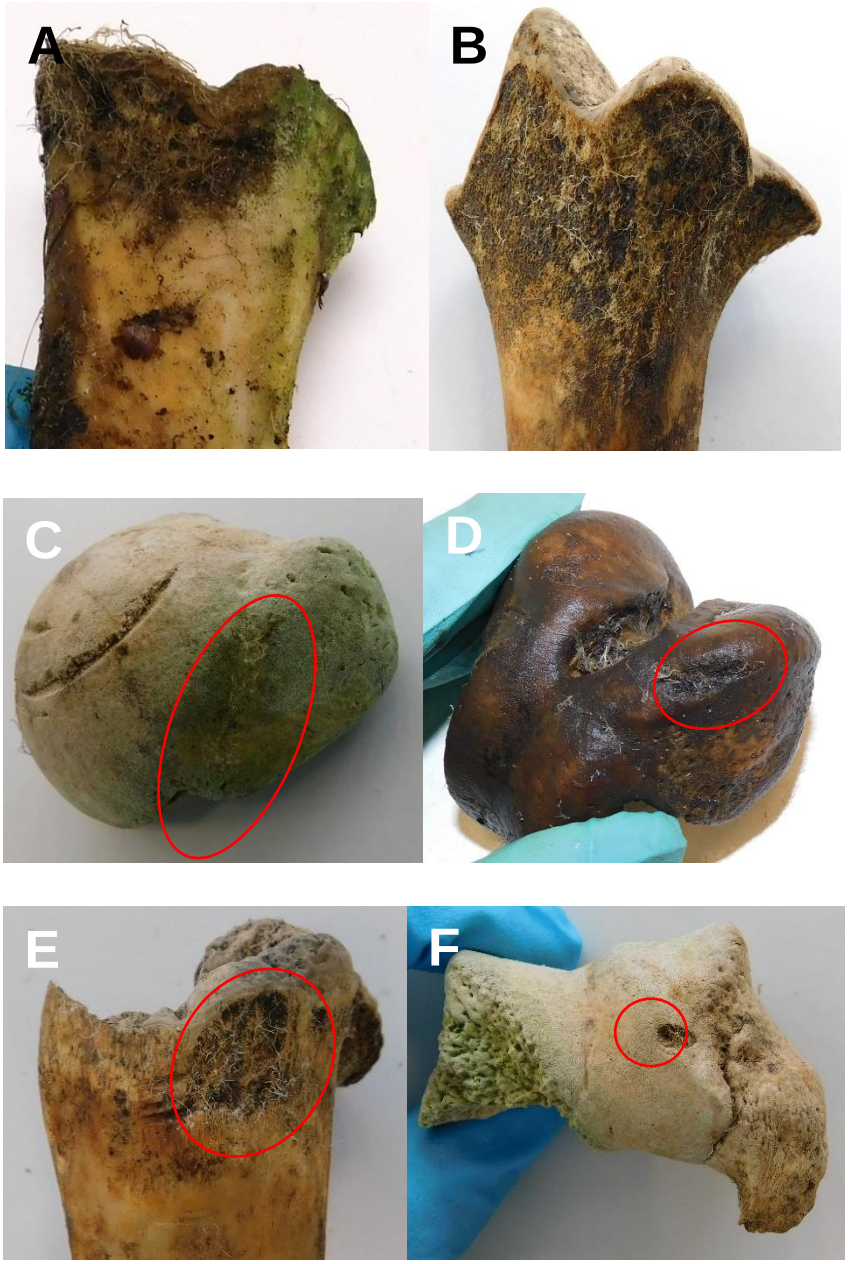


Figure 85 (A-F) – (A): Pig 5 Specimen 4 from the eight-month surface specimen area. (B): Pig 5 Specimen 2 from the eight-month burial specimen area. (C): Pig 5 Specimen 5 from the eight-month surface specimen area. (D): Pig 5 Specimen 2 from the eight-month burial specimen area. (E): Pig 5 Specimen 1 from the eight-month burial specimen area. (F): Pig 5 Specimen 5 from the eight-month surface specimen area.

The above figures show that on several of the surface specimens there are different forms of smaller irregular damage that are often in the areas of the prevalent root activity (P5S3-5) (As noted with the six-month interval). The damage ranges from an increase of surface porosity in areas that were already porous (surface close to epiphyses) or previously damaged, to specific circular patches of surface erosion.

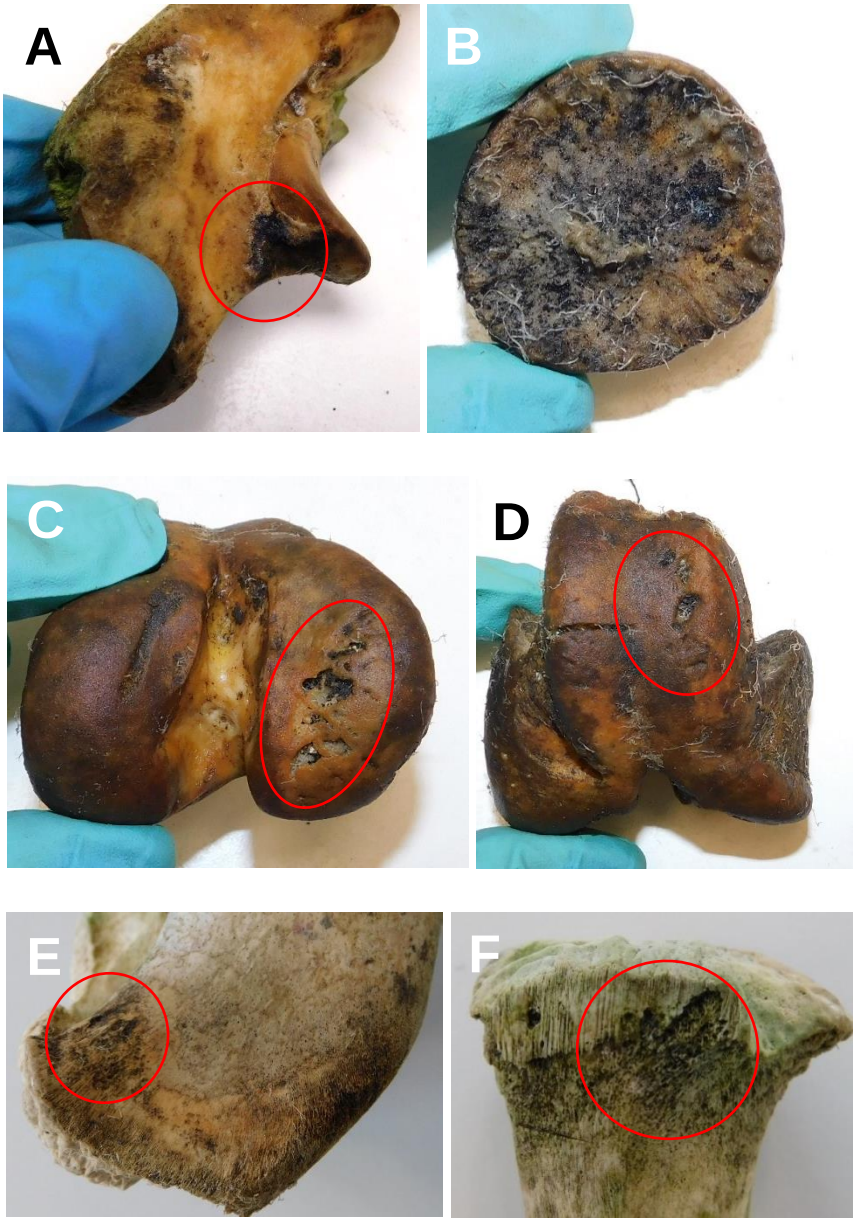


Figure 86 (A-F) – (A): Pig 5 Specimen 3 from the eight-month burial specimen area. (B-D): Pig 5 Specimen 1 from the eight-month burial specimen area. (E-F): Pig 5 Specimen 5 from the eight-month surface specimen area.

As shown in the above figures, some of this irregular damage is also in areas where a lot of the 'mites' have been found; these mites are the same ones that have been found in previous months (P5S3), therefore, could be the result of arthropod activity.

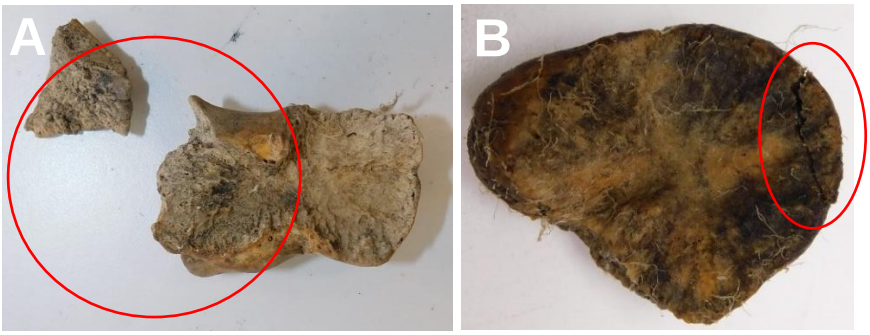


Figure 87 (A-B): Pig 5 Specimen 6 from the eight-month burial specimen area.

The figures above show there appears to be portions of the distal a proximal epiphysis of P5S6 that were only held together with the roots that grew inside and portions of the 'mite pods' that have been seen before). Whether or not they or the roots directly caused the breakage in the first place, they certainly took advantage of the available space and possibly contributed towards it (further is discussed and shown in Chapter 5).

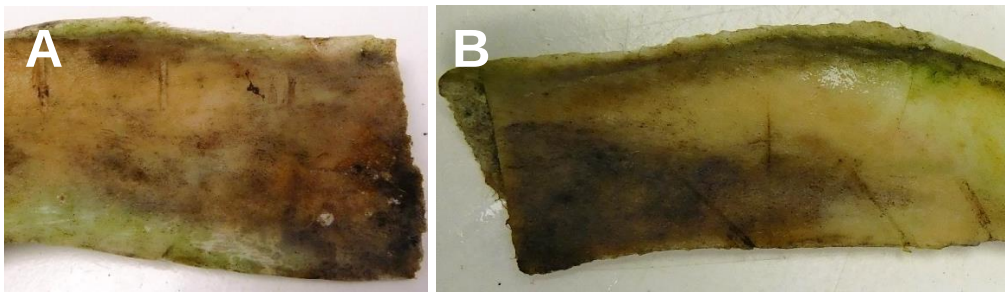


Figure 88 – (A-B) – (A): Pig 5 Specimen 8 from the eight-month surface specimen area. (B): Pig 5 Specimen 7 from the eight-month surface specimen area. It's noted in some of the areas where the bone is quite thin along the edge of the ribs, it is noted that the edge has frayed.

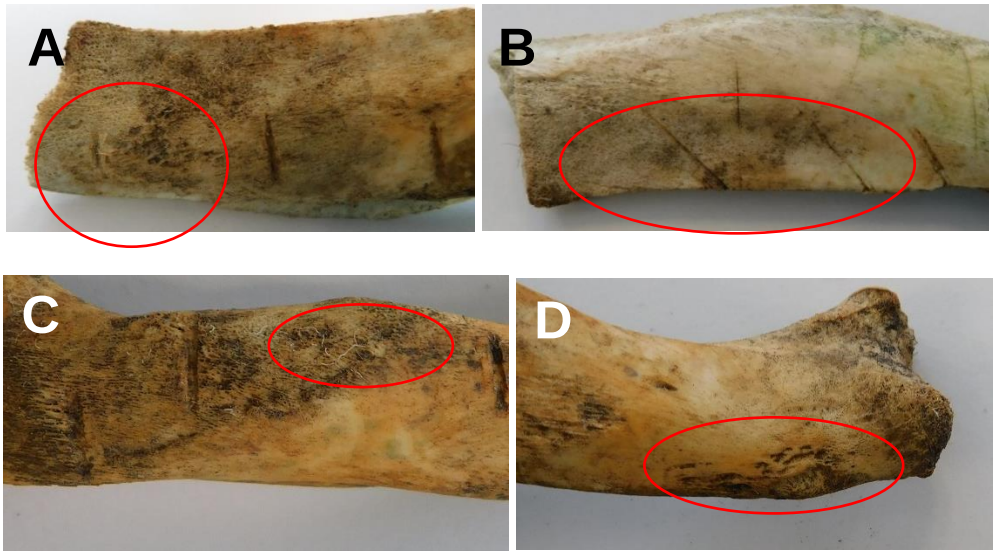


Figure 89 (A-D) – (A-B): Pig 5 Specimen 7 from the eight-month burial specimen area. (C): Pig 5 Specimen 10 from the eight-month burial specimen area. (D): Pig 5 Specimen 9 from the eight-month burial specimen area.

Figure 89 (A-D) shows examples that have been noted in previous deposition intervals, where the roots were attached between the soil surface and the rib suface, the surface looks eroded to an extent, and where the portion of the soil was already porous prior to deposition, it's appearance is worse post-deposition.

Figure 90: Pig 5 Specimen 8 from the eight-month surface specimen area.

Fungal growth can also be seen for specimens at this stage, for example figure 95 shows a rib bone (example of many) that appears to have small white dots can be seen along a portion of the surface of the bone, these white specks are believed to be a form of fungal growth.

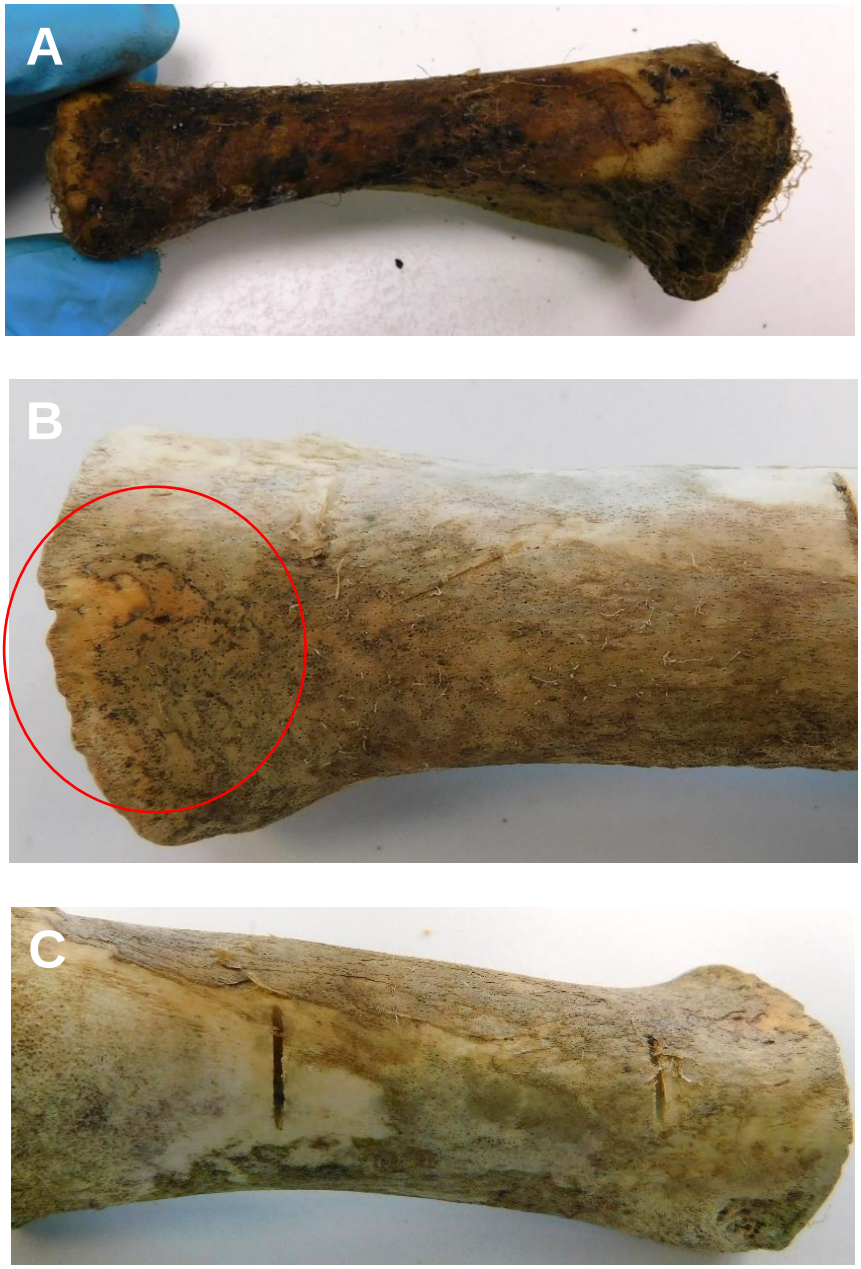


Figure 91 (A-C) – (A-B): Pig 5 Specimen 4 from the eight-month surface specimen area. (C): Pig 5 Specimen 4 from the eight-month surface specimen area.

Among the surface and burial longbones there is a large amount of surface flaking that can be seen, and associated with the growth of roots that, specifically the surface looks stripped to an extent where the cortical flaking is visible; this has been seen too occur more on the buried specimens, than the surface ones (Figure 91 (A-C).

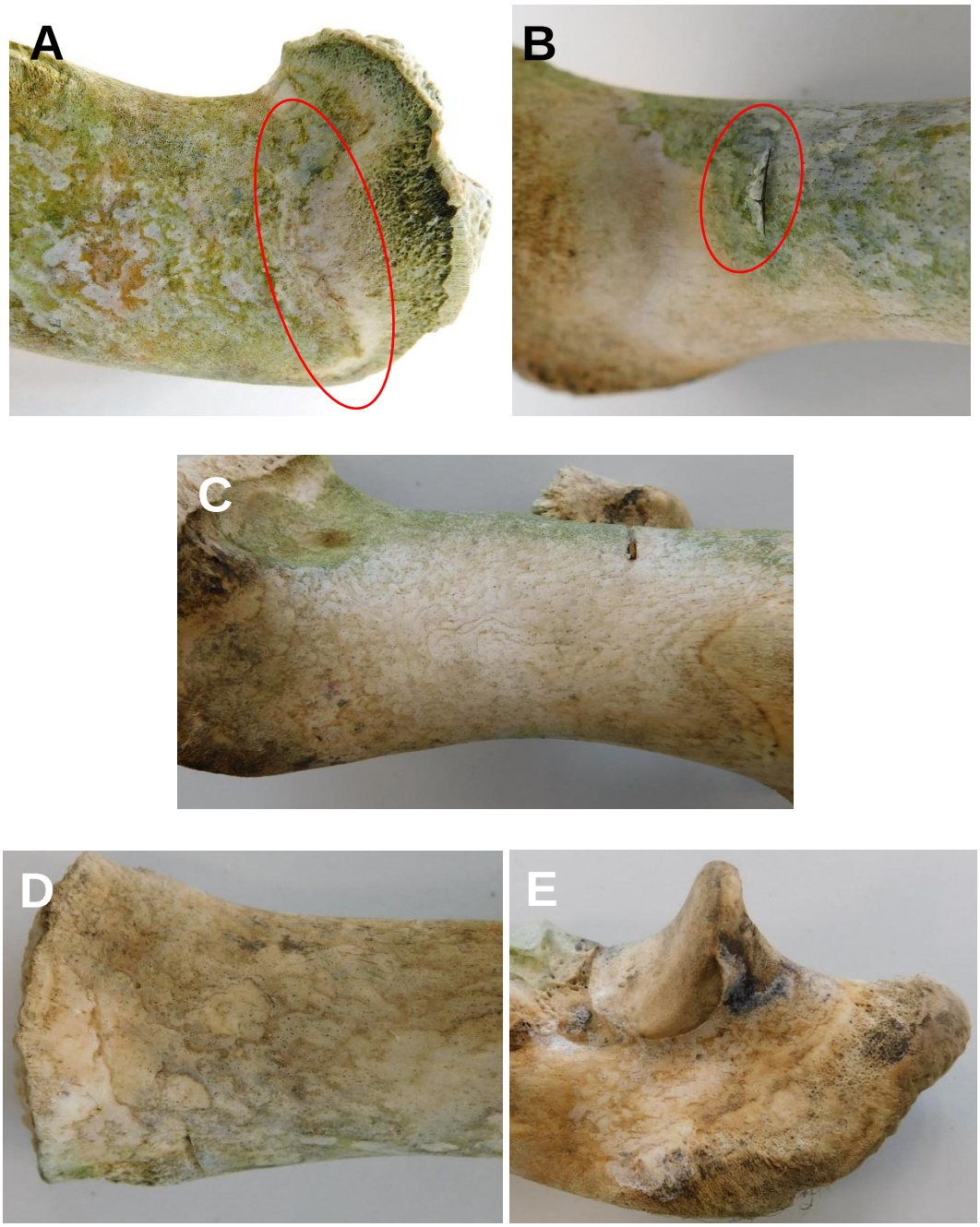


Figure 92 – (A-E) – (A-C): Pig 5 Specimen 5 from the eight-month surface specimen area. (D-E): Pig 5 Specimen 3 from the eight-month surface specimen area.

Interestingly, the surface specimens (although not as prevalent as the burial specimens) at this stage are showing the surface erosion and cortical flaking in larger frequencies than the previous intervals, where it can be seen over the majority of the surface (Figure 92 (A-E).

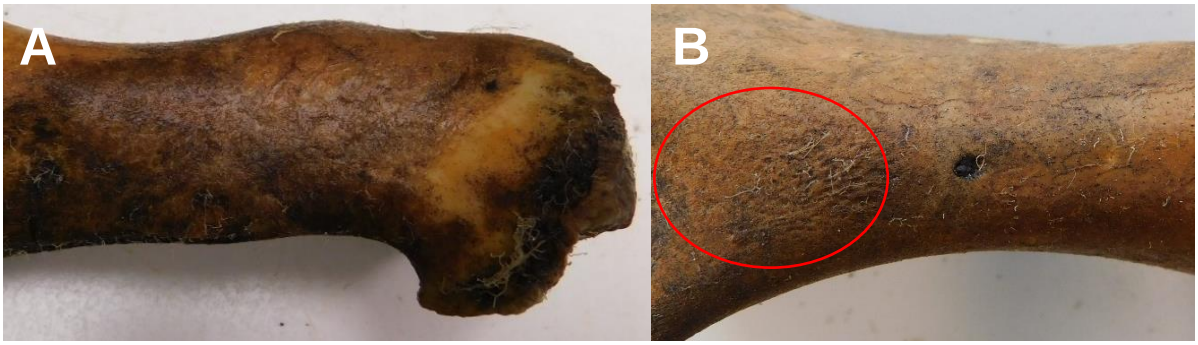


Figure 93 (A-B): Pig 5 Specimen 6 from the eight-month burial specimen area

The above figures shows that the burial specimens certainly display signs of roots growing on and attaching to them, not quite root etching, however, a pattern can be seen (similarly, to previous deposition intervals). This is also reflected in the surface specimens once they've dried and the surface is clearer and without moisture.

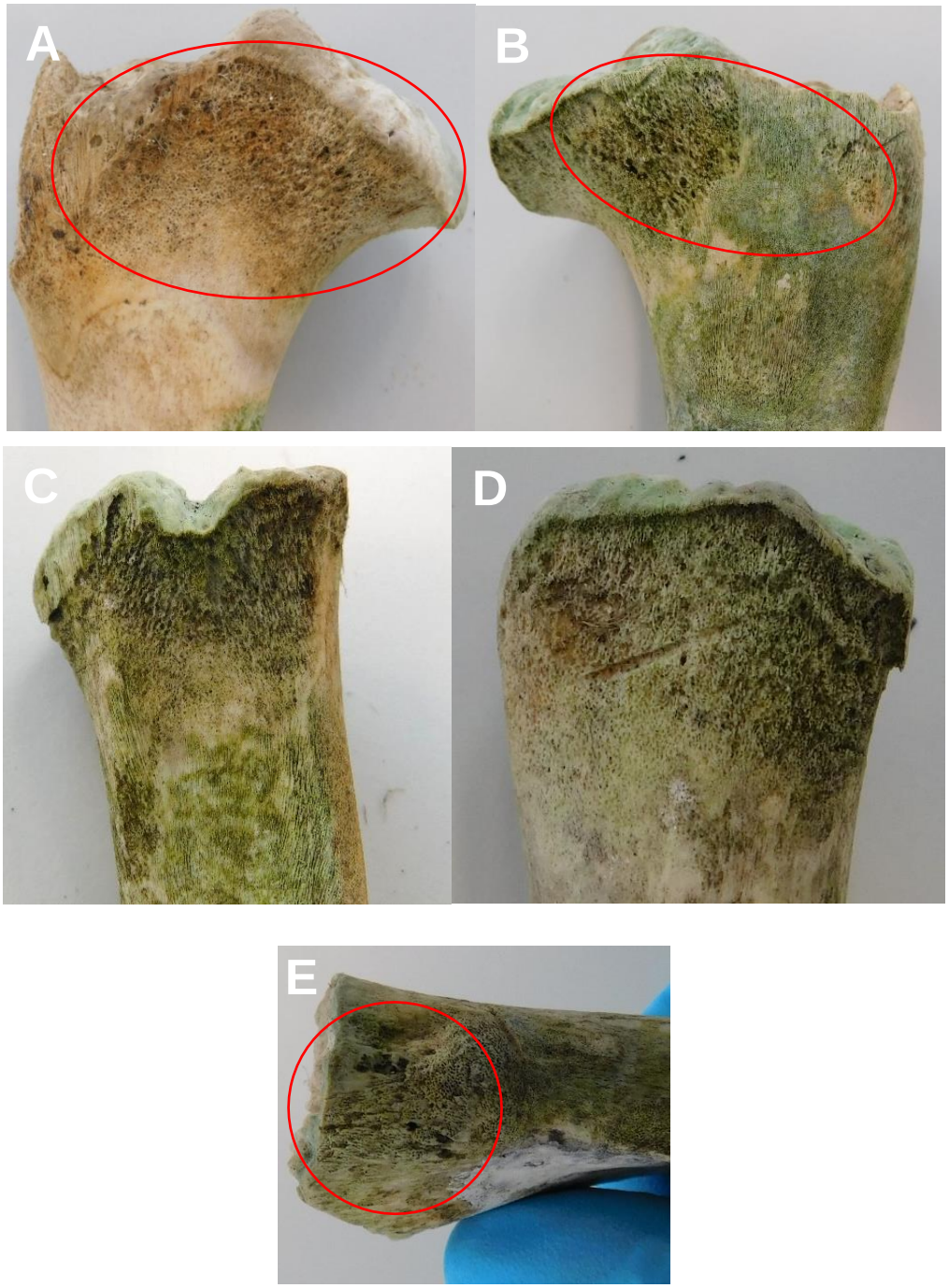


Figure 94 (A-E) – (A-B): Pig 5 Specimen 5 from the eight-month surface specimen area. (C-E): Pig 5 Specimen 3 from the eight-month surface specimen area.

For several of the specimens, there is an increase in surface porosity over a larger surface as opposed to specific local areas of irregular damage. This is in the areas where there are the 'pseudo-weathering' marks identified before, where these areas most likely have facilitated further damage by allowing the interaction of acidic soil water, macro/micro flora and fauna (Figure 94 (A-E).

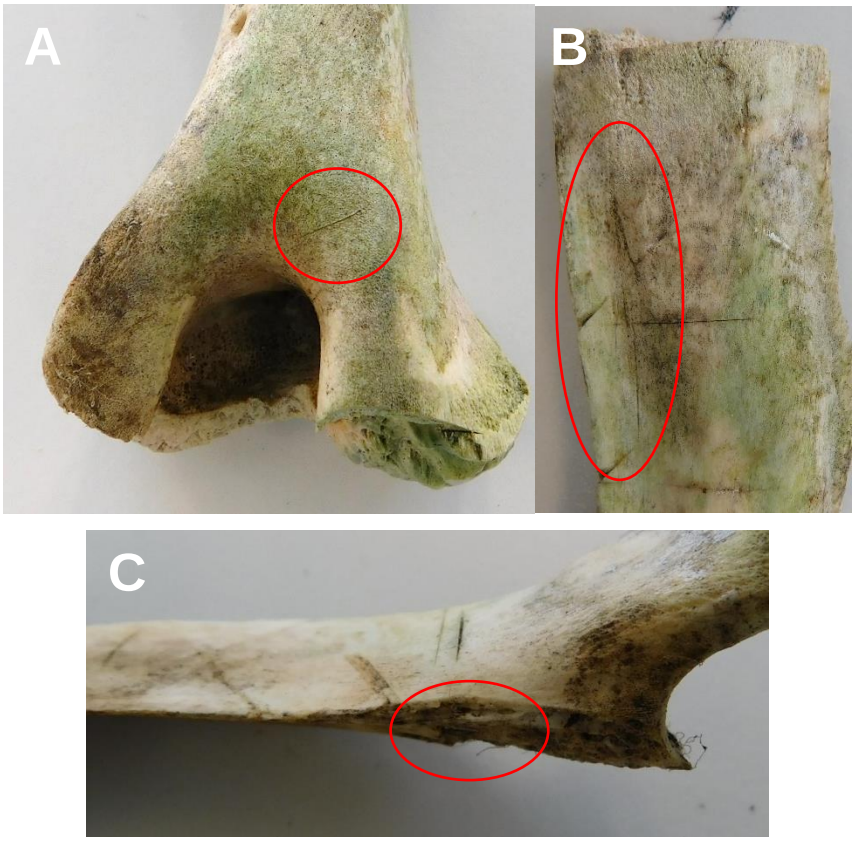


Figure 95 (A-C) – (A): Pig 5 Specimen 5 from the eight-month surface specimen area. (B): Pig 5 Specimen 8 from the eight-month surface specimen area. (C): Pig 5 Specimen 7 from the eight-month surface specimen area.

At this stage there are a few of the specimens have exhibited a form of cracking that can be seen along the surface as well as near the infliction areas (Figure 95 (A-C)).

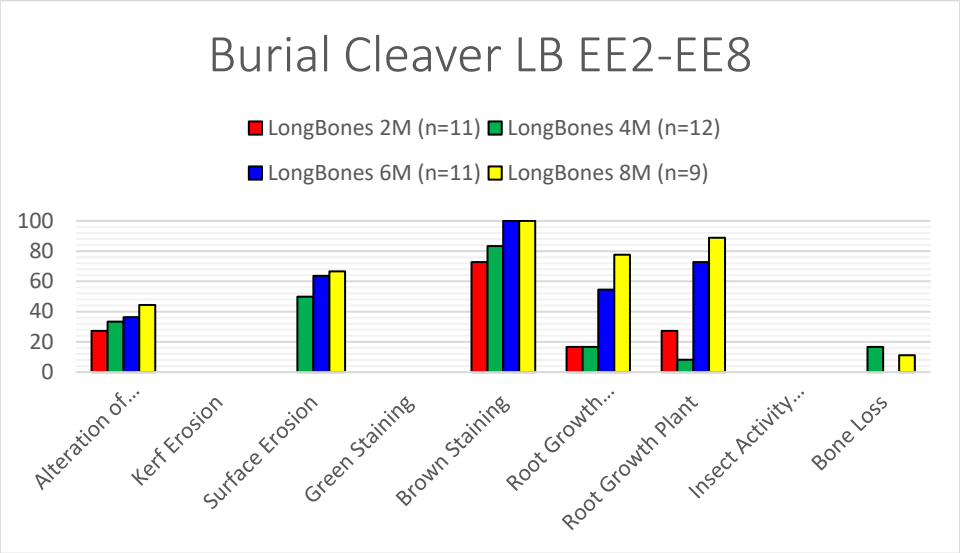
4.3 - Microscopic Changes:

4.3.1 - Qualitative Changes to Cutmarks and Surrounding Surface:

There are a number of observable physical changes that have been tracked across the specimens, to determine if the frequency of these increase or decrease across deposition interval (0-8 months) and type (Surface vs Burial). It's noted that changes are being observed and tracked, for example, if the surrounding area of a cutmark or the edge was moderately flaked or porous pre-deposition and hasn't changed notably during deposition, then it wouldn't be noted. If the flaring or porosity had increased compared to its pre-deposition state or is noted as a difference, then it should have been noted. The graphs and figures below are approximations made from the physical observable changes noted for each cutmark. Although they're categorical, in nature, they are still qualitative.

They were first compared and noted what changes could be seen based on the written Key (The key being table 3 in the method section), the objective was to simply note the presence or absence of this physical change, not the severity, so the frequency and percentage affected can be estimated and shown to determine any observable trends (The method is shown in Chapter 3 and the raw data tables can be found in Appendix Section E and the Specimen comparison sheets in Section F).

4.3.2 - Cleaver Cutmarks 2M-8M; Burial vs Surface:



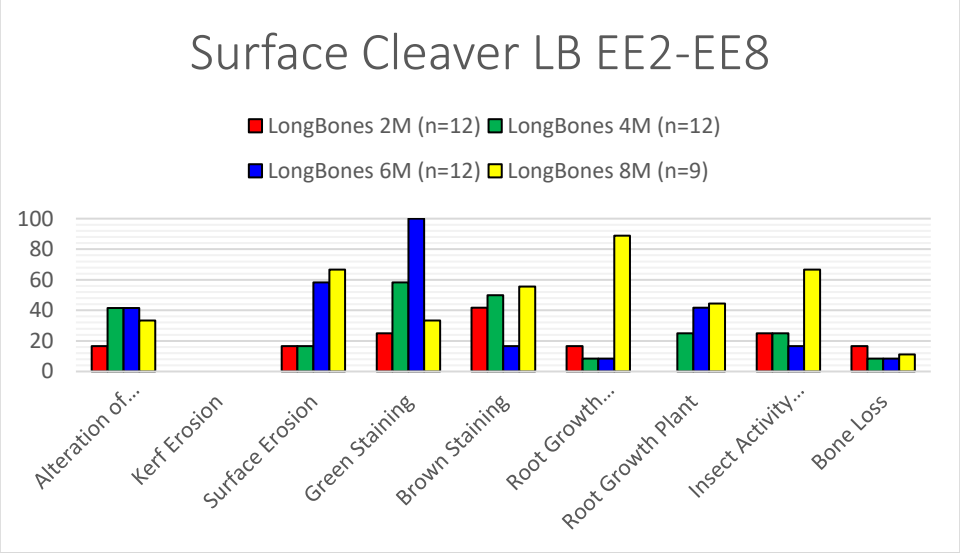


Figure 96: Physical Change Quantitative Data for Burial Cleaver Long Bones for the total eight-month deposition period.

Figure 97: Physical Change Quantitative Data for Surface Cleaver Long Bones for the total eight-month deposition period.

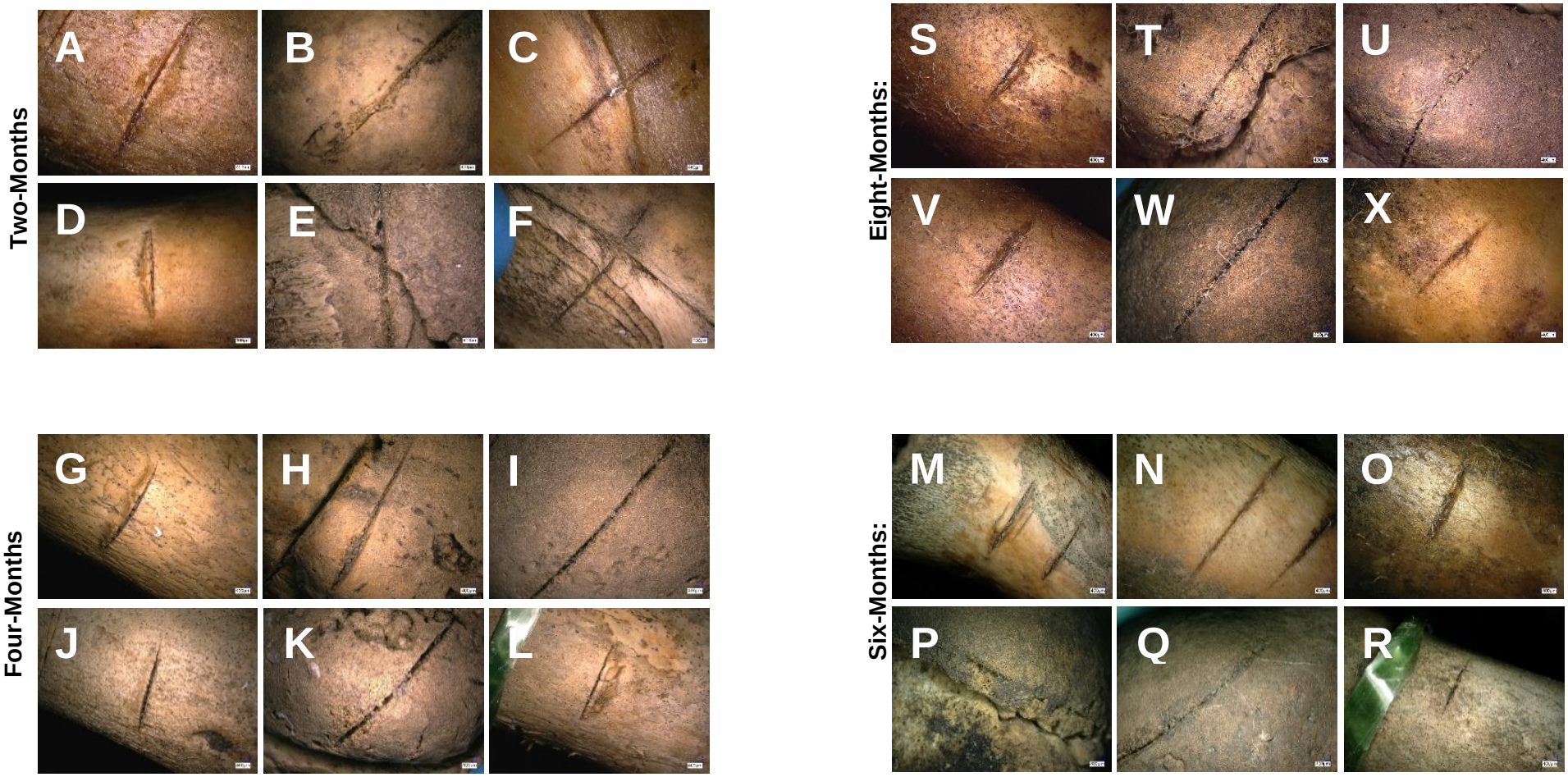
The above figures show that the categories with the highest overall percentage change are staining (brown and green), flora activity (plant and fungal root growth) and a collective increase in the alteration of edge appearance and structure (degradation,flaking, fading and fracturing). The percentage of cutmarks that appeared to have their edges altered in some form is similar between the burial (44.4%) and surface (33.3%) specimens towards the end of the deposition period. Surface erosion had increased to the same point for both burial (66.6%) and the surface (66.6) specimens, however, the changes were more gradual with the burial

specimens after four months of deposition, where as the surface specimens exhibited a sudden increase by six months of deposition.

The staining, flora and arthropod activity differed between the depositions areas, most likely due to the difference of accessibility between surfaced and buried remains. Arthropod activity (damage and presence) effected none of the burial specimen marks compared to a large amount of activity with the surface specimens (66.6%). The activity for plant root growth is certainly different as the burial specimens have largely shown more activity (88.8%) compared to the surface specimens (44.4%). Interestingly, up till six months of deposition, the activity for fungal root growth was at a minimal for the surface specimens (8.33%) and much higher fo the burial specimens (54.54%). Whereas, by eight months there was a sudden increase in fungal root activity for the surface specimens (88.8%) compared to the burial specimens (77.7%).

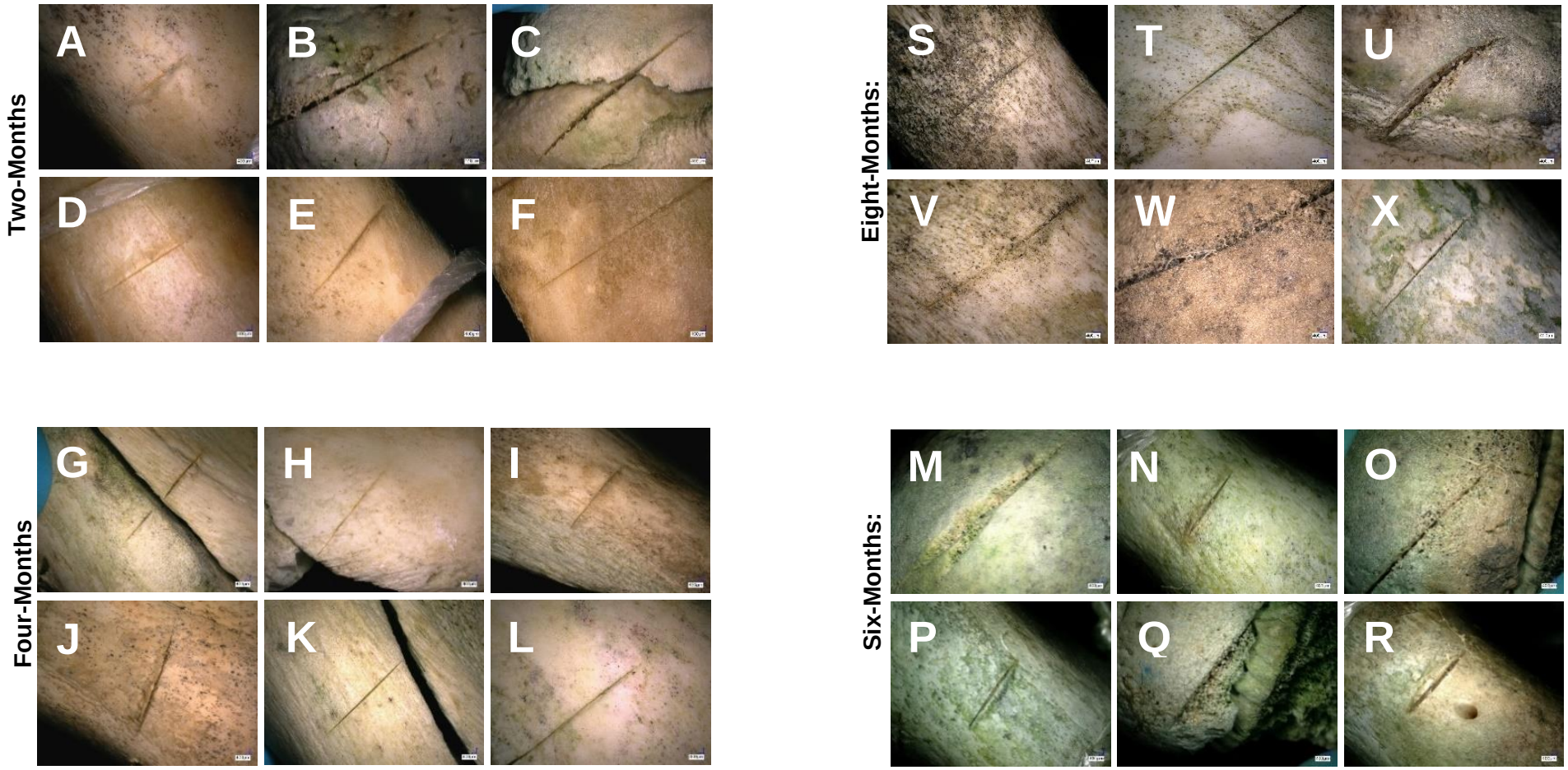
Different deposition areas exhibited different patterns of staining, most likely due to the different forms of exposure between the deposition areas. For the burial specimens, all the cutmarks were stained brown and none were stained green by the end of the deposition period. Whereas, the surface remains were varied, depending on the position of the bone to the ground; ground facing side of the bone were stained brown, grass facing side of the bone were stained green. More of the cutmarks for the surface specimens were stained brown (55.5%) than green (33.33%).Interestingly the green staining by the six month deposition reached a peak of all the cutmarks were stained green, the drastic drop is most likely the result of the bones being washed by the increase in rainfall between six and eight months, as well as the increase in temperature that would dry the specimens; hence, less of them look green stained. (A Further look at these percentages can be found in Appendix Section E under Physical Change to Cutmarks).

Burial Cleaver Marks (LongBones):

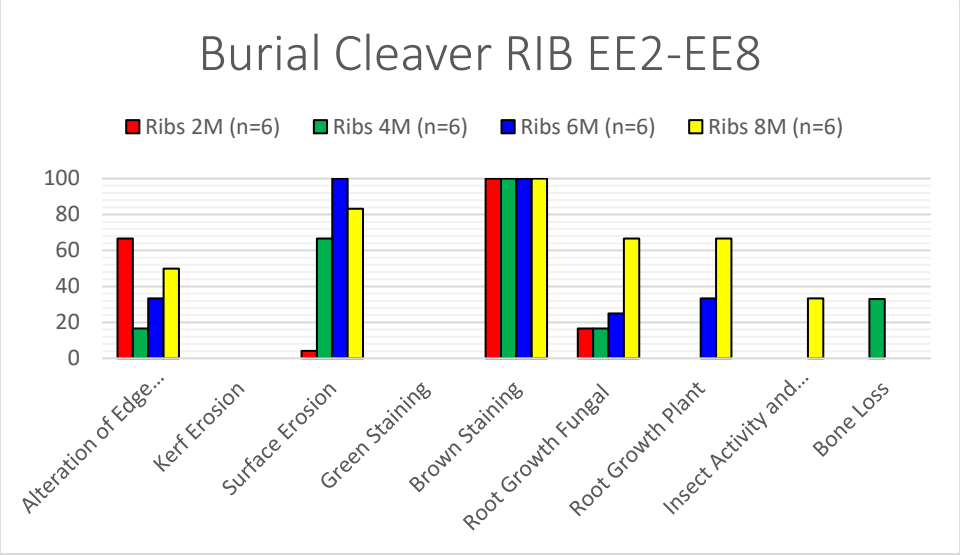


Figures 98 (A-X): show a largely overall perspective on how the burial cleaver long bone cutmarks have visibly changed, the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Spection G. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective.

Surface Cleaver Marks (LongBones):



Figures 99 (A-X): show a largely overall perspective on how the surface cleaver long bone cutmarks have visibly changed, the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Spection G. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective.



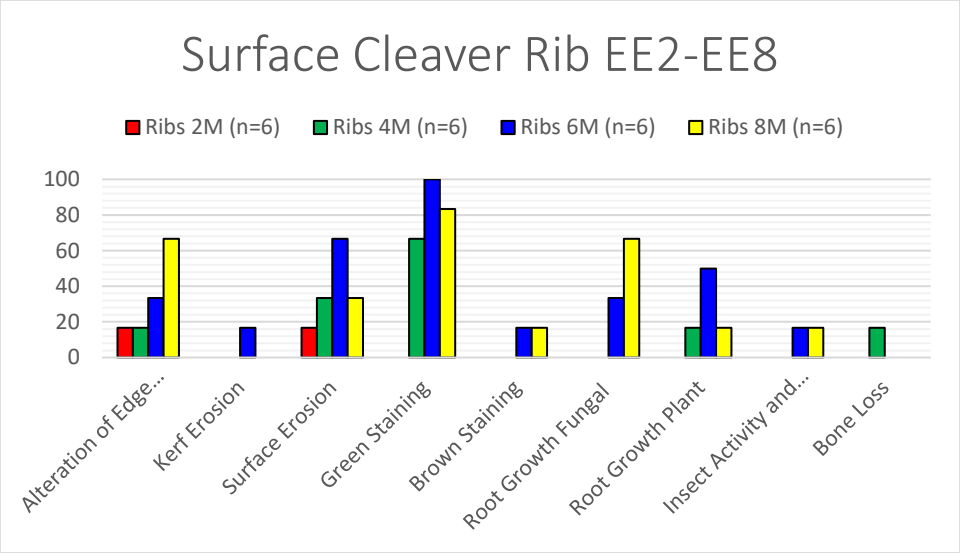


Figure 100: Physical Change Quantitative Data for Burial Cleaver Rib Bones for the total eight-month deposition period.

Figure 101: Physical Change Quantitative Data for Surface Cleaver Rib Bones for the total eight-month deposition period.

Looking at the above figures, it's clear that similarly to the cleaver marks on long bones, the ones on the ribs have reacted similarly where the categories with the highest percentage effected are alteration of the cutmark edge, staining, flora and arthropod activity. The amount of cutmarks that had shown a form of alteration to their edge appearance and structure is moderately higher for the surface specimens (66.6%) compared to the burial specimens (50%). However, there is an anomaly for the burial specimens at the two-month point, where the percentage of cutmarks affected is moderately higher (66.6%) than the eight-month point (50%). A closer look into the raw data, there is a higher amount of flaking observed initially,

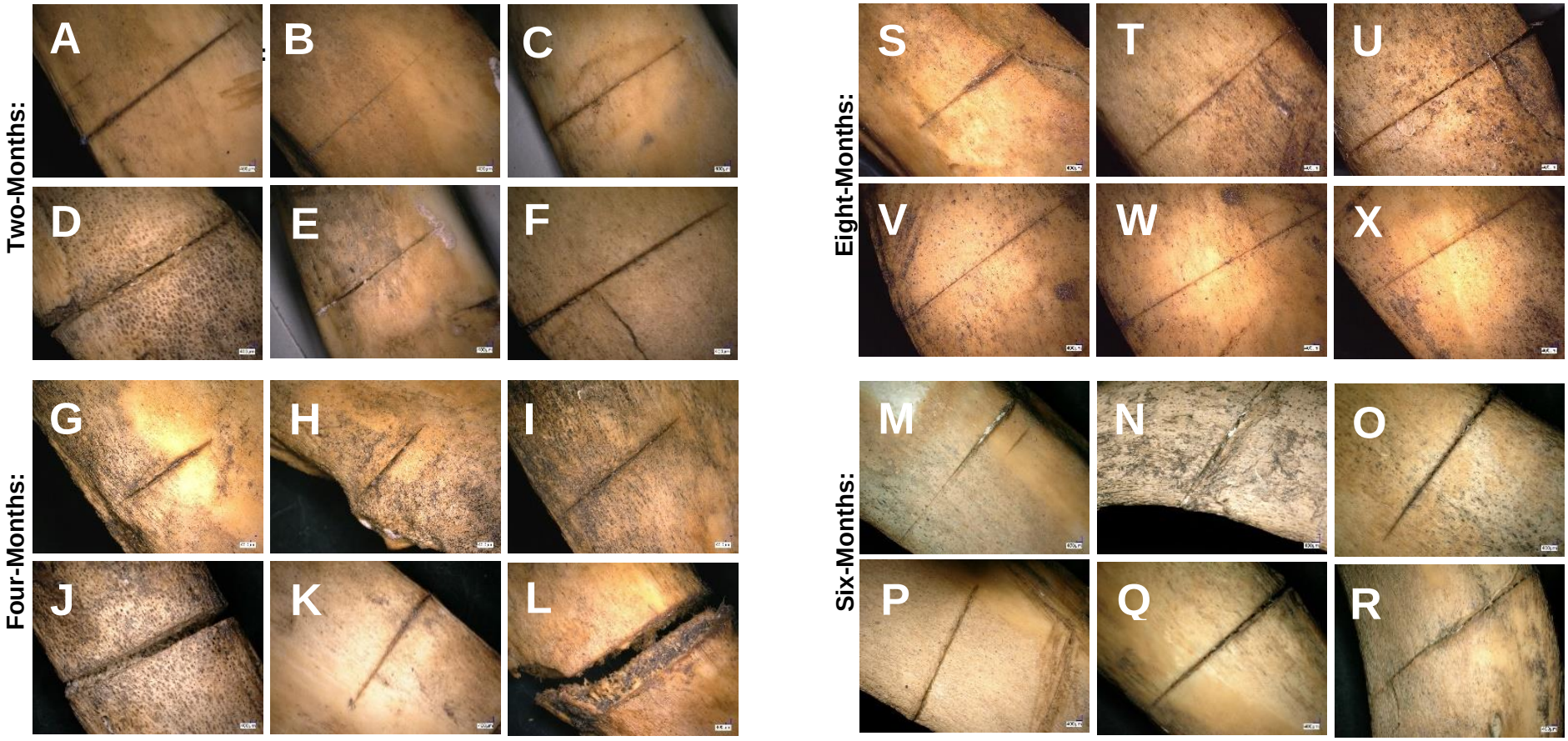
by the end of the deposition period, it's possible that any flakes/flarings that were present prior, were removed/lost during deposition.

Surface erosion for the burial specimens are much higher (83.3%) than the surface specimens (33.3%). However, the amount of cutmarks to show a form of surface erosion is moderately higher at the six-month interval than their eight-month counter parts; for the burial specimens it's only moderately higher (100% vs 83.3%), whereas for the surface specimens it's double the amount (66.67% vs 33.33%).

All of the cutmarks for the burial specimens were stained brown and none were stained green. Whereas the cutmarks for the surface specimens differed largely with more cutmarks being stained green (83.3%) and less being stained brown (16.67%). The root activity differs slightly compared to the long bone specimens, the activity for fungal root growth is the same for surface (66.6%) and burial specimens (66.6%) by the eight-month period. Whereas the activity for plant root growth differs largely with the burial specimens being higher (66.6%) than the surface specimens (16.6%).

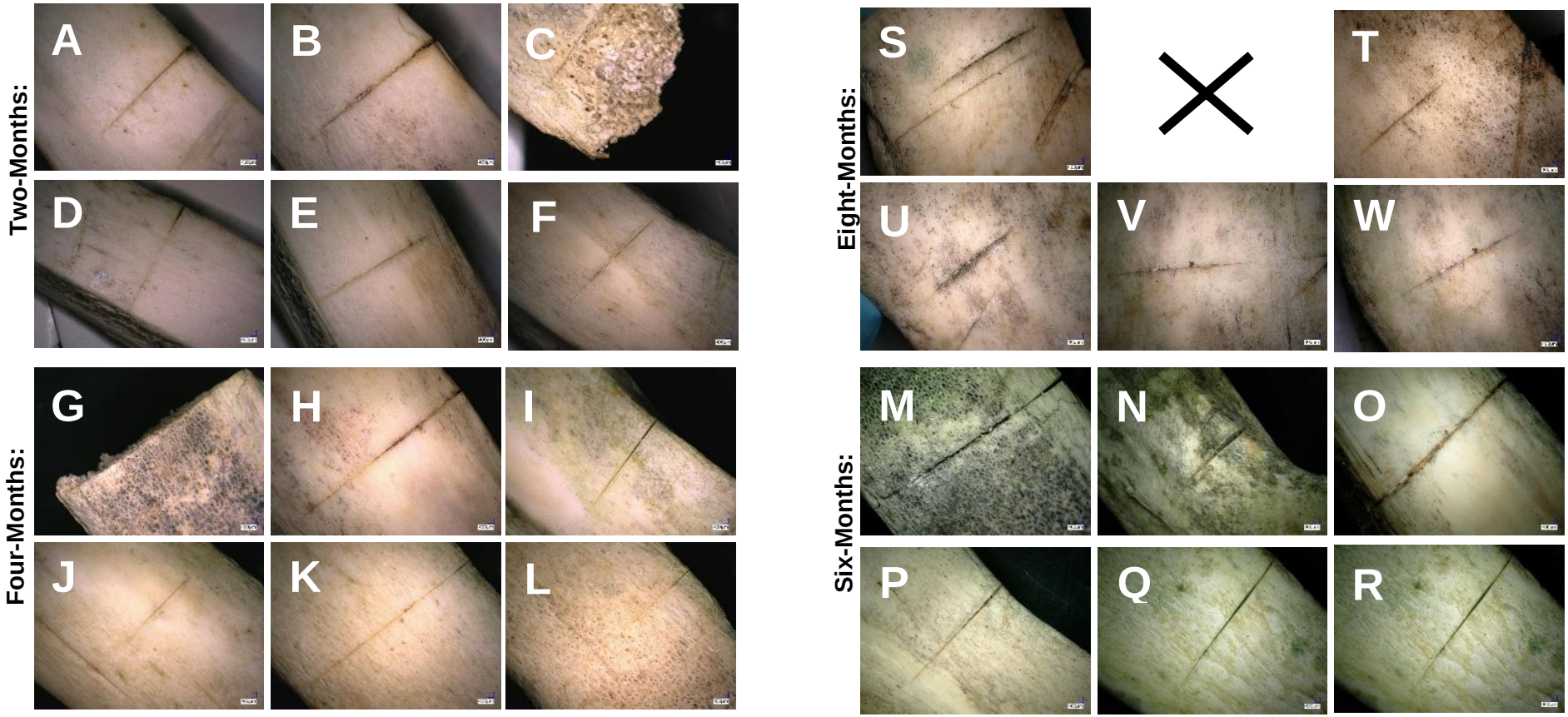
There is an anomaly with the surface specimens, by six-months, it reached a peak (50%) that is higher than its eight-month counterpart for plant root growth. This is possibly based on the activity of plant roots in general, this could just be a point of low activity before it increases again. The arthropod activity (damage and presence) for the rib specimens is opposite to the longbones, where the activity is notably higher for the burial specimens (33.3%) than the surface specimens (16.67%) by the eight-month interval. (A Further look at these percentages can be found in Appendix Section E under Physical Change to Cutmarks).

Burial Cleaver Marks (Ribs):



Surface Cleaver Marks (Ribs):

Figures 102 (A-X): Show a largely overall perspective on how the burial cleaver rib cutmarks have visibly changed the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective.



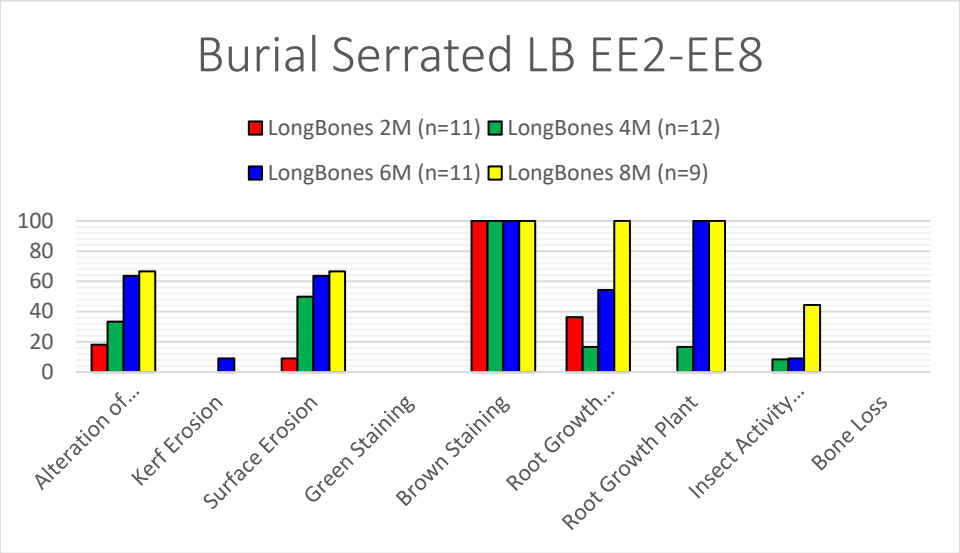
Figures 103 (A-W): Show a largely overall perspective on how the surface cleaver rib cutmarks have visibly changed the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G. The black 'X' represents a missing cutmark in this sample group. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective.

Burial Cleaver									
% Affected	**Alteration of Edge Definition and Structure**	**Kerf Erosion**	**Surface Erosion**	**Green Staining**	**Brown Staining**	**Root Growth Fungal**	**Root Growth Plant**	**Insect Activity and Presence**	**Bone Loss**
Long Bones 2M (n=11)	27.27	0	0	0	72.72	16.67	27.27	0	0
Long Bones 4M (n=12)	33.33	0	50	0	83.3	16.67	8.3	0	16.67
Long Bones 6M (n=11)	36.36	0	63.63	0	100	54.54	72.72	0	0
Long Bones 8M (n=9)	44.4	0	66.6	0	100	77.7	88.8	0	11.1
Ribs 2M (n=6)	66.6	0	4.17	0	100	16.67	0	0	0
Ribs 4M (n=6)	16.6	0	66.67	0	100	16.67	0	0	33
Ribs 6M (n=6)	33.3	0	100	0	100	25	33.33	0	0
Ribs 8M (n=6)	50	0	83.3	0	100	66.6	66.6	33.3	0
Surface Cleaver									

% Affected	Alteration of Edge Definition and Structure	Kerf Erosion	Surface Erosion	Green Staining	Brown Staining	Root Growth Fungal	Root Growth Plant	Insect Activity and Presence	Bone Loss
Long Bones 2M (n=12)	16.6	0	16.67	25	41.67	16.67	0	25	16.67
Long Bones 4M (n=12)	41.6	0	16.67	58.3	50	8.33	25	25	8.33
Long Bones 6M (n=12)	41.6	0	58.3	100	16.67	8.33	41.67	16.67	8.33
Long Bones 8M (n=9)	33.3	0	66.6	33.33	55.5	88.8	44.4	66.6	11.1
Ribs 2M (n=6)	16.6	0	16.67	0	0	0	0	0	0
Ribs 4M (n=6)	16.6	0	33.33	66.67	0	0	16.67	0	16.67
Ribs 6M (n=6)	33.3	16.67	66.67	100	16.67	33.33	50	16.67	0
Ribs 8M (n=6)	66.6	0	33.33	83.3	16.67	66.6	16.6	16.67	0

Table 7: Results for the percentage (%) affected amount for burial and surface cleaver cutmarks.

4.3.3 - Serrated Cutmarks 2M-8M; Burial vs Surface:



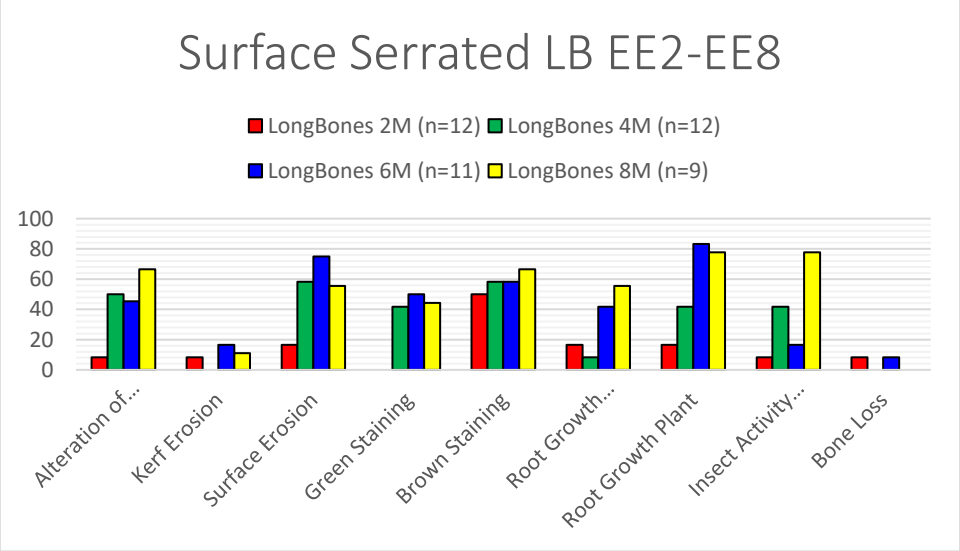


Figure 104: Physical Change Quantitative Data for Burial Serrated Long Bones for the total eight-month deposition period.

Figure 105: Physical Change Quantitative Data for Surface Cleaver Long Bones for the total eight-month deposition period.

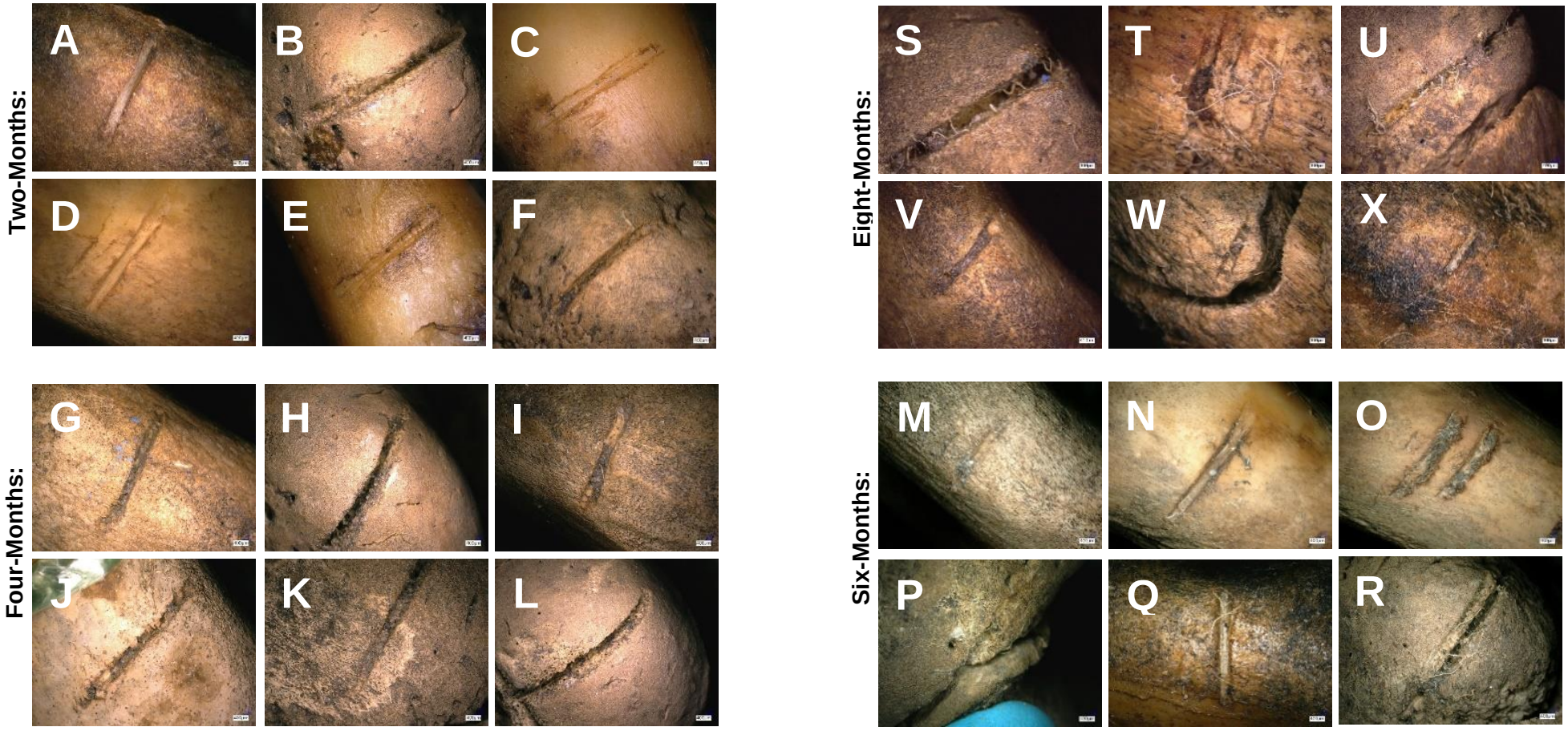
The above figures show there a greater amount of serrated cutmarks have received a greater amount of physical changes compared to the cleaver cutmarks, when comparing the raw frequency data and the percentage affected data. The amount of activity could be proportionate to the amount of available space that the cutmark offers. The larger amount of space within a serrated cutmark could facilitate further activity and physical changes to it; meaning, it allows for further interaction with macroarthropods, microflora, acidic soil water etc.

The green/brown staining of the cleaver and serrated cutmarks are similar as logically structure of the cutmark (space availability) should not influence to what extent it would stain. For example, all of the cutmarks for the burial specimens were stained brown and none were stained green. Whereas, for the surface specimens, a majority were stained brown (66.66%) and moderately less were stained green (44.44%). The recorded alteration to the edge appearance and structure is noted as the same for the burial and the surface specimens (66.6%), specifically the surface specimens experienced a sudden rise in cutmarks affected whereas the buried specimens was a gradual increase.

Surface erosion for the burial specimens was moderately higher (66.6%) than the surface specimens (55.5%), unlike the cleaver where the surface erosion was recorded as the same for both. For both the surface and burial specimens, a number of cutmarks exhibited a form of Kerf floor erosion, it was higher in the surface specimens (11.1%) than the burial ones (9.09%) by the end of the eight-month period. It was only exhibited for the burial specimens at the eight-month period, whereas it fluctuated for the surface specimens. Unlike the cleaver cutmarks where they exhibited nothing in this category. The kerf floor of the serrated cutmarks are more exposed to the elements compared to cleaver cutmarks. Supporting the above hypothesis of a greater space will facilitate further interaction and damage, there is a larger amount of gradual/accumulative root activity within the serrated cutmarks compared to the cleaver marks.

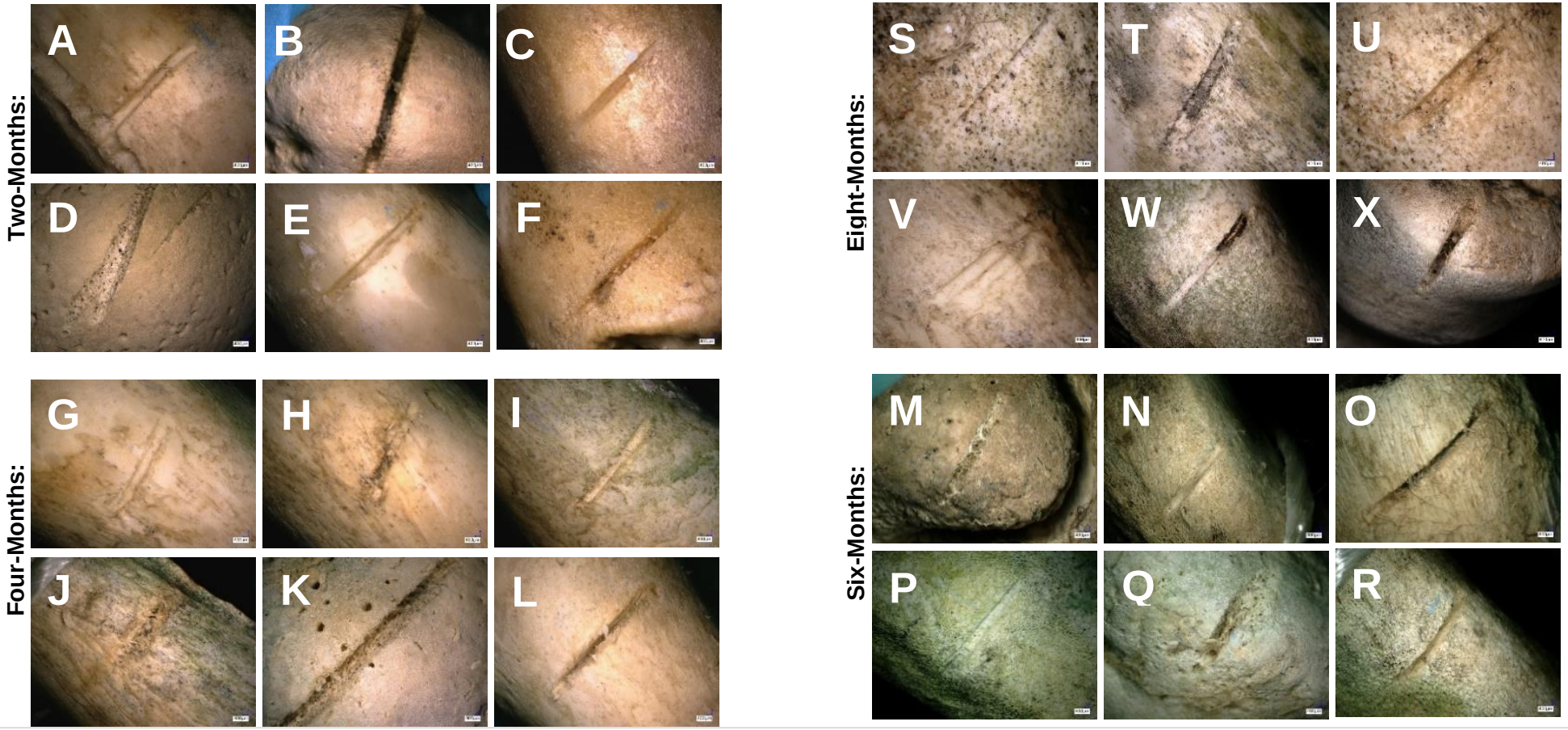
By the eight-month period, all of the cutmarks for the burial specimens had exhibited both plant and fungal root activity. It was more gradual for the fungal root activity, whereas the plant root activity jumped between two months and six months (16.67% vs 100%).Whereas, for the surface specimens, it was less overall, there were more cutmarks that exhibited plant root activity (77.7%) compared to fungal root activity (55.5%) only moderately. Interestingly, the plant root activity was considerably lower than the fungal root activity for the cleaver marks. Unlike the lack of arthropod activity for the cleaver marks on longbones, these cutmarks exhibited activity for both burial and surface specimens. With the surface specimens (77.7%) being nearly double the amount of the burial specimens (44.4%). The number of cutmarks to exhibit this activity spikes/rises by the eight-month interval rapidly (besides an anomaly at four months for the surface specimens). (A Further look at these percentages can be found in Appendix Section E).

Burial Serrated Marks (LongBones):

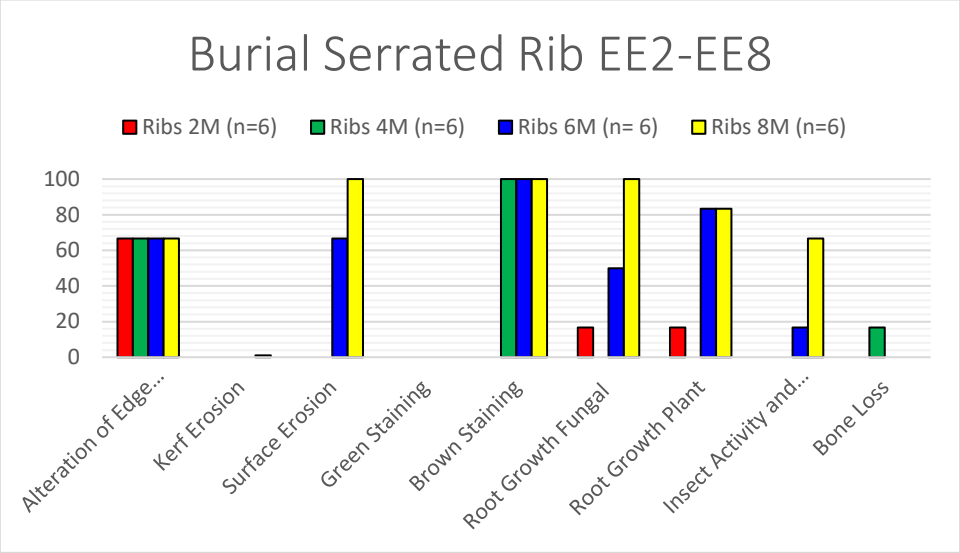


Figures 106 (A-X): show a largely overall perspective on how the burial serrated long bone cutmarks have visibly changed, the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective.

Surface Serrated Marks (LongBones):



Figures 107 (A-X): show a largely overall perspective on how the surface serrated long bone cutmarks have visibly changed, the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective.



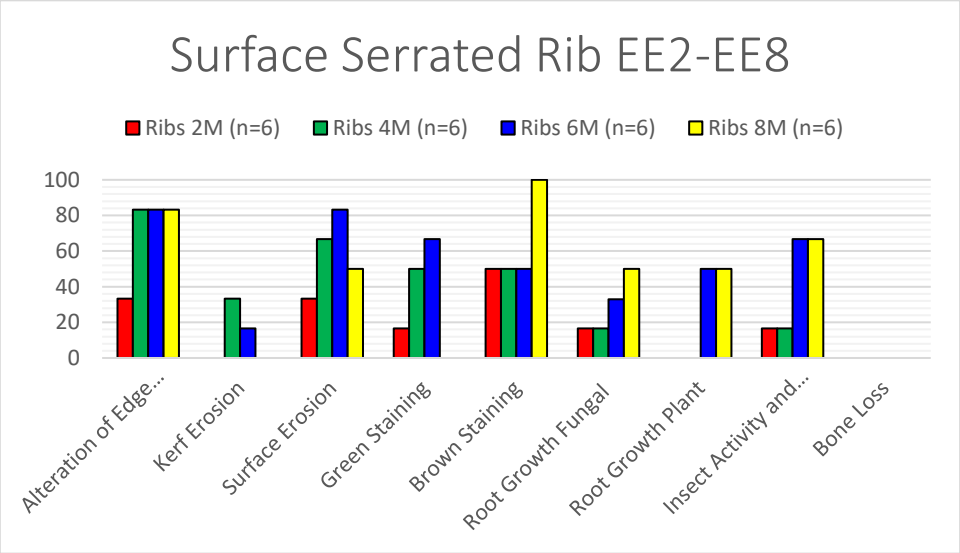


Figure 108: Physical Change Quantitative Data for Burial Serrated Rib Bones for the total eight-month deposition period.

Figure 109: Physical Change Quantitative Data for Surface Serrated Rib Bones for the total eight-month deposition period.

In the above figures, the cutmarks on the ribs exhibited larger amounts of physical changes compared to cleaver cutmarks (similar to the serrated cutmarks on the longbones). However, the serrated rib marks compared to the long bones are moderately different based on maximum amount affected and the build up towards the eight-month interval. The amount of cutmarks that showed edge alteration is the same between the rib and longbones for the burial group (66.6%) by the eight-month period, whereas it is higher for the surface rib specimens (83.3%).

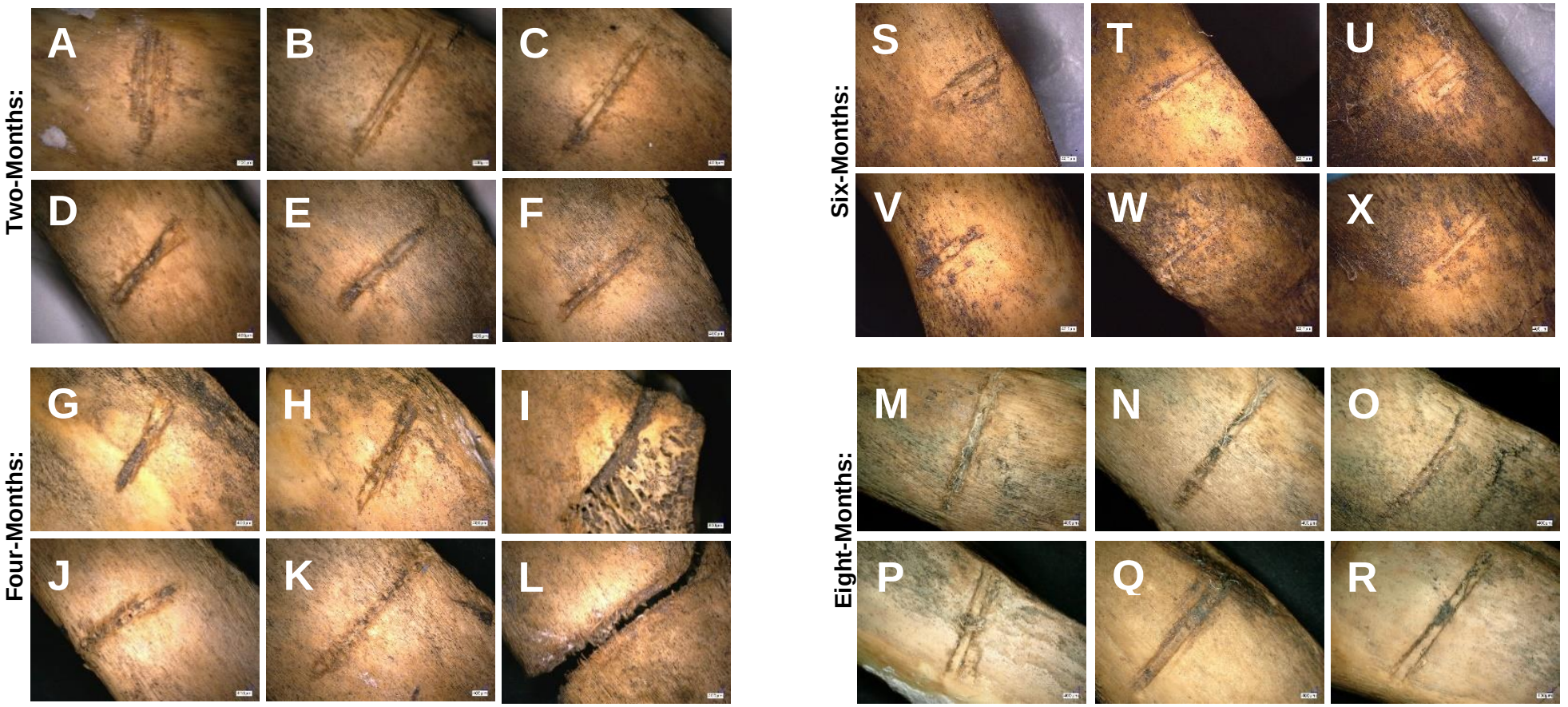
The amount of cutmarks affected peaked and levelled for the burial serrated cutmarks from the start, whereas they peaked and levelled from two-months for the surface specimens. All of the burial serrated cutmarks exhibited surface erosion by the end interval, whereas only half of the surface serrated cutmarks (50%) exhibited it. The buried specimens only exhibited surface erosion from six-month onwards, whereas the surface specimens fluctuated and has decreased compared to the six-month interval (83.3%). The ribs deposited for the eight-month stage may have been in a less compromising position or one that that exposes cutmarks less to harsher conditions. The serrated rib cutmarks exhibited a form of kerf floor erosion (similar to the long bones), with the higher activity siding with the surface specimens by six-months (16.67%) with the burial cutmarks not exhibiting this at all. None of the eight-month surface cutmarks exhibited this at all and it only peaked at four-months (33.3%). Therefore, it could be more random rather than a cumulative build.

Regarding staining, all of the burial cutmarks were stained brown by the end of the eight-month interval and none were stained green (typical trend seen here). The surface specimen cutmarks levelled from two-months (50%) till the eight-month interval where all of them were stained brown. Whereas it was a gradual build up for the green-stained cutmarks from two-months till a peak at six-months (66.7%). Then it dropped to none of the cutmarks at eight-months exhibiting this staining.

The drop could be the result of an increase in heavy rainfall then higher temperatures; thus, the bone surfaces could have been more washed. Also, the ribs being closer to the ground means they are possibly further away from the potential cause of the green staining e.g. the tall grass. Root growth activity for the cutmarks inflicted upon the rib bones differ moderately to those on the longbones. Where for the surface specimens, the amount of activity for fungal and plant root growth were equal (50%) by the eight-month interval, with a slight difference of build up; fungal growth was more gradual, whereas plant root peaked and levelled at six-months. The activity for the fungal root growth was higher as all of the cutmarks compared to the plant root activity of the burial specimens (83.3%) which is moderately lower. For the burial specimens, at four-months, none of the cutmarks exhibited any root activity, then there was a spike at six-months.

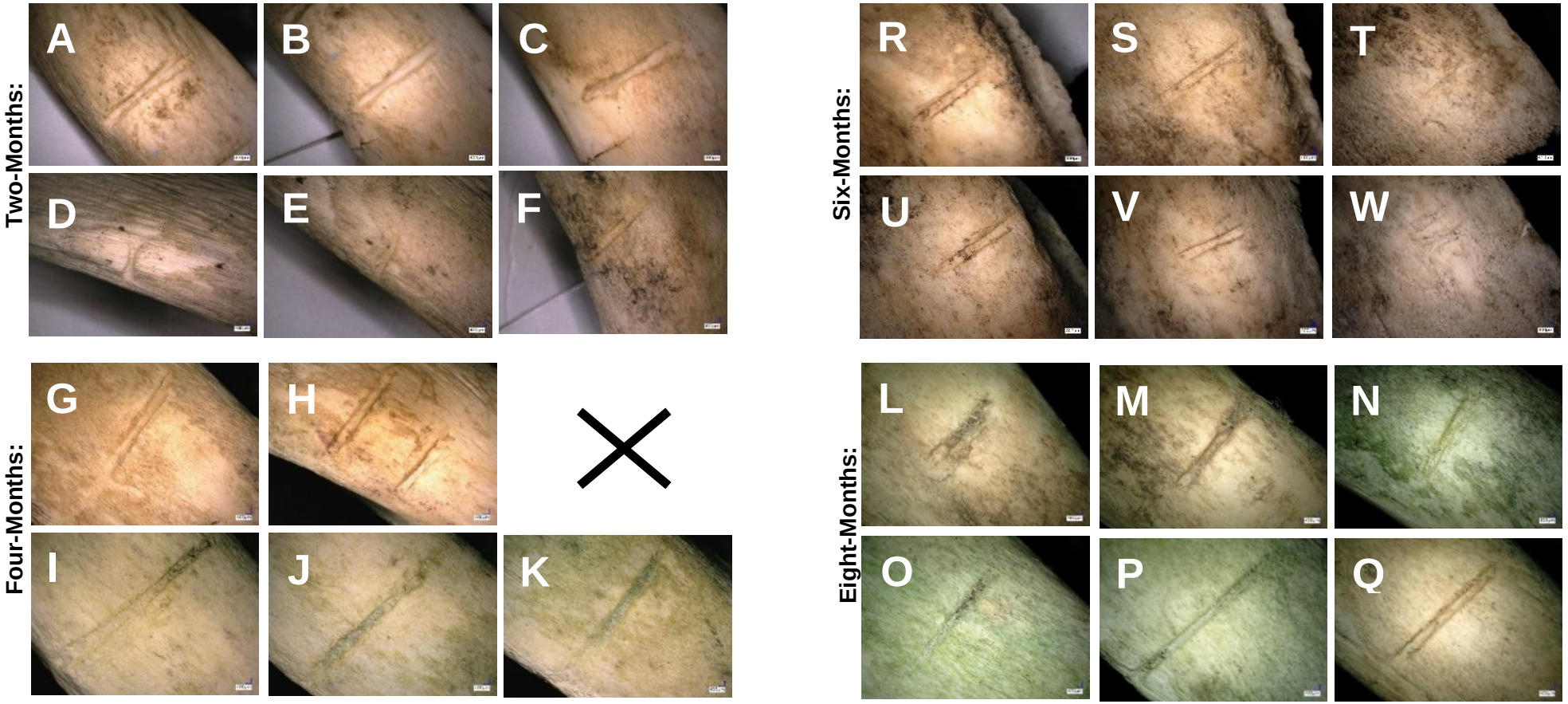
Arthropod activity for both surface and buried specimens peaked at the same amount of cutmarks affected (66.6%), interestingly, they spiked earlier for the surface specimens at six-months, compared to the spike at the end of the burial specimens i.e. eight months. (A Further look at these percentages can be found in Appendix Section E).

Burial Serrated Marks (Ribs):



Figures 110 (A-X): show a largely overall perspective on how the burial serrated rib bone cutmarks have visibly changed, the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective.

Surface Serrated Marks (Ribs):



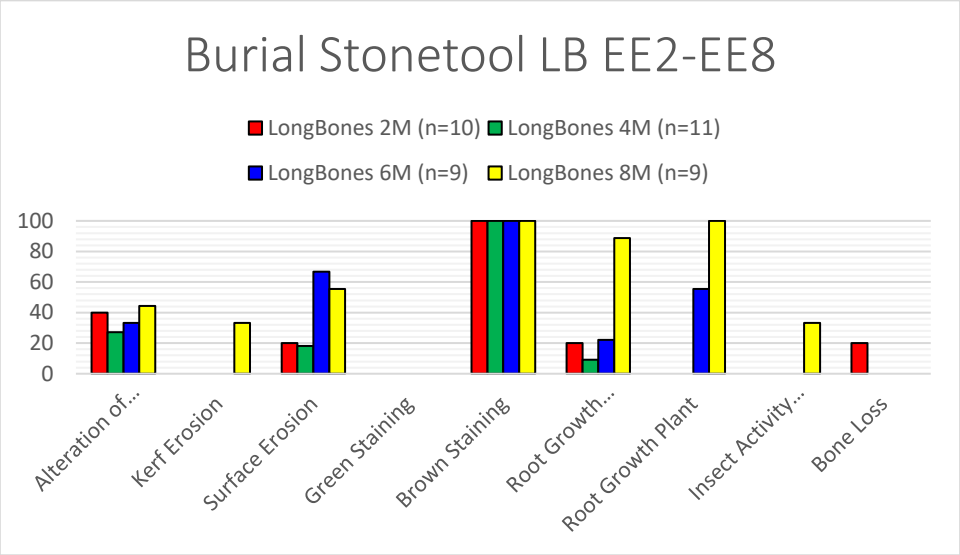
Figures 111 (A-W): show a largely overall perspective on how the surface serrated rib bone cutmarks have visibly changed, the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G. The black 'X' represents a missing cutmark in this sample group. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective. These are not all the present cutmarks on each specimen, only a random selection to show the general perspective.

Burial Serrated									
% Affected	**Alteration of Edge Definition and Structure**	**Kerf Erosion**	**Surface Erosion**	**Green Staining**	**Brown Staining**	**Root Growth Fungal**	**Root Growth Plant**	**Insect Activity and Presence**	**Bone Loss**
Long Bones 2M (n=11)	18.18	0	9.09	0	100	36.36	0	0	0
Long Bones 4M (n=12)	33.33	0	50	0	100	16.67	16.67	8.33	0
Long Bones 6M (n=11)	63.63	9.09	63.63	0	100	54.45	100	9.09	0
Long Bones 8M (n=9)	66.6	0	66.6	0	100	100	100	44.4	0
Ribs 2M (n=6)	66.6	0	0	0	0	16.67	16.67	0	0
Ribs 4M (n=6)	66.6	0	0	0	100	0	0	0	16.67
Ribs 6M (n= 6)	66.6	0	66.67	0	100	50	83.33	16.67	0
Ribs 8M (n=6)	66.6	0	100	0	100	100	83.3	66.6	0
Surface Serrated									

% Affected	Alteration of Edge Definition and Structure	Kerf Erosion	Surface Erosion	Green Staining	Brown Staining	Root Growth Fungal	Root Growth Plant	Insect Activity and Presence	Bone Loss
Long Bones 2M (n=12)	8.3	8.33	16.67	0	50	16.67	16.67	8.33	8.33
Long Bones 4M (n=12)	50	0	58.33	41.67	58.33	8.33	41.67	41.67	0
Long Bones 6M (n=11)	45.45	16.67	75	50	58.33	41.67	83.33	16.67	8.33
Long Bones 8M (n=9)	66.6	11.1	55.5	44.4	66.6	55.5	77.7	77.7	0
Ribs 2M (n=6)	33.3	0	33.33	16.67	50	16.67	0	16.67	0
Ribs 4M (n=6)	83.3	33.3	66.67	50	50	16.67	0	16.67	0
Ribs 6M (n=6)	83.3	16.67	83.33	66.7	50	33	50	66.67	0
Ribs 8M (n=6)	83.3	0	50	0	100	50	50	66.67	0

Table 8: Results for the percentage (%) affected amount for burial and surface serrated cutmarks.

4.3.4 - Stonetool Cutmarks 2M-8M; Burial vs Surface:



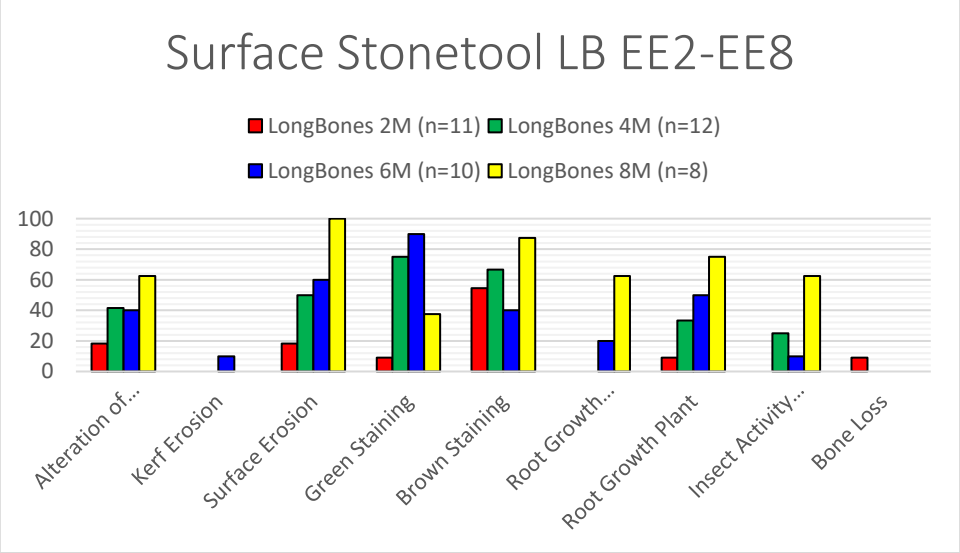


Figure 112: Physical Change Quantitative Data for Burial Stonetool Long Bones for the total eight-month deposition period.

Figure 113: Physical Change Quantitative Data for Surface Stonetool Long Bones for the total eight-month deposition period.

The stonetool cutmarks shown to exhibit a greater amount of physical changes to the cleaver inflicted cutmarks (like the serrated cutmarks); hypothetically the full breadth of the cutmark could make it easier to interact with the micro-flora/fauna. The categories with the higher percentage change here is staining, flora activity, arthropod activity and an alteration to the cutmark edge appearance and structure. The surface specimens exhibited a greater amount of changes regarding edge alteration (62.5%) more than the burial specimens (44.4%) by the end of the eight-month interval. The build-up of physical changes was more gradual with the

surface specimens compared to the burial specimens, they dipped minorly at four months and gradually rose up to the eight-month values.

The surface specimens have exhibited a higher amount of notable surface erosion by the end of the eight-month interval as all the cutmarks have exhibited it, compared to the burial specimen cutmarks (55.5%). The surface value is nearly double the value of the other cutmark types, the burial value is more/less the same, meaning this appears to be unique to this cutmark type. Surface and burial specimen group cutmarks exhibited a minor amount of kerf floor erosion, the amount overall is higher than the serrated cutmarks; potentially could be the result of the unstable kerf flooring of the cutmark type. At the eight-month interval, only the burial specimens exhibited this change (33.3%), with none of the surface cutmarks exhibited it. There was a small amount of the surface cutmarks at six-months that exhibited this effect, it is most likely an anomaly.

All the burial cutmarks by the eight-month period were stained brown and none were stained green (typical pattern at this point). There is a variable difference for the surface cutmark group as it depends on exposure and positioning of the bone specimens. By the end of the eight-months, the brown staining is much higher (87.5%) than the cutmarks that exhibited green staining (37.5%). There was a reduction in green-stained cutmarks from six-months (90%) to eight-months (as seen previously). This could be the result of rainfall increase washing followed by an increase in temperature.

All of the burial specimen cutmarks have exhibited a form of plant growth, with a moderately lesser amount of cutmarks that have exhibited fungal root growth (88.8%). Similarly, there is a higher proportion of fungal root activity (75%) for the surface specimens than plant root activity (62.5%). Despite the different amount values, the pattern is similar between burial and surface specimens. Overall these values aren't as high as the serrated cutmarks, however they are more than the cleaver cutmarks. This adds to the hypothesis that activity and interaction is proportionate to available space within the cutmark, for certain factors. Factors this does not include is staining, as this frequency of this factor wouldn't be influenced by structure necessarily, more so, the positioning of the bone specimen.

The arthropod activity is higher in the surface specimens (62.5%) than the burial specimens (33.3%) (similar to other tool types). Interestingly, another trend here is repeated where the amount of cutmarks to exhibit arthropod activity for burial specimens is either very low or non-existent till the eight-month interval when it spikes. (Further look at these percentages can be found in Appendix Section E.

Burial Stonetool Marks (LongBone):

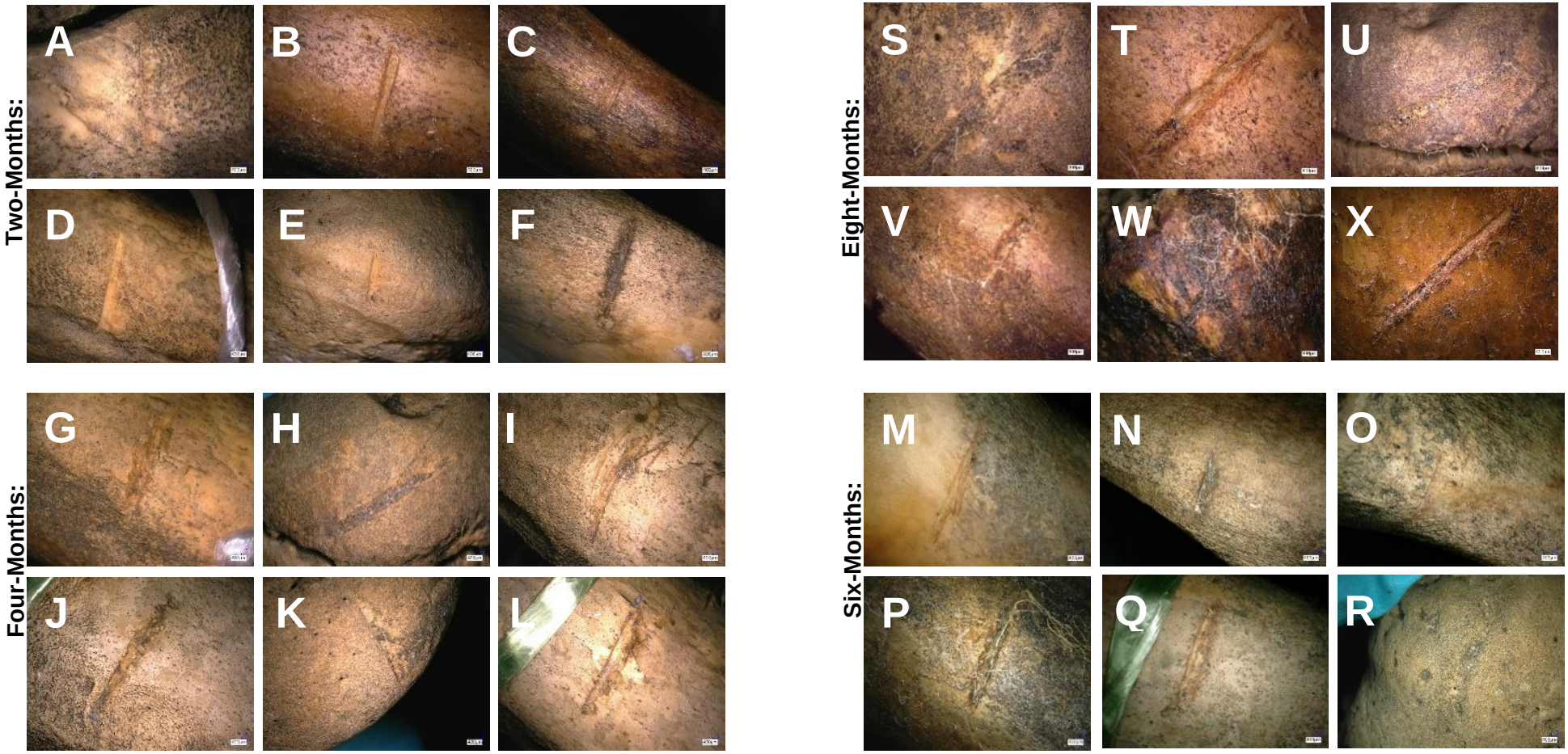
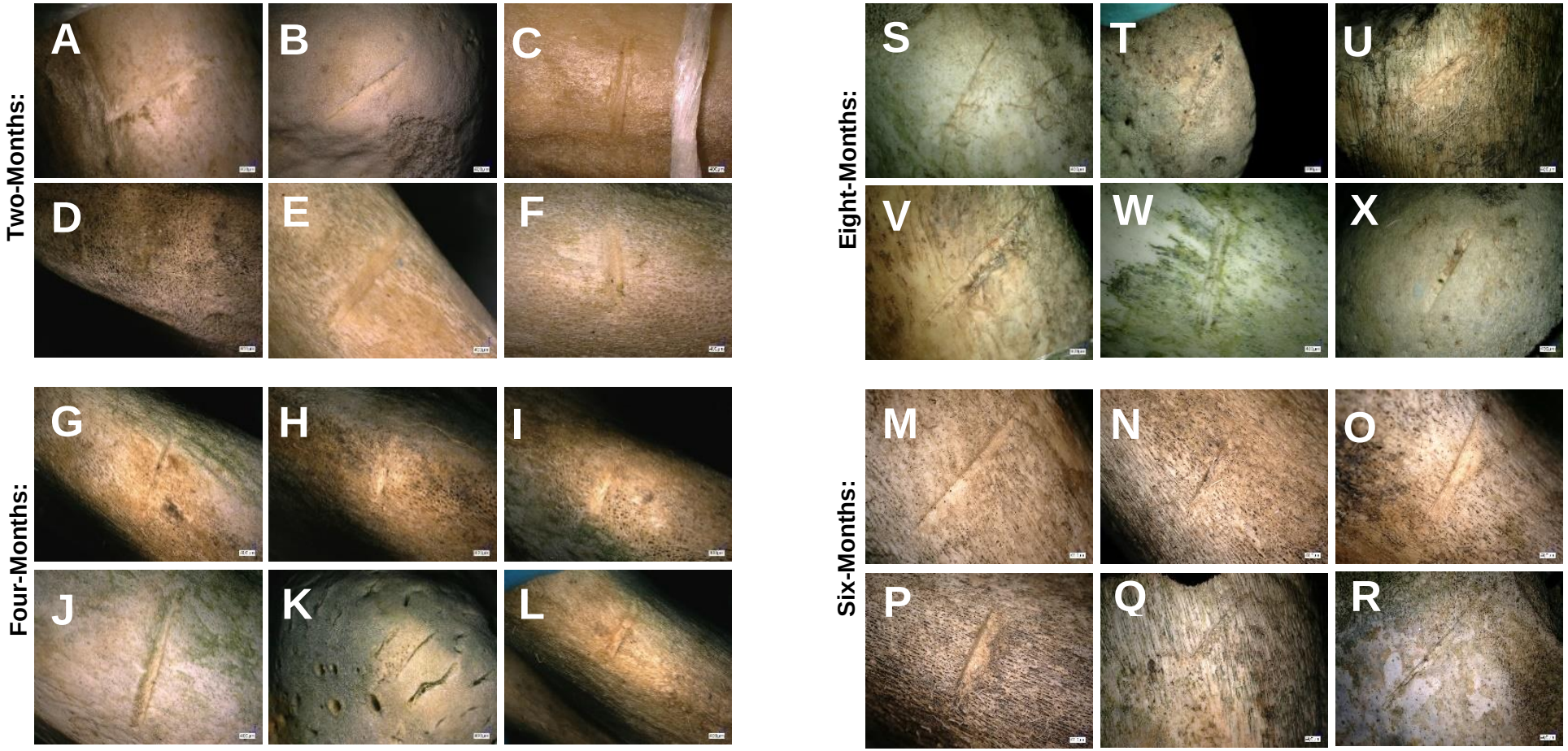
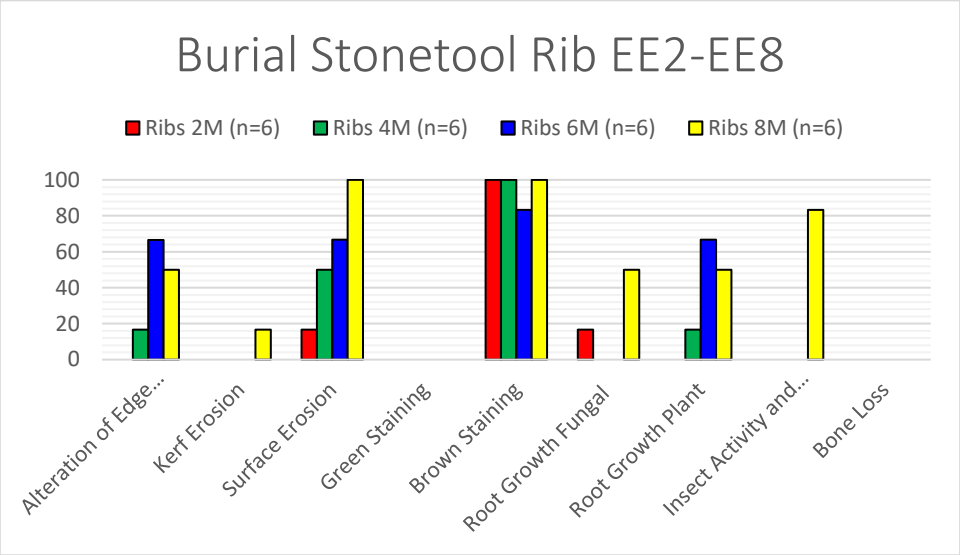


Figure 114 (A-X): show a largely overall perspective on how the burial stonetool long bone cutmarks have visibly changed (not all the cutmarks), the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G.

Surface Stonetool Marks (LongBones):



Figures 115 (A-X): show a largely overall perspective on how the surface stonetool long bone cutmarks have visibly changed (not all the cutmarks), the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G.



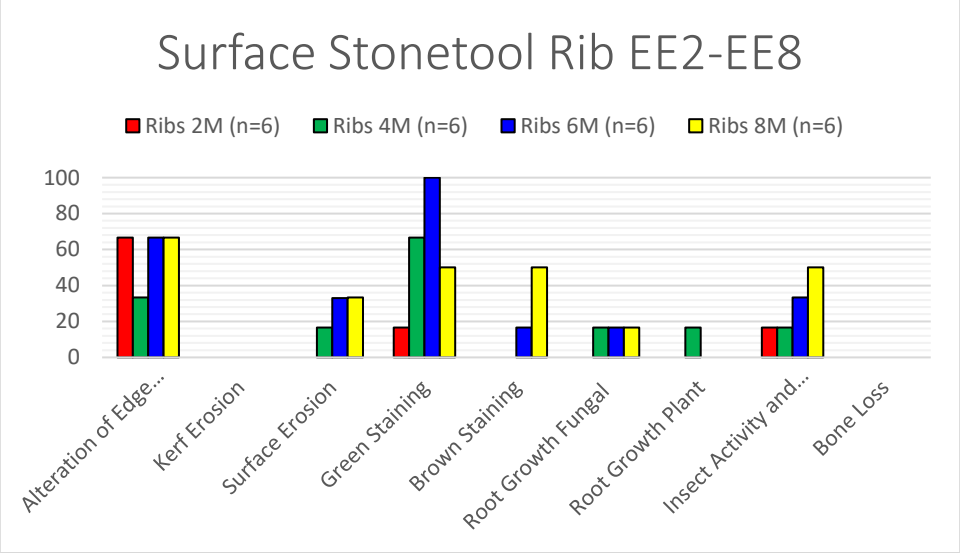


Figure 116: Physical Change Quantitative Data for Burial Stonetool Rib Bones for the total eight-month deposition period.

Figure 117: Physical Change Quantitative Data for Surface Stonetool Rib Bones for the total eight-month deposition period.

The amount of cutmarks that exhibited edge alteration is moderately higher in the surface specimens (66.6%) than the burial specimens (50%) (similar to the long bones). The surface specimens (besides an anomaly at four-months), are all the same throughout. Whereas the burial specimens show a rapid increase between four and six-months, then a moderate decline by eight. As the stonetool marks are variable in shape, they may not exhibit gradual/equal proportion of physical changes compared to the other cutmark types.

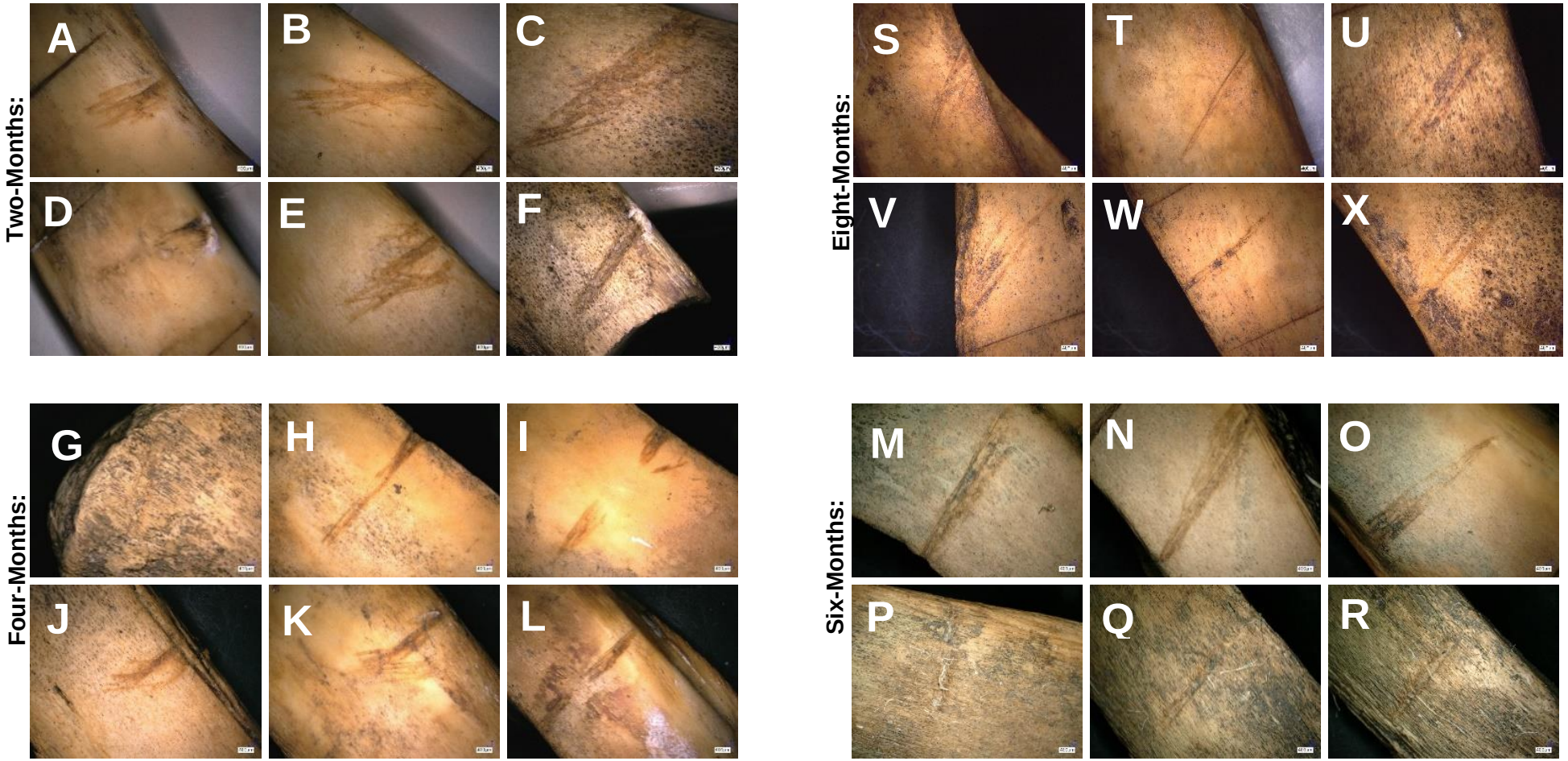
The burial specimens exhibit the greater amount of surface erosion as all the cutmarks have exhibited it in some form by the eight-month interval, as opposed to the surface specimens (33.3%). This is the opposite pattern that occurred for the longbone specimens; however, this is close to what the other rib cutmarks exhibited also i.e. a greater amount of burial specimen cutmarks showing this change compared to surface.

All the burial specimen cutmarks have been noted as stained brown by the end of the eight-month interval and none stained green (typical pattern), with a small anomaly at six-months (83.33%). The surface specimens are quite variable, by the eight-month interval, the same amount of cutmarks exhibited green and brown staining (50%). However, brown staining didn't start occurring till six-months and then rapidly increased by eight. Green staining gradually increased all of the cutmarks exhibiting this at six-months, to then drop by eight-months significantly. This has been seen previously and it's thought that heavy rainfall washing the bones followed by a temperature increase could have caused this (as well as positioning of the bones).

The root activity for these cutmarks are quite variable (a possible reflection of the cutmark structure and space availability). For the burial specimens, there is an equal amount of activity for fungal and plant root growth (50%) by the eight-month interval. However, the build-up is different, for the plant root activity, there was a minor amount at two-months, followed by a flatline and then a large increase by eight-months. Whereas for the fungal root activity, it started at four-months, spiked at six-months and then dropped by eight-months. For the surface specimens, there was a moderately higher amount of cutmarks that exhibited fungal root activity (16.67%) as opposed to the there being no plant root activity recorded by eight-months. However, at four-months, there appears to be a small sign of plant root activity (16.7%) only, the fungal root activity peaked at four-months and levelled till eight.

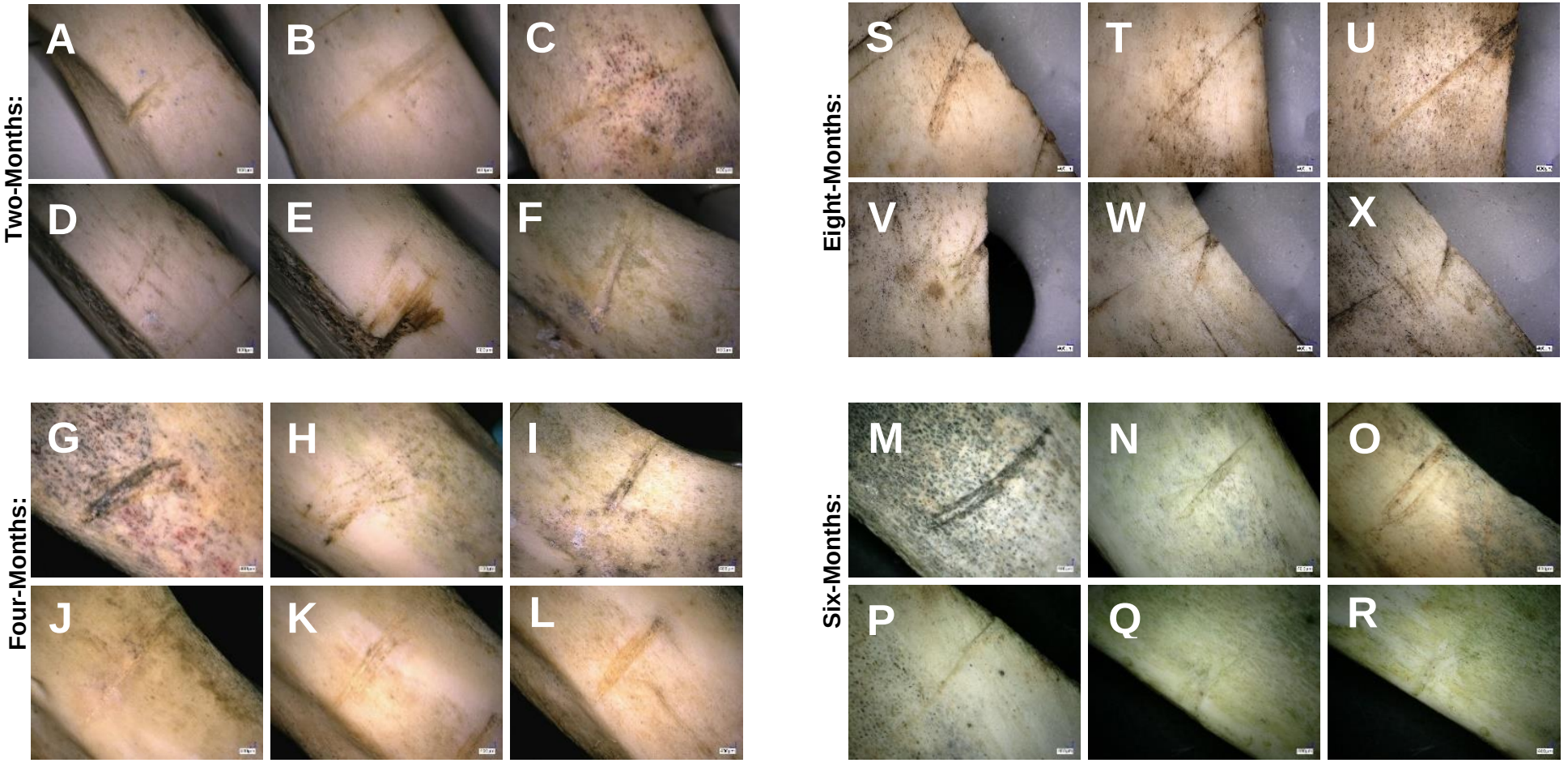
The burial specimens exhibited a higher amount (83.3%) of arthropod activity than the surface specimens (50%) by the eight-month interval (as seen previously). For the burial specimens specifically, there was no activity till the eight-month interval where it rapidly spiked; this was minorly seen with the cleaver cutmarks, however the peak was small (33.3%). The increase was gradual for the surface specimens. The activity for the burial specimens is much higher with these rib cutmarks compared to the longbone specimens. This could be due to the rib bones being closer to the ground, and therefore have easier access than the longbones if the arthropods origin is from the soil (hypothetically speaking). (Further look at these percentages can be found in Appendix Section E).

Burial Stonetool Marks (Ribs):



Figures 118 (A-X): show a largely overall perspective on how the burial stonetool rib bone cutmarks have visibly changed (not all the cutmarks), the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G.

Surface Stonetool Marks (Ribs):



Figures 119 (A-X): show a largely overall perspective on how the surface stonetool rib bone cutmarks have visibly changed (not all the cutmarks), the changes are evaluated in greater detail with their association with the environmental changes in Chapter 5. The specific cutmarks above in the figure wall can be viewed with more detail in Appendix Section G.

Burial Stonetool									
% Affected	**Alteration of Edge Definition and Structure**	**Kerf Erosion**	**Surface Erosion**	**Green Staining**	**Brown Staining**	**Root Growth Fungal**	**Root Growth Plant**	**Insect Activity and Presence**	**Bone Loss**
Long Bones 2M (n=10)	40	0	20	0	100	20	0	0	20
Long Bones 4M (n=11)	27.27	0	18.18	0	100	9.09	0	0	0
Long Bones 6M (n=9)	33.3	0	66.67	0	100	22.22	55.55	0	0
Long Bones 8M (n=9)	44.4	33.3	55.5	0	100	88.8	100	33.3	0
Ribs 2M (n=6)	0	0	16.67	0	100	16.67	0	0	0
Ribs 4M (n=6)	16.6	0	50	0	100	0	16.67	0	0
Ribs 6M (n=6)	66.6	0	66.67	0	83.33	0	66.67	0	0
Ribs 8M (n=6)	50	16.6	100	0	100	50	50	83.3	0
Surface Stonetool									

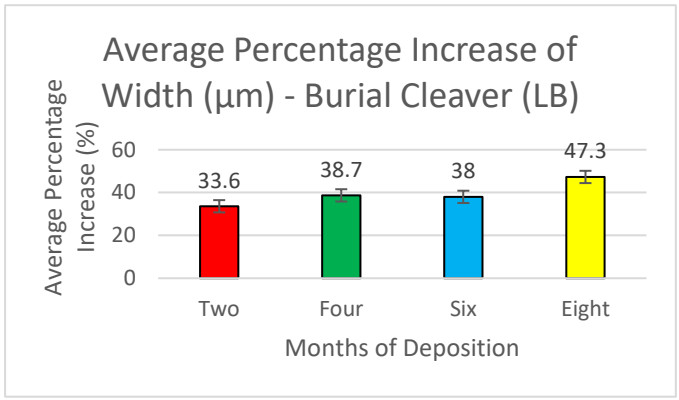
% Affected	Alteration of Edge Definition and Structure	Kerf Erosion	Surface Erosion	Green Staining	Brown Staining	Root Growth Fungal	Root Growth Plant	Insect Activity and Presence	Bone Loss
Long Bones 2M (n=11)	18.18	0	18.18	9.09	54.54	0	9.09	0	9.09
Long Bones 4M (n=12)	41.6	0	50	75	66.67	0	33.33	25	0
Long Bones 6M (n=10)	40	10	60	90	40	20	50	10	0
Long Bones 8M (n=8)	62.5	0	100	37.5	87.5	62.5	75	62.5	0
Ribs 2M (n=6)	66.6	0	0	16.67	0	0	0	16.67	0
Ribs 4M (n=6)	33.3	0	16.67	66.67	0	16.67	16.67	16.67	0
Ribs 6M (n=6)	66.6	0	33	100	16.67	16.67	0	33.3	0

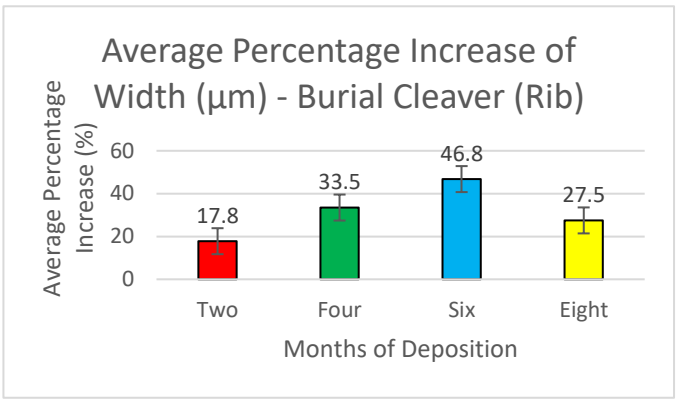
Table 9: Results for the percentage (%) affected amount for burial and surface stonetool cutmarks.

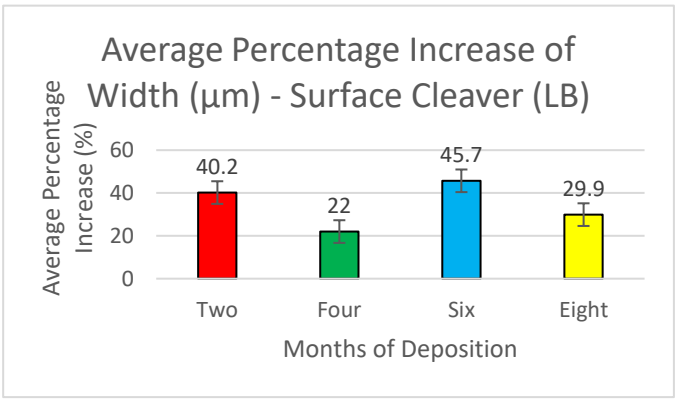
4.4 - 2-Dimensional Quantitative Cutmark Measurements:

There is a discernible pattern among the increase in width among the cutmark types, deposition interval and specimen type. The expectation was to see a percentage increase of width that was exponential across the deposition periods; it appears that there is a definite percentage increase, however it mostly varies across the deposition periods. Most likely if the time frame was larger, the percentage increase may rise with a longer deposition period.

4.4.1 - Cleaver Cutmarks 2M – 8M:







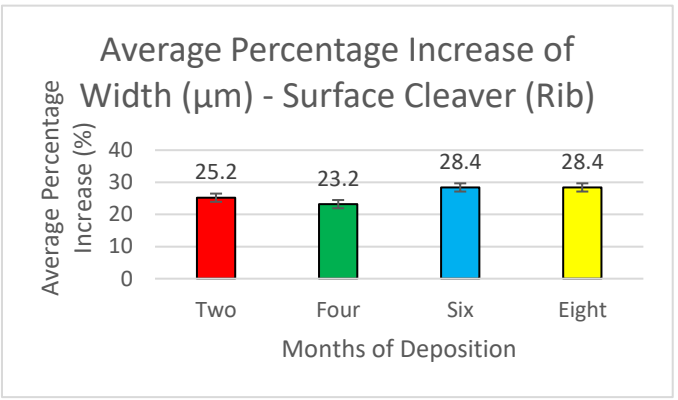


Figure 120: Average Percentage Increase (%) of Width (µm) for Burial Cleaver Long Bones for the total eight-month deposition period.

Figure 121: Average Percentage Increase (%) of Width (µm) for Burial Cleaver Rib Bones for the total eight-month deposition period.

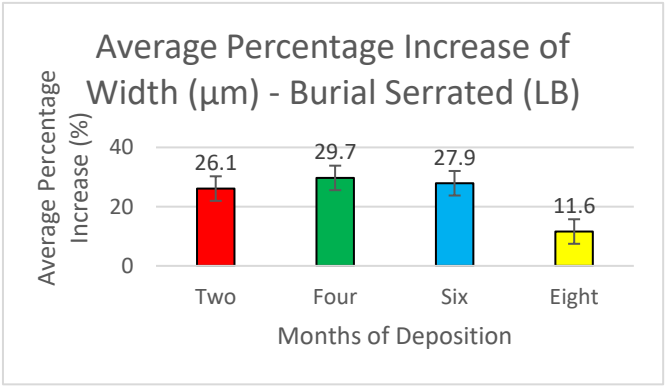
Figure 122: Average Percentage Increase (%) of Width (µm) for Surface Cleaver Long Bones for the total eight-month deposition period.

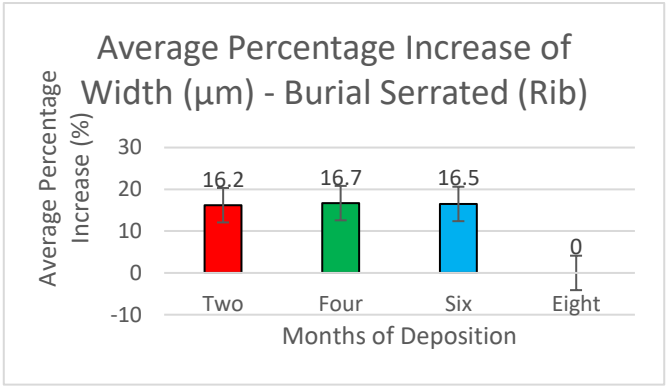
Figure 123: Average Percentage Increase (%) of Width (µm) for Surface Cleaver Rib Bones for the total eight-month deposition period.

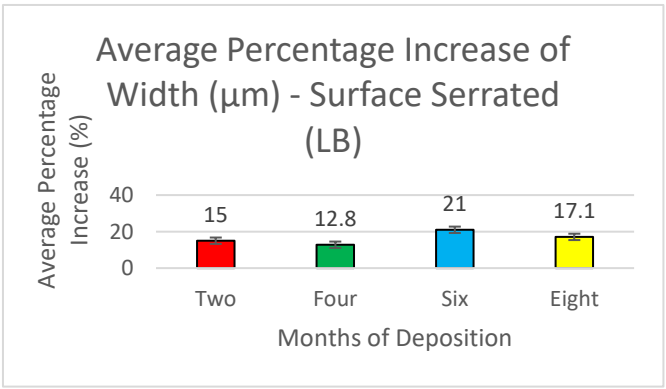
The above figure shows there is an overall percentage increase in width for the cutmarks that can be seen. Specifically, the greater width increase leans slightly more towards the burial specimens for cleaver cutmarks inflicted upon ribs and longbones as opposed to the surface specimens. There is a difference between longbones and rib bones in average maximum and minimum percentage increase; with the longbones having the greater maximum increase for

each deposition area. Meaning the cutmarks on the longbones could be prone to more change, however, this is tenuous.

4.4.2 - Serrated Cutmarks 2M-8M:







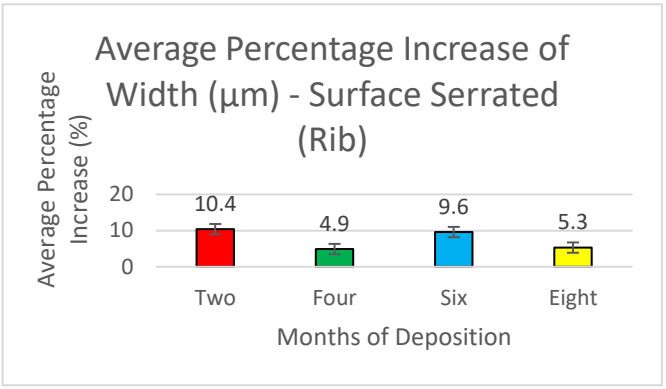


Figure 124: Average Percentage Increase (%) of Width (µm) for Burial Serrated Long Bones for the total eight-month deposition period.

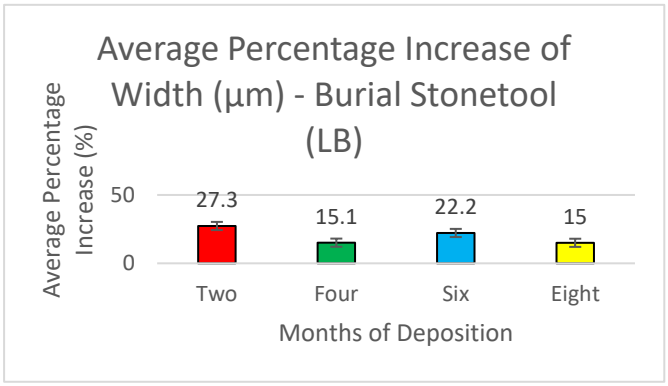
Figure 125: Average Percentage Increase (%) of Width (µm) for Burial Serrated Rib Bones for the total eight-month deposition period.

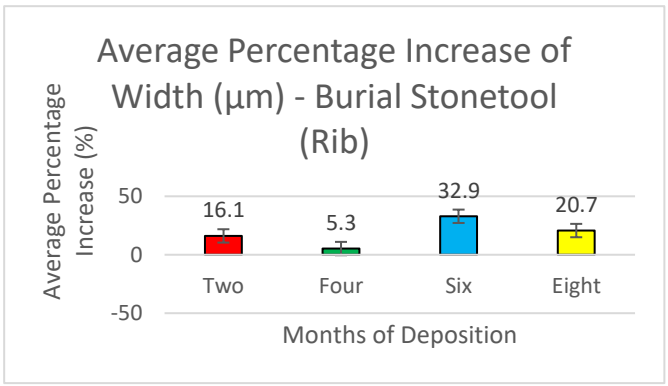
Figure 126: Average Percentage Increase (%) of Width (µm) for Surface Serrated Long Bones for the total eight-month deposition period.

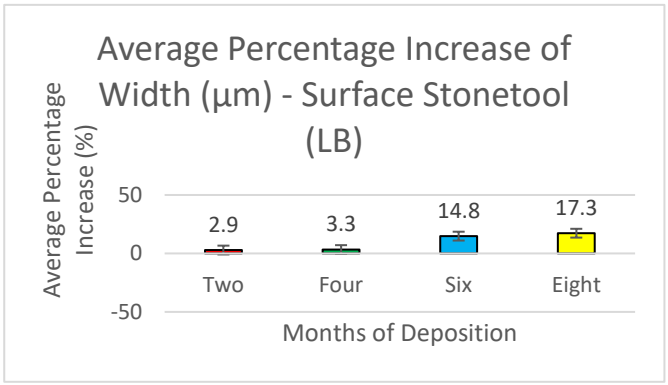
Figure 127: Average Percentage Increase (%) of Width (µm) for Surface Serrated Rib Bones for the total eight-month deposition period.

These, figures show that there is a greater increase in width among the burial specimens compared to the surface specimens (similarly, to the cleaver cutmarks). The lower 'percentage increase' occurring at the eight-month interval is seen as an anomaly as it's opposite to the expected trend. Most likely there are more factors at play such as the density of the eight-month sample specimens compared to the rest or way the bones were positioned. There is an overall pattern here which the serrated cutmarks did increase in width across the experiment indefinitely. Comparing the cutmarks on the longbones to the ribs per deposition area appears to show a similar trend to the cleaver cutmarks, with the longbones having the greater maximum increase for each deposition area.

4.4.3 - Stonetool Cutmarks 2M-8M:







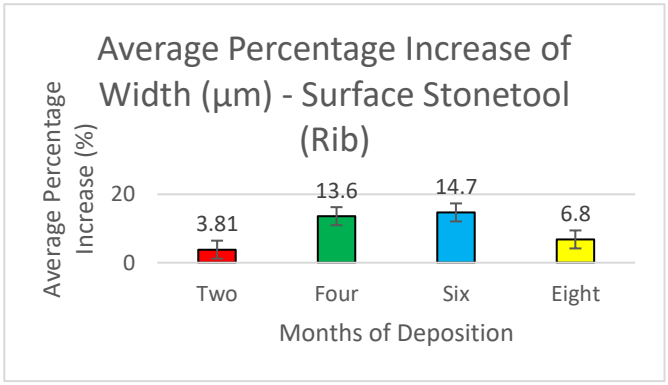


Figure 128: Average Percentage Increase (%) of Width (µm) for Burial Stonetool Long Bones for the total eight-month deposition period.

Figure 129: Average Percentage Increase (%) of Width (µm) for Burial Stonetool Rib Bones for the total eight-month deposition period.

Figure 130: Average Percentage Increase (%) of Width (µm) for Surface Stonetool Long Bones for the total eight-month deposition period.

Figure 131: Average Percentage Increase (%) of Width (µm) for Surface Stonetool Rib Bones for the total eight-month deposition period.

The results for the stonetool cutmarks in the above figures are more varied, however, they follow the current established trends, with there being a greater overall increase in width for the burial specimens as opposed to the surface specimens. The rib bones have a greater maximum for the burial groups compared to the long bones. The values spike for four and six-months of deposition followed by a decrease for the surface rib bone cutmarks.

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4.5 - Current Trends between the Qualitative and Quantitative:

The main trends outlined are the cleaver cutmarks (rib and long bones) have the higher overall percentage increase (17.8% minimum; 47.3 maximum). Whereas the serrated cutmarks (ribs and longbones) have the smallest overall percentage increase (0% minimum; 29.7% maximum). The stonetool cutmarks have a more varied range compared to the serrated and cleaver cutmarks (2.9% minimum; 27.3% maximum).

Specifically, the common pattern is there is a greater increase of width of the cutmarks in the burial group compared to the surface group, as well as the cutmarks that were inflicted upon the longbones as opposed to the ribs.

Interestingly, is the cleaver marks have the smallest average width (202μm for longbones and 120μm for ribs), serrated marks have the largest average width (815μm for longbones and 803μm for ribs) and stonetool marks have a middle ground range (741μm for longbones and 539μm for ribs).

This implies that the size of the initial width of the cutmark is inversely proportionate to the increase in width during deposition. When comparing these values to the physical change results, the pattern is the opposite. Where the size of the cutmark is proportionate to the amount of physical changes that can be observed to the cutmark.

For the long bones; the serrated cutmarks slightly have the highest percentage physical change when it comes to edge alteration (the factor that could contribute most to an increase in width) (approx 60% of cutmarks affected by eight-months). Cleaver cutmarks are the smallest percentage affected when it comes to edge alteration (approx 40% of cutmarks affected by eight-months); stonetool cutmarks are more or less in the middle (approx between 40-60% of cutmarks affected).

For the ribs, the serrated cutmarks have the highest percentage change also when it comes to edge alteration (approx 60-80% being affected). Whereas the cleaver and stonetool cutmarks more or less are the same in regard to how many cutmarks have been affected by edge alteration.

Therefore, there could be other factors at play that could be contributing to the increase in width rather than just purely physical changes to the cutmark. Another factor could be the structure of the cutmark type' the 'V' shaped structure for the cleaver cutmark could be subject more to peeling/flaking and delamination possibly. Whereas, the serrated cutmarks are deeper and more structurally sound with their square 'U' shape; so, they could be less prone to change in size compared to the cleaver cutmarks. There could indeed be a link to the physical

changes, although the serrated cutmarks received a greater amount of activity, they could be less prone to change in size due to its ‘stronger structure’.

The reason for the serrated cutmarks receiving more root and arthropod activity regarding physical changes could be due to the amount of available space there is within the cutmark. The occurrence of staining and surface erosion is most likely due to the position of the specimen within the ground or on the surface (discussed further in Chapter 5).

It should be outlined that ‘percentage increase’ is based on the difference before and after deposition, for a cleaver cutmarks that starts at 190µm, a forty percent recorded increase would mean its final width is 266µm. Whereas for a serrated cutmark starting at 800µm, a twenty percent increase would mean its final width is 960µm. Although the cleaver cutmarks have a ‘larger percentage increase’, the actual difference in width compared to the serrated cutmarks is lower.

Nonetheless, the key perspective here is how much did the individual cutmark type increase across the deposition intervals. These percentage figures are important because it gives the perspective of how much did the singular cutmark type change within its group across time; hence why they are used compared to a simple difference in microns.

4.5.1 - Intra-Observer Error:

One cutmark of each tool type was chosen to be used for this test, to be remeasured (ten times) four weeks after the initial measurement done and then five weeks (ten times) after the initial measurement done. Then using IBM SPSS, an Independent T-Test was ran for each tool type to determine the authors ability to measure over time, this test revealed that there was no significant differences (Sig 2-tailed) between the original measurement, average measurement at four weeks and average measurement at five weeks for each cutmark tool type ($P > 0.05$). Further details of the independent T-test conducted for the original cutmarks width of the chosen mark and the post-original measurements can be found in Appendix section D.

Then the original measurements were compared to the four- and five-week measurements separately to determine the percentage difference between them to be able to list the ‘percentage error range’. The maximum and minimum values were chosen for each cutmark type and are the following.

For the cutmarks it was found if any width ‘percentage’ value is within the range of a 5% decrease or 2% increase of width, then it cannot be distinguished between human error and an observed (actual) results. The values vary minorly between the cutmark types; raw data for

these results can be found in Appendix Section E under Intraobservor Error Calculation. This reflects how accurate the author is at measuring the different cutmarks, and regardless of tool type they are within the same range bracket. Meaning if any of the average percentage increase values above are within this small range, they most likely aren't legitimate measurements and could be the result of intra-observer error.

4.5.2 - Limitations:

There were certain limitations to measuring cutmarks two-dimensionally, firstly there is the issue of visibility and therefore accuracy. The measurement is only accurate, if the photograph of the cutmark has high resolution, is clear and detailed. There is the issue of making sure the cutmark is positioned correctly for both pre-deposition and post-deposition photographs, for an accurate comparison (Length is used as a reference point here).

In addition to limitations, it should be noted that the recorded values are quite variable despite the noted discernible pattern, this could be reflecting the hypervariable situation that the specimens are in that is a consideration in a Forensic Taphonomy experiment. However, it most likely is reflecting the accuracy of the method. There are more accurate methods that could provide more reliable results, these were explored briefly during this experiment, these being the creation of Polyvinylsiloxane moulds of the cutmarks to be scanned using 3D microscopy and scanning of the cutmarks themselves to create 3D digital models.

Unfortunately, there were complications that occurred as a part of the moulding process that was reflected in the initial analysis when visiting the Natural History Museum in London to use the Alicona infinite focus microscope. This halted any useful information that could be used during this research process, so, another avenue regarding three-dimensional analysis of the cutmarks had to be investigated (further information on the complications regarding the moulds can be found in Section A of the Appendix).

Chapter 5 – Discussion:

5.1 - Environmental Variables:

It's been stated previously that degradation of skeletal remains will differ based on the local environment it is in, however, it will still largely be affected by the climate zone it is in also. The ES soil is based in Wareham, England, and largely the UK is known as a maritime temperate zone (MetOffice 2012). There have been different comparative studies that have compared the rates of decomposition in different climate zones; for example, remains deposited in temperate climates supposedly have a higher survival rate than those in a semi-arid climate (Isaac 1967; Behrensmeyer 1978; Tappen 1994; Fiorillo 1995; Andrews and Armour-Chelu 1998; Miller 2009). For tropical environments, it depends on how protected the specimens are with the ground vegetation, this and the constant moisture and lack of wet/dry cycles can slow down the rate of weathering (Peterhans *et al.*1993; Pokines 2009). Regarding temperate climates, it is argued they can be particularly destructive due to the fluctuating temperature and rainfall between the seasons (Pokines and Ames 2015). However, the actual local environment may be more influential regarding degradation than the climate zone largely, depending on the amount of vegetation, UV exposure and acidic soil water the remains experience. The surface remains at the Experiment Site (ES) were made sure to be in a place with no shade/coverage, little vegetation, complete exposure to the weather (Fernandez-Jalvo and Andrews 2016). Although the climate zone is a temperate one (and therefore its destructivity is debatable), the remains are in the most compromising position they can be in. For the buried remains, the following cross-linking factors are discussed on whether they have contributed towards the soil matrix having a high destructive potential for the remains.

The ES soil can be seen as a hostile environment for the deposited skeletal remains. The soil texture class fell between the 'loamy sand' and 'sandy loam' category, meaning the majority fraction is Sand and the minority is Clay. With a lower clay content, the soil does not retard decomposition to the extent that it would with a higher clay content and lower water movement (see Chapter 3). The moisture content of the ES soil was relatively low at the start of the experiment (7.48% for Topsoil and 5.25% for Burial). Soils within this texture class are often well draining, meaning any increase in moisture within the topsoil, would result in similar increase in the burial layer; this occurred within the ES soil (see Chapter 4.1). The increase in moisture within the earlier months is explained by rainfall, higher humidity and minor snowfall, while a decrease in the later months is explained by the natural increase in temperature and lower precipitation through spring and summer (see Appendix Section E). There is no evidence that that the presence of buried remains influenced moisture values, as results are similar to those from the control area. However, the potential for the presence of bones to

influence moisture levels does exist if the presence of bones encourages plant and root growth, which can improve moisture retention in soils (Pokines and Symes 2013).

The ES soil is classified to have a ‘low organic content’ based on the calculated ‘Grams of Organic Carbon Per 100g of Soil’. Sandy soils typically have a low amount of organic carbon (due to the lack of protection to the organic matter molecules), which declines with depth. There is a small difference in organic carbon between the topsoil and burial layer within the ES soil; the difference is likely based on the topsoil having a larger amount of dead plant matter, microbial biomass, plant residues, humus and microfauna (Cambardella 2005; Jat *et al.* 2018). It was determined that the changes observed across the deposition intervals, were not significant, and that the controls did not differ significantly from the main group (see Appendix Section D). Regardless, the low organic content indicates the soil matrix is particularly degradative towards anything organic within it, including organic bone content.

The relative bulk density of the ES soil (1.26g/cm^3 average) was found to be close but lower compared to the ‘typical’ values for sandy soils; in addition to this, the porosity values are within the typical range with this texture class (see Extended Analysis in Appendix Section A.2.4). There is a small difference in densities as compaction is a factor that contributes towards a higher bulk density (and therefore lower porosity) (McKenzie 2010; Chakraborty and Mistri 2017).

Once the bones were deposited, the values fluctuated in a logical pattern, the soil was disturbed, homogenised and aerated. The topsoil and burial values were close at two-months, then a reversal back occurred closely to the original values. The controls were not significantly different compared to the main values. This, in addition to the homogenising reversal observation indicates that there is little evidence that the bone specimens did not influence the significant changes. The ES soil overall had similar densities between the layers, meaning its kept to its highly permeable nature, therefore, factors that are influenced by this and groundwater movement (e.g. ion movement), changed similarly between the layers.

The pH(CaCl2) of the soil was classified as highly acidic throughout the experiment, (4.6-4.7) statistically the values did change significantly; the soil became mildly more acidic within the burial layer and fluctuated in the topsoil layer. It is possible that the decomposing remains caused a slight increase in soil acidity (see Extended Analysis in Appendix Section A.2.5). However, this pH increase increased over a longer period and the remains were deposited in a defleshed state, therefore, it is not viable to suggest that these changes were caused by the bone’s presence. Nonetheless, the soil pH stayed within a highly hostile pH range for the remains, and therefore, still can facilitate destruction of the bone surface.

The metal ion content of the soil was measured to investigate the effects of the bones on the surrounding soil and vice-versa. Appropriate signs of leaching were found within the soil across time, with an increase in calcium and phosphorus and a decrease in iron as stated in the literature (Pate and Brown 1985; White and Hannus 1983). These significant changes are likely to be the result of the bones exchanging ions with the surrounding soil. The controls initially showed no difference when compared to the main values, however the mobility of the ions and the proximity of the bones to the control area was brought into question. The new controls are close to the original pre-deposition EE0 values, thus indicating the specimens likely have contributed towards these changes, as there is little else that could have.

The first total microbial activity values were classified as 'acceptable' for the ES soil as similar values were found with another study that used this method at a site of similar agricultural history (see Extended Analysis in Appendix Section A.2.7). There are separate hypotheses for the significant changes within each depth. The topsoil microbial activity levels correlated with the moisture content and organic content changes; this is consistent with published sources with how it should change in the soil (See Extended Analysis in Appendix Section A.2.2).

The burial value changes fluctuated largely and is inconsistent with any of the other environmental variable changes. It is hypothesised this could be the result of either a nutrient shock from the remains or a type of predator-prey cycle from bacteriophagic/mycophagic microorganisms such as Nematodes. A nutrient shock can occur from the influx of nutrients being released from the specimens that is encouraged by a soil environment that accelerates decomposition i.e. a sequential release of nutrients can be toxic for the soil microbes and therefore affect their population dynamics (Breton *et al.* 2016).

The nematodes are likely to be involved as their populations within the burial area increased rapidly, less in the topsoil and nothing significant in the control areas. Several of the Nematodes were identified to be bacterial and fungal feeders. Their increased presence is likely to the caused by the release of nutrients from the bone specimens, that are feeding the surrounding microbes, in turn the Nematodes can feed on those microbes within the decaying organic matter (see the Extended Analysis in Appendix Section A.2.8). There are multiple theories of the activity of Nematodes within a predator-prey cycle with bacteria/fungi, ranging from a change in nutrient cycling to selective grazing. The controls are initially thought to be no different to the main values, however, new controls were collected and compared; they support the hypothesis that these observed changes to the microbial activity of the soil are local to the burial plot with the remains (further research needs to be done to support this).

The range of macroarthropods found on the specimens across the experiment support the hypothesis that the remains had an impact on the biotic agents within the environment. There are possible traces left on the bone surface and within the cutmarks, that could be a result of the interaction of the macroarthropods. The major orders found on the specimens initially in the earlier months were Diptera and Coleoptera larvae. The larvae range between those that have been found on skeletal remains before (*Piophilidae*) to those that are usually associated with advanced decomposition (*Stratiomyidae* and *Elateridae*) (See Extended Analysis in Appendix Section A). With the latter months, the variety of organisms increased largely where Gastropods and even Araneae were found on and around the skeletal remains. The current hypothesis is they are using the remains as a type of habitual structure as well as a source of more nutritious plant and fungal matter, supported by the nutrient analysis of the roots that was conducted (see Extended Analysis in Appendix Section A.2.9).

There is evidence that the bone specimens have had an impact and contribution towards some of the environmental changes within the soil matrix. Comparing these changes with the variables to those found in the literature, suggests that the ES soil has a high destructive potential. This has certain implications regarding a forensic investigation, establishing that for the duration of a short deposition period, the hostility of the soil remained.

5.2 - Comprehensive Summary of the Changes to the Bone Surfaces:

Various factors cause macroscopic alterations to bones deposited on the ground surface (subaerial deposition). These factors include UV exposure, temperature variation, wet/dry season change, freeze-thawing, insect activity etc (Child 1995; Allison and Bottjer 2010; Rogers 2010; Dupras and Schultz 2013). Within Taphonomy experiments there are other factors to consider that can influence what modifications occur, e.g. relative position of the ground, amount of soft tissue to start with (fleshed/defleshed/archaeological), depth of deposition, as well as preparation of remains (freezing or cooked).

Skeletal remains exposed to certain conditions can result in various forms of erosion to the bone and trauma present, this experiment is specifically interested in the potential damage to the bone surface and trauma post-skeletonization, within a short-term period. The following is a further discussion and analysis of what physical changes to the bone surfaces of the surface and burial deposition group can and has occurred.

5.2.1 - Staining:

In particularly hostile environments, the bone specimens can exhibit surface cracking and exfoliation due to additional environmental conditions, such as cold, heat, moisture and wind (Dettmeyer *et al.* 2013; Dupras and Schultz 2013). Bones bleaching occurs in relation to their position relative to the ground surface, this was noted in most of the surface specimens where the upward facing side was bleached further with addition of green staining.
Green staining can occur from the bones interacting with plant and tree materials such as green algae growth or chlorophyll staining, which can occur within the first year of exposure (Calce and Rogers 2007; Dupras and Schultz 2013). The surface specimens were left on the grassland surface, so the staining is likely from the green grass surrounding them; it is noted that staining occurs best in moist, shady areas in terrestrial scenes (Ubelaker 1997). Given the little number of hours of sunshine, high humidity and fluctuating rainfall levels in the experiment area (according to MetOffice Weather Station at Hurn), this facilitates reasonable conditions for this effect to occur.

Green staining was observed from two-months of exposure post-skeletonization, indicating this environment has the right conditions for this ‘organic’ staining. It intensified throughout the first six-months of deposition and it levelled/decreased by eight-months; this decrease is likely to be the result of the increasing temperature and rainfall that could have washed the bones followed by rapid drying. Minor green staining, bleaching and loss of soft tissues were the main observations noted during the initial two/four-months. However, there was an observable difference between the side of the bones that were stained green and those stained brown.

Those facing up had to experience the UV damage from the sun as well as the full exposure of precipitation, the soil facing side reacted certainly to the increased root activity throughout the experiment.

The burial specimens were stained brown/tan, the longer the deposition periods, the darker the colouration got (as well as removal of soft tissue and grease). It is based on the soil type has been associated with well-drained soils and oxidising conditions; the presence of tannins, iron oxides and varying levels of organic content in the sediment are considered the main influencers of it. The light brown/tan colour could be due to the soil being low in organic matter and comprised of smaller quartz crystal grains without pigmentation coatings (Dupras and Schultz 2013).

5.2.2 - General Larger Surface Modifications:

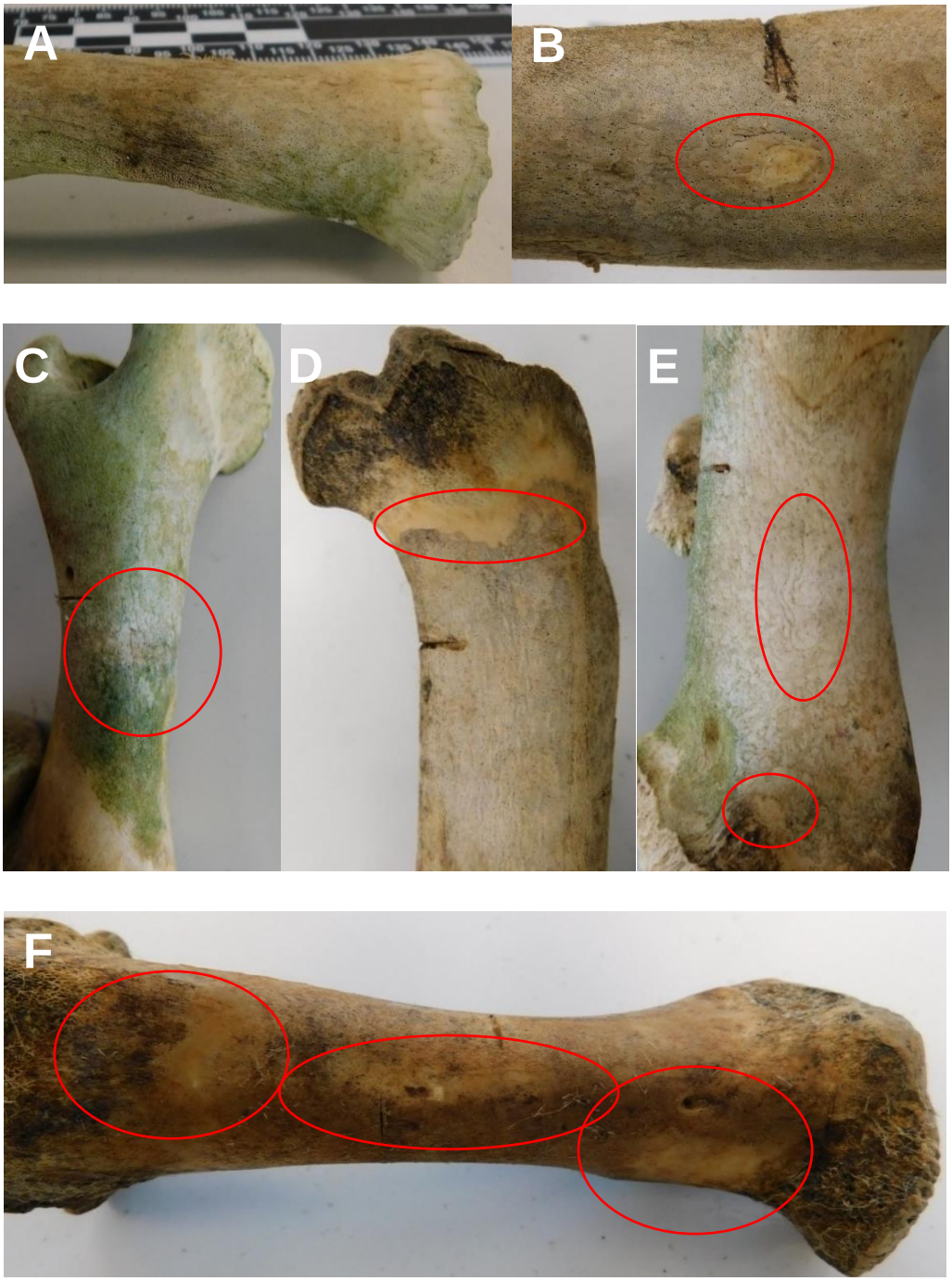

Figure 132 – (A-F): (A): Pig 2 Specimen 5 from the four-month surface specimen area. (B): Pig 4 Specimen 4 from the four-month burial specimen area. (C): Pig 2 Specimen 2 from the six-month surface specimen area. (D): Pig 4 Specimen 2 from the six-month burial specimen area. (E): Pig 5 Specimen 5 from the eight-month surface specimen area. (F): Pig 5 Specimen 1 from the eight-month burial specimen area.

As shown in the above figures there are certain modifications that can occur, according to (Cunningham *et al.* 2011), commonly there can be larger forms of surface damage such as

pockmarking (surface erosion) and cortical flaking. By six-months for the surface specimens, the overall surface porosity of the bone has certainly increased to an extent, as well as an increase in irregular damage; this irregular damage, is potentially the result of either insect activity or root activity where the bone is most porous. (discussed further below). However, the burial specimens exhibited smaller areas of surface erosion and flaking at first during the four-month period, then by eight-months nearly every specimen exhibited larger areas of cortical flaking and surface removal.

Other forms of damage to the cortical layer can be seen as a 'marbling' pattern on the diaphysis of the bone as well as 'pock mocks' on the surface (Figure 12.4 and 12.6 for Cunningham *et al.* (2011)); both have been seen on the current experiments remains. This study's experiment conditions are similar despite the different geographic location and the soil being clay loamy texture class; it is a highly acidic (4.4-5.2 pH) and short-term based bone degradation study (8 months). This experiment is only comparable to the surface remains as it did not include burial specimens.

Conversely, another experiment has shown little modification over a similar short time frame (8-months) for skeletal remains. However, erosion, cracking and cortical flaking were observed along with fungal colonization of the bone marrow and surface by the end of the 24-month experiment (Rogers 2010). In Rogers (2010), erosive damage to the cortical bone was not seen until twelve months of deposition despite plant/fungal growth being observed within the first four-months. The respective experiment site was acidic (pH[water]: 5.54), this reinforces the notion that the rate and process of decay is dependent on the local environmental factors and the state of the deposited skeletal remains (Mann *et al.* 1990; Tibbett and Carter 2008; Goff 2010); therefore, observed damage to the bone surface will differ even with similar soil conditions between experiments. The burial specimens in the current thesis displayed a higher frequency of overall cortical flaking compared to the surface specimens. The acidic soil is likely the contributor towards this; however, decomposition is retarded more in the soil compared to surface remains (Mann *et al.* 1990; Tibbett and Carter 2008; Goff 2010). Though, those studies are specifically about soft tissue decomposition till skeletonization. Therefore, it's possible to suggest that once remains have skeletonized that the burial environment is more destructive than the surface environment towards the bone surface.

The depth of the bones should be considered, as for the current experiment they are buried at a 'shallow burial depth' of approximately 24cm, and according to Rodriguez (1997) and Weitzel (2005), shallow burials of less than 1ft will experience temperature fluctuations similar to the ambient temperature; therefore, if shallow enough, decomposition won't be retarded

enough to make a large difference between the surface and burial remains (as they would feel these fluctuations). However, during this experiment, a computational model was developed to numerically calculate the depth at which the bone specimens are not significantly affected by diurnal temperature variations using only the surface air temperature data (from the MET office) and physical properties of the soil (Porosity, Moisture Content and Relative Bulk Density). It was found that for the buried specimens, they theoretically were at a depth (approximately 24cm) that wouldn't experience surface temperature fluctuations similar to the ambient temperature (maximum depth: 14.5/14.6cm per Table 10 below). Therefore, it allows the one to suggest that decomposition processes of the skeletal remains that are influenced by temperature, most likely reacted differently for the buried specimens compared to the surface ones).

Date	**Numerical Damping depth [cm]**	**Error [cm]**	**Analytical damping depth [cm]**	**Thermal Diffusivity [m^2/s] – at the damping depth**
11/10/2018	10.5	1	13.76	6.88 x 10^(-7)
11/12/2018	14.5	1	13.78	6.90 x 10^(-7)
11/02/2019	13.5	1	14.38	7.52 x 10^(-7)
11/04/2019	11.5	1	14.58	7.73 x 10^(-7)
11/06/2019	14.5	1	14.6	7.75 x 10^(-7)

Table 10 – Calculated Damping Depths for each 'deposition' interval date for the experiment at Wytch farm from October 2018 – June 2019.

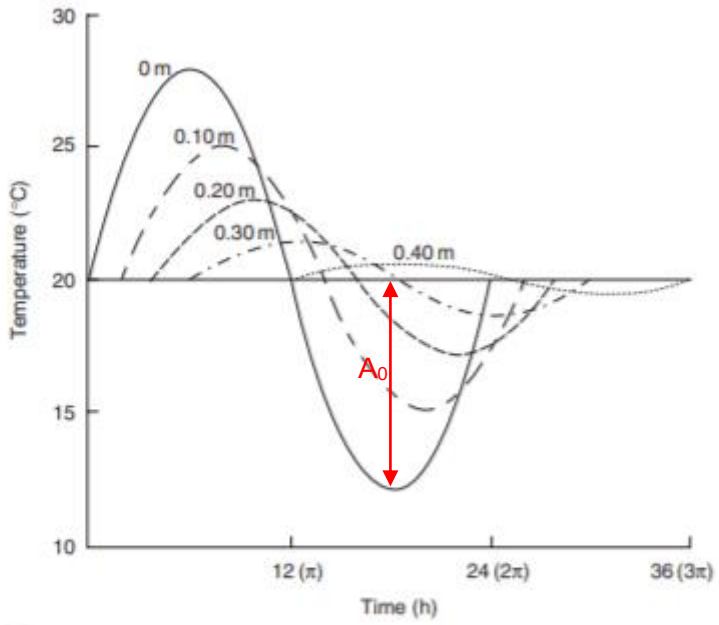

Fig. 12.3. Idealized variation of soil temperature with time for various depths. Note that at each succeeding depth the peak temperature is damped and shifted progressively in time. Thus, the peak at a depth of 0.4 m lags about 12 hr behind the temperature peak at the surface and is only about 1/16 of the latter. In this hypothetical case, a uniform soil was assumed, with a thermal conductivity of 1.68 J/m sec deg (or 4×10^{-3} cal/cm sec deg) and a volumetric heat capacity of 2.1×10^6 J/m³ deg (0.5 cal/cm³ deg).

Figure 133 – This is an edited copy of figure 12.3 from Hillel (1982) which shows the idealised variation of soil temperature with time for various depths.

The diagram above is an example of sinusoidal diurnal temperature variation, the difference between the temperature peak and the average is the temperature amplitude (A_0). As heat flows through the soil, that amplitude value decreases with the depth (e.g. from 0m to 0.3m it decreases) and gets closer to the average. Fundamentally amplitude is a parameter that characterises the variation of soil temperature about an average value. The lack of influence of temperature variation to skeletal remains at a certain depth is due to thermal lag and diffusion. Energy is transferred and diffuses into the soil and is dampened, the longer the energy source stays or the more there is, the further depth it can penetrate. The aim of the computational model noted above, was to calculate the damping depth (as listed in Table 10 above); the depth at which the bone specimens will not be affected by diurnal surface temperature variations. This is calculated on a diurnal timescale for soil using hourly air temperature data from the MET office and properties of the soil which are calculated after sample collection. The damping depth (as listed in the table above), is calculated by the temperature amplitude decreasing by a fraction 1/e (1/e is always known as 0.37 i.e. 37%) of the amplitude at the soil surface (Hillel 1982). Justification for the use of a numerical model as opposed to solving it analytically can be found in Appendix Section C as well as further information regarding equations used, heat maps, temperature profiles and the model itself.

5.2.3 - Potential Modification from Fungal/Bacterial & Flora Activity:

Damage from acidic soil such as corrosive removal of bone mass, is dependent upon the acidity and length of exposure. Andrews and Fernandez-Jalvo's study (2016) illustrates visible acid corrosion on a bone surface; although, this is an example of long-term damage, resulting in windowing of the cortical bone and exposing the trabecular bone.

Fungal activity/consumption of bone will appear as tunnels and cavities known as 'Wedl tunnels'. According to Kontopoulos *et al.* (2016), fungal damage in favourable conditions (high oxygen availability, high humidity, low soil pH) can occur within even the first few weeks of post-deposition. However, such damage did not occur until after the first-year post-mortem in the Riseholme experiments. Hackett (1981) identifies three major types of fungal damage (Wedl tunnels and non-Wedl tunnels) which are identifiable via macroscopic and microscopic inspection (Kontopoulos *et al.* 2016; Pesquero, Bell and Fernandez-Jalvo 2017).

Dissolution as the result of microbial attack for example focuses in discrete zones known as Microscopic Focal Destruction (MFD). Microbes from the burial environment penetrate the canal and then attack the osteon tissue (Dixon *et al.* 2008). They penetrate the bone using the natural spaces in it also by releasing enzymes and amino acids (Child 1995); this can be facilitated by other diagenetic alterations and chemical processes (arthropods, pH etc) that remove minerals, thus disrupting collagen integrity which makes it more amiable to proteolysis by non-specific enzymes (from microorganisms) (Nielsen-Marsh *et al.* 2000). Figure A.292 of Fernandez-Jalvo and Andrews (2016) shows an example of the long-term changes to the bone surface from bacterial attack.

The damage done by fungi, algae and bacterial such as channels and cavities in bone can be filled with the remains of them, of which can lead to a secondary colonisation of the bone. Mites, bacteria and other organisms (arthropods) can move into the already affected structures i.e. tertiary colonisation (Sorg and Haglund 1996). Such colonization can also occur in other cavities and openings such as cutmarks as seen in Gent 2018 (unpublished dissertation) and this current thesis.

The cavities on the current experiment specimens have been present since pre-deposition and are unlikely from bacterial/fungal attack. However, the cavities have been observed to increase in size, channels and larger bores/pits have formed over time. These cavities are noted as 'pseudo-weathering' marks which are often mistaken for 'pitting' or 'windowing' caused by weathering/erosion. It is common among juvenile *Sus scrofa* remains (figure 12.9 in Cunningham *et al.* 2011). Nonetheless, it's a possibility that these cavities have worsened/degraded further from soil erosion, weathering or interactions with fungal

roots/activity. Their nature as cavities facilitate further damage, once soft tissue and upper periosteum of the bone is removed, they are exposed and allow interactions with arthropods, acidic soil water, plant roots and microbial contact (Ubelaker 1997; Walden 2017; Cunningham *et al.* 2011). Therefore, it allows for an increase in potential of surface degradation (and therefore, cutmark degradation).

There was a noted increase of plant and 'fungal hyphae' activity on the bone surface and within the cutmarks from the four-month interval. They could be identified as mycorrhizal fungi hyphae fungal roots just based on where they were found (majority of the time attached to plant matter) and their morphology. Most hyphae are either pure white or yellow and can actually be misidentified as plant hair roots (Islam 2008); its unsurprising they're found here as it's been suggested that in some nutrient poor soils, mycorrhizal fungi could have a direct involvement in the decomposition process (Swift *et al.* 1979).

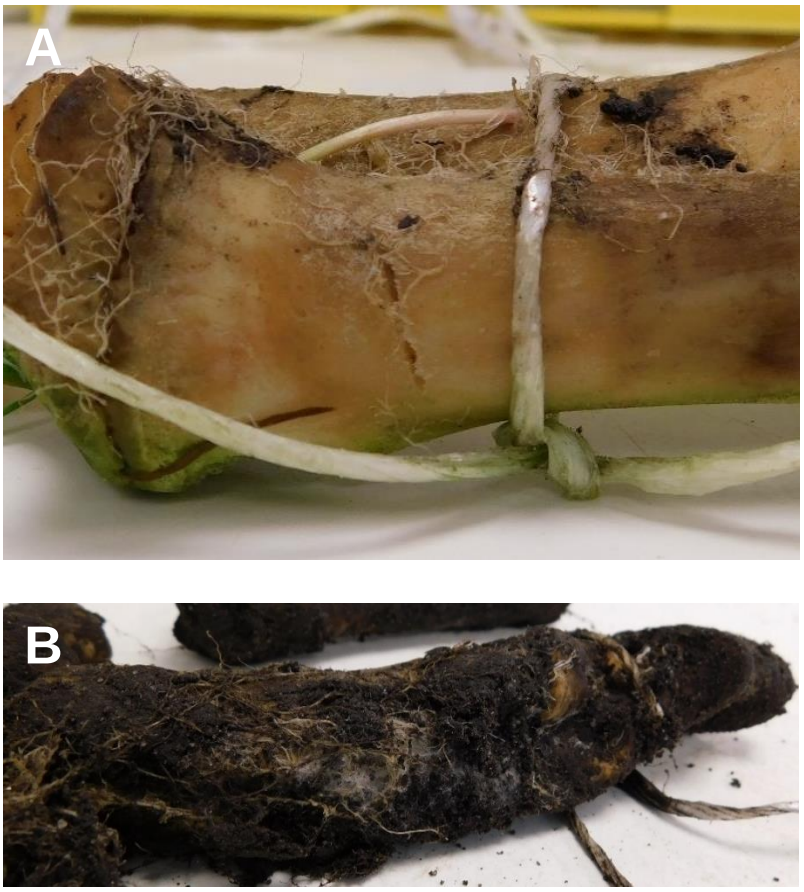

Figure 134 (A-B) – (A): Pig 3 Specimen 5 from the four-month surface specimen area. (B): Pig 1 Specimen 6 from the six-month Surface specimen area.

Like the burial specimen in the figure above, a majority of the fungal hyphae roots were seen growing on the plant roots surrounding the specimens (creating a potential microenvironment for the specimen) (Pokines and Symes 2012). This activity supports the argument that this hostile environment is sufficient for fungal activity to occur, however, it has been established that in acidic environments, fungi as opposed to bacteria, are more active, acid tolerant and aren't as strongly influenced by a shift in pH (Rousk *et al.* 2009; Rousk *et al.* 2010; Pepper and Gentry 2015). It's been commented on before on the extent of the invasiveness of plant roots to bone, specifically finer roots can actually travel through the medullary cavity and split long bones; whereas larger roots have the ability to disintegrate/degrade the cancellous bone cavities and produce greater openings (Pokines and Symes 2012; Tibbett and Carter 2008). The process of mineral dissolution of the apatite component of bone being assisted by acidic soil and the acidic by-product created by the roots, therefore, they can leave surface impressions (root etching) or larger holes/cavities (Nawrocki 1995; Schultz 1997). Invasive roots can cause surface damage (etching) to cortical bone whilst the later decomposition of the roots attached to the bones produces acidic compounds that can cause further surface damage (Behrensmeyer 1978; Lyman 1994; Schultz 1997; Cox and Bell 1999).

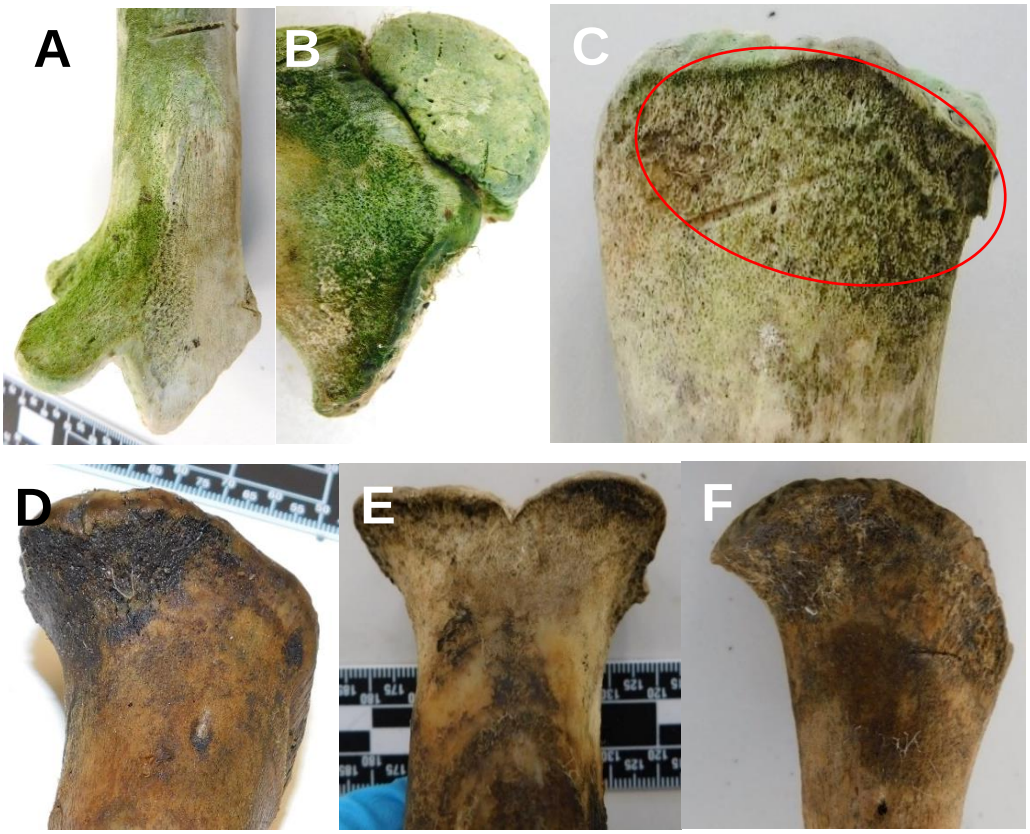

Figure 135 (A-F) – (A): Pig 3 Specimen 4 from the four-month surface specimen area. (B): Pig 3 Specimen 1 from the six-month surface specimen area. (C): Pig 5 Specimen 3 from the eight-month surface specimen area. (D): Pig 1 Specimen 2 from the four-month burial specimen area. (E): Pig 4 Specimen 1 from the six-month burial specimen area. (F): Pig 5 Specimen 2 from the eight-month burial specimen area.

Figure 135 (A-F) shows the specimens that have experienced a lot of root activity. Specifically, in areas where the bone specimens were already porous (Pseudo-weathering 'marks' nearer the epiphyses), the roots had attached and grown within the pores. Visibly, the more porous areas closer to the epiphyses notably have a greater amount of activity than the rest of the specimens. It is hypothesised that the activity progressively worsened throughout the deposition periods, the longer the bones were deposited for, the larger spread/mass of roots there were in the more porous areas towards the rest of the bone.

Figure 136 (A-C) – (A): Pig 5 Specimen 4 from the eight-month surface specimen area. (B): Pig 5 specimen 5 from the eight-month surface specimen area. (C): Pig 5 Specimen 1 from the eight-month burial specimen area.

There are certain specimens that are examples of the potential damage this activity can cause shown in figure 136 (A-C). The implications of this damage specifically is that these roots contribute towards the mineral dissolution process that occurs within bone degradation (stated above when discussing the nutrition of the roots). Root etching and invasive roots causing damage to the bone surface has been explored heavily in the recent 30 years, however, there is a lack of documentation/records of specific timings in lieu with amount of activity.

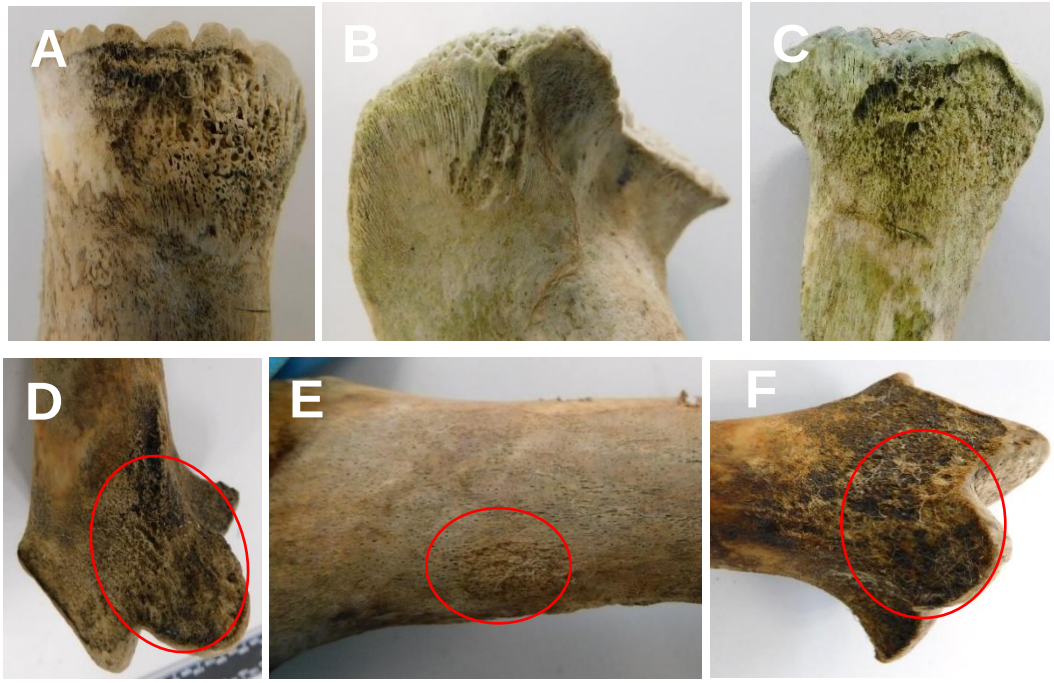

Figure 137 (A-F) – (A): Pig 2 Specimen 6 from the four-month surface specimen area. (B): Pig 2 Specimen 1 from the six-month surface specimen area. (C): Pig 5 Specimen 3 from the eight-month surface specimen area. (D): Pig 4 Specimen 4 from the four-month burial specimen area. (E): Pig 1 Specimen 6 from the six-month burial specimen area. (F): Pig 5 Specimen 2 from the eight-month burial specimen area.

In addition to this larger surface damage, as depicted in the above figures, there were several forms of 'irregular damage' that have been noted in this progression of root growth, that are believed to be the direct result of it (although it's not the only cause). It's been discussed previously if these forms of 'irregular damage' are the result of fungal root activity and potentially due to percolating ground water (Nicholson 1996; 1997). Note, some of the 'green stained sides' have received this damage also, as it was noticed as time went on, a larger number of roots grew underneath, around the side and over the bone specimens.

The damage to the bone surface increased in frequency and over a larger scale over time; these observed modifications are similar to ones noted in a few studies; however, these studies suggest these modifications occurred after several years of burial (Nicholson 1996/1997). Whereas, the burial specimens within the current study have received a couple of these modifications within four-eight-months post skeletonization in the ES soil; Figure 3 of Nicholson (1996) shows a surface modification that looks similar to one in Figure 137(E) above, as well as the damage to the more porous areas in Figure 137(D/F).

The specimens in Nicholson's study appear more degraded, as they were deposited for several years. However, the soil pH is very acidic (3.2-4.5pH) in the aforementioned study; thick layers of fungal mycelium, hyphae and fine roots covered their bones. These bones showed extensive cortex modification in the forms of shallow channels and oval pits; a majority of the eight-month burial specimens exhibit these effects in a less intense form. This adds weight to the current hypothesis that a majority of taphonomic modifications to bones actually occur within the first year post-skeletonization or at least start progressing within the first year.

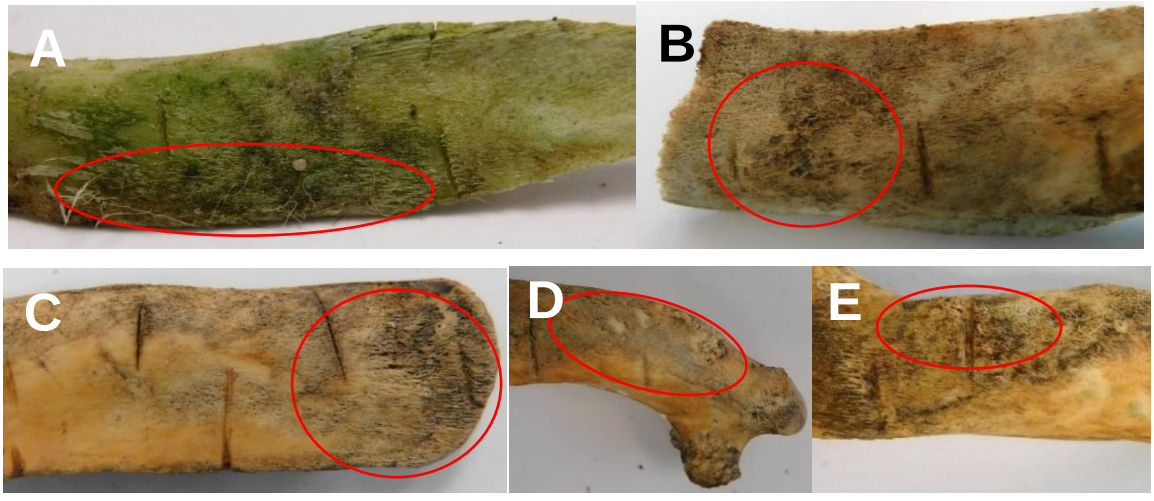

Figure 138 (A-E) – (A): Pig 2 Specimen 10 from the six-month surface specimen area. (B): Pig 5 Specimen 7 from the eight-month surface specimen area. (C): Pig 1 Specimen 8 from the four-month burial specimen area. (D): Pig 1 Specimen 9 from the six-month burial specimen area. (E): Pig 5 Specimen 10 from the eight-month burial specimen area.

Regarding the rib bones the irregular damage appeared in the later stages instead, however, the irregular damage occurred mostly on the epiphyses (proximal and distal) of the long bones for both surface and burial remains (Figure 138 (A-E)). Roots were attached towards some of the porous areas of the ribs where most of the damage can be seen. It has been discussed before that long bones are more prone to flaking of the outer cortical layer of the bone, whereas ribs are more likely to have loss of bone at/near the articular facets and sternal ends (Cunningham *et al.* 2011).

5.2.4 - Arthropod Activity/Damage:

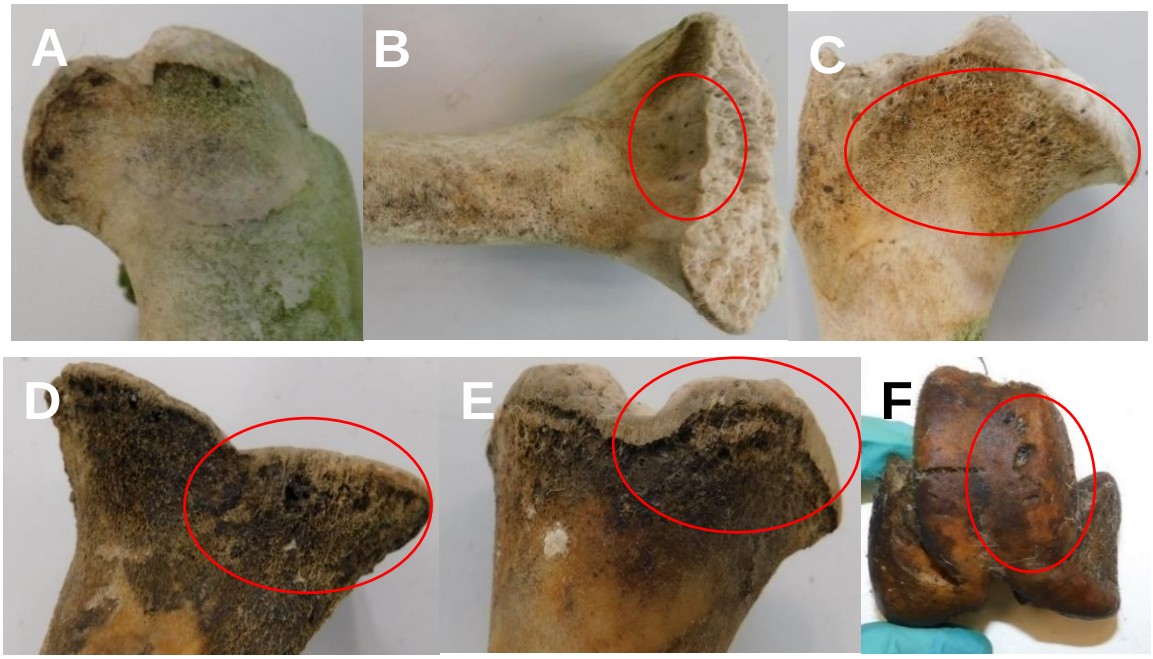

Figure 139 (A-F) – (A-B): Pig 3 Specimen 1 from the six-month surface specimen area. (C): Pig 5 Specimen 5 from the eight-month surface specimen area. (D): Pig 4 Specimen 4 from the four-month burial specimen area. (E): Pig 1 Specimen 6 from the six-month burial specimen area. (F): Pig 5 Specimen 1 from the eight-month burial specimen area.

The above figures show potential evidence of damage from arthropod activity coupled with the invasive root activity; the majority of them look like bore holes within the porous area near the epiphyses (labelled as holes according to Serrano-Brañas *et al.* (2018). For the surface remains they were mostly found after six-months, whereas they started to occur on the burial specimens interestingly at four-months. Overall, they had a relatively equal spread across the epiphyses by the end of the eight-month period.

Dermestes is the common family of the Coleoptera order that is known to cause damage to the bone surface. Figure 144(B) has small surface tunnels with bore holes in the ends, it looks very similar to damage inflicted by *Dermestes maculatus* in a recent study (Figure 25 of Parkinson 2012). This specific genus is known to cause damage in a short time frame (Zanetti

et al. 2014); remains have been recovered with damage to the ribs, acetabulum and humerus from this family (Schroeder *et al.* 2002). The larger surface holes/pits in the buried remains could have been the result of the Dermestid, they look similar to what is shown in Figure 31 in the above study. Dermestid traces such as grooves, marks and pitting have also been found on human/dinosaur bone in longer-term research (Schroeder 2002; Britt 2008). These markings on the epiphyses in Figure 144(F) look similar to those found in Huchet (2014) study (Figure 3) which is noted as surface damage from *Dermestes* beetles. There weren't any *Dermestes* larvae found, however, a *Dermestes* beetle and several other Coleoptera larvae was collected.

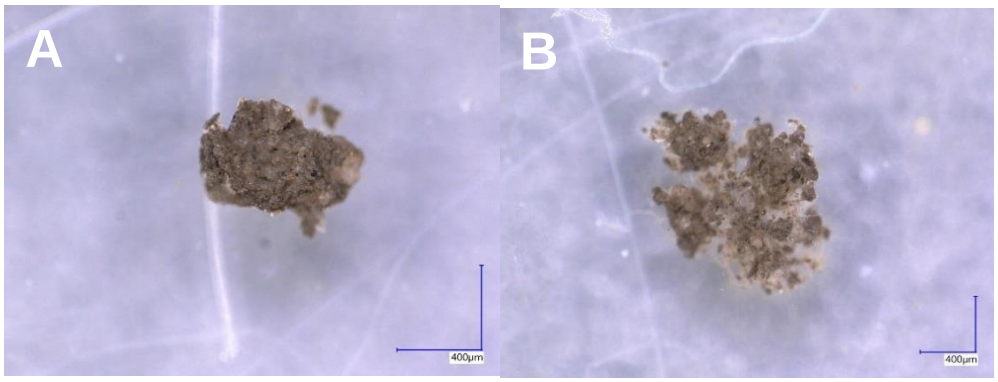

Figure 140 (A-B): 'Pods' that were found associated with the two-month specimen groups; these specifically were found on Pig 1 Specimen 4 from the two-month burial specimen group.

The above figures showed microscopic, grey 'pod-like' amalgamation of soil grains and fungal roots. It's been suggested that in addition to the potential damage caused by arthropods, it's believed that some of the irregular damage found on the burial and surface group specimens, could be the result of invasive roots in lieu with microscopic mite activity. It was not obvious at first as a little amount was found on one specimen on a surface bone only.

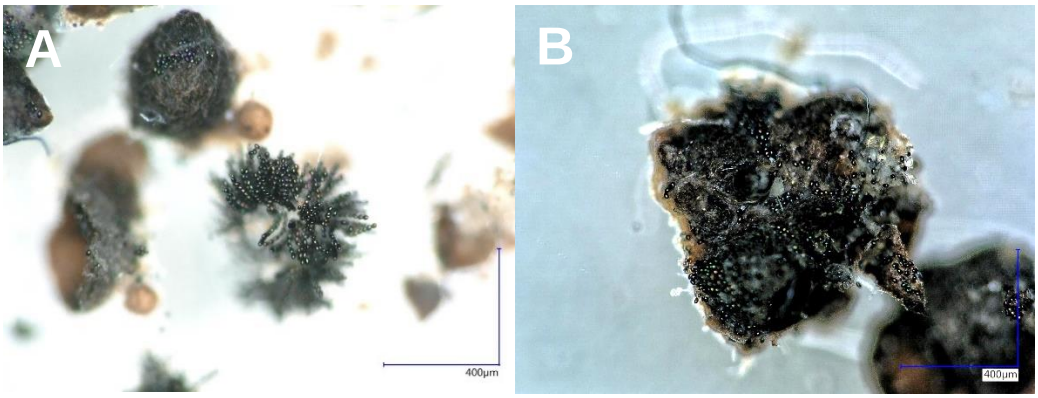

Figure 141 (A-B): 'Pods' that were found associated with the four-month burial specimen group.

The above figures showed a greater look under the microscope, which revealed that these are in facts mites (of a kind) within these pod-looking mixtures; the formation and presence is

considered unorthodox according to another researcher (*Pers comms* Damian Evans); however, not too unorthodox as mite activity on bone is heard of.

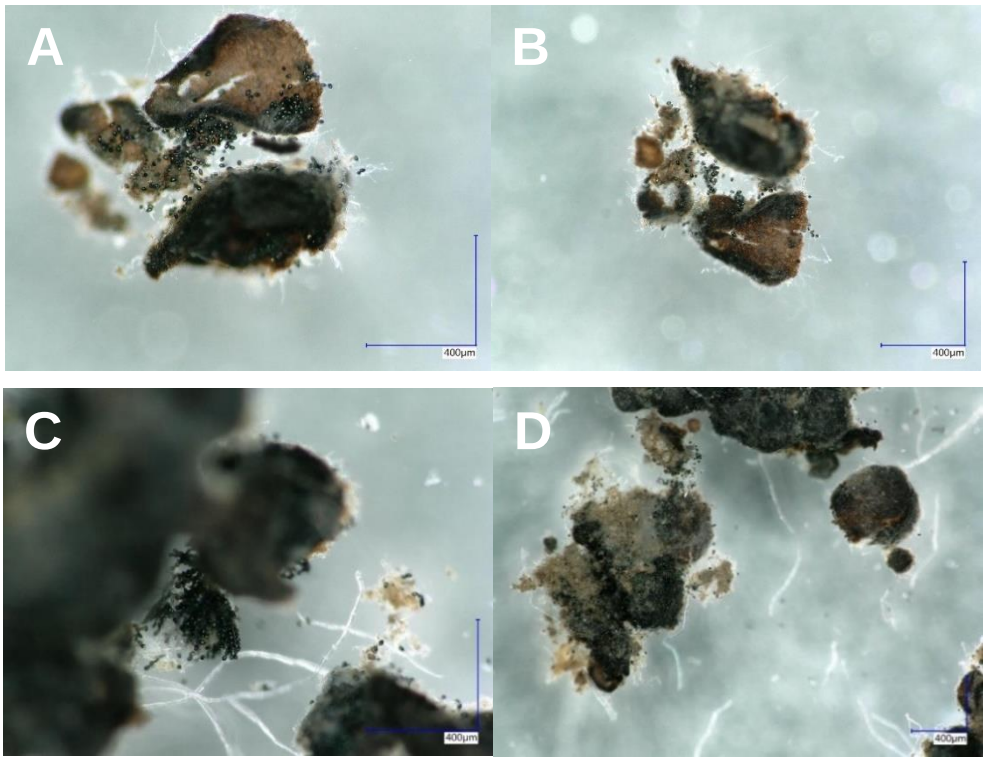

Figure 142 (A-D) – (A-B): 'Pods' that were found associated with the four-month surface specimen group. (C): 'Pods' that were found associated with the six-month burial specimen group. (D): 'Pods' that were found associated with the eight-month burial specimen group.

The above figures show more of these 'mite pods' and a further look revealed that they also have small white, clear, fungal hyphae roots holding them together and growing within them. Where they were present, they covered a large spread of the area, mostly between the unfused epiphyses of the bone specimens and the porous areas near.

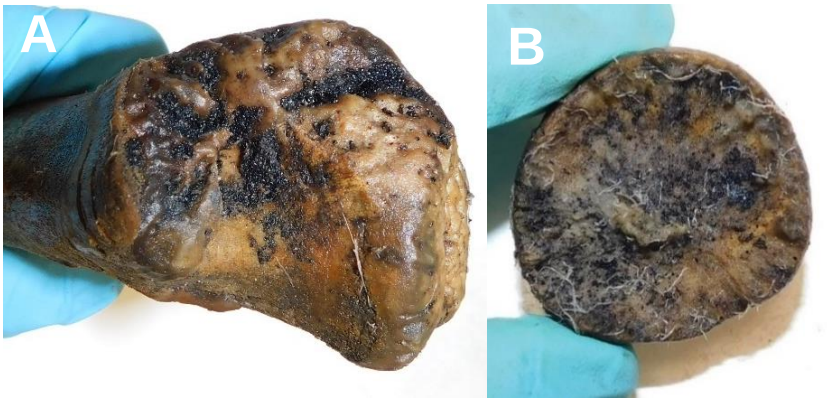

Figure 143 (A-B) – (A): Pig 1 Specimen 2 from the four-month burial specimen area. (B): Pig 5 Specimen 1 from the eight-month burial specimen area.

The above figures are examples of what these 'mite pods' looked like on a macro-scale. For the burial specimens at first, they were found mostly throughout the unfused epiphyses where the cartilage was preburial, this of course spread further to the porous areas (more on the burial specimens than surface).

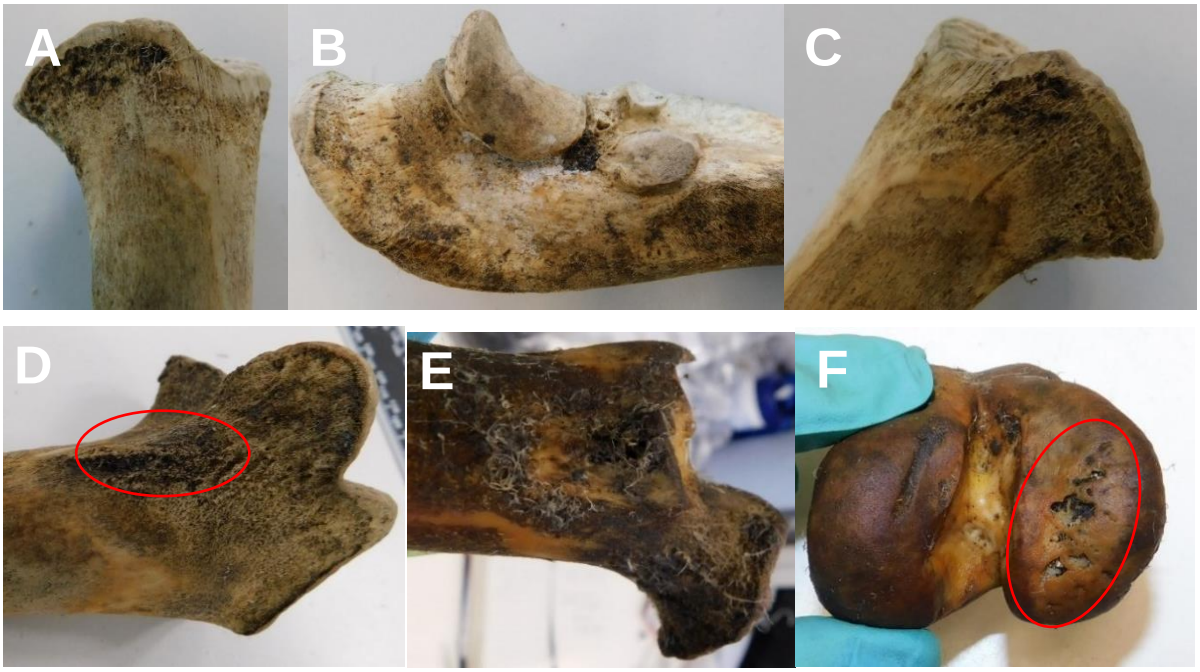

Figure 144 (A-F) – (A): Pig 5 Specimen 3 from the eight-month surface specimen area. (B-C): Pig 5 Specimen 4 from the eight-month surface specimen area. (D): Pig 4 Specimen 4 from the four-month burial specimen area. (E): Pig 1 Specimen 6 from the six-month burial specimen area. (F): Pig 5 Specimen 1 from the eight-month burial specimen area.

The above figures are examples of the potential damage that has been associated with the mite activity and root activity; For the two-month surface specimens it was unclear what they were at first and that the root growth was most likely the only causative agent to the irregular damage. however, by four/six-months they had been found within a few of the crevices, by

eight-months, a plethora were found in the porous areas and across the epiphyses of the specimens. Their presence here and within the cutmarks (shown/discussed later) certainly is an interesting phenomenon and the implication of their presence is there might be more going on regarding the degradation of bone than once thought.

Various forms of mites have been previously associated with damp soil conditions as well as soil surrounding corpses (Szelecz *et al.* 2018). Mites have been found with buried skeletal remains, mostly in archaeologically funerary contexts from different periods (Radovsky 1970; Schultz 1986; Beisaw 1996; Sorg and Haglund 1996; Aufderheide 2003). There is research regarding their associated indirect/direct relationship with small invertebrates damaging skeletal material. However, there is a plethora of research that has discussed the presence of mite during the different stages of decomposition (Tibbett and Carter 2008; Braig and Perotti 2009; Tibbett and Carter 2009).

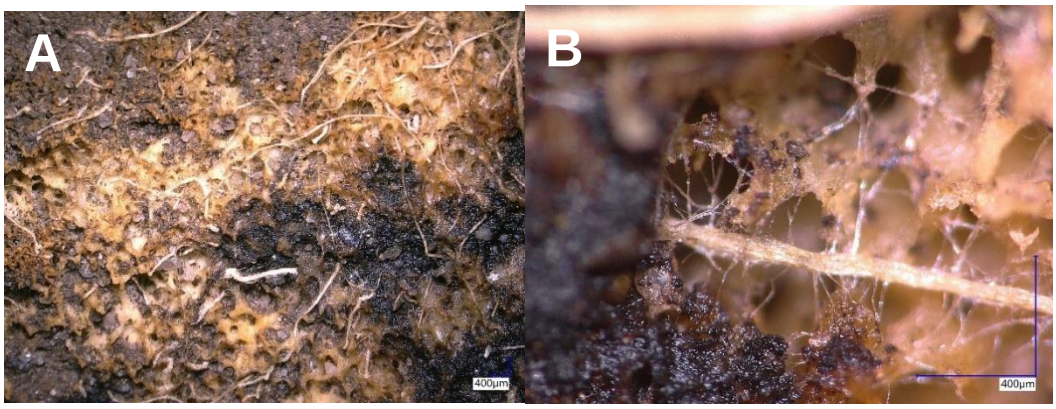

Figure 145 (A-B) – (A): 'Pods' that were found associated with the eight-month burial specimen group. (B): 'Pods' that were found associated with the eight-month burial specimen group.

The above figures show under the microscope, what the mites looked like around the porous areas of the bone, under inspection they are completely covering the spongy structure of the cancellous bone along with fungal hyphae roots that can be seen.

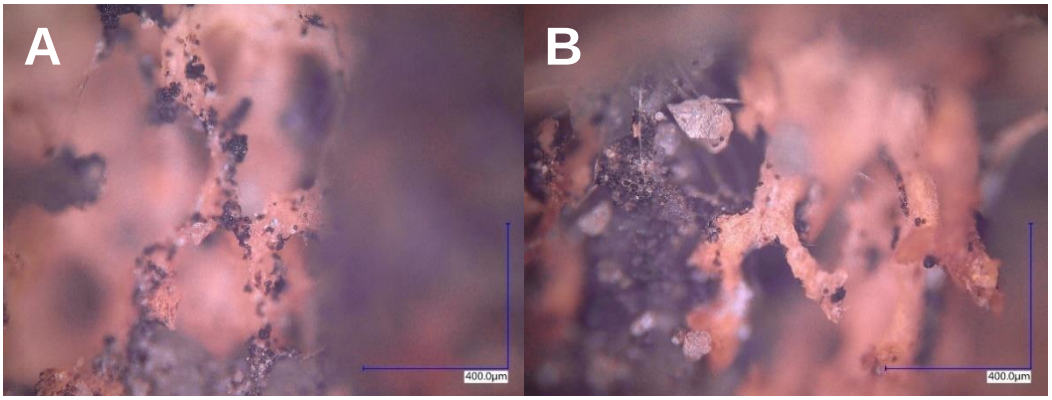

Figure 146 (A-B) – (A): 'Pods' that were found associated with the eight-month burial specimen group. (B): 'Pods' that were found associated with the eight-month burial specimen group.

The above figures reveals that they completely covering the trabeculae bone tissue; it's reasonable to believe that the fungal hyphae are being used to assist in holding the mites and the 'pods' together to the bone. Whether or not they are actually damaging is difficult to say as there would need to be further research into prolonged stages of having these mites in the bone structure.

There is weight to the hypothesis that these mites might be a destructive agent to the bone surface/matrix; they have been found in a broken/damaged area of one of the eight-month bone specimens. During the removal of the soil for that specimen, parts of the distal and proximal epiphyses broke off, it had the typical black/grey pods and a further inspection was conducted under the microscope.

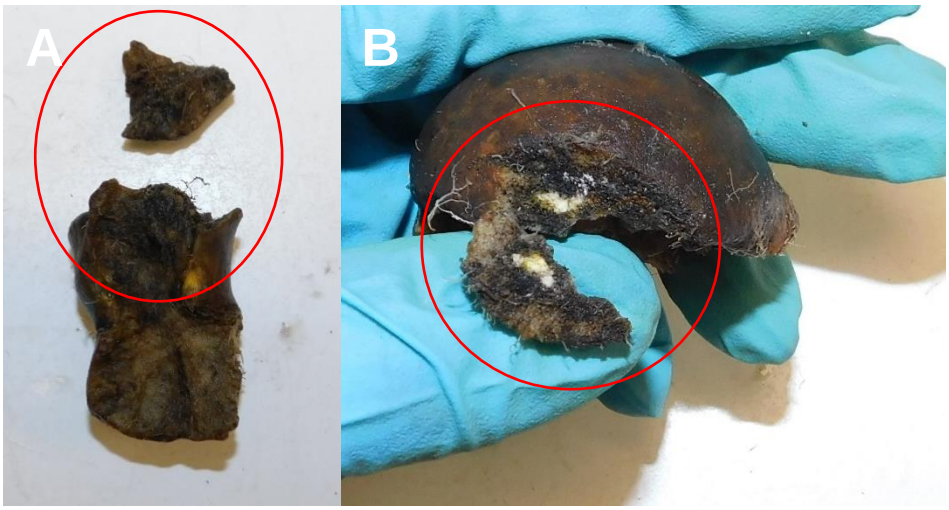

Figure 147 (A-B): Pig 5 Specimen 6 from the eight-month burial specimen area.

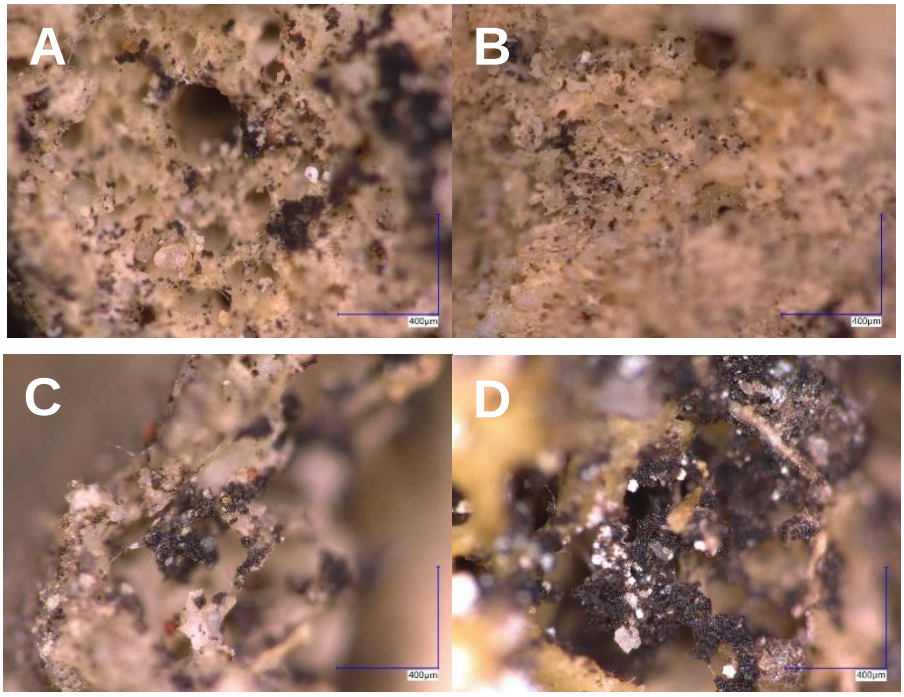

Figure 148 (A-D) – (A): Distal epiphyses broken separate part of Pig 5 Specimen 6. (B): Distal epiphyses broken area of bone of Pig 5 Specimen 6. (C): Proximal epiphyses broken separate part of Pig 5 Specimen 6. (D): Proximal epiphyses broken area of bone of Pig 5 Specimen 6.

The above figures show that there is a plethora of these mites & pods between the area of breakage and the crevices and around the surface. This supports the hypothesis that these very much invasive mites found with the fungal roots attached to the bones are also a causative agent of destruction towards the bone structure and surface. Of course, the degree of destruction in the bigger picture is minimal, however, this phenomenon should be explored further in greater detail as stated in the surface specimen section.

5.3 - Comprehensive Summary of the Changes to the Cutmarks:

5.3.1 - Qualitative Changes to Cutmarks and Surrounding Surface:

This assessment of qualitative changes revealed an obvious however taciturn hypothesis that hasn't been discussed nearly at all in the literature (Calce and Rogers 2007). The purpose of the current study is to establish whether certain physical alterations to the cutmarks on bone could be identified and whether there is a distinct pattern across the deposition periods and specimen areas. Also, whether these physical (potentially degradative) alterations can be linked to the measurement changes with the cutmarks individually.

Ten categories were chosen based on what was found and what was likely to be observed; they were divided and regrouped into nine categories to assess the presence/absence of these forms of activity. There are four notable but niche changes to the cutmark edge (Degradation/Flaking/Fading/Fracturing), that were grouped together totally as 'Alteration of Edge Appearance and Structure'. Whereas, the author decided to split the staining into brown and green, as well as plant and fungal root activity separately; to assess how much of a divide there is between them.

Activity is based on an absence/presence notion, for example, if it was noted that for Cutmark A for Specimen 1 has shown a minor amount of edge flaking, then it would be noted that this cutmark has exhibited signs of 'Alteration to etc…'. If it does not exhibit the physical change, it will be noted as absent. Examples are given in Table 6 in the results section of what some of the changes look like, of course, all the changes observed are not restricted to these photos exactly; only the given an idea of what should be observed. There is a wave of fascinating trends here that were not expected, this particular form of research has not been looked into at this level of detail. Regardless of cutmark type, bone it was inflicted upon, and deposition area, seven out of the nine categories displayed a large amount of activity for these physical alterations/occurrences. The summarised changes observed have been outlined in Table 11 below specific to which changes were frequent and which were not, below this is a further discussion and analysis of said changes and the associated data in Figures 96-119 and tables 7-9.

Areas	Alteration of the Edge Definition and Structure	Kerf and Surface Erosion	Green and Brown Staining	Plant and Fungal Root Growth	Insect Activity and Presence	Bone Loss
Burial	The edges of the serrated cutmarks appeared to be the most affected compared to the cleaver and stonetool marks. The buried cutmarks appear to have exhibited a minorly higher amount of alteration compared to the surface cutmarks	Surface Erosion here appeared to increase generally over the deposition periods with slight consistency. Kerf Floor Erosion occurred randomly without a recognisable pattern other than a slight increased activity with serrated cutmarks	Green staining did not occur at all for any of the buried cutmarks. Brown staining appeared for a high number of the cutmarks from two months onwards.	Root activity appeared to affect the serrated cutmarks more than the other cutmark types. The growth by the eight-month period appears consistent among the cutmark types. However, the growth over time appears to be inconsistent	Buried cutmark insect activity occurred more for the serrated cutmarks than the cleaver and stonetool cutmarks across the deposition periods.	This occurred infrequently and randomly and therefore there is little pattern to infer.
Surface	The edges of the serrated cutmarks appeared to be the most affected compared to the cleaver and stonetool marks.	Surface Erosion similarly to the buried cutmarks appeared to increase generally over the deposition periods with less consistency than the buried cutmarks. Kerf Floor Erosion occurred randomly and infrequently without a recognisable pattern other than a potential linked activity with the moments of increased insect activity.	Green staining appeared on most of the surface cutmarks with a reasonable amount of variability; it appeared on an increasing number of cutmarks till eight months where there was a drop. Brown staining appeared to generally increase across the deposition periods generically, with variable exceptions.	Root activity appears to affect the serrated cutmarks more than the other cutmark types. Plant and fungal root activity generally appears to be exhibited less for the surface cutmarks than the buried ones (with exceptions).	Surface cutmarks experienced a greater number exhibiting insect activity compared to the buried cutmarks. Similarly, the serrated cutmarks within this group exhibited this activity more so than the other cutmark types.	This occurred infrequently and randomly and therefore there is little pattern to infer.

Table 11: This is a small point summary of the raw results outlined in Tables 7-9 and Figures 96-119 to be further elaborated in the sections below.

5.3.2 - Staining and Surface Erosion:

Staining will differ definitely based on whether it's buried or not, buried remains will not experience any form of green staining (unless a large abundance of copper is in the ground). Surface specimen cutmarks will stain differently based on their relative position to the soil side or grass side of the surface specimen area (Dupras and Schultz 2013). The extent to which the cutmarks/bones are stained, can suggest/hint the length of deposition or amount of exposure the bone and cutmark has received; it also indicates to what extent the remains have interacted with the environment (Dupras and Schultz 2013). All the buried specimens experienced brown staining and no green staining across the cutmark types; there is not a discernible pattern for the proportion of the green stained cutmarks to brown stained for surface specimens due to the difference in relative position to the ground.

Regarding surface erosion, there is a passable pattern of difference between the buried and surface cutmarks. The cutmarks inflicted upon the longbones and ribs, the burial group have a minorly greater amount that exhibited a form of surface erosion. The anomaly here is the stonetool marks inflicted upon the longbones have a higher surface erosion percentage for the surface group as opposed to the burial group.

Logically, the surface erosion could be worse (minorly) for the burial group due to their constant exposure to the acidic soil and groundwater in the soil matrix. Whereas, for the surface specimens, it will vary based on their relative position to the soil side or the grass side; one will be facing the soil turf, the other will feel the direct experiences of the weather changes (e.g. direct UV and rain exposure).

The levels of surface erosion within each specimen area group are relatively similar values (for long bone and ribs) for the burial cutmarks with only a minor pattern of difference for two values (Burial cleaver rib group and burial stonetool longbone group) by eight-months. One difference being a decrease from all the cutmarks in the six-month rib group exhibiting a form of surface erosion, whereas by eight-months, only the majority do. After looking into the specific sub-categories for edge alteration, it appears, the amount of edge flaking decreased by eight-months specifically (result of extended erosion potentially).

For the surface specimen cutmarks, they have similar values to each other, aside from the surface stonetool values for the long bones which are much higher; for the ribs they have similar values except for a minor difference for the surface serrated cutmarks. The implication here is the surface specimen cutmarks will always have a greater amount of variability compared to the buried specimens based on their varied relative position to the ground. Unlike

burial specimens which if they're all within the same layer and close proximity, they most likely will feel the same influences from the soil matrix as each other.

5.3.3 - Root Activity and Arthropod Activity:

Plant and fungal root growth and arthropod activity (damage and presence) are the other prevalent factors found in this study. It is hypothesised that the structure and size of the cutmarks influence how much activity in these categories actually occur. Within this hypothesis, it is suggested that this level of activity in the soil in general is occurring because the soil is a hostile, low nutrient, degradative environment; and the introduction of these remains have had a large impact due to the amount of uses it's brought into the surrounding microenvironment.

The available space within a cutmark is hypothesised to influence the root and arthropod activity i.e. there is a greater amount of root growth (plant or mycorrhiza hyphae) and presence of insects (mites specifically), if there is a larger amount of space for them to be active in. This concept is supported by the fact that the serrated cutmarks, with the largest initial width (815µm average for longbones and 803µm for ribs) have shown to have the largest percentage of cutmarks affected by root activity (fungal/plant) certainly for the buried longbone and ribs. For the buried ribs, the activity for fungal/plant roots is equal individually by eight-months for stonetool and cleaver marks; whereas, the serrated marks on ribs have a moderately higher amount of plant root activity. However, with the longbones, aside from the serrated marks where all are affected by both root types, the plant root activity is moderately higher than fungal for cleaver and stonetool cutmarks.

The activity differs slightly between the root types for the surface longbones, where the serrated cutmarks are the highest overall for fungal root activity, whereas the cleaver cutmarks are for plant root activity. The root activity for surface cleaver cutmarks on longbones were a very low value up till the eight-month interval increase. So, across the deposition periods, the serrated cutmarks for surface longbones had the consistently higher amount. There was very low root activity for the stonetool cutmarks for surface ribs; the plant root activity is similar between serrated and cleaver with the cleaver marks being slightly higher, and fungal root activity is higher for the serrated cutmarks inflicted upon the surface ribs.

The certain amount of variation between the longbones and the ribs is logical as the cutmarks will differ based on the different densities, shape and surface area of the bones they were inflicted upon; this will affect the infliction and thus creation of space within the cutmark. The serrated cutmarks are those with the highest amount of activity exhibited for these categories. Although root activity is hypothesised to be influenced by space availability, plant root activity

on longbones/ribs occurs more in buried remains, and fungal root activity follows this mostly. Aside from a minor difference for the surface cleaver longbone values, which are slightly higher than the burial (unknown reasons).

The arthropod activity is hypothetically proportionate to the available space within a cutmark, it will also be based on whether or not it is buried, (as discussed above), it will differ based on access to the remains. Arthropod activity is less likely to be prevalent for buried remains as they are harder to access as opposed to the surface remains (Marais-Werner *et al.* 2017; Iancu *et al.* 2018). The burial and surface serrated cutmarks are mostly higher than their burial surface counterparts for longbones/ribs; the surface cutmarks for all types are mostly higher than their burial counterparts for longbones/ribs. The anomaly out of both patterns (serrated marks having the highest activity and surface marks having the highest activity) is there was no activity till eight-months when the burial stonetool marks spiked higher than the burial serrated marks and then the surface stonetool marks on the rib bones.

5.3.4 - Alteration of the Cutmarks Edge and Appearance:

This category is hypothesised to be influenced partially by the space availability within the cutmark; greater space means greater activity of roots and arthropods (and introduction of acidic soil water). Therefore, a more likely chance to degrade/change the cutmark edge. However, it is also suggested that it is based on the initial structure of the cutmark made by the tool instead. The burial values are minorly higher than the surface for long bones (aside from the burial stonetool values being moderately lower than the surface), the serrated values are the same for burial vs surface comparison for the longbones. For the ribs, it is the opposite, all surface values are minorly higher than the burial ones with the serrated marks having the highest only slightly (unknown reasons).

The common trends specific to tool type are serrated marks minorly have the higher values for burial longbones, ribs and surface ribs (with stonetool marks being lower and cleaver marks being the same). Serrated and stonetool marks roughly have the same value for surface longbones, with the cleaver mark values being much lower.

After the raw values were investigated, it shows the serrated marks appear to suffer from more edge flaking by the eight-month deposition period; this could be encouraged by the fact that a serrated cutmark is more prone to flaking. However, it is noted that where the serrated mark values are higher, it is only a minor increase, and the results vary across the deposition period, therefore, it should be taken lightly.

5.3.5 - Bone Loss and Kerf Floor Erosion:

Some of the categories appear to be relatively random regardless of deposition specimen area, tool type and bone it was inflicted upon; these being 'Bone Loss' and 'Kerf Floor Erosion/Degradation'. The only passable pattern with the latter is that it the serrated and stonetool marks exhibit it more than the cleaver, other than that, there really isn't a discernible meaningful pattern.

5.3.6 - Summary:

To summarise, the investigated categories of physical changes to the cutmarks all are hypothetically influenced by different scenario-based factors i.e. whether they're buried or not, relative position to the ground if on the surface, available space within the cutmark and potentially an influence based on a tool class feature itself.

There are notable larger trends that can be identified regarding these, and they are the following:

- Staining for the surface specimens is more variable than the buried specimens based on the relative different positions they have to each other; there isn't a definable difference between the cutmarks here.
- Surface erosion appears to occur more for the buried remains than the surface specimens, therefore, trauma on skeletal remains are more likely to suffer degradation from this if buried; aside from a few differences, within their own groups, the cutmark types reasonably get affected similarly by the end of the deposition period.
- Plant and Fungal Root activity appear to occur more for the buried remains than the surface and therefore is more potentially degradative; within their own groups, the serrated cutmarks are those with the highest amount of activity for both roots in the burial group. For the surface it varies between the root types, the serrated cutmarks are highest overall for fungal activity, and the cleaver are highest for plant root activity.
- Arthropod activity appears to be minorly higher in the surface specimen group than the burial specimen group and therefore is more potentially degradative; aside from a few differences, within their own groups, the serrated cutmarks are those with the highest amount of arthropod activity.
- Alteration to the Cutmarks Edge and Appearance appears to be minorly higher for most of the burial long bone specimens. For the ribs, the surface specimens' values are minorly higher than the burial ones; within their own groups, the serrated cutmarks have minorly the higher values mostly overall.

5.4 - Two-Dimensional & Three-Dimensional Changes to Cutmarks:

This study revealed certain patterns that were unknown previously, even though it was limited to only one measurement (Kerf Width). It was estimated that there would be a larger increase in width over the deposition periods individual to the tool type. However, the results are quite variable and therefore should be taken lightly, nonetheless, there is a discernible pattern amongst the groups.

The variability comes from the observation that there was not a constant/consistent increase, e.g. the average percentage increase of width for surface cleavers in long bones, decrease from two-to-four-months, increases to six, then decreases at eight. There are definitely more factors at play, although all the cutmarks were inflicted as similarly as possible; the densities of the bones will differ, also, their position within the soil and to the ground may obscure some areas of the bone surface from potential destructive/taphonomic agents.

The cleaver cutmarks show that over time there is a moderate increase in width over time, however, the serrated cutmark values are all relatively similar (within the 10% bracket of each other) until eight-months where there is a drop for serrated marks within both deposition areas unknowingly. The stonetool cutmarks are too random to suggest whether they increase or decrease over time, which could reflect the variability within this tool type, as they were the hardest to ensure they were inflicted the same.

Two patterns can be suggested from the overall data:

1. The burial specimens have a slightly higher maximum increase among the groupings compared to the surface specimens regardless of tool type.
2. The cleaver cutmarks appear to have the highest individual maximum increase, and the smallest individual minimum increase regardless of bone and specimen area type.

It should be noted again that (2) is referring to the percentage (%) increase of an individual cutmark, not the actual difference in microns, the author is interested to see to what extent will the cutmarks width increase relative to its initial dimensions.

Comparing these results to the qualitative physical change results (although, should be taken lightly) births an interesting hypothesis. Aside from staining and arthropod activity, other physical changes that were observed were found to be exhibited more by the buried specimens as opposed to the surface specimens, this could indicate that they may have contributed towards the change in width. However, looking at tool type, the physical change results rank the serrated cutmarks to be slightly higher as the cutmark that exhibited greater physical change. For the width measurements, the cleaver cutmarks exhibit greater increase in width (although difficult to compare to other cutmarks if percentage increase vs actual increase is used). This is not an issue or contradiction; the physical changes could still have

hypothetically contributed towards the change in width; it is hypothesised that the structure of the cutmarks may influence its sensitivity to change from interactions.

It can be suggested that even though the serrated cutmarks appeared to have a greater number that exhibit physical changes from interactions with external stimuli; the square-U structure of a serrated mark is less prone to change as it is a stronger structure. Whereas the V-shape of the cleaver mark could make it more prone to peeling/perforation of the cutmark wall i.e. it is not structurally sound/stable. Therefore, the cleaver cutmarks, although they minorly exhibited fewer physical changes, could have been affected by them more based on its 'weaker' more unstable structure.

There is an inherent difference between serrated and non-serrated (cleaver for example) bone trauma based on how they're inflicted. Although it's argued in Humphrey and Hutchinsons (2001) that sharp weapons cause little crushing and fracturing compared to blunt-force instruments, nevertheless crushing/fracturing can still be caused by sharp-force trauma, specifically with hacking trauma, compared to incision trauma (Thompson and Inglis 2009). In this context, serrated marks come under incision trauma due to their nature of creation i.e. a force being applied across the surface of the bone with a sharp instrument creating a superficial mark over the surface. Regarding characterisations, what's unique about hacking trauma is the observation of associated blunt force injuries, these injuries are due to bone failure when there is enough force delivered in the strike of the weapon which results in surround structural failure, sometimes in the form of compressive fractures beyond the incised wound (Annand 2018). In some cases, the SFT known as hacking trauma has been described as BFT with a sharp implement as it can have characteristics of a blunt force injury such as radiating fractures and plastic deformation (Martin and Anderson 2014). By contrast, other sharp implements such as a serrated blade, are unlikely to create compressive fractures due to the lack of direct force perpendicular to the bone surface; so sawmarks as opposed to cutmarks from hacking might have less structural deformations because of this lack of directly applied energy (Kimmerle and Baraynar 2008). Fractures from trauma are created when the stress from an applied dynamic force (such as hacking trauma) extends beyond the yield of the bone's competency, so the strain becomes too much (Lynn and Fairgrieve 2009). As supported by some studies in Chapter 2, bone failure and fractures are more likely to occur as a result of an applied force, therefore, it's logical to hypothesise that the dynamic infliction of trauma using a cleaver blade would create more structural failures and osseous deformations compared to a scraping of the bone surface from a serrated blade. Thus, the structure surrounding the cleaver marks themselves, could be weaker and thus more sensitive to physical changes.

This possible hypothesis has a foundation, however, there needs to be far more research into these specific phenomena as well as investigating other tool types, longer deposition period (18 months would suffice), different soil types and a greater amount of measurements to record. If done correctly, then this hypothesis could either be supported or another could replace it that better explains the changes that have been recorded.

Overall, the base pattern amongst the tool types and deposition specimen areas is, from two-months onwards, an increase was seen regardless, of which has implications within a forensic investigation that have not been previously discussed in depth. The implications is, there is evidence, that the cutmarks inflicted upon remains can change their widths within a relatively short period of time. This brings up issues for 'wound-matching' scenarios that have been discussed in the community previously. There is a large amount of research that has been conducted to determine if the dimensions of a blade can be calculated from the dimensions of the cutmark and to see if a match can be made as a result.

This has useful consequences for a forensic investigation, if skeletal remains are found either dismembered or have signs of cutmarks on the bones, using certain techniques can assist in determining not just the tool class, but specific dimensions like thickness of the blade also.

The studies range in what type of cutmarks are investigated, tool type and what scanning/optical equipment is used. They reveal that certain features of the cutmark can be used to match blades to cuts. The basic studies start off with identifying solely the origin of certain butchery marks and if they were made with stone tools; moulds of the cutmarks were created and optical and scanning electron microscopes were used to determine what caused the butchery marks (Greenfield 2013).

Certain investigations have explored specifics such as the target traits of striations that can be determined from microscopic photographs; these can provide a reasonable match to the blade if measured correctly (Symes *et al.* 2010; Black *et al.* 2017). There are recognised studies that establish basic metrics such as kerf width can approximate the thickness of a blade through the use of stereoscopic digital microscopy (Bailey 2010; Divido 2014). There have been investigations that have determined how to easily measure cutmarks by using 3D optical microscopy and calculating the impulsive force that is exerted through using a stimulation platform; from this, characteristics of a knife mark on bone could be profiled much further than one does with non-metric analysis (Shaw *et al.* 2011).

Micro-computed Tomography has been frequently used in this research area, creating 3D models using this technology. Although it is expensive, and time consuming, it has proven to reveal and abundance of information such as size, shape and width. This technique allows the user to determine the size and shape of the blade used to injure the bone surface (Thali *et al.* 2003; Rutty *et al.* 2013).

Among these studies, commonly, there is a range of techniques that can be used to assist in identifying class features within a cutmark, complete metric recordings and then this information is used to approximately match a specific blades thickness and type to a cutmark. However, they have yet to discuss whether the inflicted cutmarks are in fact accurate reflections of the blade that inflicted them. The current research here establishes that a tool type still can be determined in relatively easy conditions i.e. knife mark vs serrated mark vs stonetool mark. However, it is revealed that there are certain qualitative and quantitative physical changes that can occur to a cutmark within a short-term period of deposition. The 3D models revealed that striations for some of the cutmarks became more difficult to see by the six-month deposition periods, linear ridges of the cleaver marks showed extensive degradative change and the overall surface texture surrounding the cutmark has increased in porosity. There is an overarching pattern with the 3D models that support the above findings from the 2D microscopy results. These observed physical changes could alter the cutmarks enough that accurate measurements cannot be recorded from them (depending on the environment it's deposited in i.e. the higher the destructive potential, the higher the change).

This is only a hypothesis, it will need further research specifically into using Confocal microscopy and Micro-CT scanning with a much larger sample size, time frame and a range of environments with different preservative/destructive potential. A foundation has been set for this research area and has allowed the author to use this and suggest that in forensic investigations, if skeletal remains are found and they have cutmarks on them, it should not be assumed that they accurately reflect the tool that was used to inflict it. Further investigations into the physical and geochemical chemicals of the soil the remains were deposited in/on will need to be conducted as well as using weather reports to determine the destructive potential of the soil and surface environment. It is a possibility that if the remains are left in a more preservative soil, then the reconstruction methods will be more accurate as there would have been less taphonomic agents to interact with the bone/cutmark.

Unfortunately, due to lack of samples, time and some logistical issues, another soil type was unable to be sourced for this current experiment, however the author conducted a type of pilot experiment in 2017-2018, of which part of the research can be compared to this one.

Most of the specimens for that pilot experiment were reburied (as part of that experiment), and some of the specimens were just left for six-months without reburial as a control, these have been compared to the six-month cutmarks that were for this current experiment. The issue is, these cutmarks (pilot) weren't inflicted using a controlled device, and therefore are quite different. However, it is still a good comparison as the soil was a completely opposite to the current experiment i.e. it wouldn't be considered a destructive soil.

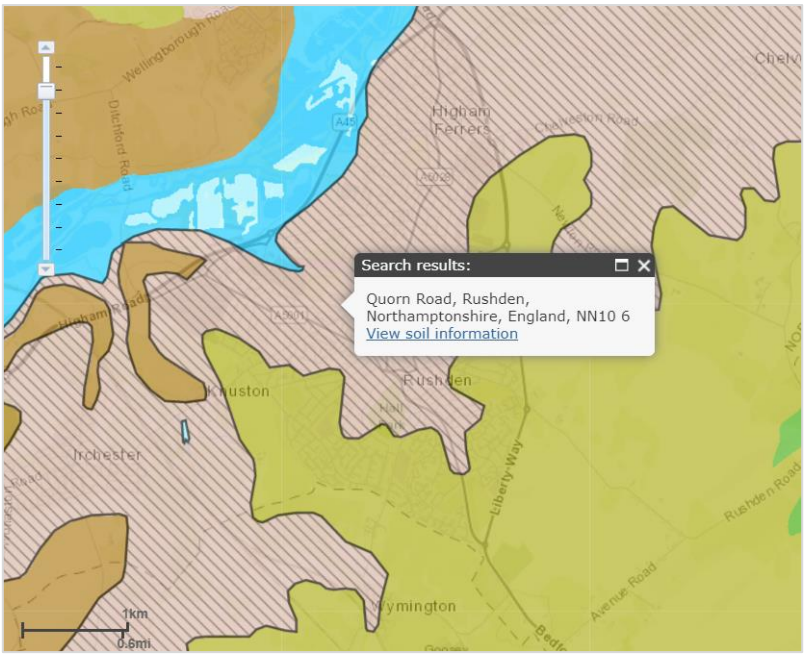

Figure 149: Map of Experiment Location for Pilot Study at Quorn Road Allotment plots, Rushden, Northamptonshire.

The figure above is cropped from the LandIS Land Information System – Soilscapes viewer, the soil type (for the pilot experiment) is listed as “Freely draining lime-rich loamy soils” with a relatively high fertility. These soils usually can be quite alkaline, however the pH for the site was recorded as 7.4 averagely (neutral soil), and the soil itself is part of an allotment plot for growing large amounts of vegetation.

It was found within the experiment, that not many changes between pre and post burial occurred between for these controls, aside from some minor staining and insect activity, there wasn’t any noted larger differences. Even though, they weren’t measured, it’s believed that appearance and structure wise, they’ve changed minimally (Gent 2018 unpublished data) (Photographs of these controls can be found in Appendix Section G). This gives further reason to investigate the differences in effects of destructive vs preservative soil.

5.4.1 - Summary:

To summarise, 2D and 3D microscopic techniques certainly have their advantages when it comes to recording and analysing trauma. There is a plethora of methods to use that range in user interface, time, and expense. It’s been stated in the results section that Micro-Computed Tomography would be the next steppingstone for this research area as it has advantages for finding out more about taphonomic modification to the structure of the cutmark.

Regardless of this, investigating into the change in measurements of the cutmarks was remotely successful, albeit should be taken lightly as further research is needed to support the suggested hypotheses. The hypotheses being, the change in width is most likely a result of

the destructive potential of the soil as well as the weathering conditions at Wytch farm; as well as a possible link to the ecological interactions seen between the cutmarks and the deposition area i.e. the physical changes that have been noted to occur.

The implications of this research is the assumptions that are made during forensic investigations or forensic-based research cannot be taken without consideration of the environment and potential ecological interactions that the remains were found; these assumptions being that one can accurately reflect dimension and physical information about the tool from the cutmark it inflicted. Thus, further research is needed in this area to be able to support the use of these brilliant and fascinating methods, and to better improve their accuracy as well as utilizing the knowledge of the environment that the remains were found in.

Chapter 6 - Conclusion:

The present study has established several possible hypotheses for explaining some of the phenomena that have been observed throughout this experiment. They support previous studies that show skeletal remains can have an impact on the local microenvironment in which they are deposited.

- Specifically, there are signs of leaching from the bone specimens within the soil in the early stages of the experiment, as well as a possible influence on the microbial and microorganism total abundance.
- The destructive potential of the soil is reflected in the macroscopic changes to the bone surface, of which certain changes such as cortical flaking/erosion, root damage, possible bio-erosive damage from arthropod activity and other surface modifications are the result of this specific environment.

The destructive soil and degradative surface environment has certainly contributed towards the physical changes towards the cutmarks explicitly; it was found that the positioning of the bone as well as the available space within the cutmark itself influenced the amount of change that was observed.

- It was found that cutmarks on buried remains actually experience slightly greater changes than the surface specimens, these changes include surface erosion, root activity and an overall alteration to the cutmarks edge and structure. Logical changes were identified such as there being a moderately higher amount of arthropod presence within the cutmarks for the surface specimens than the buried ones.
- Regarding the amount of space, the serrated cutmarks experienced the greater amount of noted ‘physical changes’ compared to the other tool types. It is also hypothesised that the structure of the cutmark will dictate the amount to which these physical changes will affect the measurements e.g. kerf width.
- Although the cleaver cutmarks displayed the least amount of physical changes overall, they showed the greatest change in width; theoretically it could be because the structure of the cleaver V-shape mark is prone more to damage from these physical changes as opposed to serrated or stonetool marks; this is reflected in the kerf width measurements in the study.

It is hypothesised further that in bone-destructive soils, such as in this experiment site, the ecological interactions between the microenvironment and the cutmark/surface on the skeletal remains are far more of an issue regarding the implications in a forensic (or archaeological) investigation; compared to if the remains were found in a more bone-preservative soil (suggested based on the comparison of the cutmarks to Gent 2018 Unpublished pilot experiment). There were not any changes that were most apparent in the early stages and

were not seen later or vice versa, the changes mostly increased through time for the duration of the experiment. Observing these contributed to understanding the process of cutmark deterioration in the different deposition environments and the relationships between the cutmark type and the specimen area.

The soils destructive potential was determined successfully by investigating the 'important' variables that are possible influencers for the degradation of skeletal remains.

- A simple workflow was created to be able to obtain this basic data if the instruments are available with minimal soil use.

The experimental approach for analysing the cutmarks on the bone employed in this study was found to be advantageous in exploring the capabilities in 2D and 3D microscopy.

- It's evident that there are greater techniques that can be used in identifying 'taphonomic' modifications to the appearance of cutmarks on bone such as 3D Focus Variation based Microscopy and Micro-CT scanning, which is earmarked for future research in this area.

Ultimately, the implications of this study within the subject of Forensic Taphonomy is that it impacts certain investigative techniques and assumptions utilised in forensic investigations.

- Techniques that reconstruct blade dimensions from cutmark dimensions rely on the assumption that the cutmark measurements will reliably and accurately reflect the thickness and angle of a blade edge; this research demonstrates that such assumptions can be flawed and that in future such techniques should consider the potential post-depositional changes made to cutmarks in different burial environments.
- An investigation into the cross-linking environmental variables and using the data to determine the destructive potential of the soil is a technique that should be used further in these investigations. If the skeletal remains are found within a destructive or preservative soil type, that factor specifically can influence the rate of degradation of the bone surface and therefore the cutmark's appearance and longevity.

A greater amount of research is needed to fully support the proposed hypotheses in a larger, more national scale, so that the environment the skeletal remains (both juvenile and adult) that are found in can be investigated. Then based on the 'destructive potential', one can determine whether or not the damage to the bone surface as well as the measurements from the cutmarks, accurately reflect the length of deposition as well as whether the wound can be matched to a suspected weapon.

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Appendix:

The Appendix is a digital appendix located on the attached USBs to the Hard Copy, it comprises of nine sections (A-I) which are briefly outlined below:

Section A – Extended Analysis:

- Results Extended Analysis Moulds
- Extended Analysis of Environmental Variables

Section B – Ethics, COSHH and Risk:

- Ethics and Risk Assessments

Section C – Force and Temperature Model Extra Information

- Diurnal Temperature Variation Model
- Velocity Inflictor Model (CID)

Section D – Statistical Analysis Results Documents:

- Control and Main Value Comparison Tests
- Normality, Significance and Correlation Tests for Environmental Variables

Section E – Excel Documents and Data:

- Environmental Variable Excel Results
- Intraobservor Error Calculations
- Physical Change to Cutmark Observations
- Weather Data METOffice Raw
- Width Measurement Cutmark Documents

Section F – Specimen Sheets:

- Current Soil Matrix Profiles
- Specimen Cutmark Comparison Sheets

Section G – Photos:

- Confocal Microscopy Photo Results Bordeaux
- Keyence Microscopic Photos of Cutmarks
- Undergraduate Pilot Study Control Photos

Section H – Method Guides:

- ICP Method
- SOILMAN3

Section I – PDF Copy of Thesis:

- Undergraduate Thesis
- MRes Thesis