# THE UNDERSTANDING OF HOW DIFFERENT ENVIRONMENTAL BURIALS MAY AFFECT THE DECOMPOSITION RATE OF HUMAN REMAINS

**by**

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# *Abstract*

Human taphonomy, within a forensic setting, explores the decomposition of human remains. This field has proved highly valuable within the criminal justice system, where some high-profile cases have included Naya Rivera amongst others. However, within a practical setting there are multiple different environments encountered within forensic practice which introduce individual limitations. Of primary concern are burial environments. The purpose of the study was to explore how different burial environments affected the decomposition process. In order to understand this limitation a study was set up whereby pig was used as an analogue for human decomposition with this being placed within seven different burial environments specifically, sand, soil and water *(chapter three),* over a four-week burial period. The study found that the epidermis, adipose, muscle and weight of the meat sample were the primary factors varying during the decomposition process. Where certain environments showed to have an accelerated effect on decomposition *(chapter three).*

To further investigate burial environments, a survey was developed and distributed to various forensic professionals from different regions of the world. Survey responses were used to explore standard methods and techniques for the recovery of human remains within sand, soil and water based burial circumstances *(chapter four)*. The survey was used to understand how different regions of the world experience diverse environments and the difficulties encountered by practitioners. From the responses it was concluded that different regions of the world experience a broad range of environmental factors which need special consideration. Interestingly, there appeared to be inconsistencies of fully developed standard protocols, which will ultimately have numerous implications within forensic investigation.

This thesis aims to address some of these challenges and provide further insight into the effect of burial environments on decomposition rates.

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# 1.0 Introduction

One of the most physically and emotionally demanding roles for forensic professionals is the recovery and identification of human remains (Moran, 2012). Each case regarding the recovery of human remains will have its own range of investigative priorities and environmental challenges (Moran, 2012). To fully understand the process, it is important to outline the different context in which human remains may be buried and how this may aid development of current recovery techniques and methods.

Recovering human remains is not a practice that has been recently introduced. It is however a practice that is getting more exposure in modern culture due to the integration with modern technology and its association with crime investigations (Foltyn, 2008). Recovering human remains not only develops knowledge on human taphonomy the study of the decomposition of human remains, but also expands our understanding of geoscience and contributes to the consideration of environmental circumstances.

Taphonomy is defined as the study of the transition of plant and animal organisms after death (Blau, 2014). The practice was being used to study prehistoric human remains and recovered human remains in a historical context, however the application of human taphonomy quickly developed into studying recent deceased humans as a crucial element of criminal casework (Blau and Ubelaker, 2016). The fascination with human bodies after death can be traced back to Ancient Egypt (Mark and Mark, 2016). Many techniques were developed in this time due to religious beliefs and the cultural ideology of the afterlife; because of this cultural dedication, present day forensic practices have gained substantial knowledge on the preservation and decomposition processes of human remains (Mark and Mark, 2016). In the past, excavation projects aimed at exploring historical landmarks have utilised hands-on practical methods to recover human remains. In 1777, Giuseppe Fiorelli created a technique that would revolutionise the excavation and recovery of historical burial sites (Amery and Curran, 2011). When exploring the historical site of Pompeii, human remains were discovered within layers of rock, ash and stone. Pockets within the ash had created a capsule where human skeletal remains were left untouched surrounded by a body imprint similar to fossil markings upon a stone. Giuseppe instructed the pockets to be filled with a plaster and left to harden. Upon return, the excavators would then chip away at the outer layer of ash to reveal the victim's final posture (Amery and Curran, 2011). Since 1984 archaeologists have developed this technique by using a clear resin, as seen in *figure 1.1* (Sheldon, 2017). An epoxy resin is injected into the void around the victim's bones and left to harden. This creates a transparent cast which allowed close details such as hairstyles and facial features to be observed.

*Figure 1.1: Resin Cast of the Lady of Oplontis (Sheldon, 2017)*

Religious beliefs and respect of the deceased was a key purpose for Egyptians developing mummification techniques. It was understood that preserving the human body was a "*natural continuation of the journey after death*" (Sheldon, 2017). Some of the oldest documented human remains date back to the fourth millennium BC, however there was no elaborate effort to purposely preserve the body. In this case, the preservation of the remains could be due to the geological and environmental factors such as hot temperatures and dry weather conditions of Egypt's climate. At this time, many deceased citizens were buried without a casket or body coverings in the desert. Due to the climate and conditions, the bodies were preserved, and this changed mummification within Egyptian society (Ikram, 2015).

## 1.1 Buried human remains

In recent years, buried human remains lay within church yards and recognisable cemeteries, however, many lie in unrecognised burial sites due to years of structural development (Richards, 2017). In modern society the connotations of found human remains is commonly linked to criminal investigation and homicide cases, however the reality is that uncovering human remains in the UK is a frequent occurrence due the mass population the country has held. According to the Basic Overview for the Recovery of Human Remains from Sites Under Development (Ossafreelance, 2004), the discovery of human remains on an undergoing development site is common and if human remains are uncovered then all work will be stopped immediately, and the police will be informed. A representative from the coroner's office, forensic osteoarchaeologists and experienced excavators will attend the site and

confirm if the remains are modern or archaeological (OssaFreelance, 2004). Osteoarchaeologists will then be able to implement the necessary procedures. When excavating, basic principles apply in all archaeological contexts, and these are outlined by the Advisory Panel on the Archaeology of Burials in England (APABE) and the British Association for Biological Anthropology and Osteoarchaeology (BABAO) (OssaFreelance, 2004). Due to ethical considerations, handling human remains requires specific knowledge and training that would not apply to other archaeological disciplines.

Within a forensic setting, searching for clandestine graves, defined as an unrecorded burial (Pringle, Jervis, Cassella and Cassidy, 2008) requires the experience and knowledge from various professionals across multiple disciplines to develop a search strategy. However, using a multi-disciplinary search team introduces new methods and techniques to the investigation which would typically be used in their individual disciplines. Methods used in searches include various scanning applications, remote sensing which uses oblique aerial photography and thermal colour imagery to scan the search areas (Salsarola et al., 2015). Common and well publicized police scanning methods such as cadaver search dogs and mass foot searches are also applied in the early stages of the investigation (Komar, 1999).

A common search method within forensic investigation is Ground Penetrating Radar (GPR), a non-invasive technique which uses electromagnetic pulses that reflect and refract signals to produce 3D images. The method requires the electromagnetic signal to reflected off buried interfaces and structures at various depths, *figure 1.2,* so the returning signal can be subsequently detected by a receiver antenna at the surface of the search area (Salsarola et al., 2015).

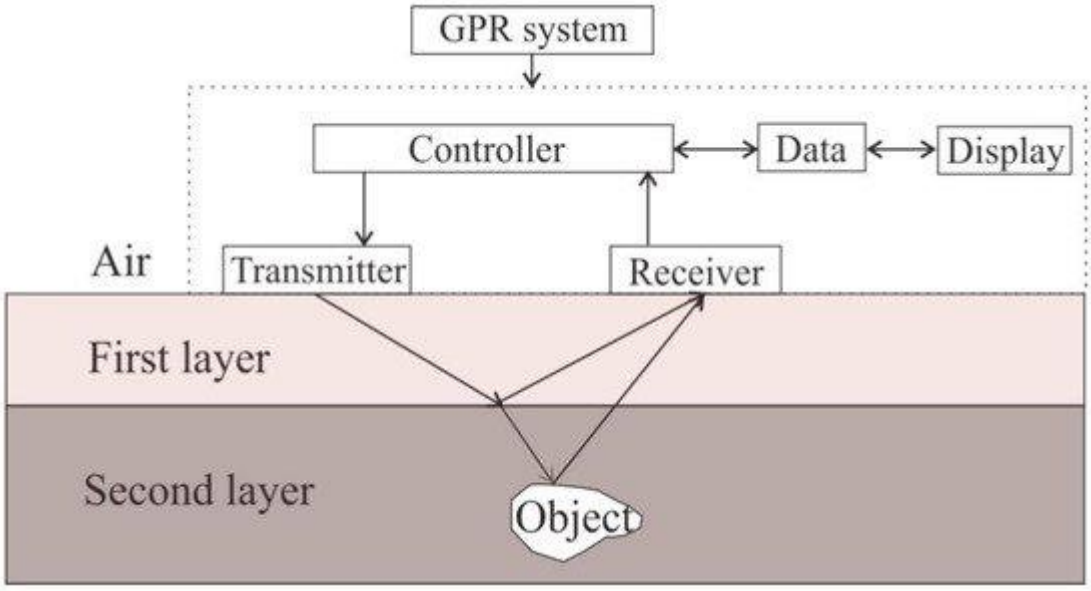



*Figure 1.2: Simplified figure of how a GPR system operates (Wang et al., 2019)*

Famously, GPR was used during the Greyfriars Project (2012) to distinguish the burial site of Richard III. Three documented search areas were examined using GPR, the data recorded was then used to decide which of the areas to excavate, ultimately leading to the discovery of the remains of Richard III and the lost friary (Mirza, 2014).

Multiple studies which used GPR within a forensic setting led to an initial standardisation of data collected under different conditions (France et al., 1992). It was concluded that environmental conditions can be a mitigating factor on the success of using GPR. The signal loses less energy in sandy dry soils, therefore it can penetrate to greater depths, in comparison to denser terrains which absorb more energy (France et al., 1992). It was also found that soils rich in rocks and stones frequently caused false positive readings (Pringle et al., 2012). Humidity can also contribute to the absorption of the electromagnetic signal which can limit the transition of energy, therefore hindering the identification of targets within the soil (Schultz, 2007). When searching for human remains within clandestine burials it was found in Schultz's study (2007) that GPR does have limitations, several variables contribute to the detection of anomalies in the signal recorded by the receiving antenna. The presence of a corpse, soil modifications induced by excavation, presence of fabric and synthetic materials can all lead to signal anomalies (Schultz, 2007). The burial of homicide victims in sand based clandestine graves, such as beaches and coastal environments, is less frequent when compared to other terrestrial environments consequently there are limited publications and literature relating to the recovery of coastal clandestine burials (Saye and Pye, 2004). Common forensic practice of sand-based searches includes both conventional investigative methods such as 'site walk overs', the use of cadaver search dogs (Lasseter, Jacobi, Farley and Hensel, 2003), and geo-forensic search methods. Like soil-based burials, geo-forensic and geophysical methods include electrical resistivity surveys and electromagnetic surveys (Ruffell and McKinley, 2008).

When a burial site has been located, excavation techniques and methods are carefully considered, and a procedure can be developed. Complications can occur if the human remains have skeletonized (Dupras, Schultz, Wheeler and Williams, 2011). This can lead to technically challenging excavation procedures, due to the many factors surrounding skeletal remains. To have a successful and safe excavation in these circumstances, it is crucial that archaeologists and all the members involved are aware of the number of bones to expect per person. However, it may be hard to determine which bones belong to which person if the burial site is multi-occupied or a mass grave. Recovery of the skeletal remains can be affected by different factors such as soil conditions, degree of previous disturbance, and the completeness of skeleton (Gareth-Jones and Harris, 1998). If there is advanced

decay within the bones it might not be possible to excavate them intact, therefore it is essential that the preservation state is documented, as seen in *figure 1.3*. The preservation state can be recorded in many ways on different platforms. Measured drawings, digital scanning, photographs, positioning systems and detailed written records are all methods in ensuring the entire site is documented as accurately as possible (Dupras, Schultz, Wheeler and Williams, 2011).


*Figure 1.3: Archaeologist documenting and recording the human remains found at the excavation of Priory Close, Northallerton, North Yorkshire (Randerson et al., 2015)*

Within modern day excavations, human skeletal remains are subject to many technological examinations. An example of this is radiocarbon dating which is the analysis of isotopes incorporated into bone and teeth. This analysis method can be used to build a character profile which can contribute to historical findings (Richards, 2017). Within a forensic investigation setting, radiocarbon dating analysis can be used to create an ante-mortem profile for the victim. Facial reconstruction techniques are also often used on skeletal remains for both investigative and historical disciplines (Saunders, 2002). Radiocarbon dating and facial reconstruction were both used within the Greyfriars Project. Both analytical techniques were used to collect historical data to create a facial profile for Richard III. Within

a forensic setting, facial reconstruction is a crucial tool when creating a profile for missing persons and for claiming identity of the victim.

An important consideration within the recovery of human remains is determining the post-mortem interval (PMI) or, in other words, estimating the time since death (Vass, 2011). Determination of postmortem interval relies upon knowledge of the stages of human decomposition, these can be divided into several predictable and distinctive stages which are: fresh, bloated, decay, post-decay, and dry/skeletal. Research has been carried out to define each stage and has also tried to approximate the length of each of these stages, however due to the multiple mitigating factors that affect the rate of decomposition this outcome cannot be standardized (Dautartas, 2009). Galloway (1989) suggested that a body is considered "fresh" within the first 24 hours to 48 hours after death. After this, the body moves into the "decomposed" stage and finally into the "dry" stage.

The fresh stage begins instantly from the moment of death, as the heart stops beating the cells in the body are deprived of oxygen and pH changes then start to occur (Costandi, 2015). The structural integrity of the cells begins to break down and cellular enzymes are released leading to autolysis (Love and Marks, 2003). The internal bacteria within the gastrointestinal tract then begins to digest soft tissues from the organs (Percival, 2009), early post-mortem indicators; livor mortis, rigor mortis and algor mortis may begin to occur during this stage.

The bloated stage of decomposition includes the first visible signs of decay. A build-up of various gases produced by bacteria inflames the abdomen. Bloating can also be visible around the tongue and eyes due to gases causing them to protrude (Vass and Barshick, 2001). During the bloated stage the skin will discolour, and some areas may create a marble effect (Love and Marks, 2003). This stage of decomposition is primarily affected by environmental conditions namely, moisture, temperature and various bacteria can alter the duration of this stage (Janaway, 1996). When the bloated areas deflate and internal gases are released, the tissues begin to break down giving the body a wet appearance with a potent odour (Percival, 2009). It has been observed that various compounds can contribute to the odour (Gill-King, 1997) including a variety of sulphur-containing compounds which attract a range of insects (Costandi, 2015).

The fluids then drain from the corpse through the orifices, particularly the nose and mouth. Once the bloating decreases, initial skeletonization begins and the remaining soft tissue continues to deteriorate, this is the stage where skin slippage will also start to occur (Love and Marks, 2003). Internal tissue starts to become increasingly exposed to the surrounding environment which allows oxygen to enter, increasing the aerobic bacterial activity which consequently accelerates the decomposition of the remaining tissue (Rodriguez and Bass, 1983). The final stage of decomposition is the dry stage, also

known as skeletonization, this process may have very little remaining muscle, and skeletonization is apparent over the entire body (Rodriguez and Bass, 1983). At this stage, the determination of time since death can be difficult due to the bone preservation which alters and depends on multiple environmental circumstances, such as scavenging and burial environment. However, recovered bones can be used in the identification process to identify sex, height and characteristics as mentioned previously.

A large variance of factors can affect each stage of the decomposition process, some may accelerate or prolong the process. The most frequently studied variables are temperature, moisture, entomological activity, exposure to elements and burial conditions. Temperature can accelerate or prolong decomposition rates, with research showing that warmer temperature will promote decay whilst colder conditions will delay decomposition (Smith, 1984). Bacterial activity increases in warmer climates which contributes to higher rates of decomposition (Micozzi, 1997). Surrounding ecological matter like plants and shading can also affect the entomological activity thus rapidly affecting the decomposition rate. However, extremely high temperatures can stop bacterial growth and replication (Micozzi, 1997). Freezing cold temperatures can severely slow down the rate of decomposition due to the lack of entomological activity with the cold acting as a preservation agent (Micozzi, 1997). A moisture rich environment can accelerate the rate of decomposition in comparison to dry, arid conditions (Smith, 1984). Mant (1987) showed that dry soil with good drainage had been conductive to mummification. This is due to a combination of heat and dehydration of the body.

Decomposition can also be affected by the personal physical conditions of an individual (Stuart, 2003). It is observed that obesity and body mass index can play a role in the rate of decomposition (Sutherland, 2008). A study was conducted by Sutherland (2008) where piglets where buried and left to decompose and compared against adult pigs. The study concluded that body mass index does play a role in the formation of adipocere, a form of arrested decay of postmorterm soft tissue (Ubelaker and Zarenko, 2011), and ultimately the rate of decomposition, with smaller pigs decomposing more rapidly that larger pigs.

The purpose of studying various mitigating factors within the rate of decomposition is to accurately and precisely predict a post-mortem interval (Dautartas, 2009). Accumulated degree days (ADD) are used as a standardized unit to measure PMI, where the principle behind this method is the relationship between temperature and development (Anderson, 2000). ADD is calculated by taking the highest and lowest temperature of the day to find the average then finding a summation of each consecutive day. It takes approximately one thousand two hundred and eighty-five accumulated degree days to complete full decomposition (Miller, 2002).

Post-mortem intervals can be determined by using common indicators which are present in the early stages of decomposition, indicators include algor mortis, livor mortis and rigor mortis. Algor mortis occurs when the body starts to cool after death. After death the accumulation of blood, which is no longer circulating, leads to drainage and gravitational pooling which creates visible red and purple areas on the skin causing lividity (Kaatsch et al., 1994). Livor mortis begins within an hour post-mortem and can take up to eight hours to fully complete, however the process can be affected by other variables (Baden and Hennessee, 1989). If the body is moved after the eight-hour time period, the lividity is fixed, and the visible red and purple areas will continue to be visible (Dautartas, 2009). This can be useful for estimating PMI but also for suggesting if the body has been moved from its primary placement (Perper, 1993). The common and well-known process of rigor mortis can also be used to estimate time since death. Rigor mortis is the stiffening of muscles in the body, occurring around two to four hours after death. The process is fully developed between six and twelve hours then after twenty-four hours to thirty-six hours the muscles will begin to relax again (Janaway, 1996). Stiffness is caused when adenosine triphosphate (ATP) is no longer created, as ATP causes relaxation of the muscles, lack of the substance causes the whole body to become stiff. As the variation in the duration of rigor mortis is only very slight, it is useful for medical examiners to determine an accurate time since death (Dautartas, 2009).

Entomological activity is also used as a PMI indicator, there has been a plethora of forensic entomology research where medical and criminal professionals noted that the life cycle of certain species of insects could be used to predict a timeline of death (Greenberg and Kunich, 2002). It is widely accepted that an accurate determination of PMI can be achieved by correctly identifying insects and determining their life cycle stage (Dautartas, 2009). Knowledge of other species such as blowflies, lice, cockroaches and their behaviour can also lead to a more accurate time of since death estimation (Haskell et al., 1997).

The development of technology and facilities has allowed researchers to critically analyse the entomological processes which occurs with the decomposition of human remains. When the body starts to decompose, any bacteria present in the gastrointestinal tract destroy any soft tissue this then produces liquids and gases. Hydrogen sulphide, carbon dioxide and methane are then emitted, these create volatile molecules called apeneumones which have been shown to modify the insect behaviour (LeBlanc, et al 2010). According to studies conducted in 1950 by Ashworth, it was found that sulphur bases compounds were responsible for initially attracting flies to the decomposing carcass, but it was ammonium rich compounds that induced the flies to lay eggs (Ashworth, et al., 1994).

Estimating an accurate post-mortem interval requires the age of the larvae to be determined, as mentioned previously. This is completed by measuring the length and dry weight of the oldest larvae

(Joseph et al., 2011). Another significant application of forensic entomology is to determine whether a body has been moved after death. It is reported that there is a difference in the species of insects involved in the process of decomposition of a human body depending on the environment the body has been left to decompose (Chen, Hung and Shiao, 2004). Therefore, if there is evidence of a species playing a role in decomposing the body that would not belong in the environment where the body is located, this could indicate that the body has been moved from a crime scene or place of death (Chen, Hung and Shiao, 2004).

An example of this was highlighted in the case of Leanne Tieran (2001). Tieran had been missing since November 2000 when her remains were discovered in a wooded area in August 2001 (Herbert, 2020). When the remains were found, pathologists examined the body and stated that the body had not been buried in the woodlands since her disappearance (Dennis, 2002). The decomposition of her body was not in the stage of decay as what would be expected in a soil burial and her body had been moved to the area a long period of time after her death (Dennis, 2002). It was concluded that her body had been frozen and stored at low temperatures for seven months before it was deposited in the wooded area nine months after her disappearance (Dennis, 2002).

Soil is composed of both mineral and organic matter which is obtained from the decay of plant residue, entomological organisms, animal remains and microbial tissues (Junger 1996). Air, water, and gas obtained from the atmosphere also contributes to 20-30% of soil composition (Junger 1996). There are many physical and descriptive characteristics of soil including colour, density, settling time, size gradient, microscopy, pH and conductivity (Dudley, 1976). Like all disciplines, there are limitations within soil science research. Soil composition can change across different landscapes and differ between different layers within the soil. Because of this, soil samples taken at the surface will have a different composition than deeper layered soil (Dawson & Hiller 2010). The analysis of organic matter is extremely complex because of the vast diversity and variables soil samples can contain.

Soil science within a forensic setting is of importance as forensic investigations. Soil science has been successful employed in a range of investigations (Dawson & Hiller 2010). Rape and murder cases rely on trace evidence to place a suspect at a crime scene. Soil on a suspect's personal item such as footwear, clothing, tools, and vehicles can all be used to place the suspect at the scene of the crime. Forensic soil analysis would also investigate affecting factors which match the case, such as broken glass, human hair, and paint fragments (Dudley, 1976).

The value of studying human remains and the process of decomposition is important in forensic investigation. However, within the UK there are no facilities that carry out human taphonomy research, therefore researchers must use animal cadavers to represent human remains within forensic research.

There are several factors that are shared between humans and pigs these include various anatomic and physiological traits. Organ placement, the size and function of multiple organs, skin similarities and some disease progression are similar between humans and pigs (Graves, 2017). The intestinal flora, hair follicles and sweat glands have all been observed to be similar to humans, therefore it is widely accepted that pigs can be used as models within many scientific disciplines (Nielsen et al., 2014). The greatest dissimilarity between pigs and humans are the bones as these have a different microstructure (Harasanyi, 1993). Physical differences such as limbs are proportionately smaller than human limbs and their skeletons have adapted to a quadrupedal stance. There are limitations and advantages of using pig cadavers to stimulate humans, a large advantage is that pig carcasses can be very cost effective and easily accessible. Therefore, it is common that studies using pigs have a large sample selection meaning that the data is more accurate (Matuszewski et al., 2019). As the pigs being used in the studies are bred for consumption, it has a smaller ethical consideration as there is no living participation (Festing and Wilkinson, 2007). However, in recent years there has been a cultural change in the view of animal testing, therefore studies using animal carcasses may have to go through further ethical evaluation. The obvious limitation of using pigs is that these are not identical to humans, therefore any conclusions drawn from these studies may not be the same when applied to human decomposition (Schotsmans et al., 2012). Pigs do not share the same living conditions or lifestyle as humans therefore, humans are the preferred subject when studying forensic taphonomy as the current techniques to estimate the time of death do not consider these variables and therefore the post-mortem interval estimation can be deemed as subjective (Zhou and Byard, 2011). Pig cadavers have contributed to many science disciplines, Schotman's study (2008) highlighted the criminal uses of hydrated lime and quicklime on buried remains, due to the criminal ideology that lime products mask the smell of decay and speeds up the decomposition process. This ideology is the same principle as the Egyptian technique of using resin and oil to mask the smell of decomposing tissue to limit entomological activity (Schotsmans et al., 2012). The study used pig analogues to simulate buried remains covered in hydrated and quicklime, it was concluded that lime slows down the rate of decomposition within a buried environment (Schotsmans et al., 2012).

Studies that do not use pigs as human analogues are carried out in Human Taphonomy Facilities (HTF). The research is conducted on donated human bodies, commonly termed cadavers, these are then placed under numerous controlled conditions (Williams, Rogers and Cassella, 2019). The post-mortem changes are then monitored and documented to contribute to forensic and biological services. The rate of decomposition is affected by various factors, mentioned in William's study (2019); temperature,

humidity, soil conditions, insects, cause of death, body mass, burial conditions such as coverings and clothing were the main affecting factors. Vass (2002) conducted a study of the chemical composition of decomposing remains, the aim of the research was to develop 'biomarkers' to determine the post-mortem interval (PMI). The study consisted of human bodies decomposing in a human taphonomy facility (HTF) over the course of four years, tissue samples were then collected and analysed for amino acids and neurotransmitters. The biomarkers were then matched and compared until a time since death could be estimated, thereby ensuring a scientifically accurate PMI (Dautartas, 2009).

In 2008, a study was conducted by Dautartas (2009) at the Anthropological Research Facility at the University of Tennessee on how different human coverings could affect the rate of decomposition. Six fresh human cadavers were used in the study; two were covered in plastic tarpaulin, two were covered in cotton thermal blankets and the remaining two cadavers were left uncovered to represent a control. The study concluded that the uncovered bodies where the first to show signs of decomposition due to entomological activity, however this was delayed in the uncovered bodies which were exposed to increased sunlight (Dautartas, 2009). This study highlights the importance of studying wrapped human remains as these conditions are extremely frequent within real life cases. In the case of Leanne Tiernan (2001), Tiernan's body was found wrapped in green plastic bags, with a black bag covering her head. The body was then wrapped again within a duvet cover and tied with twine (Dennis 2002).

## 1.2 Human remains within aqueous environments

Understanding how burial conditions, including burial water, may affect the decomposition process is fundamental for successful investigation. The process of decomposition of human remains submerged in water is generally slower compared to land deposition sites, this could be due to the colder surrounding temperatures and the lack of common entomological activity. When comparing water environments, saltwater decomposition is at a slower rate than fresh water, this could be due to fresh water being absorbed in the circulatory system causing organs to swell. Saltwater draws fluids out of the blood and the salt content has shown to slow down the bacterial activity (Heaton, Lagden, Moffatt and Simmons, 2010). The decomposition of human remains in a marine setting also have various factors that can affect the process (Ellingham, Perich and Tidball-Binz, 2017). Current and wave action can damage and weaken the soft tissue connection of the joints, on the upper limbs the first to disarticulate are the wrist joints followed by elbow and shoulder joints (Haglund, 1993). The jawbone is also frequently observed to disarticulate. However, joints and connecting soft tissue can be preserved by the presence of clothing or wrapping. Cloth and netting are the usual preferred concealment when

depositing victims, as plastic wrapping can trap air which can allow object to float, wrapping can also restrict abdominal bloating which reduces the chances of the body resurfacing.

*Figure 1.4* shows a human body which has been submerged for 70 days, where the joints are disconnected and the wrist and elbows are still intact, yet the mandible (jawbone) has been disarticulated. The rate of decomposition is affected if the remains are in an enclosed environment or if left exposed to scavengers. If enclosed, adipocere is frequently observed (Ellingham, Perich and Tidball-Binz, 2017). Adipocere is formed by lipid and tissue fat which decomposes into a wax, cast-like texture, meaning that the body is encased in the substance and can be preserved and remain unchanged for long periods of time (Kahana et al., 1999). It was reported that adipocere developed as early as thirty-eight days post submergence on the human remains recovered from an East China sea shipwreck (Kahana et al., 1999).

*Figure 1.4: Human body after 70 days of submersion (Ellingham, 2017)*

A study in 2002 monitored the decomposition process at various depths of the Pacific Ocean using pig carcasses as human analogues. At the shallow depths, 7.5 m and 15.2 m 50% of the carcasses were floating (Hobischak and Anderson, 2002). The carcasses which were placed in water of 94 – 99 m depth sank immediately. Fourteen days later the carcasses were partially skeletonized, this could have been due to scavenger activity. However, the researchers noted that when oxygen levels had dropped to hypoxic levels of below 2.0 mL/L there was no scavenger activity and the carcasses where left intact. Carcasses placed at a 300 m depth were immediately consumed by lysianassid amphipods, the species first consumed the internal organs then the skin which consequently skeletonized the carcase within four days (Hobischak and Anderson, 2002). Scavenging appears to be more common on the skeletal

remains of submerged bodies, *galathea* (squat lobsters) and other shellfish have been photographed gnawing on bone as seen in *figure 1.5* (Schuliar et al., 2014).

*Figure 1.5: Galatheae scavenger marks on a femur bone. (Ellingham 2017)*

Over the recent years the number of human lives lost at sea has risen dramatically (Cattaneo et al., 2015). Therefore, there is an increase in human remains that need to be recovered and identified. Between 1988 and 2013 14,309 people were reported to have lost their lives in an attempt to cross the Mediterranean Sea, (Kovras and Robins, 2016). In 2014 and 2015 the combined number of recorded fatalities was 7191 and this number is suspected to be higher due to many victims not being recovered or identified (Kovras and Robins, 2016). Mass disasters also contribute to the death toll on maritime forensics. The sinking of MS Spice Islander I killed 1500 people in 2011, the crash of Air France flight 447 in 2009 took 228 lives and the sinking of Sewol ferry in 2014 which caused 304 fatalities are all examples of mass disasters in which the victims' bodies were left to decompose within a large body of water (Ellingham, Perich and Tidball-Binz, 2017). For identification purposes, human remains are bagged in a consistent manner under the water to eliminate the loss of physical evidence (Winskog, 2011). The area surrounding the remains is thoroughly examined and documented, including the recovery depth in case any future diving to the area is needed for investigation (Winskog, 2011).

The recovery of human remains from deep sea environments, remote operated vehicles (ROV) equipped with colour video cameras are used (Dumser and Türkay, 2008). The camera footage is then viewed by forensic practitioners to develop a safe and effective recovery plan. When diving is required for recovery, the divers have specific cadaver handling training. The training includes how to recognize human tissue in different states of preservation in order to avoid or minimise damaging the remains and not expose the divers to any form of biological hazard (Winskog, 2011). During the recovery, the psychological impact on the divers is also taken into consideration and a psychologist is on board at all times to support the recovery crew.

In extreme deep-sea recoveries, bagging of the remains cannot be done manually, therefore remote operating vehicles (ROVs) can be equipped with robotic arms to do this procedure via visual control, *figure 1.6*. Intact jointed remains are collected and placed into a metal container; smaller body fragments are placed individually into the container. Winskog (2011), stated that around 60% of maritime disasters are identified through odontology based on availability ante mortem data. Highly preserved remains can be sampled for DNA analysis if the soft tissue is still intact, however DNA can still be extracted from skeletal remains (Holmlund et al., 2008).

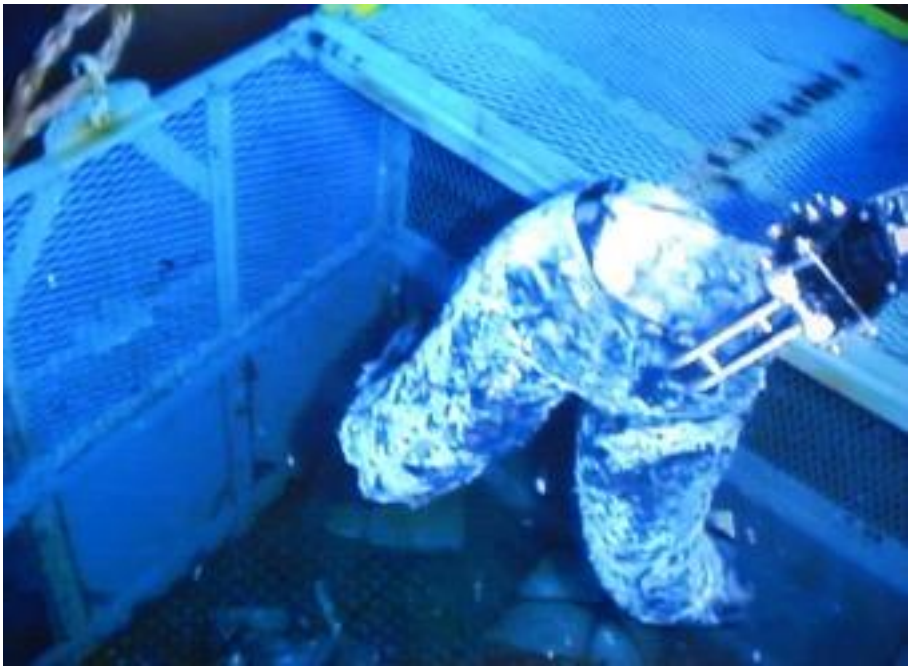


*Figure 1.6: ROV robotic arm recovering human remains. (Ellingham 2017)*

Modern policing and investigation methods into these cases involve creating a theoretical model of water body using pre-existing records (Beres & Haeni 1991). The rate of turbulence within water is important in understanding the hydrology of the search. To locate a body submerged in water, it is vital to understand that the body has potential to be transported considerable distances from the original deposition site (Bassett & Manhein 2002). Ocean current records and water circulation maps have also been replicated for many open water environments, these are used for predicting fish migration, oil spill movement and analysis. Mapping can also aid in the estimation of travel patterns for certain objects. The same model is used within forensic investigation to investigate missing persons either due to homicides or suicides (Ruffell & Mckinely 2015). The World Health Organization (WHO) reports that drowning is the third leading cause of unintentional fatality worldwide, reporting more than 370,000 deaths annually.

## 1.3 Project Aims

The study of decomposition has been frequently studied to contribute knowledge and theories to a wide range of scientific disciplines including medicine, health, biological and environmental science. However, the forensic application of this research has not been examined in great depth, nor the special considerations which need to be given to this evidential type. Or how these environmental factors may affect forensic procedures such as recovery and identification methods particularly given the variable environments encountered within this field. A summarised, there are various factors affecting PMI estimation, however there is a lack of standard consistency throughout the different fields, this in turn can have significant effects upon a criminal investigation. Research within the UK is also limited due to the legal restrictions on the use of human remains for forensic taphonomy research. The UK has no body farms; facilities that utilise human remains for forensic research. Because of this, research regarding decomposition utilises animal cadavers as human analogues. This causes limitations within forensic research as human decomposition under different burial conditions and circumstances cannot be fully understood or observed.

The aims of this research are to investigate decomposition in environments routinely encountered within forensic investigation, namely soil, sand and water using porcine as an analogue to human. Additionally, the research aims to probe procedural knowledge from expert practitioners to gain an understanding of differences in standard operating procedures, to determine if these are fit for purpose.

# *2.0* Methodology Introduction

## *2.1.* Materials for environmental decomposition

The environments selected for the experiment were those that are frequently used as deposition sites. The environments chosen were soil, sand and water. It was important to have a clear representation of these sites to place the project into a forensic setting, therefore three variations of soil and three variations of natural water were used. To keep consistency, all environmental samples were collected in Kent, this therefore represented burial sites within the county.

### *2.1.1.* Soil and Sand

Three variations of soil were chosen for the project, two ground soils and one commercial compost. Commercial sand was also used for the sand based burial environment.

- Soil A was collected from Elham, Kent.
- Soil B was collected from Sittingbourne, Kent.
- Soil C was commercial compost John Innes No 1.
- Sand was commercial builders' sand.

The soil collection areas were analysed using 'Soilscapes' viewer from the Cranfield Soil and Agri-food Institute (CSAI) created by Cranfield University (Hallett, Sakrabani, Keay and Hannam, 2017), as shown in *figure 2.1*. This was to give a clearer evaluation of the soil collected using a detailed national soil map designed to give ecological information on a given geographical location. Soilscape also provided data on different properties for the soil collected in the selected areas, *see appendix table A.1.*

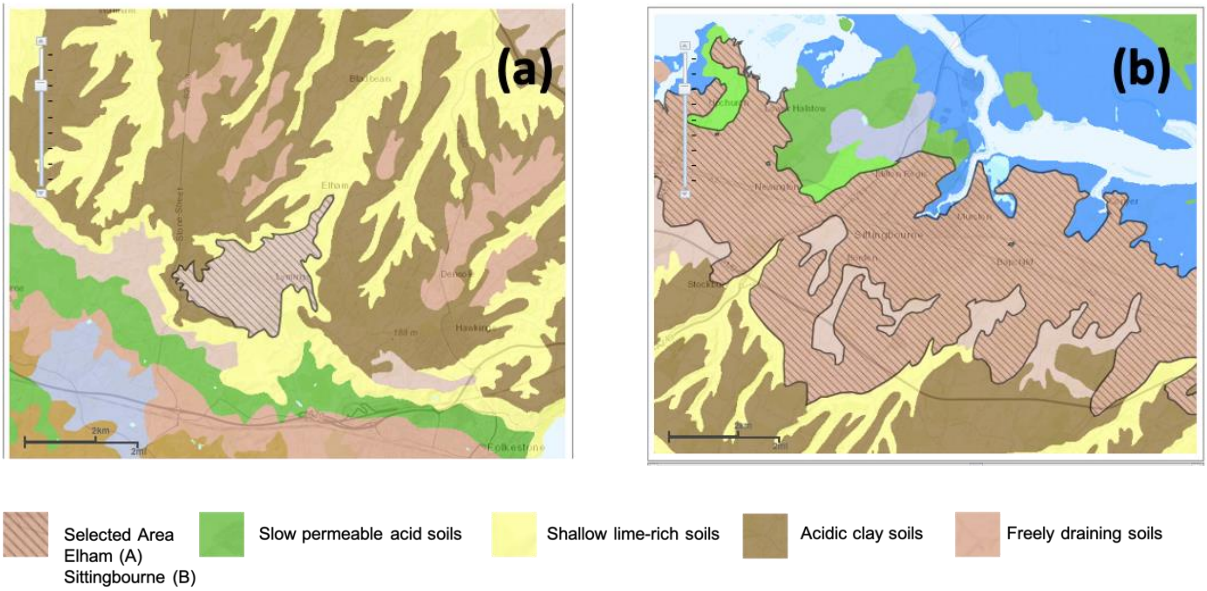



*Figure 2.1: Soilscapes (*Cranfield University, 2020) *map of the collection area of Soil A and B.*

The third soil sample (Soil C) was a commercially available and manufactured compost, John Innes No 1, the compost was chosen to show a clear differential variation of soil. As compost is manmade, its composition is easily accessible and understood. The 'Nutrient Guide' given on the packaging stated that John Innes No 1 has a level 3 – 4 scoring, meaning that the compost provides low- medium level of nutrients to aid with seeding and growth (see *figure 2.1*). This level allows for a more consistent growth medium and improves moisture and nutrient retention. The pH of the compost is measured between pH 6 and pH 7 which is stated as the optimum pH for ensuring a sufficient amount of available nutrients (John Innes potting compost / RHS Gardening, n.d.).

Consisting heavily of loam, compost forms the base of plant nutrition containing essential micro-elements and organic matter which provides nitrogen to plants. Sphanum moss peat and sand is also added to compost to increase the total porosity of the substance and improves the water retention whilst sand allows for excess water drainage to prevent waterlogging. Compound fertilizers are also added into John Innes mixtures: nitrogen, phosphates, and potash are all added into the compost to aid in top growth, root growth and flowering (John Innes potting compost / RHS Gardening, n.d.).

### *2.1.1.1.* Soil collection and pre-treatment

Approximately 12 L of soil from each site was collected for the study. Using a shovel, soil was collected from roughly 25 cm under the surface. This was because the first 20 cm under the surface is topsoil (Stracher, 2019) and as this study was representing the burial of human remains within shallow graves the subsoil layer was used.

The soils, including the commercial compost, were then placed in an enamel 41.5 x 30 x 5 cm roasting tin to be dried. The soils were then placed inside an Heratherm Advanced Protocol Oven at 80°C for 48 hours to eliminate any water and possible entomological activity which could have been active in the soils. Prior to drying the soil, any large stones, plant remains and manmade substances such as pot fragments were removed by hand.

### *2.1.1.2.* Sand collection and pre-treatment

Approximately 15 L of commercial builders' sand was purchased for the study, builders' sand was chosen as collection of beach sand was not possible. As the sand was wet when purchased, within an enamel 41.5 x 30 x 5 cm roasting tin, the sand was placed inside an Heratherm Advanced Protocol Oven at 80 °C for 48 hours to eliminate any water and possible entomological activity which could have been active in the sand.

### *2.1.2.* Water

Water from three different sources were collected to be used for the experiment to represent bodies which are disposed of in aquatic environments and to observe how variables such as salinity, may affect the rate of decomposition.

It was important to collect samples from different bodies of water to consider the variation in characteristics.

- Water A Sea water was collected from Herne Bay, Kent UK which is situated on the south coast of the Thames Estuary flowing into the North Sea.
- Water B Pond water was collected from Canterbury, Kent UK. This source was selected due to the rich layer of algae and plant substance as well as the undisturbed condition of the water.
- Water C Flowing stream water was collected from Lenham, which is part of the river Stour. However, the current of the water was not reproduced within the experiment.

### *2.1.2.1.* Water collection and pre-treatment

15 L of each water variation was collected for the study. The sea water was collected on the shore of Herne Bay using two 10 L buckets and funnelled into three colour coded water carriers. The pond water was taken from the pond side and taken from a depth of approximately 26 cm, the water was then funnelled into the correct coloured water carrier bags. The stream water was collected using the same method as the sea water, it was then funnelled into the correct coloured water carrier. All nine water carriers were transported to the laboratory by car and stored until needed.

### *2.1.3.* Meat preparation

To represent human remains, a pig analogue was used to observe the decomposition within different environments. The cut of pig used in the experiment was boneless pork loin (*figure 2.2*) bought from a butcher. This was chosen as loin has both a high lean meat percentage and fat layers, therefore it was a realistic representation of human remains.

The pork loin weighed 5.5 kg and consisted of both lean meat and fat. The fat appeared as thin layers which ran through the entire cut and was more prominent at the ends of the meat. This was cut into one hundred and thirty pieces each having a weight variation of 30 g-37 g. This was achieved using anti-stab gloves and scalpels. Weight as opposed to volume was used as weight allowed for better control within the experiment. Since muscle is denser than fat, 1 gram of muscle would occupy less space than 1 gram of fat. Therefore, cutting the samples into volumetric units would have produced less consistent samples when compared to samples cut into a ratio of muscle and fat. Once the meat was cut, it was placed into individual ziplock bags and contained in a black sealed plastic box. The box was then stored in a refridgerated storage room. The refridergated room was set to 4$^{o}$C, however due to the communal use of the room there was a fluxation of temperature with the maximum reaching to 6 $^{o}$C.

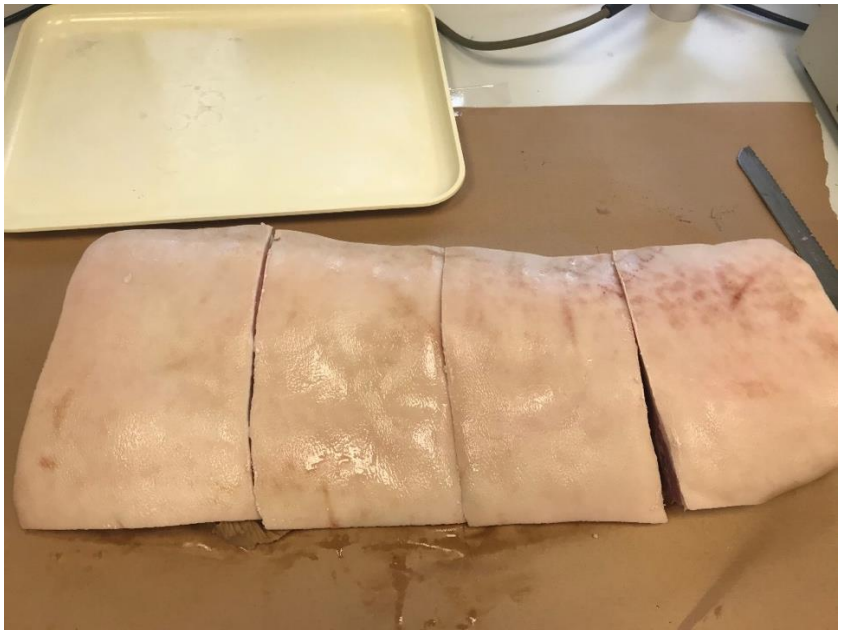


*Figure 2.2: The boneless pork loin used in the project, cut into quarters.*

## 2.2. Methods

This section will highlight the methods and apparatus used for the practical research project. Including where the project took place and the specialised equipment used.

### *2.2.1.* Sample environment

All samples detailed in section 2.1 were housed in a temperature-controlled room, *figure 2.3*. This environment was selected to limit the number of variables such as sunlight exposure, temperature, humidity, and entomological elements.

A temperature of this room was set at 26 °C a week prior to the project start date to observe if there were temperature fluctuations. The temperature did show fluctuations of ± 1 °C and when working inside the temperature control room as the door was left open, consequently this made the temperature drop 2 °C.

*Figure 2.3: Temperature-controlled room used for experiment.*

### *2.2.2.* Sample preparation

To minimize sunlight exposure and replicate burial conditions, red pint cups were used, *for dimensions see figure A.1.* It was important to replicate burial conditions for the aging of samples therefore having red coloured cups eliminated the risk of sunlight being exposed to any of the environment samples and affecting any data.

#### *2.2.2.1.* Soil based sample environments

Red pint cups were filled with 200 g of the selected soil. One piece of meat was placed inside the cup and covered with another 200 g of the same soil therefore representing a full buried piece of remains. Brown paper was then secured on top of the cup using elastic bands and Sellotape to eliminate the risk of spillage and contamination from any other environments. Each cup was then labelled with the correct exhibit number and stored inside the temperature-controlled room.

#### *2.2.2.2.* Sand based sample environments

For the sand samples, the same preparation was taken as the soil samples. The pint cups were filled to 200 g with sand, the meat was then placed inside the cup and covered with another 200 g of sand to

ensure a complete burial of the meat. The cup was then covered using the same technique as the soil samples, labelled with an exhibit number and placed inside the temperature-controlled room.

### *2.2.2.3.* Water based sample environments

For the water samples, red pint cups were filled with 400 ml of the selected water variations. To ensure the structure of the meat was not compromised and damaged by the side or bottom of the cup, the meat was suspended in the water.

The suspension device was created by fixing two wooden tongue depressors into a cross like shape and securing them with elastic bands, see *figure 2.4*. The meat was then cradled within a nylon string structure and connected to the wooden apparatus and placed into the water cup therefore creating a suspension. The cup was then securely sealed with saran wrap, Sellotape, and elastic bands to eliminate the risk of spillage and contamination. The water cups were labelled with the correct exhibit number and stored inside the temperature-controlled room alongside the other exhibits.

*Figure 2.4: Wooden suspension apparatus used for decomposing the meat samples within water environments.*

### *2.2.3.* Exhibit labelling

The exhibit number was creating using a key, representing each environment, the type of environment variation such as saltwater, pond water, compost etc., and the week number, *table 2.1*. The experiment was prepared for sixteen weeks of observational analysis; therefore, one hundred and twelve samples were created as well as twenty-two control samples.

*Table 2.1: Coding system in place to create the sample exhibit numbers. Soil A = Eltham, Soil B = Sittingbourne, Soil C= Compost. Water A' = Sea , Water B' = Pond, Water C' Stream.*

| Environment | Variation | Week Number (1-16) | Exhibit Number |
|---|---|---|---|
| Soil | A | 1 | S A 1 |
| Soil | B | 1 | S B 1 |
| Soil | C | 1 | S C 1 |
| Sand | D | 1 | D 1 |
| Water | A | 1 | W A 1 |
| Water | B | 1 | W B 1 |
| Water | C | 1 | W C 1 |

The core process of the experiment was to take one cup from each individual environment each week, analyse the sample and the discard the sample by autoclave. There were seven environments therefore seven cups were taken out of the temperature-controlled room each week.

### *2.2.4.* Sample recovery

Wearing Personal Protective Equipment (PPE) including gloves and masks, the week appropriate cup was taken out of the temperature control room for examination. Due to the meat decomposing within different environments, the recovery method for each environment had to be adjusted due to the

variation of factors. Weekly sensory observations where recorded which included the odour of the samples, integrity of structure, environmental saturation and any other observational changes. After the laboratory observations were complete, the soils and environments were discarded, and the meat was then autoclaved by technician staff. All samples were photographed weekly using Samtaian portable photographic light box and using a Nikon D3300 camera with a 18.0-55.0 mm lens model. The light box provided high quality LED lighting and 2200 lumens, which made the surroundings three times brighter than ambient light. Additionally, this light box enabled continuity of lighting quality on all the photographs therefore limiting subjectivism.

#### *2.2.4.1.* Sample recovery from soil environments

The meat was removed from the soil and placed within a weighing boat. The soil which surrounded the buried meat was collected into a falcon tube, labelled with an exhibit number, and stored for further analysis. A delicate cleaning process was carried out which included the removal of excess soil and a deep tissue clean using distilled water. The 'deep tissue' clean was the process of removing the hard soils which had saturated into the meat so the colour underneath could be seen. This enabled for clear photographic evidence of decomposition. After cleaning, the meat sample was weighed and then placed onto a piece of a paper which had been previously labelled with an exhibit number ready to be photographed.

#### *2.2.4.2.* Sample recovery from sand environments

Similarly, to soil recovery, when recovering the meat from the sand the meat was placed on a weighing boat whilst the sand which surrounded the meat was collected, labelled and stored in a falcon tube. The meat was then cleaned using distilled water, the cleaning process for the meat recovered from sand had to be much more delicate compared to other environmental samples. This was due to the sharpness and exfoliating characteristics of the sand and to ensure the meat would not get damaged due to harsh cleaning. After the cleaning process the meat was weighed and placed onto a labelled piece of paper ready to be photographed.

#### *2.2.4.3.* Sample recovery from water environments

The meat was placed into a weighing boat and the nylon strings were cut, releasing the meat from the wooden suspension device, *figure 2.5*. Due to the structure of the meat, the sample remained in the

weighing boat to be weighed and photographed. The water which remained in the cup was also photographed then funnelled into a falcon tube to be later be analysed and filtered.

*Figure 2.5: Holly Harrison cutting the meat free from nylon string during water recovery process.*

### *2.2.4.4.* Decomposition grading post recovery

In order to provide quantification data for this current study, factors of decomposition values were calculated for each sample post recovery, then compared within chapter three. The decomposition factors considered for rating were odour, compressibility and weight gain/loss percentage change.

*Table 2.2 shows odour rating criteria*

| Scale | Criteria | Description |
|---|---|---|
| 0 | No smell | No odour present |
| 1 | Fresh meat | Familiar aroma of raw meat, before consumption. |
| 2 | Musty | Aroma from the meat has musk undertones. |
| 3 | Spoiling meat | Odour is unpleasantly pungent. |
| 4 | Foul | Odour is severely unpleasant and fetid. |
| 5 | Extreme odour | Severely unpleasant, unable to remain in room. |

*Table 2.3 shows compressibility rating criteria*

| Scale | Criteria | Description |
|---|---|---|
| 1 | Very easy | Item easily regains shape after pressure removed |
| 2 | Easy | Item shows high compressibility |
| 3 | Medium | Item shows very mild compressibility, |
| 4 | Hard | Item shows very little compressibility |
| 5 | Very hard | Item not possible to compress. |

*Table 2.4 shows weight gain/loss percentage change score criteria*

| Scale | Criteria |
|---|---|
| 0 | No change |
| 1 | 1 – 20 % change |
| 2 | 21 – 30 % change |
| 3 | 31 – 40 % change |
| 4 | 41 – 50 % change |
| 5 | 51 % + change |

## *2.3.* Survey

A survey is a system used to collect information from people to describe, compare or explain knowledge, opinions or behaviour (Fink, 2003). Surveys can consist of numerous types of questions to ensure participants provide relevant responses which can be aid the research objective. Question types include free text questions, also known as open-ended which allow for participants to respond with their own words and opinions. These are also used for questions which may have too many answers to list or where answers cannot be easily interpreted (Online surveys, 2020). Multiple choice questions, whether single or multiple answers are required to be selected, allow participants to easily select their response. Questions where the answers are already given are also easier to analyse and interpret into quantitative data in comparison to free text (open ended) questions which represent more qualitative data. The aim of this research project was to gain knowledge from practitioners . To achieve this, a survey was used to obtain data from different forensic personnel from all different parts of the world.

### *2.3.1.* Survey Medium

The survey used for this study was created using Online Surveys, formerly known as Bristol Online Surveys, which is an online based system that allows researchers to create, build, distribute and analyse surveys (Online surveys, 2020). The data obtained by Online Survey is processed following the security standard ISO27001, in compliance with GDPR (Online surveys, 2020). The system was built for

educational and research institutions with a wide range of question formats, routing and access control options.

### *2.3.2.* Target audience

The target audience for the survey were forensic practitioners/personnel with experience within a large range of investigations and had no limitations on what the practitioner's role was within their forensic discipline as long as it was disclosed. The disclosure of the role was required to gain an understanding of roles throughout the forensic discipline. However, there was a strict participation criterion that highlighted participants must of have experience within investigation and had not suffered from mental health problems due to work environments.

The minimum required number of responses was twenty as this allowed for sufficient analysis and interpretation of the data. As human taphonomy studies and research regarding the affect of burial sites on decomposition is limited, it was important that the responses were of high quality rather than quantity as this allowed for a more in-depth and personal response to the question. Participants were approached using the work based social media platform LinkedIn and potential participants were sent a URL which linked them to the survey.

### *2.3.3.* Ethics

The survey questions were approved by the ethic panel at CCCU prior to approaching potential participants. It is important to adhere to ethical standards within research for numerous reasons, including protection from fabricating, falsifying and misrepresenting research data to illustrate a specific ideology (Resnik, 2015). By adhering to standards when conducting research which includes human participation, ethical approval promotes trust, accountably and shows participants that appropriate polices such as copyright, data sharing and confidentially procedures will be followed (Resnik, 2015).

### *2.3.3.1.* Participant information

Participants were provided with relevant background information for the study, this gave participants chance to decide if their expertise could benefit the study and notified participants what their responses were contributing towards. As mentioned previously, due to the sensitivity of the study and the possible triggers it could cause there was a strict participant criterion implemented. All participants were required to have experience of forensic investigation and not suffered any work-related mental health problems. To follow the necessary GDPR guidelines and in accordance with the Data Protection Act 1998, the survey remained anonymous and all responses were provided with complete confidentiality. The participants were also notified of how the responses they provided would be stored, and who could access their information.

### *2.3.3.2.* Consent

To take part in the survey, participants had to give their consent. To do this, they had to select and agree to all of the consensual statements provided, as seen in *figure 2.6*. The consent page was designed so that a response to the question was marked required, this meant the participant needed to select and agree to all statements before moving onto the next page. Therefore, ensuring complete consensual agreement into taking part within the survey.

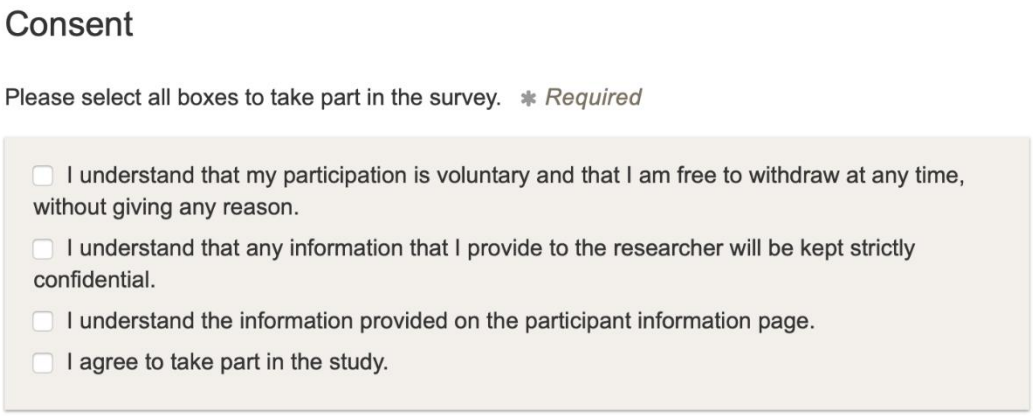



*Figure 2.6: Screenshot of the consent page of the survey.*

### *2.3.4.* Questionnaire design

The survey comprised of both free text and multiple-choice questions, it also displayed one rank/scale question. Free text questions were used to gather as much information from the respondent as possible. The free text questions held a lot of weight within the survey as these responses were being used to build comparisons between different forensic service practices. Because of this, the free text questions were marked as required.

Only one of the survey questions was programmed to be optional, this was to reduce the amount of required free text questions to decrease the risk of participants not completing the survey due to lack of interest. The optional question was also positioned near the end of the survey, and it was more beneficial that the last question was responded to. All other questions were marked required, the survey was programmed so that if a participant did not respond to the question, it would not let them continue to the next page. The question which were marked required held a high value within the survey, and these questions were the sole aim of the study. Therefore, if these questions were made optional and not responded too, then the survey would not be sufficient or effective. For this study the following question types were used, *table 2.5*.

*Table 2.5: Question classifications*

| *Question* | *Question Type* | *Required/Optional* |
|---|---|---|
| 1. Region | Multiple choice (Single answer) | Required |
| 2. Role | Free text | Required |
| 3. Responsibilities | Multiple choice (Multiple answer) | Required |
| 4. Soil based burial | Free text | Required |
| 5. Sand based burial | Free text | Required |
| 6. Water based deposition | Free text | Required |
| 7. Environmental Circumstances | Free text | Required |
| 8. Decomposition factors | Rank/Scale | Required |
| 9. Decomposition factors justification | Free text | Optional |
| 10. Challenges regarding recovery and identification | Free text | Required |

*Question 1: Region*

The participants were asked to select which region they are currently working in or the region they have spent most of their career in, *see figure 2.7.* This was to allow for comparisons of protocols from around the world. By asking what region of the world, it allowed for a more detailed analysis. By selecting a region this also allowed weather, climate and environmental conditions to be individually considered.

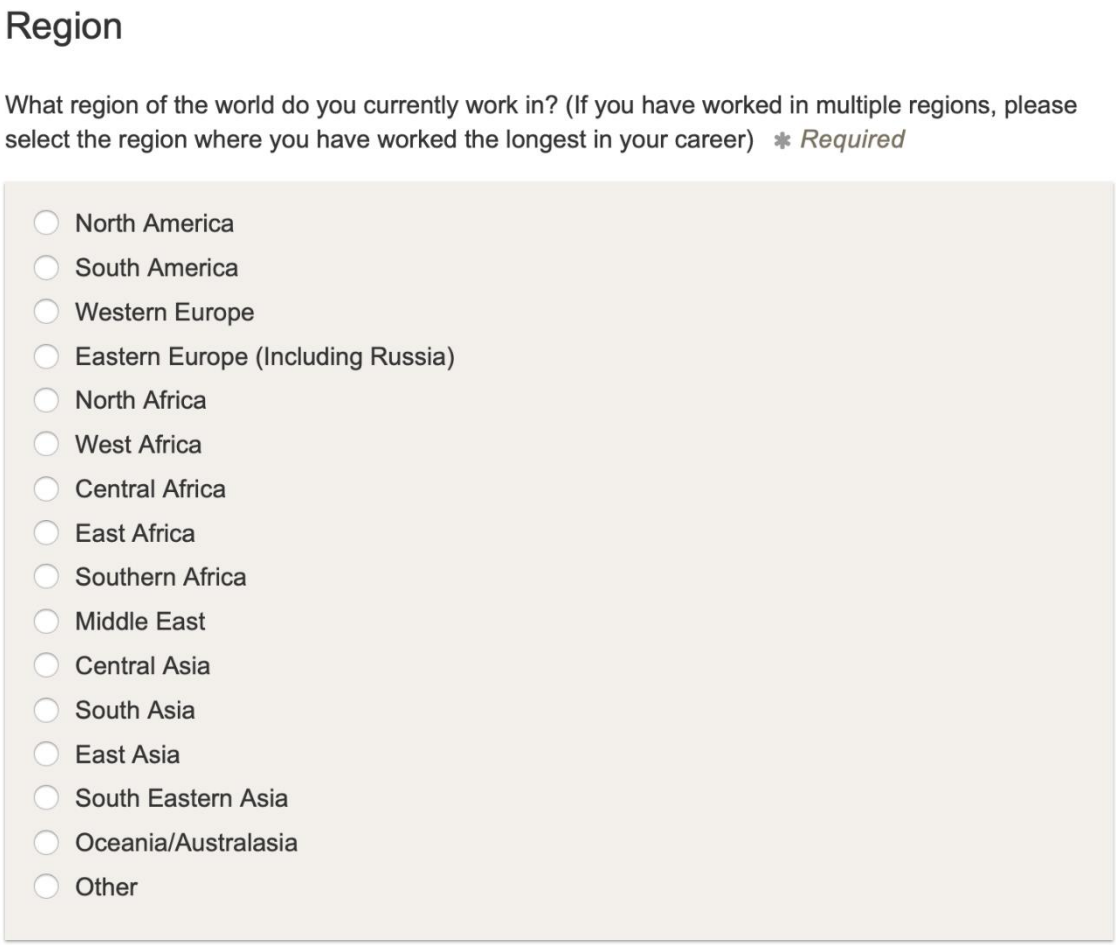



*Figure 2.7: Survey Question one, regarding region.*

*Questions 2 & 3: Role and responsibilities*

Participants were asked to disclose their roles and the responsibilities *see figure 2.8.* This was to compare the roles and responsibilities within different forensic services around the world and to also gather information and opinions from professionals across the forensic field. It was also intended to see what roles are involved within recovery teams and identification teams and if these differed region to region. The responsibilities question was created as a multiple-choice question where the participant could select multiple answers. This was developed by researching various forensic and policing job descriptions. The reason why responsibilities were listed in a multiple-choice question rather than open ended was to get an idea of how similar roles are region to region. There was also an 'other' box provided which when selected opened a free text box, this was included so that participants could enter any other responsibilities they deemed fit to disclose.

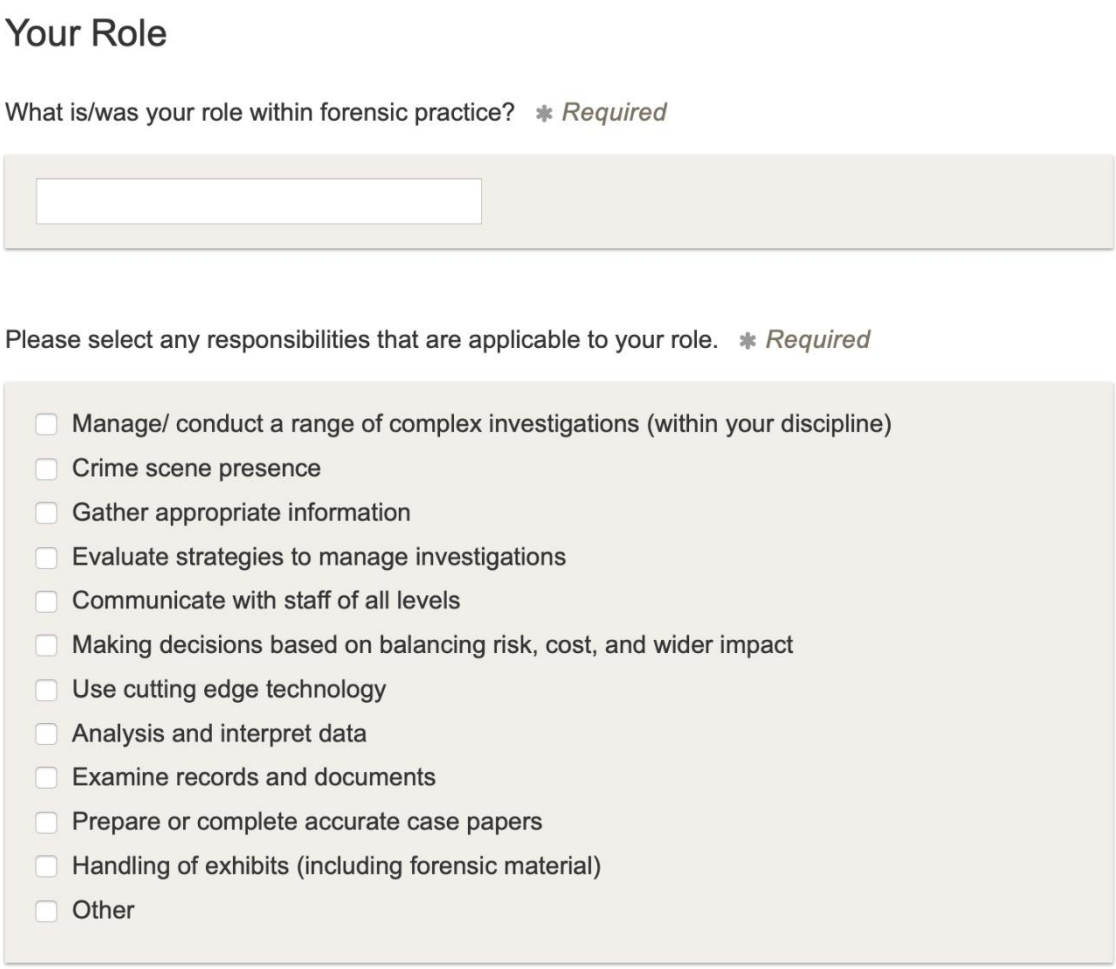



*Figure 2.8: Survey question two and three regarding roles and responsibilities.*

*Questions 4 & 5: Soil and Sand-based burial*

These questions allowed for participants to explain their specific protocols for soil/sand-based burials within their forensic services, *see figures 2.9 and 2.10*. This information allowed for protocols be compared to other similar S.O.P's (Standard Operating Procedures) around the world. By providing this information it then allowed for the comparison of real-world method applications to published literature. It also helped to explain which regions experienced more of sand/soil-based burials and which procedures could be developed in the future. The question had no limitations therefore the participant had free range of how long or short their response could be; however, the question was marked as required therefore a response was compulsory.

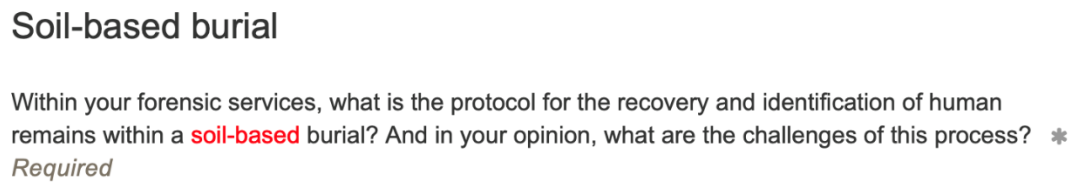



*Figure 2.9: Survey question four regarding soil-based burials.*

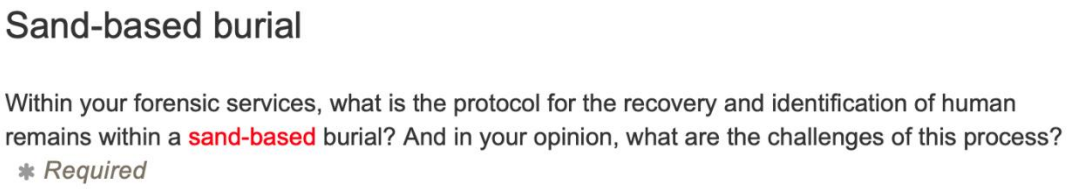



*Figure 2:10: Survey question five regarding sand-based burials.*

*Question 6: Water based deposition*

Participants were asked to explain their protocol for the recovery and identification of human remains within a water-based deposition, *see figure 2.11*. The question also highlighted the use of multi-variations of water, this was to ensure the response was not solely based on one type of water body. It was also important that participants included what water variable they were discussing, so that the response could be compare to other responses discussing the same water variation. Like questions four and five, this question had no text limitations therefore the participant could answer in full detail or however they saw fit. The main reason why this question was programmed as required, was because of the value these responses held. Therefore, it was critical that the question was answered with no limitations as these responses were aimed to be compared with real life cases regarding maritime forensics.

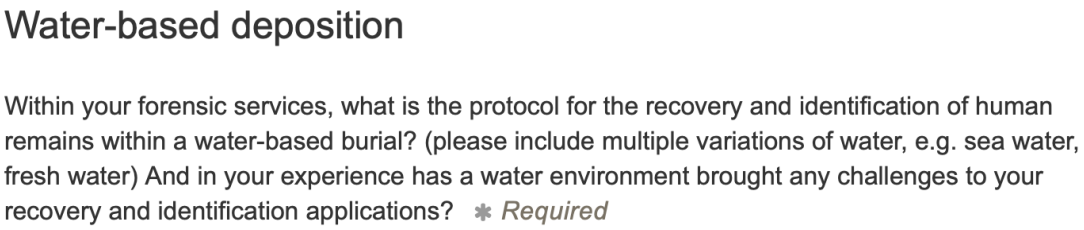



*Figure 2.11: Survey question six regarding water-based deposition.*

*Question 7: Environmental circumstances*

The following question asked the participant, if in their career they have been challenged with an environmental circumstance that has changed their routine protocol, *see figure 2.12.* By using "in your experience" this allowed participants to base their response upon their personal views which allowed for a greater flexibility of responses. This was further supported by the confidentiality and anonymity of the study. The question also highlights examples of environmental circumstances, this was to further highlight the aims of the study and gather intelligence about how environmental conditions can affect forensic investigation. It also helped to understand how different regions react to different climates, and what environmental conditions were common within those regions.

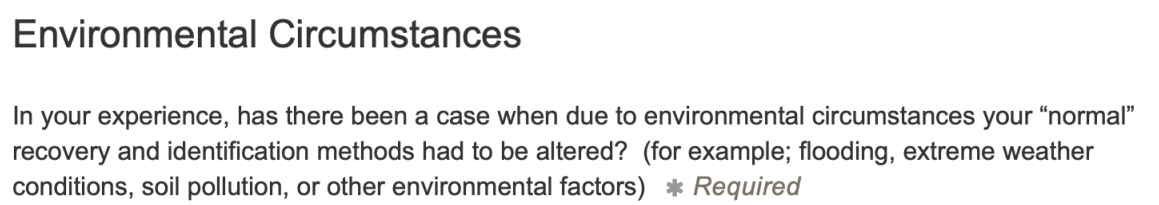
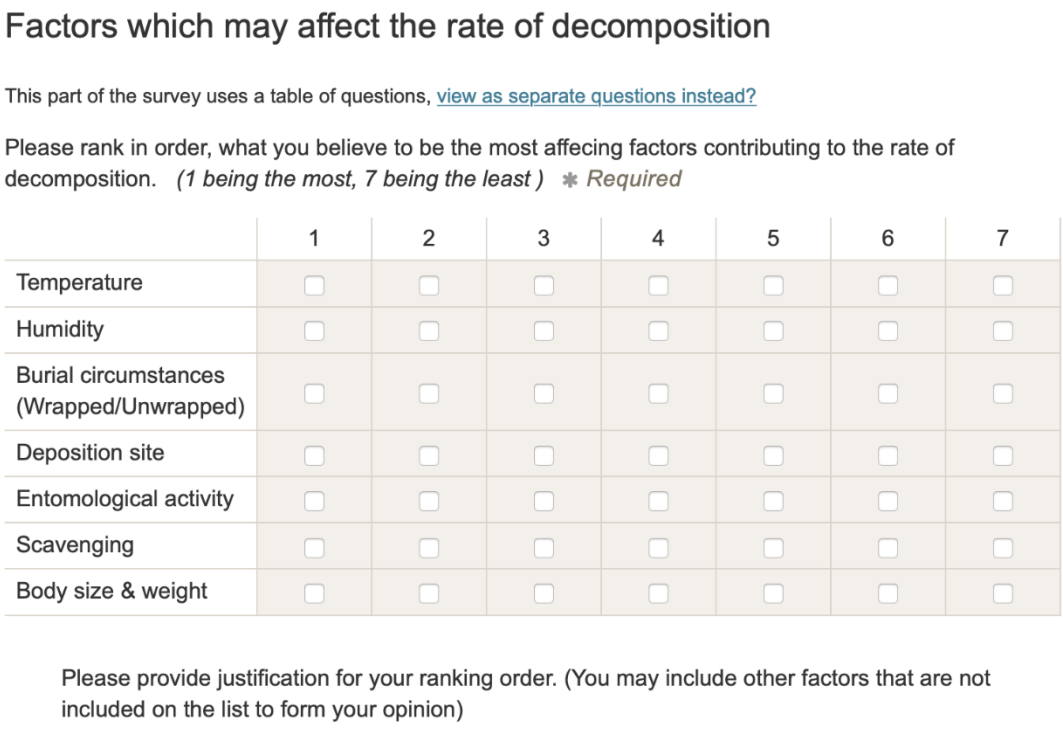



*Figure 2.12: Survey question seven regarding the environmental circumstances which may change protocol.*

*Question 8 and 9: Decomposition factors and justification*

When studying published literature regarding the decomposition of human remains, there were seven main affecting factors which were commonly observed, as summarised in chapter one. Instead of using an open-ended question to ask participants their opinion on these factors, and adding more text-based questions, a ranking grid style question was used, *see figure 2.13.* The question asked participants to rank in order the seven factors from the most to the least affecting. The participants were also asked to provide a justification for their response; however, this question was optional which was justified previously.



Factors which may affect the rate of decomposition

This part of the survey uses a table of questions, view as separate questions instead?

Please rank in order, what you believe to be the most affecing factors contributing to the rate of decomposition. *(1 being the most, 7 being the least )* * *Required*

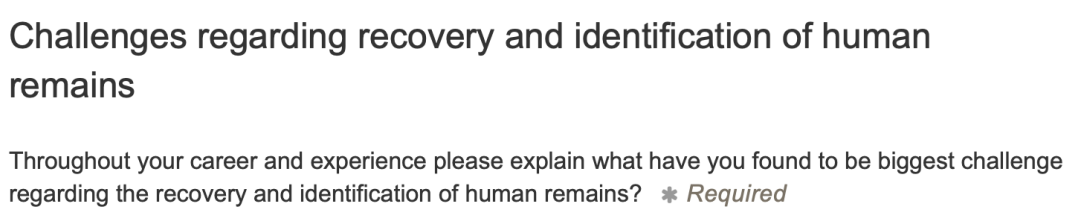
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Temperature | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Humidity | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Burial circumstances (Wrapped/Unwrapped) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Deposition site | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Entomological activity | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Scavenging | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Body size & weight | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Please provide justification for your ranking order. (You may include other factors that are not included on the list to form your opinion)

*Figure 2.13: Survey question eight ranking the factors which may affect the rate of decomposition and question nine which asked to provide justification*

*Question 10: Challenges regarding recovery and identification*

The final question aimed to conclude the study with the participants' personal accounts within investigation, *see figure 2.14*. As mentioned previously, the confidentiality and anonymity of the study aided participants to give their opinion without worrying about their identification being exposed. This question aimed to highlight what the challenges are throughout the entire recovery and identification process, it also allowed to compare what regions are challenged with similar aspects. These responses can also help focus on what research needs to be carried out in the future and what elements of current forensic services needs to be developed and improved.



Challenges regarding recovery and identification of human remains

Throughout your career and experience please explain what have you found to be biggest challenge regarding the recovery and identification of human remains? * *Required*

*Figure 2.14: Survey question nine regarding the challenges within recovery and identification of human remains*

### *2.3.5.* Use of responses

All responses to the survey were analysed using the tools provided on the online survey platform. Out of the possible fifteen regions, there were five responding regions consisting of twenty-one total participants. Both North America and Western Europe had nine respondents, Middle East, South America and Australasia had one respondent. The responses from questions four, five and six *(figures 2.9, 2.10 and 2.11)* were used to highlight the methods and techniques used for the recovery of human remains within sand, soil and water based burial environments.

North America, Western Europe, Middle East, South America and Australasia were divided into allocated sections. Within those sections the regional climates, terrains and temperature were discussed to determine what environmental factors may be present within that region. Responses from question nine were averaged and discussed within this section to highlight what affecting factors forensic personnel frequently experience. Question ten was then used to highlight the challenges each region faces and draw any similarities that forensic professionals from different parts of the world may face.

# *3.0* Decomposition under different burial conditions

This chapter will focus upon the analysis of the pre- and post- decomposition changes for meat in various burial environments. Each burial environment will be individually analysed within an allocated section. Photographic results of the decomposing meat samples will be displayed and reviewed followed by a discussion of the findings including observational changes to the sample layers; muscle, adipose and skin tissue. The epidermis layer from the meat samples which were buried within the soil environments will undergo further analysis using notations from the Munsell colour system. Due to the limited literature regarding the decomposition of human remains and the lack of information disclosed in real life case studies, the hypothesis testing for the project was based on accessible knowledge when researching human taphonomy. The project aimed to solely focus of the burial environments and how this could influence the decomposition of skin, muscle, and fat tissues. It was known that pig cadavers were often used to as human analogues within medical and forensic research therefore pig cadaver was also chosen for the project to replicate buried remains. Because of this, when hypothesising the results, the use of animal tissue instead of human had to be considered.

When researching the historical element regarding human remains, such as mummification and historic embalming techniques it was suggested that salt content, lack of humidity and moisture played a huge role in the drying of human tissue. It was hypothesised that the meat buried within the sand environment would follow a similar decomposition pattern. The skin tissue would dry, perhaps discolour but remain connected to the main body of meat during the burial period. It was suggested that the adipose layer could possibly develop into adipocere and harden due to the lack of moisture and high temperatures of the control room, creating a similar burial setting to that of historical remains found in the middle east.

Human remains submerged within an aquatic deposition site face many decomposition factors due to the nature of the environment. Entomological and scavenging activity play a huge role of the rate of decomposition, but as mentioned previously, information regarding how the properties of the water affected decomposition was scarce. Therefore, this projected aimed to focus on how water types may play a role in the decomposition of animal tissue. Previous research suggest that human remains submerged within saltwater have a slower and delayed rate of decomposition when compared to submersion within fresh water (Ellingham, Perich and Tidball-Binz, 2017) and the salt content is known to slow down bacterial activity (Heaton, Lagden, Moffatt and Simmons, 2010). Therefore, the initial hypothesis was that there would be a minimal difference of decomposition when recovering the saltwater samples from week one and week two.

As human remains found in water are known to heavily disarticulate (Haglund, 1993), it was hypothesised that the muscle and fat tissue of the submerged meat samples would tear and separate from the skin tissue. Human remains that are clothed or covered within material when submerged are likely to form adipocere (Ellingham, Perich and Tidball-Binz, 2017). As the samples within the current project were not covered or clothed, the formation of adipocere was not initially hypothesised, instead it was predicted that the fat tissue of the meat samples would become structurally remain soft with high levels of compressibility, not hardened or wax like to that of adipocere formation.

As soil burial sites have many variables based on geological factors, there is currently no standard control in which an estimation on how soil-based burials can have an affect on the role of decomposition. This project aimed to create that standard control by eliminating some of those variables and focusing primarily on soil type. Based on previous literature it was hypothesised that the meat samples buried within the soil environments would show colour change, enhanced decomposition odour and change in both texture and shape.

Based on previous literature regarding soil properties and applying this to how a soil burial environment may affect the rate of decomposition it was hypothesised that the meat samples buried with the three chosen soil types would have different rates of decomposition. Colour and odour were two factors that were hypothesised to have the most noticeable change. It was understood prior to the start of the project that the meat tissue samples would show signs of discolouration due to general meat spoilage.

## *3.1.* Sand burial environment

For the sand burial environment, commercial builders' sand was used to replicate a sand based human body deposition site. As mentioned in *section 2.1.1,* all meat samples were buried in the allocated burial environments and stored in the temperature control room to decompose. Each week one meat sample was recovered from the sand environment and the decomposition was analysed.

## *3.1 .1.* Results for burial in sand-based conditions

Following the coding system which was used to label the meat samples and burial environments, *see section 2.2.2*. The burial periods ranged from one week to four weeks, therefore the meat samples for

this burial environment were labelled D1, D2, D3 and D4. Prior to burial and after recovery, each meat sample was weighed and photographed to compare pre- and post-decomposition. This is displayed within the *figure 3.1*, each meat sample within the discussion will be referenced by the letter allocated in this figure.

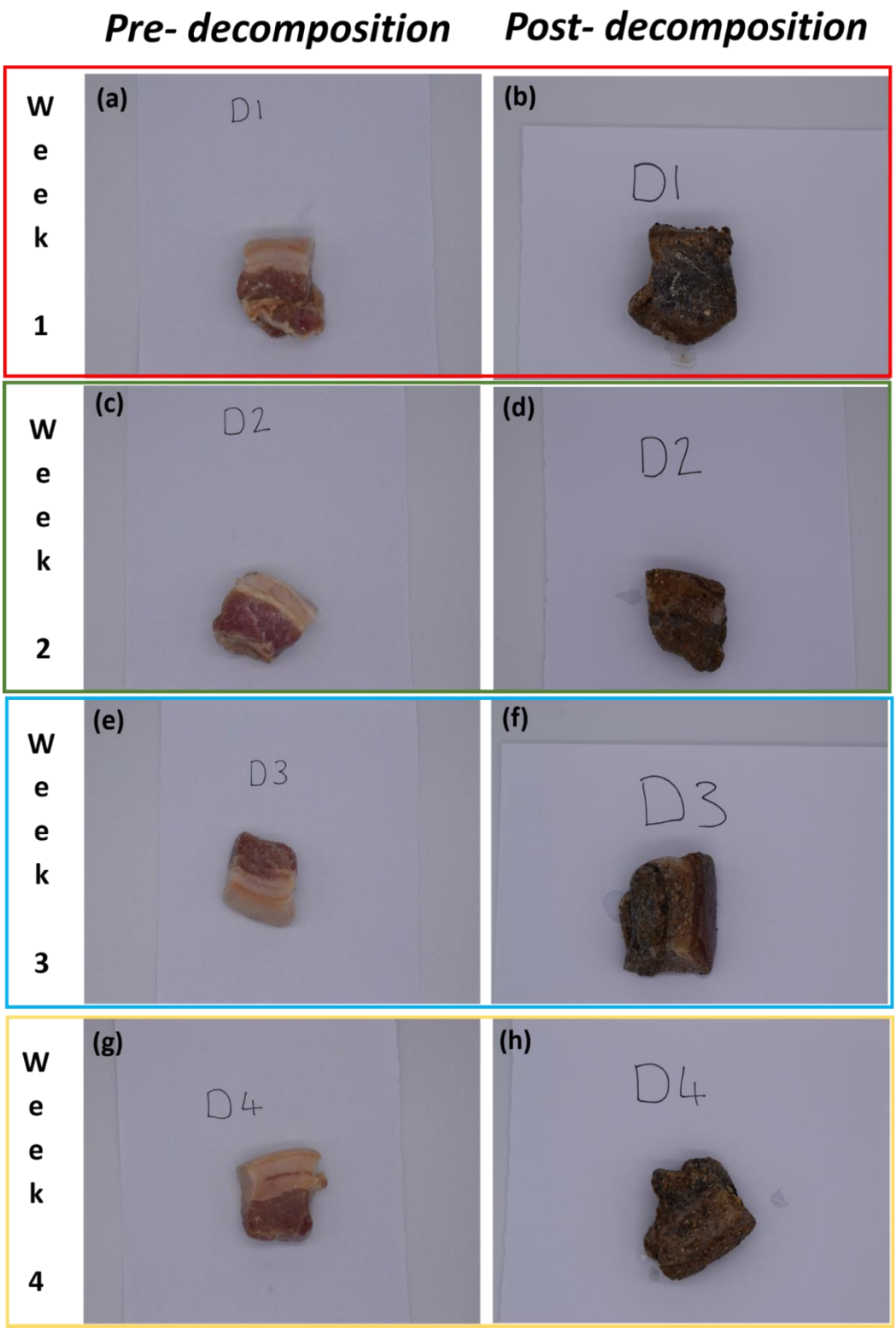



*Figure 3.1 showing photographic observations of the meat samples pre- and post-decomposition buried within sand. Images are labelled in chronological order from week one through to week four. All pre-decomposition photographs were taken prior to entering the sand environment and are then represented in their decomposed state labelled post-decomposition.*

Prior to burial each meat sample had several differences including shape, size, and various layer thickness. For the meat samples within the sand environment, the muscle layer content varied in size, in some samples *(figure 3.1* (e) *and* (g)*)* the muscle layer was observationally smaller compared to the other samples. The thickness in adipose also appears to vary throughout the samples, with *figure 3.1* (c) appearing to have the least adipose present and *figure 3.1* (e) and (g) having the larger adipose content. All samples had fascia, defined as masses of connective tissue (Schleip, Jäger and Klingler, 2012) present prior to burial, which is seen predominantly in *figure 3.1* (a). The meat samples originated from the same cut of meat as shown in *figure* 2.3 *(section 2.1.3),* it was not possible to control the thickness of this layer due to the uncontrolled variable of the pig anatomy.

The skin layer on all samples showed various indications of decomposition within the four-week examination period. *Figure 3.1* (a-b) shows evidence of decomposition after a period of one week. The skin on both *figure 3.1* (b) and (h) had been perforated by the sharp components of the sand environments. Whereas the skin layer on *figure 3.1* (d) and (f) appeared to form a hardened skin texture accompanied by a dark discolouration, as hypothesised. The muscle layer on *figure 3.1* (b) was completely saturated by the fine sand granules, which can explain the dark discoloration change on this sample when compared to *figure 3.1* (a). When cleaning this sample post recovery, the saturated sand was extremely difficult to remove from the muscle tissue, additionally the sand and distilled water combined exposed a silky film which covered the entirety of the sample. The high level of fascia present within *figure 3.1* (a) and (b) could also be seen within figures *3.1* (c) and (d) post cleaning process, these appear as white, almost transparent, patches which are scarcely exposed under the wet sand. A sensory observation, from the recovery process was noted in relation to the hardness of the adipose layer. During week 1 this layer showed a higher degree of compressibility compared to weeks 2 – 4. During weeks 2 to 3, the compressibility of the adipose layer decreased. It should be noted that the compressibility of the sand samples was considered later in the study when analyzing quantification data. However, the adipose layer on the week 4 sample showed to be more porous compared to week 3.

In forensic studies that use pig cadavers as human analogues, research has suggested that the body mass of the carcass could be a potential variable for the rate of decomposition (Sutherland, Myburgh, Steyn and Becker, 2013). Matuszewski's (2014) study found that pig carcasses within their small and medium body criteria had a rapid decrease in mass and stabilized at an average 20% of their original body mass. The researchers stated that the primary result of their study demonstrated that carcass

mass is a 'factor of key importance' when analysing decomposition, due to the affect body mass has on the different decomposition stages (Matuszewski, Konwerski, Frątczak and Szafałowicz, 2014).

To further explore the applicability of this study to the current research, the weight changes of the meat samples within the sand environments throughout all the burial periods, the difference between the weight prior to burial and post recovery were calculated into a percentage. *Figure 3.2* illustrates the weight loss percentage change throughout the studied burial periods. The weight loss percentage increased over the four weeks, meaning that the longer the meat samples were buried, the more weight was being lost. The biggest weight loss increase was between weeks two and three. Observationally, between those two weeks the epidermis on the meat samples had significantly hardened, suggesting an increase of moisture excretion causing an increased weight loss percentage.

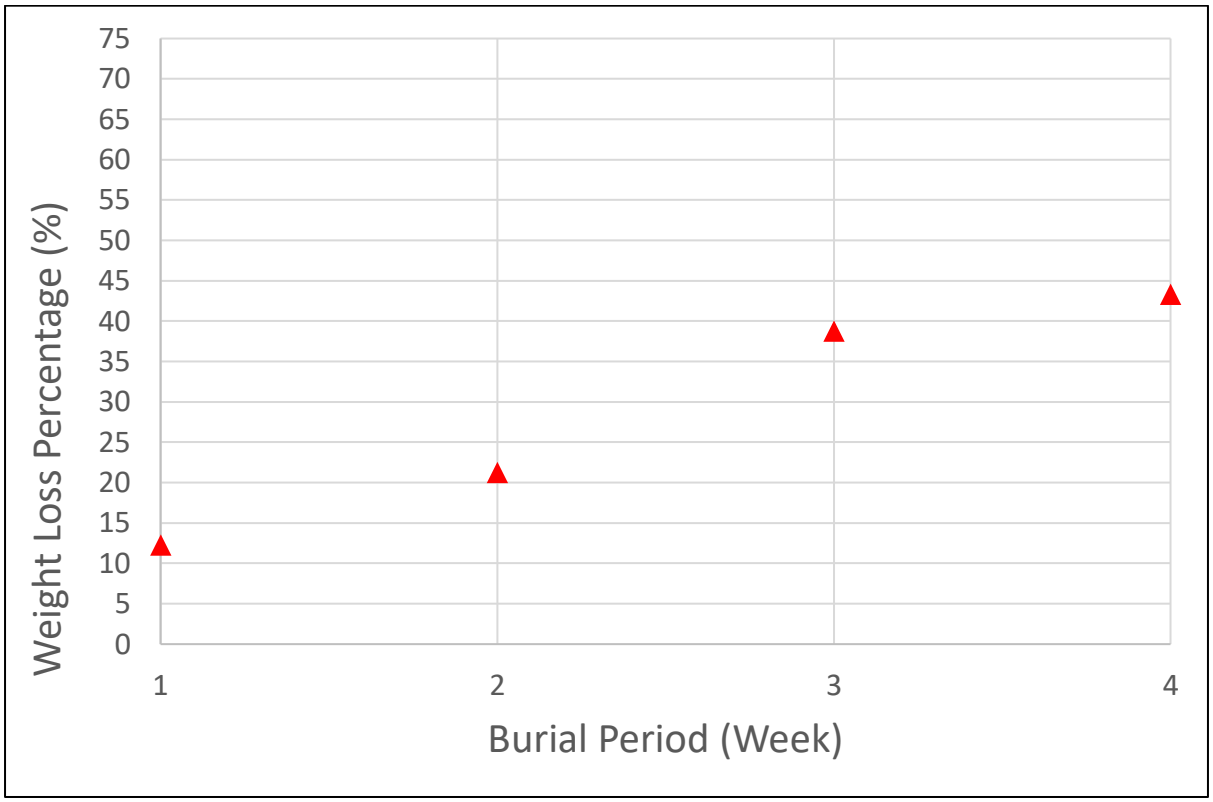



*Figure 3.2 shows the change in weight loss percentage over the weekly burial periods for sand.*

### *3.1.2.* Discussion for burial in sand-based conditions

Meat is described as extremely perishable due to the presence of chemical and enzymatic activities (Lulietto, Sechi, Borgogni and Cenci-Goga, 2015). The nutrient composition and high-water content both contribute to creating a habitable environment for the growth of a wide variety of microorganisms (Dave and Ghaly, 2011). The three basic mechanisms responsible for the spoilage of meat are microbial growth, oxidation, and enzymatic autolysis (Dave and Ghaly, 2011). The development of familiar spoiled meat product characteristics such as strong odours and slime formation are the result of the breakdown of fat, proteins, and carbohydrates (Lulietto, Sechi, Borgogni and Cenci-Goga, 2015). Ray and Bhunia (2013) stated that the starting total microbiota within raw meat is approximately $x10^2$ - $x10^3$ cfu $gr^{-1}$ which consists of a wide variety of species. The volume and variety of microbiota species within meat products is affected by a range of different environmental conditions such as temperature and storage conditions.

Firstly, within this experiment, it must be noted that the meat was stored within a temperature controlled refrigerated room prior to the start of the study. As discussed in *section 2.1.3* the temperature of the refrigerated room was set at 4°C, however due to the communal usage, there was a temperature fluctuation between 4°C and 6°C. This fluctuation led to premature decomposition prior to the experiment. Refrigeration storage can limit the growth of 10% of the total microbiota (Lulietto, Sechi, Borgogni and Cenci-Goga, 2015), during storage the dominant microbiota can cause deterioration by releasing volatile compounds and slime formation. Research has shown that lactic acid bacteria (LAB) appear in the early stages of decomposition of vacuumed packed meat (Chenoll, Macián, Elizaquível and Aznar, 2007). LAB then contributes to the development of ropy slime (Chenoll, Macián, Elizaquível and Aznar, 2007). As mentioned in *section 2.1.3*, the meat samples were stored in zip lock bags within the refrigerated storage prior to the experiment, providing a slightly similar environment to that of a vacuumed environment. Since the decomposition process had already started prior to the samples entering the cups, this indicates that additional decomposition fluid was introduced early to the burial environment, therefore delaying the drying process within the first week.

LAB and the formation of ropy slime may have contributed to the adhesive characteristics of the skin layer, therefore possibly explaining why the meat sample from week one *figure 3.1 (b)* showed that the coarse sand (sharp components) had penetrated the skin layer. The skin layer on *figure 3.1* (d) and (f) showed a complete dark discoloration which could be an indication of necrosis. In humans, necrosis occurs when there is death to a bodily tissue and causes a dark discolouration of the epidermis (Trump,

Berezesky, Chang and Phelps, 1997), variants of necrosis have also been found within pigs (Park et., 2013). The indicative necrosis could also be attributed by the dehydrating properties of the sand (Kumar and Madhusudhan, 2012).

The new formed hard texture of the skin layer could have acted as a protective barrier and limited LAB growth and skin adhesiveness. Decreasing the adhesive properties of the sample would therefore reduce sand perforation within the skin, which is shown in the samples between two and three. However, during week four, *figure 3.1(h)*, showed an increase of perforation by the sharp sand components within the skin layer. This could be affected by the adipose layer and moisture content, as it is observationally larger than the previous week samples. The hardened epidermis of this sample also appeared to be thinner when compared to other samples. This could suggest that the muscle layer and the larger adipose layer may retain more moisture, as research has shown water holding capacity can change within meat post-mortem (Judge et al., 1989). This may limited the drying process of the epidermis as more moisture was absorbed by the surrounding sand, therefore affecting the "curing process" and causing the skin layer to be thinner than previous samples. With the hardening of the skin creating a barrier, as hypothesized, this prevented any moisture from draining through the skin layer. This would lead to moisture retention within the adipose layer, aiding the adhesive texture, which could explain why there was a large sharp sand fragment buried within the adipose layer, *figure A.7.* The adipose layer appears smaller on *figure 3.1* (a) and (b) when compared to the other samples. There is still some perforation within this layer from the coarse sand, which suggests that the structural integrity of this layer was still soft. The texture change of *figure 3.1* (d) was evident due to the decreased level of sand perforation within the adipose on this sample. Observational notes carried out during the recovery process addressed that when cleaning this sample, the excess sand was easier removed than compared to the cleaning process of *figure 3.1* (b), therefore leaving the layer more exposed as higher amount of excess sand was easily removed. Apart from texture change, there were limited changes of the adipose layers for all samples. *Figure 3.1* (f) showed an area of dark discoloration, however there was a slight discoloration of this layer on this sample prior to the start of the experiment, *figure 3.1* (e). This was also evident on *figure 3.1* (c). Nevertheless, the discoloration seen on *figure 3.1* (f) could be an indication of the adipose layer drying out, as the color change is similar to that of the skin layer. As mentioned previously, it is possible that as the epidermis had hardened, this then eliminated any moisture being excreted through the skin layer, therefore retaining moisture within the adipose would be excreted by the muscle layer. This exchange of moisture may have contributed to the weight loss that was seen throughout all the samples, s*ee figure 3.2*, the longer the burial period the more moisture is excreted from the meat sample into the surrounding sand. Moisture was a major contributing factor to the decomposition changes observed. Due to the decomposition process already beginning prior to

the burial of the samples it could be suggested that moisture had already started to excrete from the sample layers during the early stages of the experiment.

## *3.2.* Soil burial environments

To replicate a soil-based burial, three types of soil were used to imitate common human body deposition sites. Soil A was collected from Elham and Soil B was collected from Sittingbourne, both situated in Kent, UK, the third soil (Soil C) was commercial John Innes No. 1 compost. As mentioned in *section 2.1.1* the samples were buried and stored in a temperature-controlled room. Each week one sample was recovered from all environments and the decomposition evidence was analysed.

### *3.2.1* Soil A Results

Following the coding system which was used to label the meat samples and burial environments, *see section 2.2.2*. The burial periods ranged from one week to four weeks therefore the meat samples for this burial environment were labelled SA1, SA2, SA3 and SA4. Prior to burial, each meat sample was weighed and photographed to compare pre- and post-decomposition. This is displayed within the *figure* 3.3, each meat sample within the discussion will be referenced by the letter allocated in this figure.

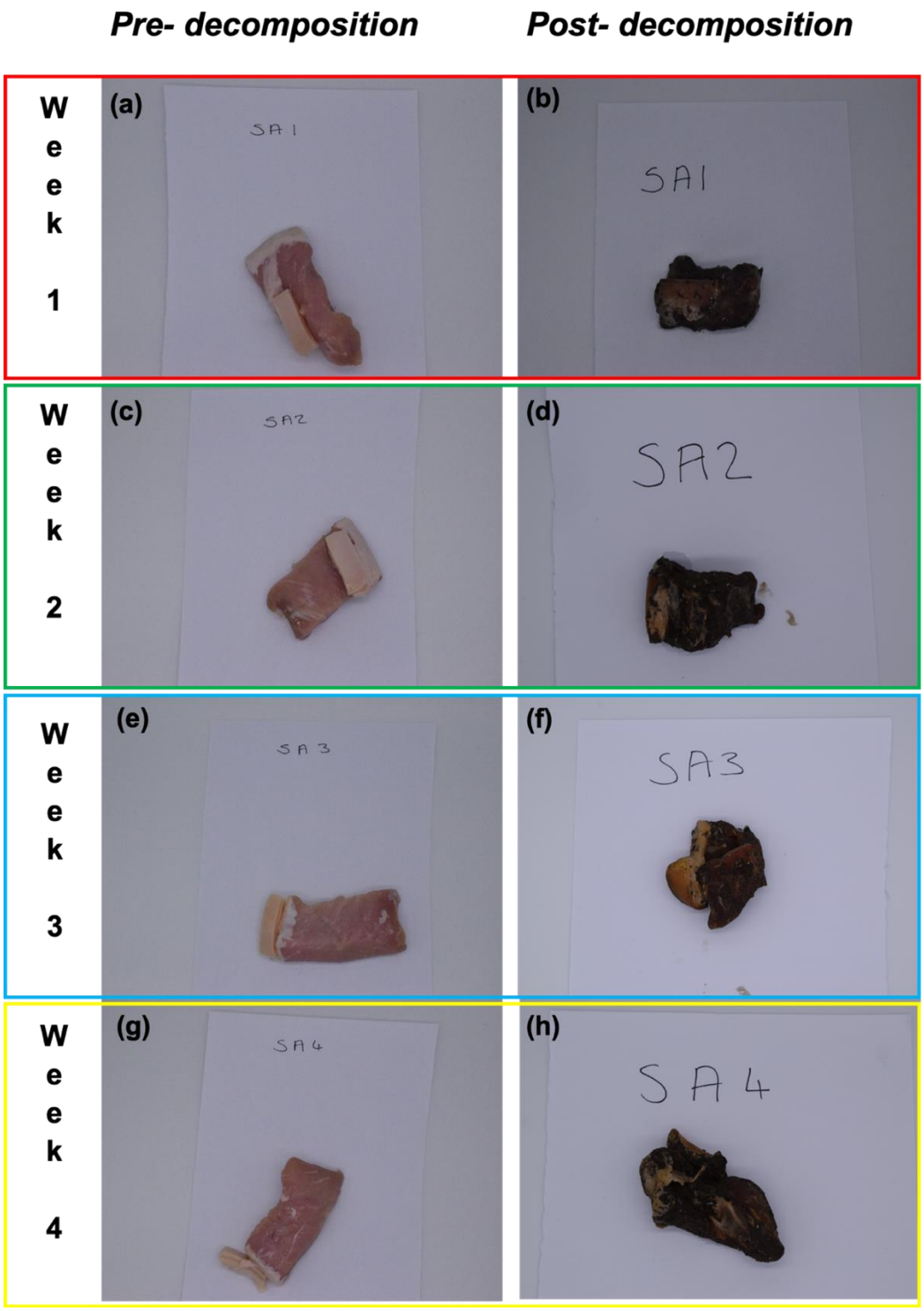



*Figure 3.3 shows photographic observations of the meat samples pre-decomposition and post-decomposition buried within soil A, collected from Elham Kent. The images are labelled in chronological order from week one through to week four. All pre-decomposition photographs were taken prior to entering the soil environment and are then represented in their decomposed state labelled post- decomposition.*

Prior to burial each meat sample had several differences, including shape, size and various layer thickness. For the meat samples within Soil A environment, the shape of the samples was very similar, being mostly composed of a large muscle layer, *figure* 3.3 (c) appearing to have to smallest muscle layer. The skin layers appeared to be loosely bound to the main body of the sample prior to burial, this was evident in all samples for Soil A. There also appeared to be very little adipose for all the samples, possibly contributing to the frailness of the loosely bound skin layer. Throughout the muscle layers on all samples, white fatty veining, or fascia, was present. The muscle layers also appeared to have slight dark discolouration prior to burial due to early decomposition.

Skin layer present on *figure* 3.3 (b) had shown slight dark discolouration when compared to the skin layer on *figure* 3.3 (a), and there was no evidence of skin perforation by the soil environment during this burial period. There was a change in colour of the muscle layer within a one-week period, the colour changed from a flesh colour to a dark red brown colour. Even though the soil had embedded into the adhesive muscle layer, there was a small area of muscle where staining had not occurred. Prior to entering the environment, *figure* 3.3 (b) had a high amount of fascia and connective veining present, *see figure 3.3 (a).* Within the unstained area of muscle, it was possible to observe the fascia which had a distinctive white appearance. During sensory observations it was noted that this layer had a soft textural integrity, additionally the soil environment was still present on this layer after the cleaning process.

Similar to *figure* 3.3 (a), the skin layer on *figure* 3.3 (d) is also not fully attached to the specimen, this caused the adipose layer to be fully exposed to the elements. Observationally the skin is much darker compared to week one, it also appears to be smaller when compared to other samples in the study. The adipose layer on *figure* 3.3 (d) showed a creamy, yellow colouration with a high level of compressibility, which regained shape after pressure was removed. There was slight perforation from the sharper soil components within parts of the adipose, primarily towards the skin layer. The muscle layer for *figure* 3.3 (d) had a significant dark colour discolouration when compared to *figure* 3.3 (c). The soil environment appears to have stained the muscle, there was also an increase of perforation within this layer. Observationally there was a high amount of fascia and veining exposed within the muscle layer, the colour of these components consisted of dark yellow and orange tones with some areas having a white, almost transparent appearance. However, it should be noted that there was a considerable amount of fascia present in the sample prior to the experiment.

The skin layer on *figure* 3.3 (f) had a significant dark discolouration when compared to other samples. The skin appeared to have a hard, smooth glazed like appearance with no soil perforation. The skin layer had also repositioned and appeared to have slipped away from the adipose layer. The adipose

layer had a similar creamy, yellow colour to *figure* 3.3 (d), however the adipose layer on *figure* 3.3 (f) appeared to have a dryer appearance with respect to the previous week, leaving a dry, crusty texture. Although, there was minor perforation from the soil on areas which appeared to have some moisture retention. As mentioned previously, due to the uncontrolled variable of the pig anatomy, the adipose layer on this sample was slightly smaller when compared to other samples. The adipose appeared to have a different shape, which did not follow the standard layer pattern, *see figure 3.3 (e).* The prevalent observational change within *figure* 3.3 (f) was the shape of the sample. The muscle layer had contracted showing a significant decrease in size which led to this muscle layer coming into contact with the skin layer. The areas which had no excess soil covering showed a dark red colouration with a semi-opaque like appearance and a smooth texture.

The skin layer on *figure* 3.3 (g) was consistent with the other soil A samples, the skin layer was not fully attached to the specimen and was fragilely connected through string like muscle tissue. After four weeks, the skin was still connected to the specimen, *see figure 3.3 (h),* however it had shifted from the starting burial position. Not following the same colourization pattern as seen for the other samples, the skin layer on *figure* 3.3 (h) appeared to be submerged under a thick layer of soil which could not be removed during the cleaning process. The slightly exposed area of skin, showing a slight dark decolourisation; however, this was not as significant when compared to previous samples. The adipose layer on *figure* 3.3 (h) had an increased amount of soil perforation when compared to *figure* 3.3 (f), with only a small surface area exposed from the damp soil. The layer also appeared to be a lighter yellow colour, with a soft pale texture. The connective tissue between the skin and adipose was not discoloured and remained a light creamy colour, this connective tissue also kept its elasticity as the skin layer was accidentally moved during the cleaning process, *see figure A.2.* The muscle layer on *figure* 3.3 (h) was highly stained and saturated by the soil environment. There were limited areas of muscle exposure, which appeared as dark, maroon-coloured patches situated throughout the muscle layer. Interestingly, the muscle layer had also repositioned into a folded like position. This then left an opening within this area, the wound-like area appeared to be retaining surface water from the cleaning process, *see figure A.3.*

To explore the weight changes of the meat samples within the Soil A environment throughout all the burial periods, the difference between the weight prior to burial and post recovery were calculated into a percentage as discussed in section 3.1.1. *Figure 3.4* illustrates the weight loss percentage change throughout the studied burial periods. The weight loss percentage increased over the four weeks, meaning that the longer the meat samples were buried, the more weight was being lost. However, the

graph shows that the weight loss percentage increase was consistent throughout the four-week study period.

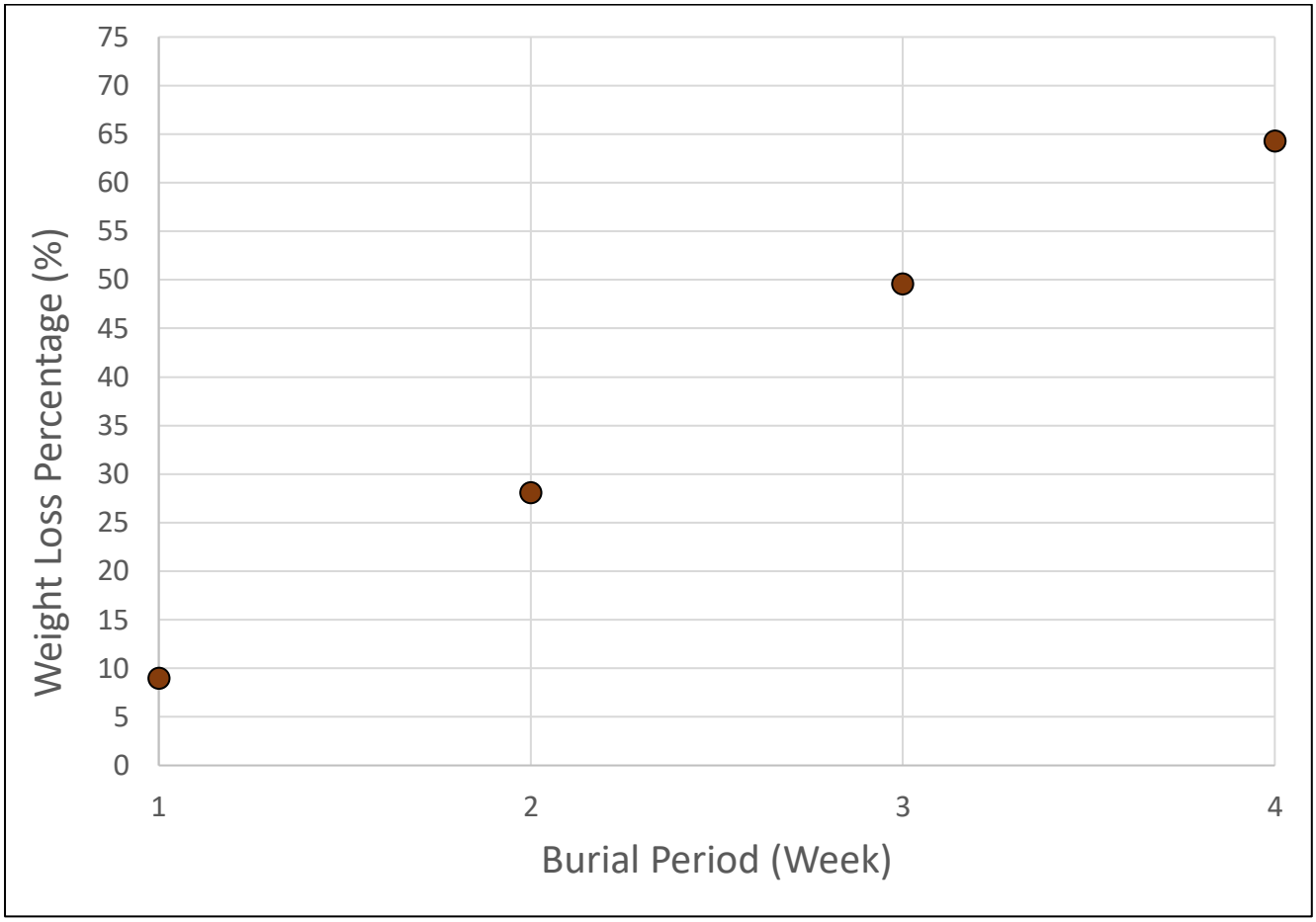



*Figure* 3.4 *shows the change in weight loss percentage over the weekly burial periods for SOIL A*

### *3.2.2.* Soil B Results

Following the coding system which was used to label the meat samples and burial environments, *see section 2.2.2.* The burial periods ranged from one week to four weeks therefore the meat samples for this burial environment were labelled SB1, SB2, SB3 and SB4. Prior to burial, each meat sample was weighed and photographed both pre- and post-decomposition. This is displayed within the *figure* 3.5, each meat sample within the discussion will be referenced by the letter allocated in the figure.

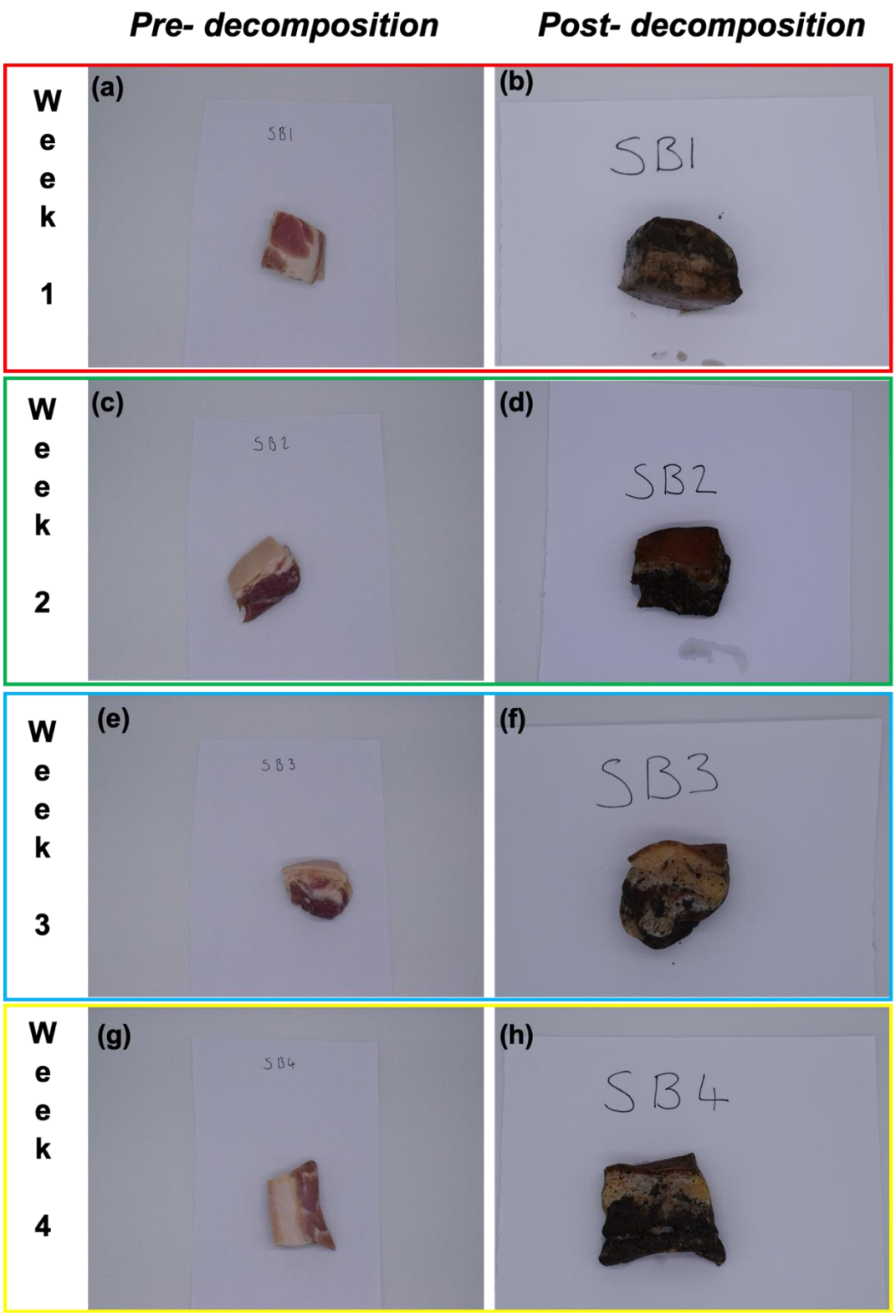



*Figure 3.5 showing photographic observations of the meat samples pre-decomposition and post-decomposition within Soil B, collected from Sittingbourne, Kent. The images are labelled in chronological order from week one through to week four. All pre-decomposition photographs were*

*taken prior to entering the soil environment and are then represented in their decomposed state labelled post- decomposition.*

Prior to burial each meat sample showed several differences, including shape, size and various layer thickness. The adipose content varied, with *figure* 3.5 (c) appearing to have the least adipose present and *figure* 3.5 (g) having the most. Fascia was present in all the meat samples barring *figure* 3.5 (a), however this sample had an unusual adipose composition unlike the other samples. The muscle layers varied for all samples, *figure* 3.5 (e) appeared to have the least amount of muscle tissue with *figure* 3.5 (c) having the most. Unlike the previous environment, there was no decomposition discolouration present on the meat samples prior burial.

The skin layer on *figure* 3.5 (b) appeared to be extremely thin, when compared to the other samples. There was also a strip of muscle layer positioned directly under the skin layer, meaning that the skin layer was attached to muscle and not adipose, *see figure 3.5 (a).* After a one-week period, the skin had discoloured from the flesh like colour to a dark orange, brown colour which was consistent in all samples soil and sand environments during this burial period. There was an extremely large proportion of adipose present on *figure* 3.5 (a), however this was only partly observed in *figure* 3.5 (b). The adipose had a similar colouration to previously discussed samples, however in *figure* 3.5 (b) the creamy pale colour was accompanied with a wet soft texture. The ratio of adipose to muscle within this tissue was slightly different, when compared to the other samples *figure* 3.5 (a) had more adipose present which immersed the muscle tissue. The muscle layer on *figure* 3.5 (b) was not as visible as the other samples, the adhesiveness of the layer had allowed for the finer soil components to remain in place even after the cleaning process. The shape of *figure* 3.5 (b) had also changed when compared to *figure* 3.5 (a), the muscle on *figure* 3.5 (b) appeared to be smaller, with the pale adipose appearing larger.

The skin layer on *figure* 3.5 (d) had also discoloured to an orange dark brown tone and there was no evidence of skin perforation from the soil environment, the scarcity of soil meant that the skin layer was fully visible. Because of this, it was clear to see that the texture of the skin was smooth, accompanied with a semi-opaque appearance. The adipose on *figure* 3.5 (c) also appeared to be thinner when compared to other samples. There was also adipose scattered throughout the sample, unlike the other samples which contain consistent layering. Due to the abundance of soil saturation and staining, the adipose layer on *figure* 3.5 (d) was harder to observe. The texture appeared to be porous and accompanied with a pale, cream colour. The muscle layer on *figure* 3.5 (d) was highly stained and discoloured to a dark brown almost black appearance due to the soil environment. Due to the staining, it was difficult to observe any other significant changes within the muscle layer. As mentioned

previously, the adipose, which was scattered throughout the muscle shown in *figure 3.5 (c),* could be seen in *figure* 3.5 (d) as light, white areas which were exposed through the muscle.

Consistent with the other Soil A samples, the skin layer for *figure* 3.5 (e) was observationally smaller than other burial environment samples. After a three-week burial period, the skin layer had discoloured, and the texture appeared to be a semi-opaque, *see figure 3.5 (f).* There also appeared to be little to no skin perforation on this sample, and after the cleaning process there was a very small amount of soil remaining on the skin surface. The adipose layer shown in *figure* 3.5 (f) appeared to have swelled when compared to pre-decomposition *see figure 3.5 (e*), there was also adipose throughout the sample, including the muscle layer. Like other samples, the texture of the adipose layer appeared to be dry and crumbly with a light, cream, pale colour. The muscle layer in *figure* 3.5 (f) appeared to have decreased in size when compared to the pre-decomposed sample, *figure* 3.5 (e). The colour of the muscle also varied throughout the layer, besides the white adipose, there were areas which were more covered in soil than others and some small areas of the muscle layer had a dark red colouring. The skin layer of this sample, *figure* 3.5 (h), was extremely discoloured when compared to pre-decomposition, see *figure* 3.5 (g). The texture of this layer appeared to be much harder than the previous samples and the edges of the layer appeared to be turned upwards. There were also no skin punctures from the soil environment, and limited soil residue after the cleaning process. The adipose layer on *figure* 3.5 (h) was thick, consistent with the pre-decomposition *figure* 3.5 (g). Observationally there was a pale-yellow colour with some areas appearing whiter than others. The texture appeared to be dry, chalky, and crumbly, some parts of the adipose layer were contaminated by the soil environment which remained after the cleaning process. *Figure* 3.5 (g) showed that there was a high content of fascia and veining, however in *figure* 3.5 (h) this can barely be seen under the heavy clay like appearance of the soil environment which had immersed the muscle due to its adhesive nature.

To explore the weight changes of the meat samples within the Soil B environment throughout all of the burial periods, the difference between the weight prior to burial and post recovery were calculated into a percentage. *Figure 3.6* illustrates the weight loss percentage change throughout the studied burial periods. Similar to *figure* 3.6, the graph shows that the weight loss percentage consistently increased throughout the four-week study period. However, the weight loss percentage only increased by 7.5 % from week three to week four. Observationally there were limited differences between the two samples, with both experiencing minor colour differentiation and similar dried adipose textures, therefore possibly suggesting the start of a plateaued rate of decomposition.

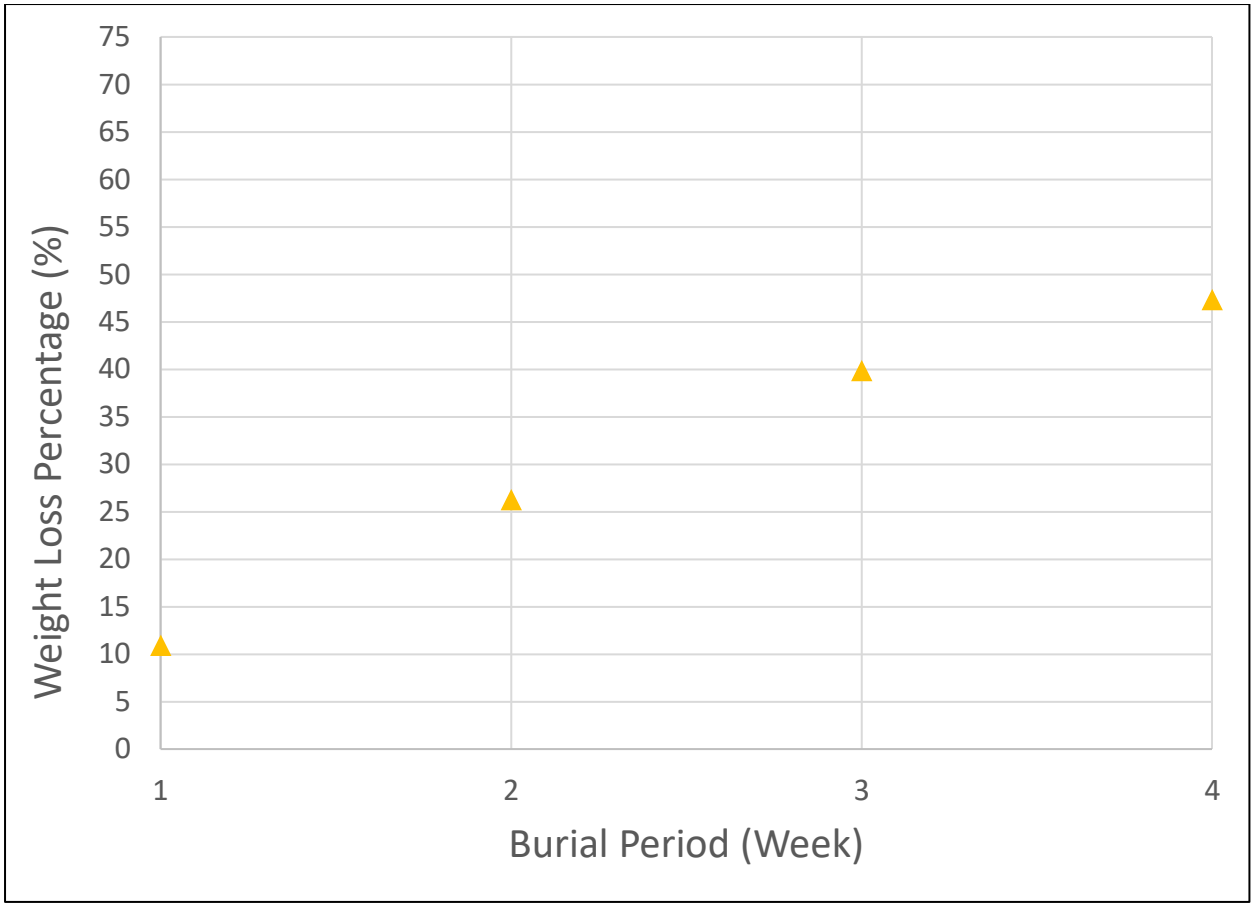



*Figure* 3.6 *shows the change in weight loss percentage over the weekly burial periods for SOIL B*

### *3.2.3.* Soil C Results

Following the coding system which was used to label the meat samples and burial environments, *see section 2.2.2.* The burial periods ranged from one week to four weeks therefore the meat samples for this burial environment were labelled SC1, SC2, SC3 and SC4. Prior to burial, each meat sample was weighed and photographed both pre- and post-decomposition. This is displayed within the *figure* 3.7, each meat sample within the discussion will be referenced by the letter allocated in the figure.

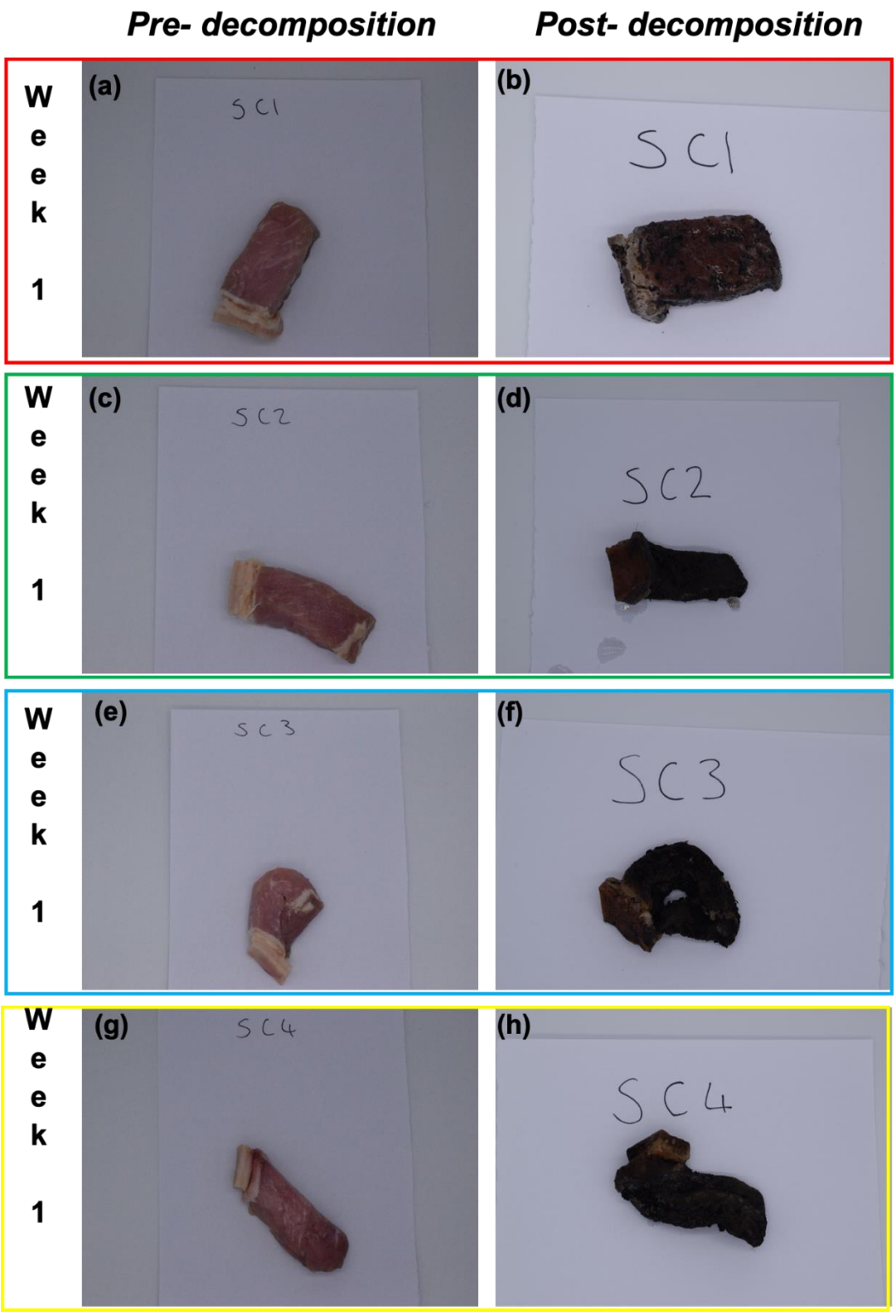



*Figure 3.7 shows photographic observations of the meat samples pre-decomposition and post-decomposition within Soil C, compost. The images are labelled in chronological order from week one through to week four. All pre-decomposition photographs were taken prior to entering the compost environment and are then represented in their decomposed state labelled post- decomposition.*

Prior to burial each meat sample had several differences, including shape, size and various layer thickness. The shape of the samples for Soil C environment burial were similar to the meat samples for soil A, in which the sample consisted of mainly muscle tissue. However, *figure* 3.7 (e) had a curled shape in comparison to the straight posture of the other samples for soil C. There was a slight discolouration prior to burial due to early decomposition on all the samples, this was more prominent on *figure* 3.7 (c). Similar to Soil A, the skin layer was loosely bound to the adipose layer on all of the samples. There also appeared to be limited adipose present on the samples, and fat was present within the muscle layers of all samples. Prior to burial *figure* 3.7 (a) had early indications of decomposition as the skin layer appeared to have slight discolouration. Over a one-week period, the skin colour had dark staining with excess soil remaining after the cleaning process however there was little perforation within the skin*, see figure 3.7 (b).* Prior to burial the adipose on *figure* 3.7 (a) had a pale, off white colour, with some areas appearing more yellow. The colouring on this sample was slightly different when compared to samples of other environments which had a pale cream, white appearance. The structure of the adipose of this sample also appeared to have a stripy and stringy formation, unlike the block layer appearance of other samples i.e., *figure* 3.5 (g). After a one-week period, the texture of the adipose was dry and crumbly. Observationally there also appeared to be some cracking within the adipose, *see figure 3.7* (b). The muscle layer of *figure* 3.7 (b) had stained and appeared to be a dark red, brown colour after a one-week burial period. There was a small amount of excess soil remaining on the muscle after the cleaning process, which may have added to the dark discolouration observation. There was a high value of fascia and veining appearing in *figure* 3.7 (a) this could also be seen in *figure* 3.7 (b) as white semi-opaque patches throughout the muscle. The skin layer on *figure* 3.7 (d) appeared to have a dark discolouration, the skin had a dark brown colouration when compared to the pre-decomposition *figure* 3.7 (c). The texture of the skin was also hard and dry with no perforation from the compost. This was also the same for *figure* 3.7 (f), however there was slight skin penetration from larger compost components within *figure* 3.7 (h). The adipose layer was heavily sodden with compost; therefore, the colouration and texture were not easily observed*, see figure 3.7 (d).* However, the adipose on *figure* 3.7 (f) appeared to be a less adhesive therefore there was less compost compressed within this layer. The adipose on *figure* 3.7 (h) appeared to have little excess soil and had a hard and solid structure. Both *figure* 3.7 (f) and (h) had a light, pale colouration. The muscle layer of *figure* 3.7 (d) was completely saturated by the compost, after the cleaning process the texture of the muscle felt moist and furry due to the texture of the compost. In *figure* 3.7 (f) and (h) the muscle layers were also completely saturated by the compost, however over a three- and four-week period the texture was much drier, and the samples appeared to decrease in size.

To explore the weight changes of the meat samples within the Soil C (compost) environment throughout all of the burial periods, the difference between the weight prior to burial and post recovery were calculated into a percentage. *Figure 3.8* illustrates the weight loss percentage change throughout the studied burial periods. The compost burial environment showed more observational changes than the other two soil environments, observationally the samples appeared to decrease in muscle mass more prominently than the other soil samples. The data shows an increased weight loss percentage over the four-week study period, the difference between weeks one, two and three were the highest weight loss percentage increases from the land based burial data. However, similar to Soil B, between week three and four, this large weight loss percentage difference had decreased to just 1.25 %. Observationally it was noted that between week three and four both samples, *(figure 3.7* (f) and (h)), had a much drier appearance and a decrease in muscle mass. The limited changes between the two samples, along with the small weight loss percentage difference suggests that the rate of decomposition is reaching a steady state.

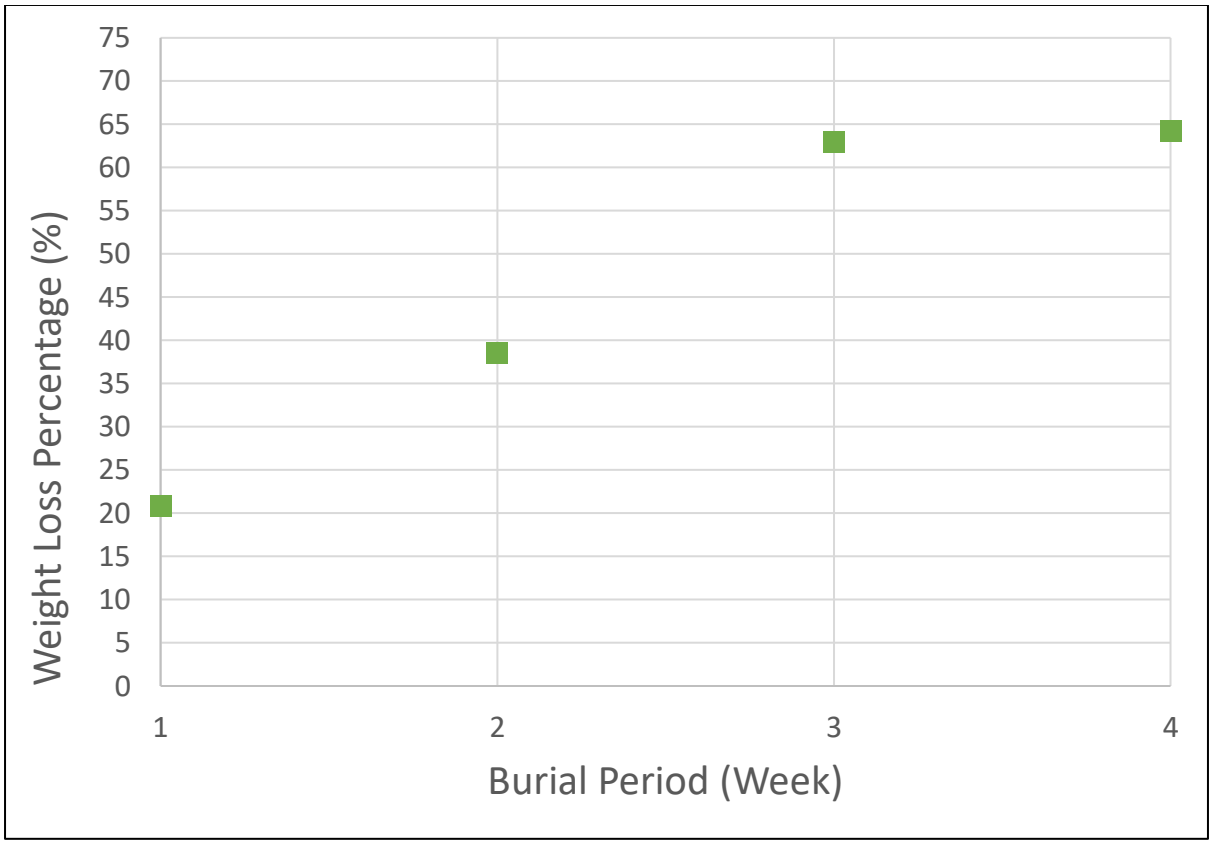



*Figure* 3.8 *shows the change in weight loss percentage over the weekly burial periods for SOIL C (Compost).*

### *3.2.4.* Soil result summary

All three soil types showed similarities and differences throughout the four-week burial period. The main decomposition indicators displayed on all of the samples were, skin discolouration and perforation, adipose texture and perforation, muscle colouration, repositioning, and weight differences. From the data provided in *figure* 3.9, the weight loss percentage patterns for Soil A and B environments are quite similar, with both having a consistent gradual increase over the burial periods. Between the two soil environments there is similar correlation between the weight loss and the observational decrease of muscle mass for all the samples when studying figures 3.3 and 3.5. However, there are significant differences within the weight change for the meat samples within the compost burial. Soil C (compost) shows a high increase in weight loss percentage of 24.41 % between week two and three, however between week three and four the percentage change is plateaued at just 1.25 %.

To further analyse and compare the weight change, quantification data was developed to provide a decomposition value in conjunction with the weight loss percentage for each meat sample, *table 3.1.* The criteria for scoring system are outlined in section 2.2.4.4. From the table, the data simplifies the study's findings, all of the meat samples lost weight over the four-week burial period. Soil A, B and sand (D) show to be consistent in increase through the scale whilst soil C appeared to jump to the higher scale indicating a sharp increase in weight loss percentage which was illustrated in figure 3.9.

*Table 3.1 shows decomposition value regarding weight loss for each meat sample.*

| **Week Number** | **Soil A** | **Soil B** | **Soil C** | **Sand (D)** |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 3 | 2 |
| 3 | 3 | 3 | 5 | 3 |
| 4 | 5 | 4 | 5 | 4 |

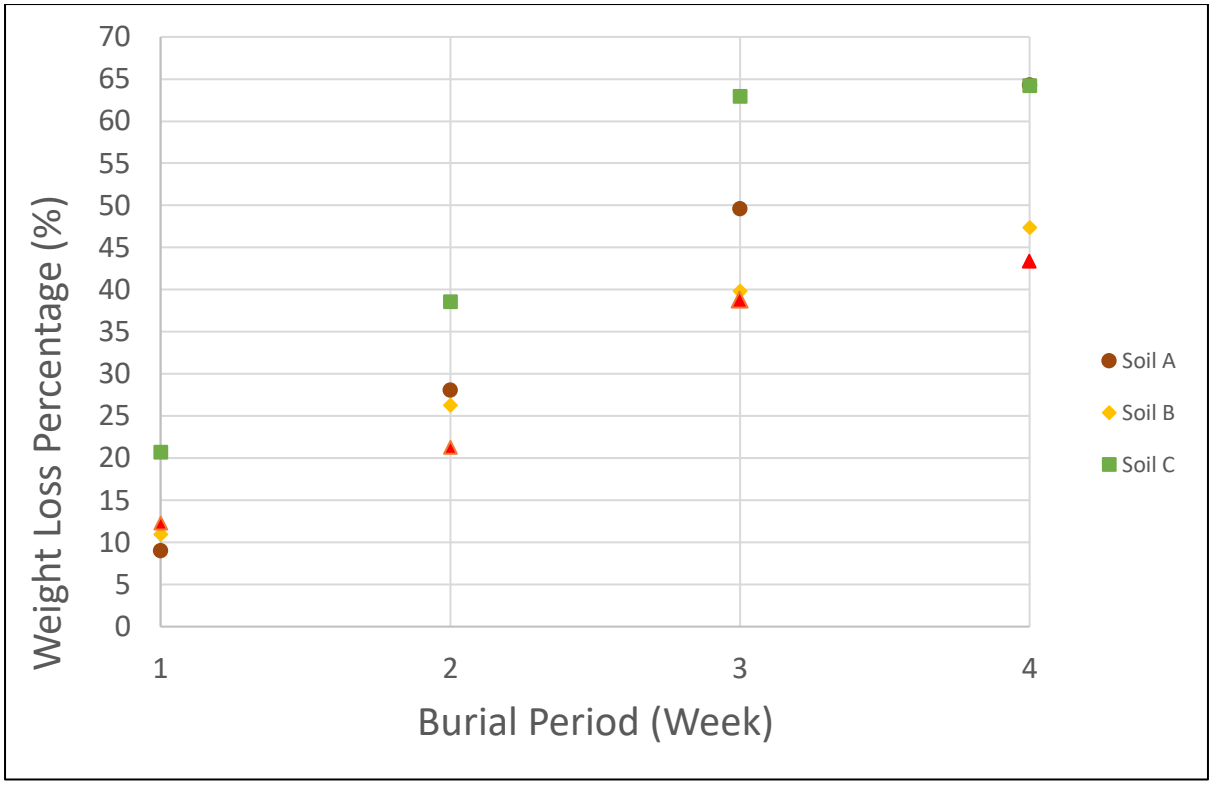



*Figure* 3.9 *shows the change in weight loss percentage over the weekly burial periods for all burial environments.*

The skin colour changes all followed a similar pattern across all of the samples, within a one-week burial period the skin colour changed from a fresh flesh to a dark orange-brown colour. All of the samples showed a similar skin layer texture; a hard-coated layer with a smooth glazed surface. Because of this, the samples showed little to no perforation from the soil environments. Due to the uncontrolled variable of the pig anatomy, the skin layer on each sample was not consistent, for figures 3.4 (a), (c) and (g) the skin layer was only attached to the body of the sample by fatty stringy tissue. All three environments show differences within the adipose layer, moisture being one of the most dominant factors of possible changes. On average, during the first two weeks of burial periods the adipose appeared wet and moist with compressibility. During this stage, the adipose had evidence of perforation by the soil environments as there was remaining soil within the moist adipose after the cleaning process. Some samples such as the compost, had compacted into the adipose, with a heavy coverage it was difficult to observe any colour or textural changes. It was common throughout Soil A and B that the adipose displayed changes after weeks three and four, the colour appeared to be a pale creamy yellow with a dry chalky consistency. The muscle layers for all samples showed to be very similar, all having a high value of staining and discolouration. The colour of the muscle showed some

slight changes within the environments mostly due to the consistency of the soil. The components of Soils (A) and (B) did not adhere to the muscle the same way the compost. The compost appeared to completely saturate the muscle therefore leaving colour analysis difficult, however profound staining could be suggested, whereas soils (A) and (B) were easily removed during the cleaning process therefore exposing the colour changes of the muscle. Some samples showed areas of prominent semi-opaqueness, the veining was also noticeable and displayed in a similar fashion.

Multiple studies, (Vass, 2011),(Megyesi, Nawrocki and Haskell, 2005), have attempted to quantify data regarding decomposition morphological changes to the body to further knowledge on the decomposition process. Megysesi and authors (2013) study developed total body scores (TBS); a body scoring method based on the decomposition stages defined by Galloway (1989). Other studies have included quantifying the degree of decomposition index, (Fitzgerald and Oxenham, 2009) and developments of quantifying accumulated degree days (ADD). In order to provide quantification data for the current study, factors of decomposition values were calculated for each sample. The decomposition factors considered for rating were odour, compressibility and weight gain/loss percentage change. The criteria of the ratings are outlined in section 2.2.4.4.

*Table 3.2 Shows factors of decomposition values for each meat sample.*

| ***SOIL A*** | | |
|---|---|---|
| ***Week Number*** | ***Odour Rating*** | ***Compressibility Rating*** |
| 1 | 3 | 2 |
| 2 | 3 | 2 |
| 3 | 3 | 4 |
| 4 | 0 | 5 |
| ***SOIL B*** | | |
| ***Week Number*** | ***Odour Rating*** | ***Compressibility Rating*** |
| 1 | 0 | 2 |
| 2 | 2 | 3 |
| 3 | 0 | 4 |
| 4 | 0 | 5 |
| ***SOIL C*** | | |
| ***Week Number*** | ***Odour Rating*** | ***Compressibility Rating*** |
| 1 | 3 | 4 |
| 2 | 3 | 4 |
| 3 | 0 | 5 |
| 4 | 0 | 5 |
| ***SAND (D)*** | | |
| ***Week Number*** | ***Odour Rating*** | ***Compressibility Rating*** |
| 1 | 2 | 2 |
| 2 | 2 | 2 |
| 3 | 3 | 3 |
| 4 | 0 | 2 |

When a cadaver is buried beneath the ground, decomposition fluids and bacteria are released into the surrounding burial environment. This surrounding environment has been referred to by literature as a cadaver decomposition island (CDI) (Fancher et al., 2017). As CDI's are associated with an increase in microbial biomass and activity (Aitkenhead-Peterson et al., 2012) it is likely that decomposing cadaver fluid is the source of this increase. However, it is important to note that within the current study the burial environment diameters were controlled, therefore creating a possible CDI which was limited to a standard dimensional area of the burial environment, *see figure 2.5 (section 2.2.2).* Previous research has shown that a decomposing cadaver has a high nutritional content due to a low carbon to nitrogen ratio and a high-water content (Carter et al., 2007). Research has shown that several factors such as scavenging and entomological activity, affect the rate of cadaver decomposition which may contribute to an increased nutrient content in the soil leading to enhanced flora sustainability (Carter et al., 2007). The scavenging carried out by animals may introduce new bacterial growth into the soil, which could affect the rate of decomposition within a burial period. Most commonly, entomological activity increases the rate of decomposition as certain bacteria, such as Staphylococcus (Vass 2001), and can attract different species which feed off the cadaver, thereby increasing the rate of decomposition until reaching a plateaued state when there is limited cadaver to feed from. However, in this project, both factors were eliminated to concentrate on how the burial environment itself affected the rate of decomposition. Odour produced by the decaying tissues can attract species for both scavenging and entomological activity. Research has shown that the recognizable odour of spoiled meat occurs when the total bacterial count on the meat is between $10^{7}$CFU $gr^{-1}$ and $10^{7.5}$CFU $gr^{-1}$ (Nychas *et al.,* 2008). Further exploration found that gram negative bacteria such as *Moraxella*, *Alcaligenes* spp, *Aeromonas* spp and other several species use depleted carbohydrates and amino acids as a source of energy (Koutsoumanis *et al.,* 2006). This combined with nitrogen and glucose compounds contributes to the famed foul odour. Microbiological analysis was not carried out within the current study; however, the meat samples radiated the recognizable odour of spoiled meat, therefore from previous research it can be suggested that similar microbiological activity had taken place. From the data provided in *table 3.2* , there appears to be a pattern in which the odour is not present in any soil types or sand during the fourth week of the burial period. This could be due to the size of the sample, or due to certain characteristics within the burial environment as samples range from musty aromas and fetid unpleasant odours, section 2.2.4.4. The meat samples in Soil A had the worst odour, with Soil B having the lowest ranked odours.

As highlighted in section 2.1.1, characteristics for both soil A and soil B had been analysed by national database; Soilscapes *(*Cranfield University, 2020). This analysis was used as it was crucial to understand the basic properties of the soil to find correlations between certain characteristics such as drainage, texture, and decomposition activity, *table A.1.* Both soils showed similar characteristics e.g., freely draining and loamy in texture. However, it should be noted that geological surveys such as that used by Soilscapes determine the characteristics in situ, where soil layers remain undisturbed. Disturbed soil samples, such as those used within the study, do not retain the in-situ properties of the soil during the collection process (Barnhart, 2018). Scientists and environmental professionals believe that disturbed soil samples are not a true representation of the underground soil. However, professionals do commonly test disturbed soil samples for geotechnical testing which does not rely on soil structure. These tests include soil texture, moisture content, nutrient content and contaminant analysis (Barnhart, 2018). Geotechnical data for the soil locations used in the current project were not available therefore, the characteristics and properties identified by Soilscapes for the soil samples used in the study, may not be the same once the disturbed soil is reburied.

Geotechnical testing considers various factors of soil that may affect drainage and compressibility. A factor contributing to soil drainage is particle size, surface to volume ratio and how this may affect compaction. Analysing sand, soil, and compost under scanning electron microscope (SEM) can be used to gain an understanding of particle size and any anomalies, such as heavy metal pollution and presence of organic matter, which may affect both compressibility and drainage.

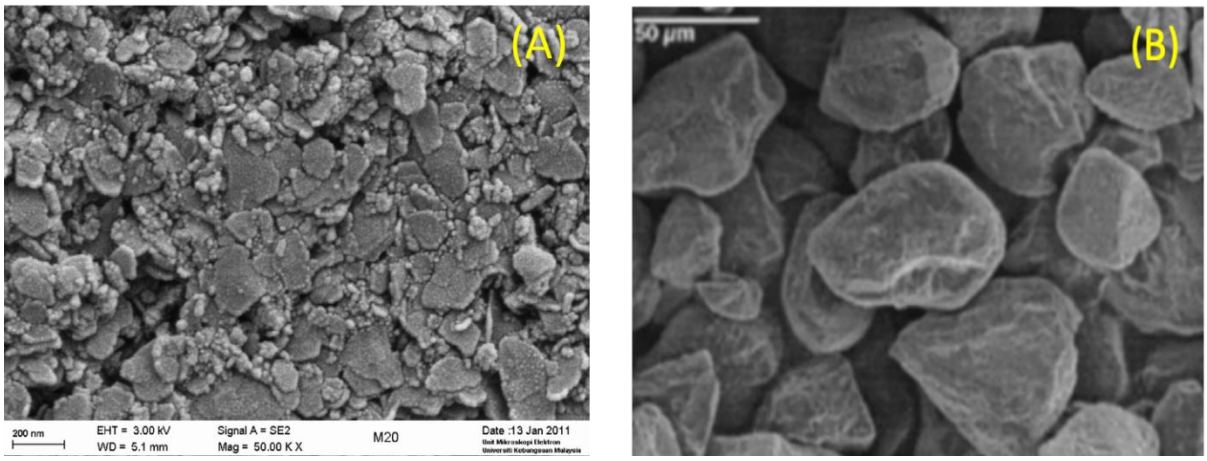



*Figure 3.10 shows scanning electron microscopy images of (a) soil (Rahman et al., 20013) and (B) sand (Alshibli and Alsaleh, 2004)*

SEM images may also provide sufficient information which may not be available to the naked eye. When comparing environments such as soil and sand, it is important to consider the composition of these environments. Soil composition is a mixture of particulates, typical sand/soil composition can be seen in the SEM images shown in *figure 3.1 0.*

A comparison of the SEM images shows that *figure 3.1* 0 (A) has a thinner, platelet type morphology whilst (B) has irregular particle sizes accompanied with a rounded shape. Soil fragments appear to have a higher degree of particle agglomeration compared to sand particles. This could suggest that moisture and decomposition fluids may not drain from the sample as easily within the soil burial environment, due to the grouping of the particles. This could suggest that moisture and fluids excreted from the sample may remain saturated within the surrounding soil and not drained freely throughout the burial environment used within this study. As sand fragments have a lower degree of particle agglomeration, see *figure 3.1O* (B), this creates a higher density of air pockets, commonly referred to as voids, which could allow fluids from the meat sample to drain into the environment.

It is also important to consider that soil can contain various amounts of organic and inorganic matter and without using elemental and microscopic analysis, the identification may remain unknown. The composition of compost can be more controlled than natural soil samples as compost is highly interchangeable and tailored for different plants. To achieve this, compost is manually mixed with organic and inorganic material whilst being prepared, *see section 2.1.1*. Due to the interchangeability factor, the fragmental composition of compost is different to that of soil. *Figure 3.11* shows a SEM image of compost, from the image it is clear that the structure of the compost fragments appears to be varied. Fragments have a wooden, bark like appearance which range from long to short, thin and thick. As the fragments are so varied, they appear to group closer together and leave limited voids. Observationally the fragments have ridged edges, this could indicate that the fragments can tightly compact around the meat sample and possibly penetrate into the sample. This could explain why the compost could not be removed during the cleaning process and had appeared to envelop the meat samples, see *figure* 3.7 (d), (f) and (h).

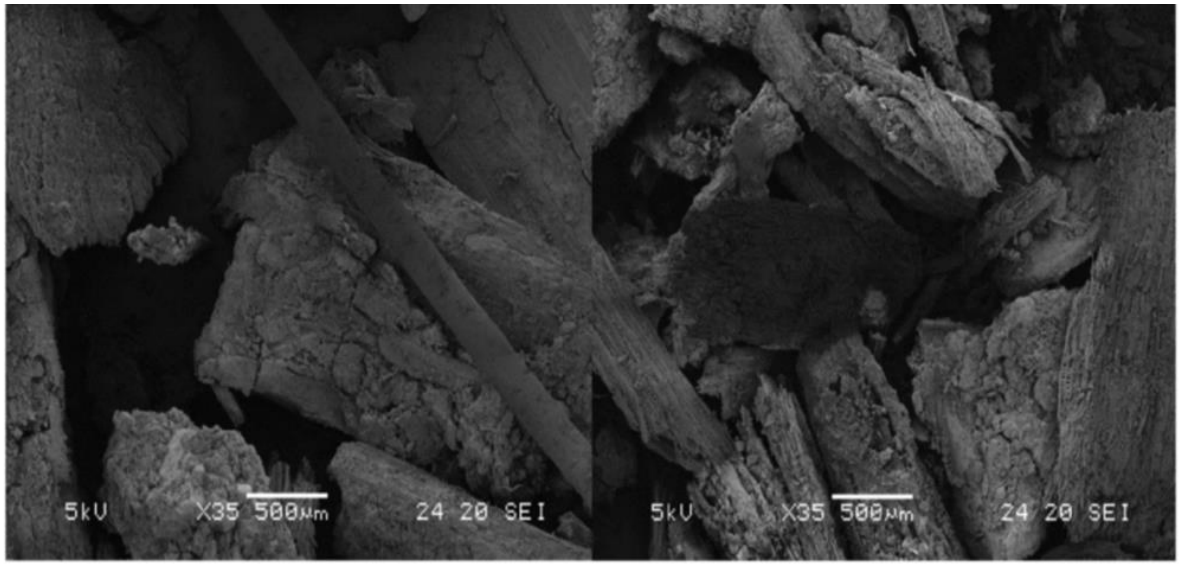



*Figure 3.11 Scanning electron microscopy image of compost, (Ramadan., et al 2018)*

Prior to the study, the samples were stored the same way for all burial environments and all samples were cut from the same piece of meat (section 2.1.3. *figure* 2.3). When studying the samples from the sand environment, it is thought that lactic acid bacteria (LAB) could be present during the first week of burial due to the storage conditions of the zip lock bags, see section 2.1.3. As the soil samples were also stored this way, it could indicate that the soil samples also had lactic acid bacteria present during the first burial periods. However, due to the lack of adhesion on the skin layer when the samples were recovered, it could be possible that the soil environment quickly eliminated the presence of LAB by draining the bacteria and fluids into the surrounding soil, essentially creating a small cadaver decomposition island. The elimination of LAB could have led to a halt of bacterial growth allowing the skin layer to dry and harden. The hardening of the skin is suggestive that it is acting as a protective barrier and preventing moisture from draining through the skin, therefore moisture is retained in the adipose possibly explaining the adhesive characteristics of this layer. The excess moisture combined with the 25°C environment of the temperature-controlled room provides a mild, damp environment, perfect for the formation of adipocere; a soap-like substance that can form from fats and lipids of a decomposing body (Forbes, Dent and Stuart, 2005).

Forbes, (2005) explored the effect of soil type on adipocere formation, using both soil and sand environments the authors concluded that when glycerol was removed from a pig sample within an anaerobic environment, saturated fatty acids are able to form adipocere and soil type played no factor within the formation, this was confirmed using elemental analysis. The study suggested that sufficient bacteria are present in decomposing tissue which may induce adipocere formation. It could be

suggested that the fat within the adipose layer seen in *figure* 3.3 (f), *figure* 3.5 (f) and (h) has formed adipocere due to possible bacterial presence being retained within this layer. However, when comparing the soils to the compost environment, none of the samples buried within the compost appeared to have formed adipocere. The absence of adipocere may be due to the close-fitting fragments of the compost tightly compacted around the muscle, which left a dry coating on the muscle layer, as seen in *figure* 3.7 (d), (f) and (h). The hardening of the fat layer had decreased the compressibility of the samples, therefore for compressibility ratings the samples were scored highly, *Table 3.2.* Soil A and B appeared to have the most compressibility in week one , in which the samples would regain shape after pressure was removed. However, over the four-week burial period, the compressibility significantly decreased, with both soil types scoring 5 in week four. The compost consistently showed little to no compressibility throughout the four-week burial period. Using this data within a real-life forensic application, it could be suggested that a human body buried in compost may have little to no compressibility and therefore be extremely delicate and challenging to recovery.

The muscle layer retained more moisture (Lorenzo, Serra-Prat and Yébenes, 2019) and due to decomposition starting prior to the study additional fluids may have been introduced to the environment early in the study. As mentioned previously, a study analysing the decomposition spoilage of meat products noted that the water content used for enzymatic reactions within meat products are measured using water activity ($a_w$), raw meat has an $a_w$ value of 0.98 – 0.99. Any value below 0.85 can result in a plateaued rate of decomposition. Applying those findings to the current study may provide a possible explanation of why the samples in the soil environments showed limited changes; except for discolouration, within the muscle layers between weeks three and four and the weight loss percentage plateaued. A possible explanation of the discolouration present within the muscle layers of all samples is the presence of metmyoglobin. It is studied within food science (Suman and Joseph, 2013) that meat contains myoglobin; a protein which stores oxygen within the muscle, like haemoglobin within blood. If meat is vacuum packed with no oxygen present, it may appear to have a purple colouration due to the protein being in a deoxymyoglobin state. When meat is exposed to oxygen, oxymyoglobin is present and meat will appear dark red. Continuous exposure to oxygen will oxidize the iron present within the meat, forming metmyoglobin which causes the meat to discolour to a brown shade (Suman and Joseph, 2013).

## *3.3.* Munsell Colour System

The Munsell colour system is a means of visually identifying and matching colour by using a scientific approach. It was created by artist Albert Munsell (Cochrane, 2014) who commonly expressed his interest in using scientific methods to measure colour. The fundamentals of the system are to be able to identify colour scientifically, therefore each sample colour is given an annotation by the analysist and this annotation is then used as the reference for that sample. Throughout the project, discolouration of the skin and muscle tissue was considered an important factor, it was hypothesised that the decomposing samples would display evidence of discolouration throughout the decomposition process. To analyse the discolouration, the Munsell colour system was considered an appropriate method.

When displaying a colour as a Munsell annotation, firstly the hue must be distinguished. Within a scientific setting, colour can be measured by its position within the visible spectrum. The Munsell system has five principal hues: Red (R), Yellow (Y), Green (G), Blue (B) and Purple (P). Five intermediate hues can also be used if there is a combination of multiple colours. The hue is then subdivided into decimals, to accurately measure the colour. The brightness (value) of the colour is then measured along with the saturation (chroma), on a scale of 0 – 10, (12 for chroma).

Although the method could be considered subjective, the Munsell colour system is a commonly used technique employed during soil analysis. Within soil science, the system is used to draw conclusions about soil composition, organic matter content, weather and topography. The Munsell colour system is a renown worldwide standard to measure soil colour (Pegalajar, Ruiz, Sánchez-Marañón and Mansilla, 2020), however the system has recently been applied within medical cosmetic procedures to attempt to accurately measure skin colour (Reeder, Iosua, Gray and Hammond, 2014). Taking the fundamental principles of the method and applying it to forensic research may provide a useful tool to scientifically analysis the skin colour change within the decomposition process.

For this study, the Munsell colour system was used to annotate the skin colour of the meat samples pre- and post-decomposition. To ensure an accurate representation of how the Munsell colour system can be developed for the use of human taphonomy, only the meat samples within a soil-based environment were included for analysis.

As all samples came from the same piece of pig, only one annotation was given as a pre-decomposition control for all of the samples. However, it should be noted that the meat was photographed first and

then analysed using the Munsell colour system it could be suggested that the colour of the skin seen on the computer screen may differ to the skin colour seen in real life.

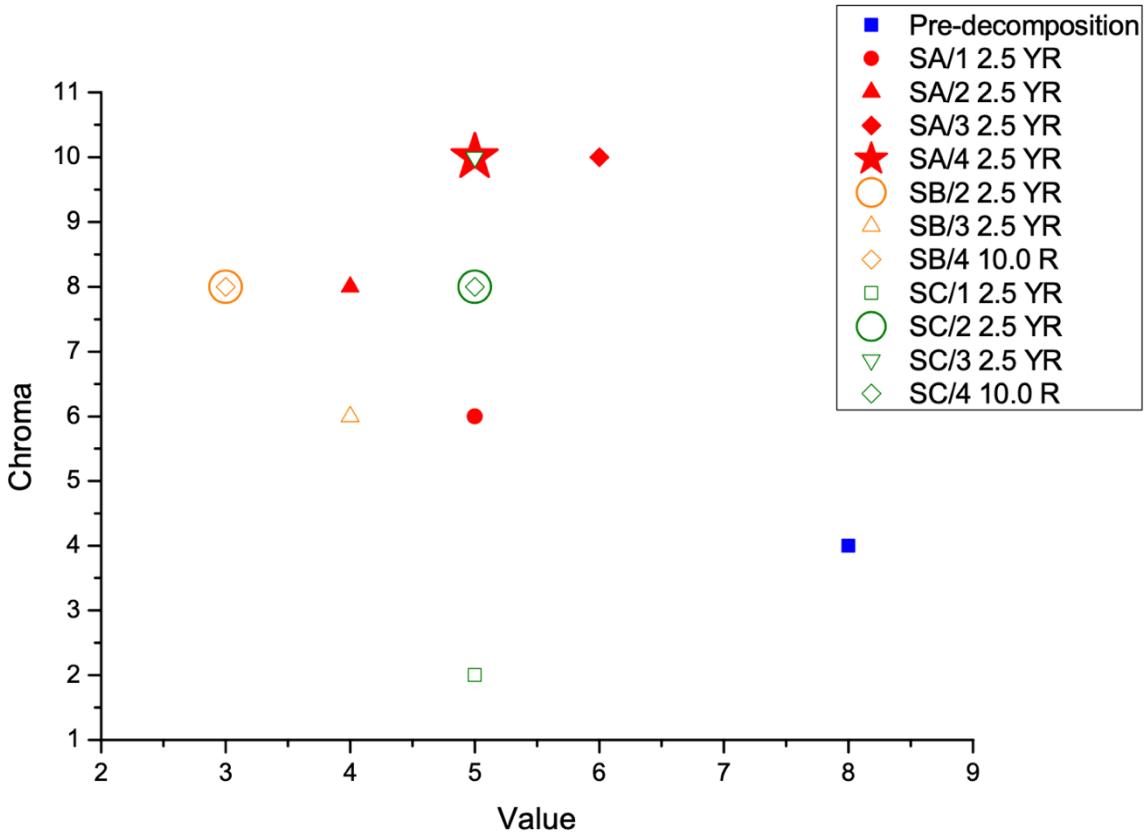



*Figure 3.12 shows graph displaying the Munsell Colour System annotations for all meat samples within the soil burial environment. Each meat sample is represented by a symbol, the symbol is referenced in the legend provided. The colour of each symbol indicates the soil type that meat sample was buried and recovered from, red = Soil A, orange = Soil B, green = Soil C (compost).*

As the meat samples were from the same source, only one pre-decomposition Munsell annotation was given for all samples. This notation was 10.00 YR (Yellow-Red), 8 (Value) /4 (Chroma) and is represented *figure 3.1* 2 as a blue square. Each meat sample was then allocated an individual symbol, the colour of the symbol indicates which soil type the meat sample was recovered from. When meat samples held the same value and chroma, *e.g., SC2 and SC4,* the size of the symbol was adjusted so both meat samples could be easily displayed on the graph.

The data shows that all meat samples changed colour over the decomposition process, sample hue changed from 10.00 YR (Yellow - Red) to either 2.5 YR (Yellow - Red) or 10.0 R (Red). The most common pre-decomposition hue displayed was 2.5 YR, however the chroma and values changed within this.

There were visible patterns within the colour changes for all burial environments over the four-week burial study period. One pattern shown within the data is that all the meat samples buried within the compost environment, *shown in green (figure 3.12),* share the same value (5) throughout the entire study period. The data also shows that the meat samples changed Hue when recovered at week four for both the Soil B and Soil C environment. The week four sample recovered from Soil B was measured as 10.00 R, when compared to 2.5 YR in week three. This also occurred within the Soil C (compost) environment, week four measured 10.00 YR whilst week three was measured at 2.5 YR, whilst Soil A remained consistent and did not change hue throughout the entire study.

There are numerous possible factors that may change human skin colour after death. Necrosis is a form of cell death, resulting from loss of membrane integrity and adenosine triphosphate (ATP) depletion (Van Wettere, 2018). Within a medical setting, necrosis develops a dark staining of the skin within the affected area. However, it could be possible that after death, the entire body is affected by necrosis as the whole-body experiences ATP depletion and loss of membrane integrity. Within the samples, there was a drastic change within skin colouration early within the study. ATP depletion causes rigor mortis which is a post-mortem change which occurs in the early stages of decomposition. Therefore, it is possible that the presence of ATP had decreased within the samples within a one-week burial period and consequently the meat sample developed necrosis which caused the dark skin discolouration. Another possibility of the skin discolouration within the meat samples buried in soil is that the close-knit fragmentation of the soils, may compact tightly around the meat sample, therefore staining the epidermis.

Overall, the advantages of using the Munsell colour system within forensic investigation is that skin colouration and/or discolouration could be used to develop post-mortem indicators. Using the system could allow for precise colour identification and a new understanding of how skin colour can alter over time. The data obtained by the study, proves that skin colour is continuously changing during the entire decomposition process. Developing this technique and creating a Munsell colour system uniquely for skin colour could aid in identifying the skin colour of a victim ante-mortem and then analysing the skin colour post-mortem to estimate burial periods and the correlating rate of decomposition.

## *3.4.* Water based burial environments

As mentioned in chapter one, bodies of water are a common deposition site for human remains. To replicate the variation of water deposition sites three water types were used. Water A was seawater collected from Herne Bay, Water B was pond water collected from Canterbury and Water C was stream water collected from Lenham. All bodies of water where samples were collected were situated in Kent, UK.

### *3.4.1.* Water A Results

Following the coding system which was used to label the meat samples and burial environments, *see section 2.2.2.* The burial periods ranged from one week to four weeks, therefore the meat samples for this burial environment were labelled WA1, WA2, WA3 and WA4. Prior to burial, each meat sample was weighed and photographed both pre- and post-decomposition. This is displayed within the *figure 3.13*, each meat sample within the discussion will be referenced by the letter allocated in the figure.

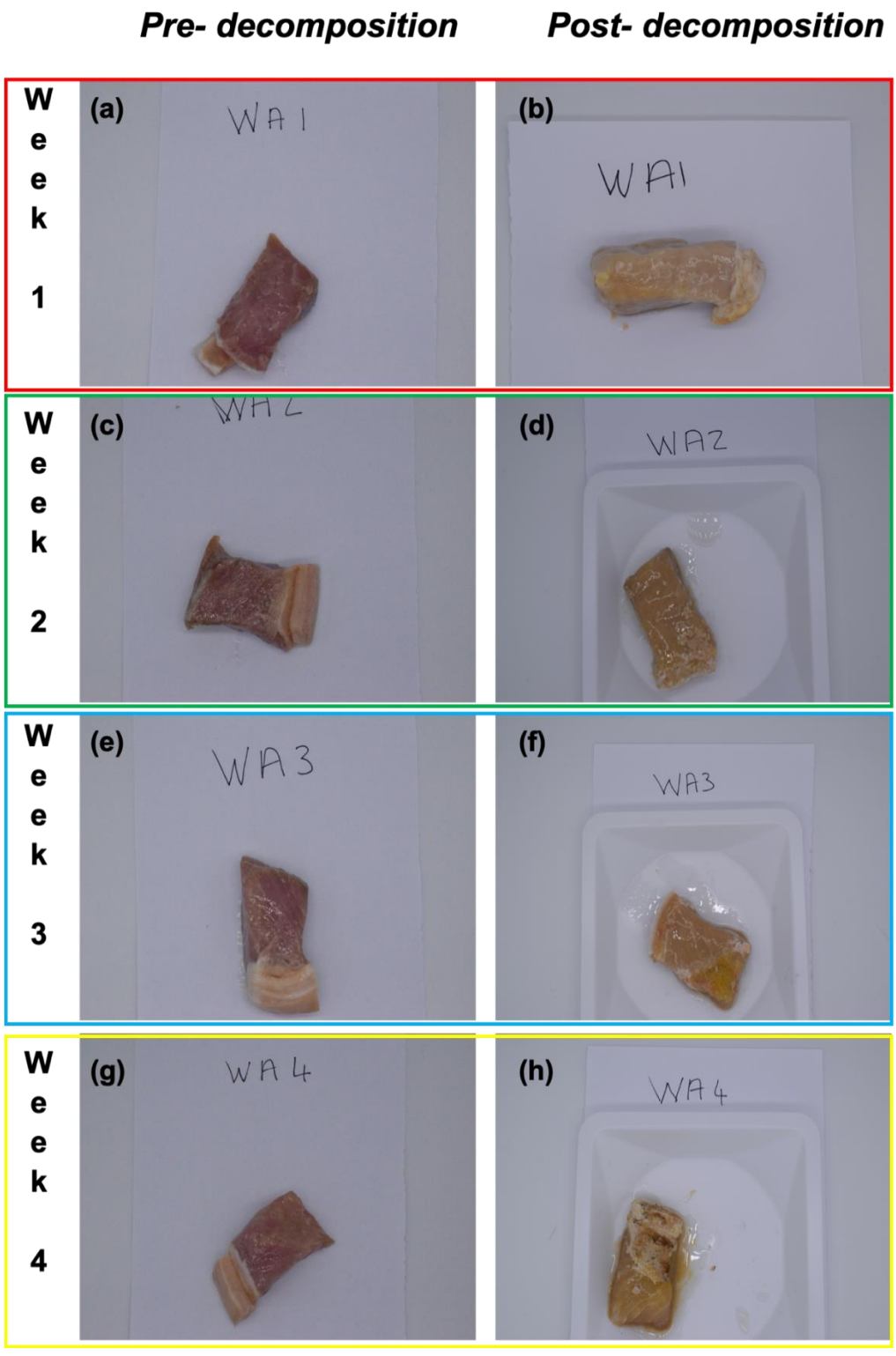



*Figure 3.13 showing photographs of the meat samples pre-decomposition and post-decomposition within water A, seawater. The images are labelled in chronological order from week one through to week four. All pre-decomposition photographs were taken prior to entering the compost environment and are then represented in their decomposed state labelled post- decomposition.*

Prior to burial each meat sample had several differences, including shape, size and various layer thickness. The meat samples used for Water A predominantly consisted of muscle tissue. There were evident signs of early decomposition due to the discolouration of muscle, adipose and skin layers for all meat samples. The discolouration was especially prominent within the adipose layers and the muscle layers, this was consistent for all water A meat samples. This is observed in the skin layer shown in *figure 3.1* 3 *(a)* where a small amount of connective tissue is attaching these layers. This may have been due a limited amount of adipose present in the sample which lacked in connective adhesion between the layers, see *figure 3.1* 3 *(a).* After a one -week burial period, the skin appeared to have lightened in colour and the adipose layer (shown in *figure 3.1 3 (b)*) had expanded and showed a swelling like appearance. This may be due to a larger surface area for water interaction with the adipose layer compared to those samples shown in the post-decomposition images for weeks 2 – 4 (*figure 3.1 3 (d), (f) and (g)*) When recovered from the water, the meat was coated with an orange-coloured film. The muscle layer on *figure 3.1 3 (b)* appeared to be structurally intact. The muscle had also changed colour, after the burial, the muscle was a lighter, paler complexion. Sensory findings found that the sample felt stiff when recovered from the water, it was also warm to the touch. The smell of the sample was also noted to be the most putrid within this environment. The skin layer on *figure 3.1 3 (c)* appeared to be attached to the body of the sample, however there was a clear decrease of adhesion between the skin and adipose layers, as discussed previously. After the two-week burial period, the water environment appeared to have an orange like appearance, similar to that seen previously, *figure 3.19*. The skin was coated in a scale like texture with a light white, grey colouring, see *figure 3.1 3 (d).* Due to the colouration of the muscle and the slime like coating of the meat, the adipose layer was not easily seen and therefore could not be analysed for significant changes. However, it was observed was that the adipose texture and appearance on this sample was not similar to *figure 3.1 3 (b).* The muscle layer for *figure 3.1* 3 *(d)* appeared darker after a two-week burial when compared to the one-week burial sample. The skin layer on both *figure 3.1 3 (e)* and *(h)* was very similar. The skin was attached to the adipose layer, but as mentioned previously there was a decrease in adhesion between the two layers. Both skin layers appeared to have some discolouration prior to burial, this could be due to the advanced decomposition state of the meat prior to the study starting, as mentioned previously. Both samples, *figure 3.1 3 (f)* and *(h),* had similar decomposition changes. The adipose layers on both samples were difficult to observe due to a thick slime coating which covered each of the samples after the recovery process. The only significant difference between the two samples was present within the muscle layer. As mentioned with previous samples, the muscle layer had been encrusted by a scale like coating. On *figure* (h), this scale coating had discoloured, and showed patches of dark brown staining. There was

also more muscle on *figure 3.1* 3 (h) which was covered by the scale coating when compared to *figure* (f) however, this could be due to the difference in burial periods.

To explore the weight changes of the meat samples within the water A environment throughout all of the burial periods, the difference between the weight prior to burial and post recovery were calculated into a percentage. Unlike the land based burial environments, the water-based burials gained weight, therefore *figure 3.14* illustrates the weight gain percentage for the Water A meat samples over the four-week study period. The trend of weight gain for water A is interesting as between weeks one, two and three there is a consistent increase on the weight gain percentage, however after week three, the percentage decreases by 10.56 % creating a curve. Observationally, the meat samples recovered from water A had structurally remained intact, with only colouration and coating differentiating between the samples.

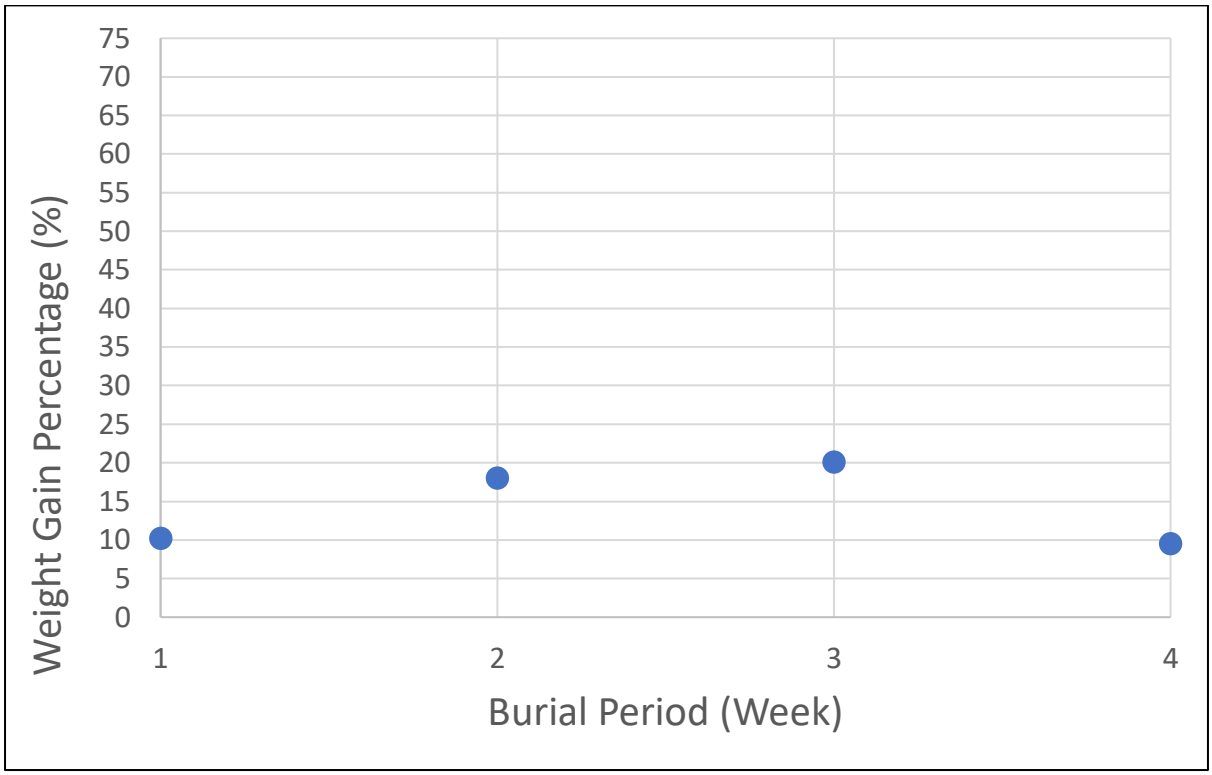



*Figure 3.14 shows the change in weight loss percentage over the weekly burial periods for water A*

### *3.4.2* Water B Results

Following the coding system which was used to label the meat samples and burial environments, *see section 2.2.2.* The burial periods ranged from one week to four weeks therefore the meat samples for this burial environment were labelled WB1, WB2, WB3 and WA4. Prior to burial, each meat sample was weighed and photographed both pre- and post-decomposition. This is displayed within the *figure 3.1*5, each meat sample within the discussion will be referenced by the letter allocated in the figure.

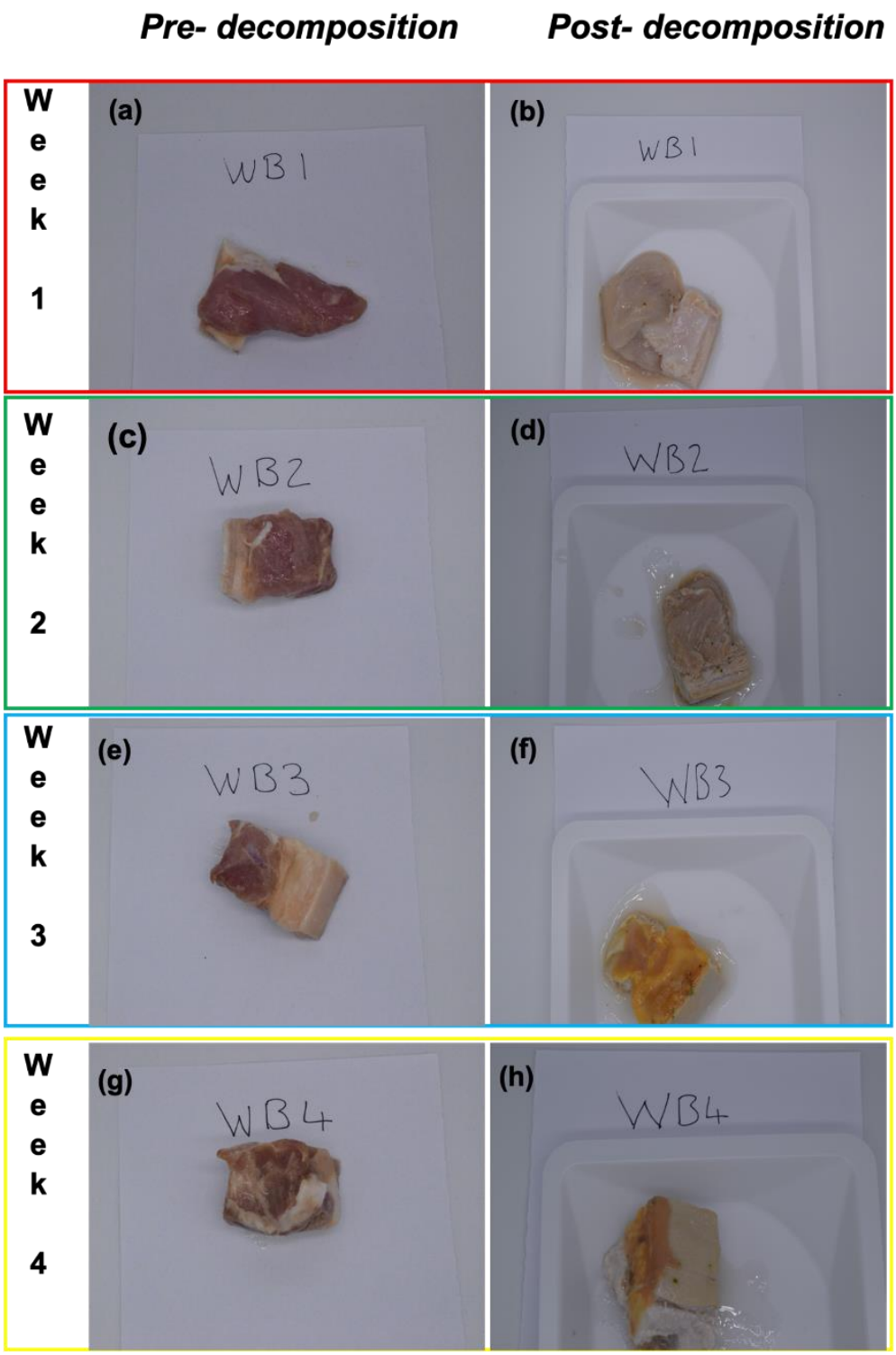



*Figure 3.15 shows photographic observations of the meat samples pre-decomposition and post-decomposition within water B, pond water. The images are labelled in chronological order from week one through to week four. All pre-decomposition photographs were taken prior to entering the*

*compost environment and are then represented in their decomposed state labelled post-decomposition.*

Prior to burial each meat sample had several differences, including shape, size and various layer thickness. The meat samples used for water C showed the largest range of differentiation between samples. The shape, muscle content, adipose ratio and presence of fascia was different for each of the samples. *Figure 3.1* 5 (e) appeared to have the most adipose present, with (c) having the least. *Figure 3.1*5 (a) appeared to have the largest muscle content of all the samples whilst *figure 3.1*5 (g) appeared to have the least. Fascia throughout the muscle layer appeared to be evident on all figures, however this was not prominent within the muscle layer of *figure 3.1*5 (a). Due to the data obtained for the exhibits shown in *figure 3.1*5 (a) and (b), it was not possible to perform a colour analysis of the outer skin layer. The skin structure of *figure 3.1*5 (b) was soft with little to no elasticity, this was noticeable when recovering the meat sample out of the water environment, this was consistent for all meat samples in this environment. The adipose layer on *figure 3.1*5 (a) prior to burial showed mild yellow discolouration, this could be due to the decomposition which had already commenced prior to the study (as discussed previously). The adipose also appeared to be delicately connected to the skin layer by loosely bound connective tissue as seen in *figure 3.1*5 (a). After a one-week burial period, the adipose layer was still connected to the skin layer however the connective tissue was more fragile, therefore making the recovery process difficult. The adipose and muscle layer of the sample, both showed a high level of discolouration, the muscle layer had a significant colour change from the dark pink colour as shown in *figure 3.1*5 (a) to a pale off-white shade, see *figure 3.1*5 (b). Similar to the adipose, the structure of the muscle had lost its integrity and become fragile during the recovery process, supporting the hypothesis initially stated. The skin layer on *figure 3.1*5 (c) appeared to be firmly connected to the body of the sample through thick layering. After a two-week burial period, the skin was still firmly attached to the rest of the sample, see *figure 3.1*5 (d). There also appeared to be a small quantity of an orange-coloured slime substance pooling around the skin layer , *figure A.4.* Dissimilar to *figure 3.1*5 (b), the adipose was firmly attached to the skin layer. Apart from a slight pale discolouration, there were limited decomposition changes. As predicted, there was a colour change within the muscle layer of the sample. The change was similar to that of *figure 3.1*5 (b), a pale off white colouration. However, there appeared to be an increase in the amount of veining observed within the sample after decomposition where these white markings covered a larger surface area of the sample.

The adipose layer on *figure 3.1*5 (e) was observationally larger than the rest of the samples. After the three-week burial period, the adipose layer was covered in an orange-coloured slime coating, see *figure 3.1*5 (f). The coating was also present after the four-week burial period, *figure 3.1*5 (h). These samples

showed minor visual decomposition changes when compared to the previous week. *Figure 3.1*5 (f) was covered with the orange slime-like coating whilst *figure 3.1*5 (h) was not and therefore was easier to observe. When recovering *figure 3.1*5 (h), the muscle layer was separating from the main body of the sample, evidence of this can be seen in *figure A.5.*

To explore the weight changes of the meat samples within the Water B environment throughout all of the burial periods, the difference between the weight prior to burial and post recovery were calculated into a percentage. *Figure 3.1*6 illustrates the weight gain percentage for the water B environment throughout the four-week study period. Between weeks one, two and three the weight gain percentages increase consistently, however there is a huge spike between week three and four where the weight gain percentage increased by 38.35 %. This large weight gain percentage change correlates with the observational changes analysed on *figure 3.1*5 (h).

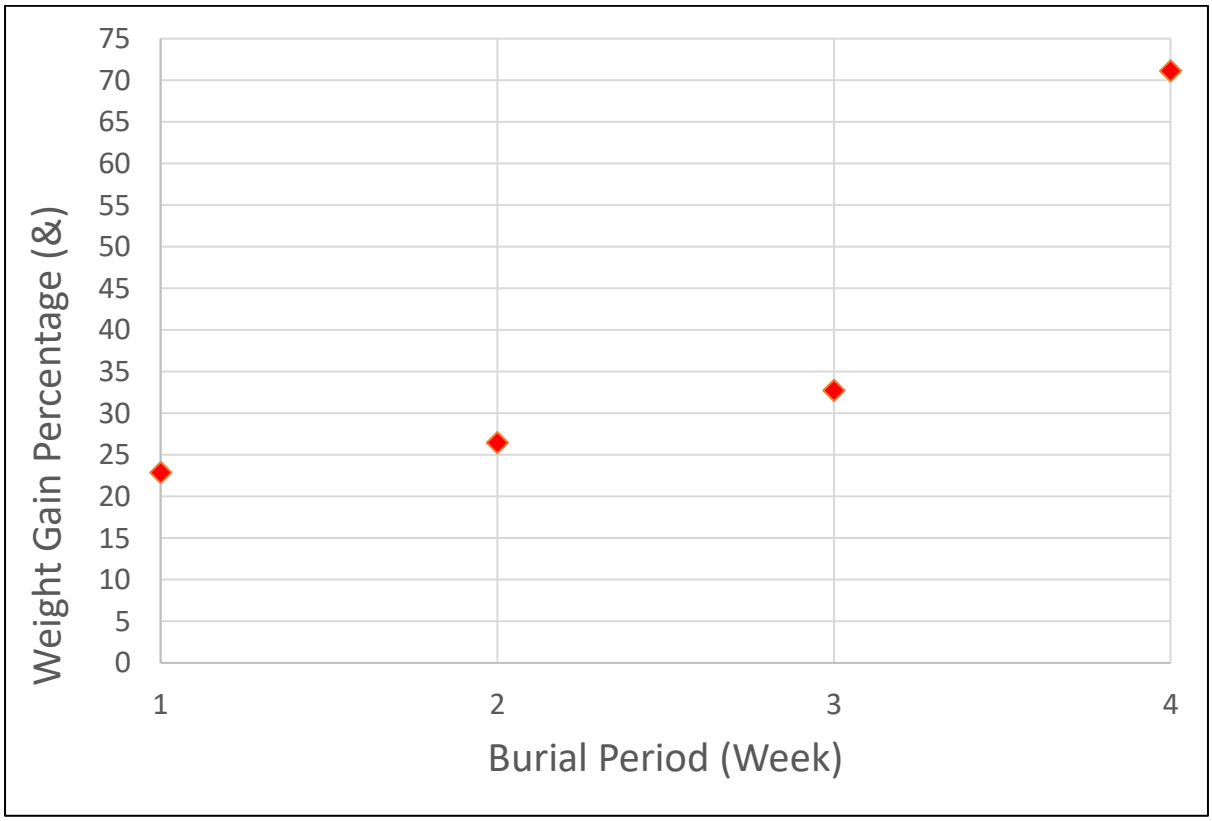



*Figure 3.16 shows the change in weight loss percentage over the weekly burial periods for water B*

### *3.4.3* Water C Results

Following the coding system which was used to label the meat samples and burial environments, *see section 2.2.2*. The burial periods ranged from one week to four weeks therefore the meat samples for this burial environment were labelled WC1, WC2, WC3 and WA4. Prior to burial, each meat sample was weighed and photographed both pre- and post-decomposition. This is displayed within the *figure 3.1*7, each meat sample within the discussion will be referenced by the letter allocated in the figure.

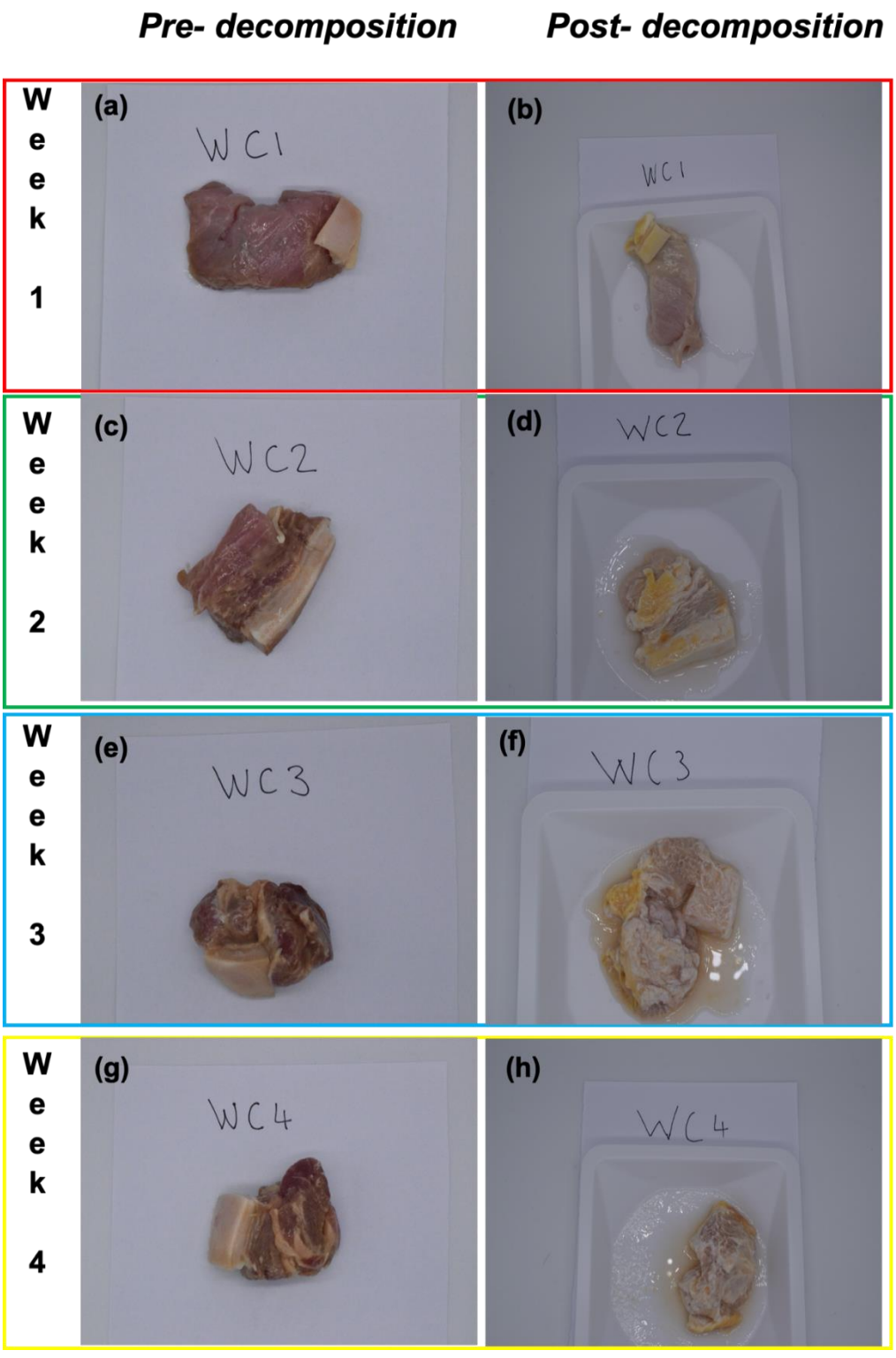



*Figure 3.17 shows photographic observations of the meat samples pre-decomposition and post-decomposition within water C, stream water. The images are labelled in chronological order from week one through to week four. All pre-decomposition photographs were taken prior to entering the*

*compost environment and are then represented in their decomposed state labelled post-decomposition.*

Prior to burial each meat sample had several differences, including shape, size and various layer thickness. Like the meat samples used within water B, the samples used for water C also had a broad range of differentiation between the samples. Similarities showed that all samples had a high presence of fascia throughout the muscle layers accompanied with dark discolouration due to early decomposition prior to burial. The characteristics of *figure 3.1*7 (a) was different to that of the other samples, *figure 3.1*7 (a) appeared to have less fascia and a higher muscle content than the rest of the meat samples used for water C. Figures *3.1*7 (e) and (g) appeared to have similar disfigured shape with the layers of the sample unidentifiable. The skin layer on *figure 3.1*7 (b) showed some discolouration after a one-week burial period. The skin had a pale-yellow consistency when compared to the pre-burial colour, see *figure 3.1*7 (a). Due to the positioning of the sample within the figures *3.1*7 (a) and (b) the adipose layer cannot be fully seen; therefore, a colour determination cannot be made. Common to figures *3.1*7, the muscle layer on *figure 3.1*7 (b) had discoloured to a pale pink within a one-week burial period. Within the muscle layer there appeared to be abrasions and marks. Most obvious of the abrasions was the large tear at the bottom the sample. The tear was present prior to burial, see *figure 3.1*7 (a) however it was not as prominent as *figure 3.1*7 (b). After a two-week burial period, the skin colour of *figure 3.1*7 (c) had turned white and was coated in an orange film which was also present on the muscle layer, see *figure 3.1*7 (d). The adipose layer on *figure 3.1*7 (d) did not show many changes but had shown some discolouration and had a grey, semi-opaque appearance. Orange film and remnants of the coating were found in the cup after the meat was recovered, *see figure A.6.* The structural integrity of the sample was still intact, as the skin layer, adipose and muscle layers could still be distinguished in their layered formation. *Figure 3.1*7 (f) and (h) showed the most changes within their decomposition. The layering of the samples such as adipose and muscle were indistinguishable due to the lack of structural integrity. Prior to decomposition, these samples showed a high degree of compaction, where a separation of the layers was not possible. After submersion, the compaction appeared to disperse, allowing for a separation of the layers.

To explore the weight changes of the meat samples within the Water C environment throughout all of the burial periods, the difference between the weight prior to burial and post recovery were calculated into a percentage. *Figure 3.1*8 illustrates the weight gain percentage for the meat samples recovered from the water C environment over the four-week study period. The weight gain percentage shows a consistent increase, with the largest increase being between week one and two (16.93 %). This

correlates with the observational decomposition data, the week one sample remained structural intact after recovery, however weeks two, three and four all appeared to had lost the structural integrity as the layers of the sample where undistinguishable suggesting that the increase of weight gain resulted from water absorption damaging the structural integrity of the meat.

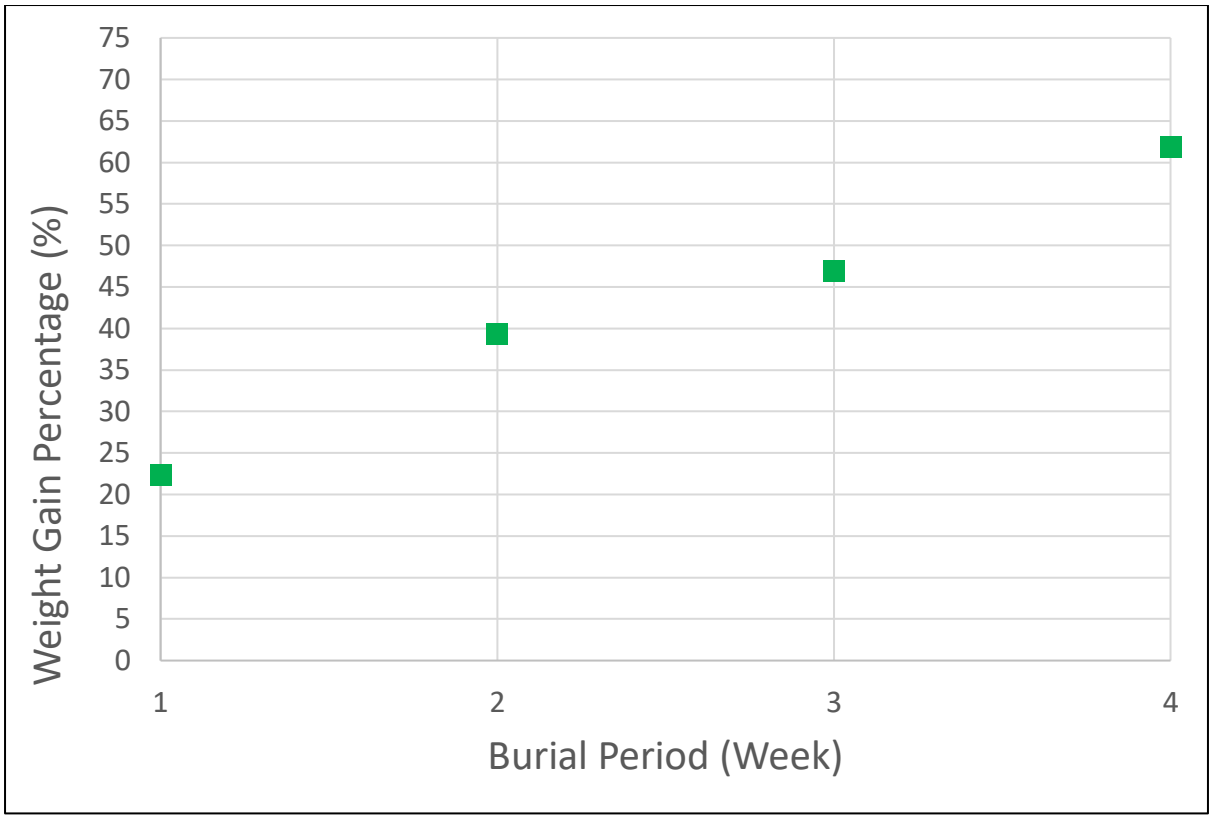



*Figure 3.18 shows the change in weight loss percentage over the weekly burial periods for water C*

### *3.4.4* Water Discussion

Similar to the decomposition of human remains within a land burial environment, remains which are submerged within aqueous burial environment are affected by factors such as temperature, animal activity, bacteria, and microorganisms (Caruso, 2016). In real world applications, human remains are commonly found clothed or covered. Clothing and coverings create a synthetic factor which may affect the decomposition rate of human remains. Within aqueous burial and deposition sites, determining the porosity of the covering or clothing material is valuable to forensic investigation as it can influence

various factors affecting both the rate of decomposition and the investigation process. Human remains found within concealments such as bin bags, plastic wrapping and bedding are indications of suspicious circumstances. Human remains found clothed or partially clothed could indicate the person fell victim to accidental death and were alive whilst within the body of water, internal body indicators would then be considered to determine the cause of death. As mentioned in chapter one, clothing and coverings including cloth and netting are usually the preferred concealment of human remains when depositing victims within a body of water, as plastic wrappings and coverings can trap air which may allow the object to float (Ellingham, Perich and Tidball-Binz, 2017). Clothing may also aid in the preservation of the body as joints and connective muscle tissue may be held together by tight clothing. Without clothing and coverings, joints and connective tissue are frequently observed to disarticulate (Ellingham, Perich and Tidball-Binz, 2017). Clothing and coverings may also aid in the detraction of scavenging and marine bacterial activity, therefore slowing the rate of decomposition (Ellingham, Perich and Tidball-Binz, 2017).

An important consideration when observing the rate of decomposition of either human remains or human analogue is that there will always be a large range of lifestyle differences which may influence various decomposition factors. Ante-mortem lifestyle choices for both animal and humans, such a diet, exercise and medical anomalies are all factors that need to be potentially considered. However, to understand how these variables may alter the decomposition process, it is fundamental to first understand the basic process of decomposition under different burial environments using one test carcass therefore for the current research project, only one pig carcass was used. After gaining a basic understanding of how burial environments may affect the rate of decomposition, human and animal uncontrollable anomalies could then be possibly considered for future research. A common lifestyle factor that may change the rate of decomposition is the fat content within the body. The higher the fat content, the more lipid and fat decomposition liquid. Within humans this is measured using Body Mass Index calculations (Tucker, Edlinger, Craig and Mattes, 2014) however when using pigs as human analogues fat content is not measured by mass index, but by a grading system due to the breed for consumption purposes (Nielsen, 2014). This is particularly important when using multiple test samples such as that used in human taphonomy research. However, there is an aspect of control regarding fat content when using pig carcasses to simulate human remains. Different cuts of the pig contain different fat contents, therefore using certain pieces of the pig allows for more control of fat ratio without having to use synthetic material to replicate a real-life burial circumstance. The current research project used boneless pork loin (*section 2.1.3*).

A large difference noted within the decomposition of the meat samples buried in water environment was the structural integrity of the samples post recovery. The structure of samples submerged in seawater (water A) appeared to remain intact, with the water remaining in the cup showing a distinguished layer of fat and oil, *figure 3.19* (A). However, this was not observed for samples recovered from both pond and stream water. The structural integrity of the meat samples had been severely compromised, especially within stream water (water C), see *figure 3.19*. As the sample was not covered or protected by clothing, it was hypothesised that the muscle and fat tissue would separate from the skin tissue based on the knowledge that human tissue is know to heavily disarticulate. The remaining water left in the cups for both pond and stream water were clouded with fat and oils emulsified within the water. This was more prominent within stream water (water C), see *figure 3.19* (C).


*Figure 3.19; shows remaining water types left in the cups after the meat was recovered at week 4 in (A) Seawater, (B) Pond water and (C) Stream Water*

During the putrefaction stage of decomposition, fats and lipids within the body become liquified and excrete from the body. This decomposition fluid is commonly referred to in literature as purge fluid (French and Jacques, 2020). The internal organs within a human body will liquify within ten days of decomposition due to putrefaction gas and ligament deterioration (French and Jacques, 2020).

Due to the decomposition of the meat samples, it was clear that decomposition purge fluid was excreted from the meat and into the body of water. Due to the oily composition of the fluid, it had not emulsified within the water and appeared to float on the surface creating a film like coating (*figure 3.19* (A)). As the burial periods were extended, the structural integrity of some meat samples were severely compromised which led to more decomposition purge fluid being excreted along with pieces of the meat sample breaking away adding to the film like coating. As the film coating within the cup built up due to the increase of decomposition purge fluid, when the meat was recovered from the cup it was pulled through the film coating which then wrapped around the meat sample, explaining the presence of the coating in *figure 3.15* (f), (h) and *figure 3.17* (d), (f) and (h).

It has been stated that saltwater decomposition proceeds at a decelerated rate compared to freshwater environments due to the salinity slowing bacterial activity (Simmons & Heaton 2013). From the data of the current study, it was clear that the salt water was aiding to preserve the structural integrity of the samples within this environment by delaying the decomposition process. Ellingham (2017) stated that within salt water, bodily fluids are drawn out of the blood whereas within fresh water, water is absorbed into the circulatory system which causes organs to swell and eventually rupture. On a smaller scale, the meat samples recovered from the stream water (water C) showed a large amount of structural damage, as hypothesised, which could have been caused by an absorption of water within the muscle tissue, leading to severe disfiguration. Evidence of water absorption can be seen in the comparison of the sample weight pre- and post-burial. To further analyse and compare the weight change, odour and compressibility values, quantification data was developed to provide a decomposition value in conjunction with the weight loss percentage for each meat sample. The criteria for scoring system are outlined in section 2.2.4.4. From the weight change data, *figure 3.20 and table 3.3,* water affects the weight of the meat samples differently to that of soil and sand burial environments. The meat samples submerged in water gained weight rather than lost weight, therefore the graph displays a weight gain percentage unlike the weight loss percentage of soil and sand. Water A (seawater) displayed the least amount of weight gain, whilst water C (stream water) showed a larger weight gain consistently over the burial periods. Water B (Pond water) showed a significantly high weight increase from week three to week four, an increase of 71.15 % of the initial pre-decomposition weight. Weight gain can be associated with the absorption of water within the layers of the sample, the increase in water content within the sample may also provide an explanation for the decrease in structural integrity which was witnessed in all water B and C samples, *see figures 3.15 and 3.17,* where the weight gain percentage was the highest.

*Table 3.3 shows decomposition value regarding weight loss for each meat sample within the water environments.*

| Week<br><br>Number | Water A | Water B | Water C |
|---|---|---|---|
| 1 | 1 | 2 | 2 |
| 2 | 1 | 2 | 3 |
| 3 | 2 | 3 | 4 |
| 4 | 1 | 5 | 5 |

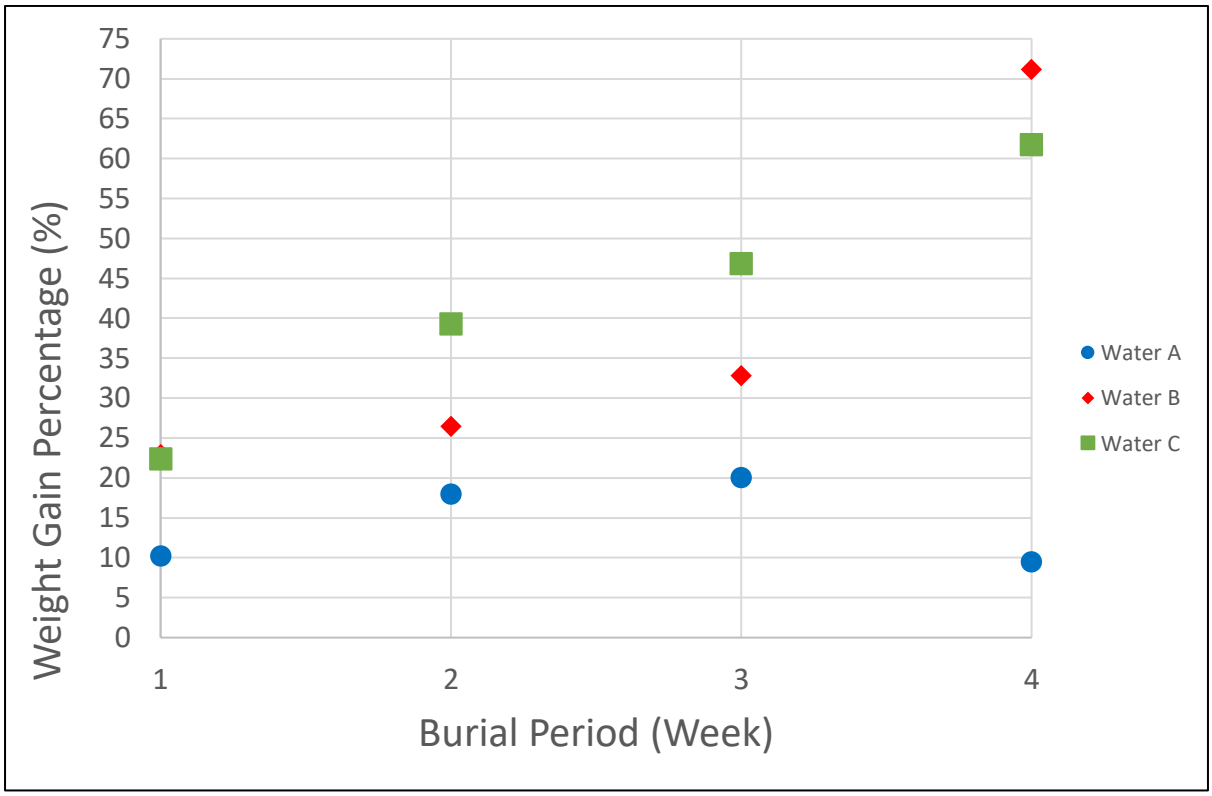



*Figure 3.20 shows the change in weight loss percentage over the weekly burial periods for all water burial environments*

Due to the complexity of how the meat samples were buried within the water environment, section 2.2.2.3, a compressibility rating was not allocated to these samples when allocating the meat samples decomposition values, *table 3.4.* As mentioned in section 3.2.5, negative gram bacteria along with nitrogen and glucose compounds contribute to the famed foul odour of decomposing meat. From the decomposition values given for the meat samples buried within the water-based environments, t*able 3.4*, the data shows that all water types displayed severely unpleasant odour within the first two weeks of the study, valued at 4 (*criteria found in section 2.2.4.4).* The odour from weeks three and four had progressed to a value 5 with researchers unable to remain in the room whilst the analysis was carried out. When compared to the other burial environments, the meat samples submerged in water had higher odour ratings during the first week than each soil and sand environment, suggesting that in a real life application, a human body recovered from an aqueous environment may have a stronger, severely unpleasant odour.

*Table 3.4 Shows factors of decomposition values for each meat sample.*

| ***WATER A*** | | |
|---|---|---|
| ***Week Number*** | ***Odour Rating*** | ***Compressibility Rating*** |
| 1 | 4 | 0 |
| 2 | 4 | 0 |
| 3 | 5 | 0 |
| 4 | 5 | 0 |
| ***WATER B*** | | |
| ***Week Number*** | ***Odour Rating*** | ***Compressibility Rating*** |
| 1 | 4 | 0 |
| 2 | 4 | 0 |
| 3 | 5 | 0 |
| 4 | 5 | 0 |
| ***WATER C*** | | |
| ***Week Number*** | ***Odour Rating*** | ***Compressibility Rating*** |
| 1 | 4 | 0 |
| 2 | 4 | 0 |
| 3 | 5 | 0 |
| 4 | 5 | 0 |

## *3.5.* Conclusion

The study found that the composition of the sand allowed for the meat samples to be dehydrated earlier within the burial periods, this then allowed the skin to harden and decolourise at an accelerated rate. The dry burial environment and the warm temperatures created the perfect environment for the formation of adipocere, the adipose on the buried meat sample had begun to harden and crust, a common indicator that adipocere is forming. Therefore, it can be concluded from this study, that

human remains found within similar environments within a real-life setting, may have increased formation of adipocere during a short burial period.

To replicate a common soil-based burial environment, three soils were used within the study. Soil A and B showed very similar rates of decomposition, samples showed similar discolouration and adipose textural changes. Therefore, from this study, human remains buried with soil from Kent, may show similar decomposition changes within a four-week burial period. However, the third soil used within the study was commercial compost (Soil C), this soil showed the most significant decomposition changes. The muscle mass for meat samples buried within compost decreased at an accelerated rate causing significant weight loss to the samples, also, the compost fully enveloped the sample which also could not be removed during the cleaning process which could have impacted the sample discoloration. From the findings accumulated from this study, there is more research that can be done on how compost burial environments may affect the rate of decomposition.

All the samples used within soil based burial environments underwent further analysis by studying the skin colour change over the burial periods. The Munsell Colour System method is commonly used within soil science, therefore was applied to this study to scientifically measure the colour change of the meat samples though the decomposition process. The findings from this application showed that compost exhibited a pattern within the colour change unlike the other soil environments. This method could be developed by further research, to be used within a forensic human taphonomy setting and help to accurately estimate post-mortem intervals in the future.

To replicate common water burial environments, water from three separate bodies of water, sea water, pond water and stream water, were collected and used within the study. Seawater was found to keep the meat samples structural intact unlike the pond and stream which did not. Stream water was found to be the most damaging on the structural integrity of the meat samples. All water samples had gained an abundance of weight, which was illustrated by the weight gain percentage graphs. Within a real-world application, the data from this study concludes that stream water may increase the rate of decomposition the most out of the studied water types.

When studying human taphonomy, there is one common factor which affects the rate of decomposition that cannot be represented within this study. Entomology is a large uncontrollable variable that can affect the rate of decomposition in numerous ways, depending on the environment. By carrying out this study in an outdoor setting would have allowed for entomological activity, which

would consequently led to inconsistent decomposition across the range of samples and lack of control against any additional mitigating factors.

By building the foundations of how certain controlled burial environments can affect the rate of decomposition, this can then allow uncontrollable variables such as entomology and scavenging to be considered as future research.

## *4.0.* Global applications of human remain recovery

In real world investigations, human remains can be found buried within various environments. Different regions of the world experience different climates and terrains, therefore, human cadavers can be found within a wide range of environmental circumstances. As mentioned previously, there is no literature stating a standard control on how burial environments may affect the rate of decomposition. Therefore, the second aim of this study to was to understand how this lack of standard control may have global implications within forensic investigation. The current study, as summarised in chapter 3, has shown that different water and soil types also play a factor in altering the rate of decomposition, the small scale of the practical element within this study highlights how large the range of variables could be, regarding the different sand, soil, and water composition all over the world. Hotter climates and dry terrain, such as desert land, may experience human cadaver decomposition much differently than regions with wet and cold climates and subsequently this may affect the recovery techniques used within the investigation.

To investigate this further, a survey was used to collect information on how different regions operate recovery plans for buried human remains within different burial environments. Countries within the responding regions are members of INTERPOL, therefore operation methods and techniques may be similar and held to high standards. Within this chapter, operating procedures for the recovery of human remains within soil, sand and water will be highlighted using the responses from the survey along with examples of real-world applications. The environment, climate and terrains from the responding regions will also be explored to highlight the difference in affecting factors and how this may alter recovery techniques and methods.

## *4.1* Introduction of survey responses

As mentioned previously and summarised in section 2.3, a survey was conducted to determine how forensic services and investigative personnel, from different areas of the globe operate the recovery of human remains within certain environments. The objective was to highlight the importance of understanding how different environments may affect the rate of decomposition, and how this can aid to develop accurate and efficient recovery plans. The survey consisted of 10 questions, which are discussed in section 2.3.4. In total, twenty-one forensic professionals from five regions of the world participated in the survey, regions included North America, Western Europe, South America, Middle East and Australasia, *figure 4.1.* The twenty-one participating forensic professionals hold various roles including, forensic archaeologists, crime scene management and investigators, lab technicians, forensic identification constable, forensic pathologists, expert witness, and medicolegal personnel.

The responses from survey questions 4, 5 and 6 were used to format an understanding of standard methods and techniques used to recover human remains within sand, soil and water burials.

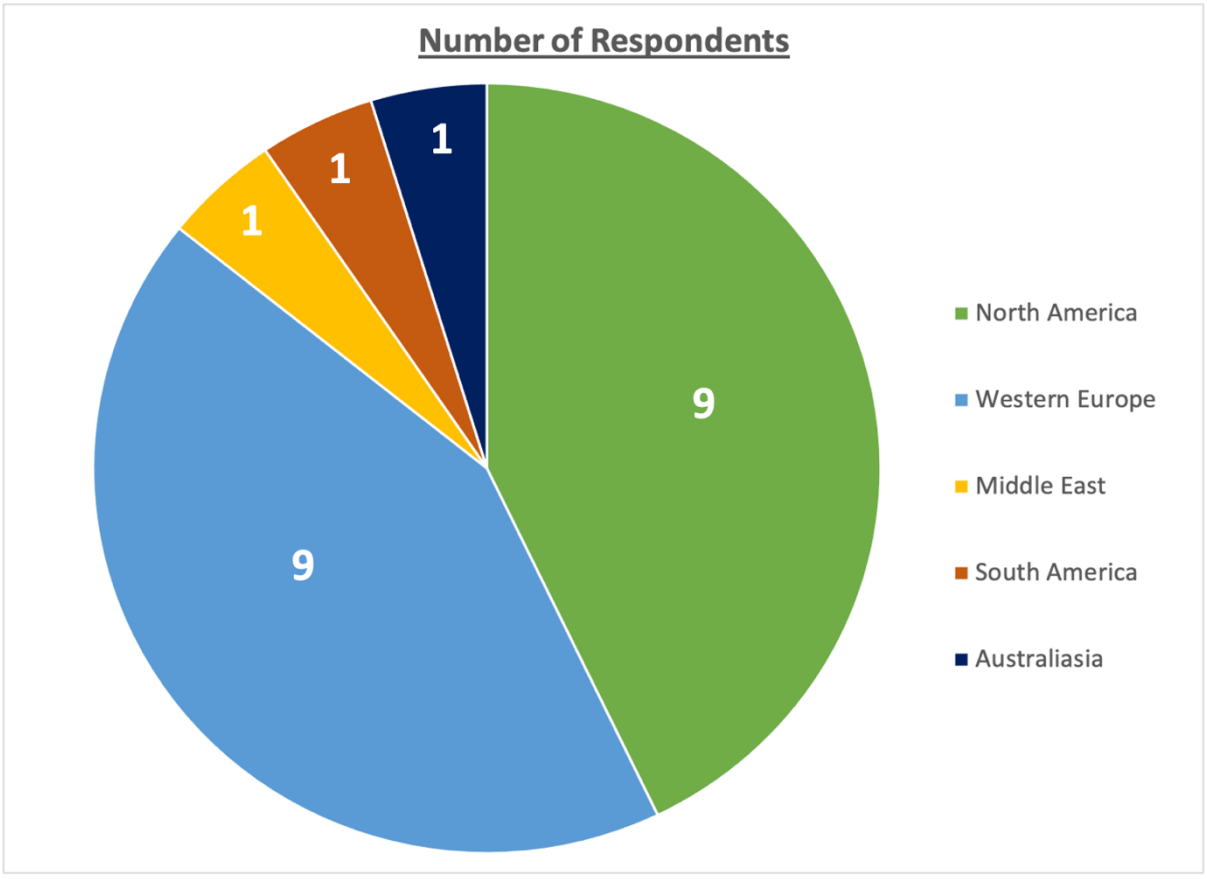



*Figure 4.1: pie chart showing the number and region of respondents from the survey*

## *4.2* Soil recovery

On average, survey respondents stated that recovery of human remains within a soil-based environment requires a multi-disciplinary approach, expert excavation, archaeological and anthropological advice are sought where appropriate. There are numerous standard methods and techniques used when recovering buried human remains, within soil however, a forensic geological recovery format is usually approached. Firstly, using datum and string the area of interest is mapped out to create a cordon to preserve the scene. The scene or area of interest is photographed and documented; this can include sketches and drawings of the site using forensic measuring equipment. The potential burial sites are then flagged by observing any vegetation changes or abnormalities using a systematic approach. For soil-based burials, equipment such as a T probe or Ground Penetrating Radar (GPR) may be used to find any soil disturbances or anomalies. Unmanned Aerial Vehicles (UAV) can be deployed to examine any photosynthetically active vegetation and detect chemical changes to surrounding vegetation, which can be used for the detection of a potential gravesite. Human remain detection K'9 units may be used if the area of interest covers a large terrain. When the gravesite is identified, the ground surface is closely examined by removing debris and fauna which is collected and analysed for trace evidence. The surface of the gravesite is examined for evidence of digging as tool marks can aid in determining what equipment was used to create the grave and extrapolate how many individuals were involved in the burial process, if tool markings are present this is photographed and accurately documented.

Using square shaped shovels, soil layers are removed from the grave and collected to be further analysed. As the soil begins to change colour, the digging equipment is swapped to trowels and brushes to ensure that any human remains, or artefacts are not damaged by larger initial digging equipment. Human remains are photographed as these are uncovered to ensure accurate and full documentation. Human taphonomy decomposition changes are documented in situ, if needed paper bags are placed around disarticulated remains to ensure these are completely recovered as the soil is removed. Once entirely uncovered, the remains are then carefully recovered from the gravesite and placed into cardboard boxes and/or bags which are sealed with evidence tape and labelled accordingly. After the remains are recovered, the soil layers are continually removed from the gravesite to ensure no evidence or skeletal material is lost. The soil is usually removed until the soil becomes sterile, and the colour is identical to the surrounding soil.

There are many challenges when recovering human remains from soil based burial sites. Respondents noted that all aspects can be challenging depending on the environmental circumstances, complexity, and age of the burial. Environmental factors that challenge the recovery include, weather, climate and terrain which may affect the equipment used for the recovery. Certain terrains can be challenging for machinery to access the area of interest. Detection equipment are commonly weather dependent, UAV's cannot be deployed in certain weather conditions such as heavy or torrential rain. Severe rain and flooding may also affect the surrounding soil of the grave, creating an unstable gravesite which can challenge the application of detection methods. Excessive moisture within the burial environmental will also influence the soil composition and water drainage, ultimately affecting rate of decomposition of the human remains. A response from a Forensic pathologist stated that one of the challenges with the recovery of human remains within a soil burial is the reliability and quality of the material recovered for identification processes.

One of the most notorious cases of soil-based buried human remains is the Moors Murders. In 1966, Brady and Hindley were convicted of abduction, sexual assault and the murders of children, Lesley Downey, John Kilbride and Edward Evans. Both Lesley Downey and John Kilbride's bodies were recovered on the Saddleworth Moor, UK (Cummins, Foley and King, 2019) following extensive foot search of multiple areas of interest, see figure 4.2. The investigation began when a witness to Edward Evans' murder reported the incident to the police, upon further investigation detectives then began to piece together evidence and information that linked both Brady and Hindley to missing children cases around the Greater Manchester area (Padnani, 2017). Incriminating photographs taken of the children and pictures of areas of outdoor terrain identified as Saddleworth Moor, led search teams to the burial site where in October 1965 the body of Downey was found (Padnani, 2017). Lesley Downey's body was visually identifiable, and her mother was able to identify clothing which had been buried with Downey in the grave (Cummins, Foley and King, 2019). Within close proximity of the first recovery, in October 1965, the severely decomposed body of Kilbride was found and only identified by clothing (Padnani, 2017). Although authorities believed there were more missing children suspected to be victims of Brady and Hindley, blistering winter conditions called off any further searches (Padnani, 2017). Brady and Hindley confessed to the murders of Pauline Reade and Keith Bennett however the gravesites have never been located and the bodies have never been recovered, even with the aid of modern-day technology, the area of interest is too vast and multiple searches for buried human remains have been unsuccessful. The outcome of this case highlights the need for more understanding on how human remains decompose within soil and marsh land burial environments. With more understanding on how the burial site affects the rate of decomposition, it could be suggested that investigators have a more accurate prediction the condition of the body, this could then aid in developing a suitable recovery and

search protocol. If human remains were found within the vicinity of this search area within current day, an understanding of how the burial environment affects the rate of decomposition could achieve a more precise PMI estimation which ultimately could link the remains to the Moors Murder case.


*Figure 4.2 showing (A) authorities digging the grave site where Lesley Ann Downey was found in 1965* (Ellis, 2017) and *(B) authorities searching for the remains of Keith Bennet in 2003* (Ellis, 2017)

## *4.3.* Sand Recovery

When researching recovery techniques for a sand-based burial, there is no published literature that highlights methods directly to sand within a forensic setting. On average, respondents to the survey highlighted that the recovery process shares the same principles as a soil-based burial, however extra precaution needs to be taken when considering sand stability. The biggest challenge with sand excavation is supporting the grave walls, ensuring that these do not collapse and damage the remains or lose evidence. Due to the sand stability, excavation team members must execute a strict recovery plan which limits the amount of weight within proximity of the grave walls.

If the area of interest is a coastal environment, accurate measurements of tide movements must be considered and included within the excavation plan to ensure the scene is not destroyed by incoming water. Variability in sand composition also has an impact on the recovery process as softer sand may be harder to remove sufficiently, one respondent noted that the south of Florida consists of copious amounts of sugar sand which causes issues and delays when recovering buried remains and artefacts.

Survey respondents also stated that the detection of human remains within a sand-based environment usually occurs frequently in archaeological projects. The excavations of mass graves usually rely on recovery plans which consider the environmental properties of sand such as stability, compatibility, and composition. For mass grave recovery, the support of heavy machinery such as excavators may be required for the initial stages of excavation to secure terrains and avoid landslides. On scene, archaeologists will apply their own disciplinary methods and techniques such as sieve screening, classification of findings and layer cleaning to ensure a successful excavation. In conjunction with soil based burial recovery, the area of interest is photographed, gravesites are heavily documented with photographs, drawings, and mapping. Once the human remains are located and exposed, they are photographed in situ, with the rate of decomposition being recorded and recognised. Commonly within sand environments, decomposition is usually in the mummification or skeletal remains phase. Due to the fragility of the human remains and surrounding buried artefacts, heavy machinery may not be a viable option. Therefore, it often takes a largely manned team to delicately brush away sand layers until the remains are exposed. Largely manned teams include professions from a wide range of disciplines, each applying their own field techniques and procedures. It was highlighted by many participants from the survey that one of the main challenges when recovering human remains from sandy terrains is working with multiple agencies who do not all follow the same procedures, therefore documentation may be low quality with no structured level of authority.

A recent case of buried human remains within a sand environment is that of James and Michelle Butler. The couple were reported missing on the 14th October 2019, after concerning family members had failed to contact the couple (Fruen, 2019). On the 27th October 2019, two human bodies; buried on top of each other, were recovered from a shallow grave on a remote section of Padre Island Beach, Texas *see figure 4.3*. Kleberg County Sheriff explained that the bodies were "*both are severely decomposed and have been taken to the Medical Examiner*" (Edmonds, 2020). On the 1st of November 2019 the bodies were identified as James and Michelle Butler (Rodriguez, 2019). Investigations then began on the unusual circumstances which had led to the couple's death.


*Figure 4.3: Image of authorities digging at the grave site situated on Padre Island Beach, Texas, where the bodies of James and Michelle Butler were recovered (Edmonds, 2020).*

As part of a routine missing person investigation, law enforcement personnel began searching the GPS location from the last-known communication from one of the couples' mobile phone which was situated on Padre Island Beach (Edmonds, 2020). The investigative team noticed something unusual located on the side of a sand dune, on closer inspection the item was identified as a ladies bra, this then led to the beach being an area of interest and the site being cordoned off (Garcia and Zaveri, 2019). Upon further investigation, a female body was recovered and due to continuous digging, a male body was also located just below the female (Edmonds, 2020). Due to the delicate burial environment, authorities had described the recovery process as "painstaking" (Garza 2019) as every effort was made to protect the evidence. This case was replicated on a smaller scale within the practical element of the current project. As discussed within the chapter 3, sand-based burials have a great affect on the rate of decomposition, especially the skin and adipose tissue. Hypothetically applying the data from the practical study to a real-life case, such as this, could help in aiding the investigative team to have a realistic and more accurate estimation of the condition of the individuals, such as James and Michelle Butler, prior to recovery. Having a more accurate estimation on the conditions of the remains may aid in the development in recovery plans and modify techniques.

## *4.4.* Water Recovery

Survey respondents stated that human remain recoveries from a water-based burial are very complex. These are usually carried out by a member of law enforcement; different world regions will deploy certain law enforcing authorities to the body of water which is of interest. For example, within the USA, the US Coast Guard will be deployed and lead the investigation.

Unless the human body is floating on the surface, task forces will be deployed for detection purposes. This is extremely common when ante-mortem data or witness statements suggests this may be the last known location of the victim. In deep sea environments, remotely operated vehicles (ROV) equipped with cameras are deployed, the images captured by the ROV are usually monitored by recovery personnel who can record and document the body of water.

Due to the high visibility of open water, the recovery process must be done quickly and effectively to respect the victim and the victim's family's privacy. Specialized personnel such as divers, are used to locate the body within the water and document the recovery depth. If possible, they will transfer the body onto a sheet and conceal it, recovery vehicles, such as fire service rigs, may intervene to help cover the body if the divers are unable. Once wrapped, the body is transferred into a special water recovery bag to minimize the loss of physical evidence. Once on dry land, the bodies can be transferred into conventional body bags.

As seen by the data obtained from the practical research element of the current study, water has a great impact on the rate of decomposition. It is common that after certain burial periods, joints and small muscles become fragile and disarticulate leading to partial remains being located. Depending on the decomposition state of the human cadaver found by the divers, they may need to use multiple bags to conceal any partial human remains. It is important to note that human cadavers that have been submerged for an extended period will have been subject to marine life interference. Aqueous environmental entomology and scavenging can range from region to region, therefore the marine biology species of the specific body of water needs to be considered to estimate the condition of the human remains.

A recent example of human remains recovered from water is Jennifer Ann Scott-Perkins. Her last registered location was Rye, Liberty Country, Texas, after she made a series of phone calls on her mobile phone which were picked up by a radio mass on her drive home on the 2nd January 2019 (Kenton, 2019). Using sonar detection equipment, the search team scanned the murky water of the nearby river where

a car was later detected (Kenton, 2019). Due to flooding which caused high waters, the rescue salvage operation was delayed until the 18th February 2019. Once able, the operation team managed to recover the car, see *figure 4.3,* which was registered to Scott-Perkins, human remains were then located inside the car, (Taylor, 2019) which were later identified as Jennifer Ann Scott-Perkins. Authorities speculate that Scott-Perkins was driving along a dirt road near to the Trinity River Bridge, due to the weather conditions, heavy rainfall had caused the river waters to rise, and authorities believe that Scott-Perkins accidently drove into the water, causing her death (Kenton, 2019).


Figure 4.4: Images showing the recovery of Jennifer Ann Scott-Perkins car, in which her body was discovered, from the Trinity River (Kenton, 2019).

Most recently, on the 8th July 2020, actress Naya Rivera went missing after renting a boat with her son on Lake Piru, California (Kanter, 2020). Authorities ordered an extensive search to begin after Rivera's four-year-old son was found alone on the rented boat which was drifting on the water. Captain Eric Bushow from Ventura County Sheriff Department told CBS News within an interview that sonar equipment along with specialised divers were used extensively to search for Rivera's body (CBS NEWS, 2020). Due to the conditions of the water, visibility was extremely poor, Bushow stated that divers had to use a "feel and grab approach", a method where the divers simply feel around the bed of the water to investigate any foreign objects. Eventually Rivera's body was found floating at the north east point of the lake by law enforcement boat crews, six days after Rivera went missing, the body was later identified as Naya Rivera using primary dental identification methods (Kanter, 2020).

## *4.5* Scavenging/ Environmental Factors

Scavenging can occur in all environments; the species and certain entomological activity will vary between climates and terrains. Human remains buried within mountainous rural areas may attract larger animals such as coyotes and wild dogs due to scarce food sources. Dry conditions, such as sand burial environment may attract various entomological species due to the scarce water and moisture sources. Within water, the range of scavenging depends on the body of water. Bodies of salt water may allow for large marine species such as sharks and certain crustaceans to feed of the cadaver. Fresh water, such as lakes, rivers and marsh could allow for large animals like alligators or flesh-eating marine life to feed from the human carcass. The depth at which the body is located can also affect scavenging, if the body of water has a limited oxygen supply at certain depths this will decrease the level of marine life present and can preserve the human remains for long periods of time.

## *4.6* Environmental Climate variations between regions

Different parts of the world experience a large range of climates, terrain, landscapes and environments. To fully understand how burial environments can affect the decomposition rate of human remains, it is fundamental that different regional environments are considered. Environmental climates can be divided into separate types including coniferous forest, deciduous forest, alpine/mountain, Mediterranean, savanna, desert, rainforest, grassland, tundra, areas of land with a permanent layer of frosted soil, and desert. Each climate type experiences a variation of average precipitation, level of humidity, daily temperatures and landscape ecology. Environmental variations may require standard recovery methods to be adapted, participants from the following regions discussed the environmental circumstances which prove challenging within the recovery of human remains.

### *4.6.1.* North America

Being the world's third largest continent, the terrain, climate and environment within North America is extremely varied (Wheeler,2015). North America consists of six countries, Greenland, Canada, United States of America, Mexico, Central America and the Caribbean. Most commonly it experiences cold winters with some areas having temperatures below zero, and warm summers (Wheeler, 2015). The various landscapes and terrain mean that a broad range of environmental factors can affect both the

rate of decomposition and the recovery process for human remains. As mentioned, scavenging and entomological activity varies within different terrains, and North America experiences landscapes consisting of mountainous, desert and rainforest like environments. Within a forensic setting, it would be expected that buried human remains would experience some level of scavenging, dependant on the area of the burial within the region.

Survey respondents were asked to disclose if they have experienced a time where their standard recovery and investigation techniques was adapted due to environmental circumstances. Weather conditions such as freezing temperatures, turbulent wind, heavy rainfall and flooding were all mentioned as circumstances which affect investigation. Freezing conditions in winter can require tents to be placed over grave sites, propane heaters are then used inside to thaw the area in which human remains have been found. Strong winds can damage areas of interest and create an unsafe environment for investigative staff, in this case tents can be erected and weighted down to provide some protection to the area of interest. Heavy rain fall can also compromise area of interests and grave sites, one respondent stated that flooding had caused the human remains to be scattered around, therefore the investigative team had to broaden their scene maps and surface area for the recovery process. Survey participants were asked to rank the following decomposition factors; Temperature, humidity, burial circumstances, deposition site, entomological activity, scavenging and human body size/weight, in order of most to least affecting. Survey respondents located in North America ranked temperature the most affecting factor then humidity, entomological activity, scavenging, burial circumstances, human body size/weight and finally deposition site the least affecting factor. As mentioned, North America experiences a large range of temperatures across the entirety of the region, therefore understanding the temperature and humidity of the burial site is of significant importance.

### *4.6.2* Western Europe

Western Europe consists of four different climate types, deciduous forest, coniferous forest and Mediterranean, Deciduous Forest is the most common climate (Wheeler, 2015), covering the majority of Western Europe, including the UK, Germany and Northern France. To the south of Western Europe, countries such as Spain; including Spanish islands, Portugal and Italy experience Mediterranean climates, with warm to high temperatures (Wheeler,2015). The northern parts of Western Europe experience cold, snowy climates with some areas experiencing permanent frosted soil (Wheeler, 2015). Survey respondents from Western Europe highlighted that the weather such as heavy rain, subsequent flooding and scavenging were all environmental factors which required adaptations to standard

recovery techniques. In one case, extreme flooding had significantly moved leachate from a grave site, consequently moving the CDI two feet away from the grave, therefore creating inconsistent soil analysis results when searching the area of interest. As mentioned previously, there is variation of scavenging depending on the terrain and climate. Schwartz (2008) found that within the UK the main scavengers are crows, they are known to frequently eat small animals and carrion, the flesh of dead animals.

Survey participants were asked to rank the following decomposition factors; Temperature, humidity, burial circumstances, deposition site, entomological activity, scavenging and human body size/weight, in order of most to least affecting. Interestingly, participants from Western Europe ranked temperature, deposition site and entomological activity as the most affecting factors. Followed by humidity, burial circumstances, human body size/weight and scavenging was then ranked the least affecting factor for the rate of decomposition. As Western Europe also experiences a large variety of climates and terrain, entomological activity will change and vary within different deposition sites, this will also be affected by the temperature of said deposition site. Therefore, by understanding the temperature and further investigating entomological presence within certain deposition sites is of high importance to study human deposition rates within this region.

### *4.6.3.* Middle East

Considered as transcontinental, the Middle East expands within Western Asia, North Africa and Southeast Europe consisting of states such as Egypt, Saudi Arabia, Yen, United Arab Emirates, Qatar and others (Ramanthan, 2005). The climate consists of extremely hot temperatures and dry conditions (Zhang , 2005); however, cities close to the coast experience high levels of humidity due to water vapour from the surrounding Mediterranean, Black, Red and Caspian Seas (Zhang , 2005). The region comprises of notoriously inhospitable vast deserts and mountain ranges with high peaks located in rural parts of the region with scarce human inhabitants. Areas with dense human population are commonly large built-up cities situated on the coast of the region.

The respondent stated that the Middle East predominantly faces very hot and harsh weather conditions with humidity being stated as a large affecting factor within investigations. However, research shows that the Middle East experiences extreme weather anomalies that would change the standard protocols for investigation. Dust and sandstorms are a perennial problem across the region, causing serious health and infrastructure complications, studies have shown that the frequency and intensity of the storms are increasing regularly (World Meteorology Organisation, 2017). Significant decreases

in annual rainfall is causing successive droughts, leading to both environmental and economic difficulties. Survey participants were asked to rank the following decomposition factors; Temperature, humidity, burial circumstances, deposition site, entomological activity, scavenging and human body size/weight, in order of most to least affecting. The survey respondent from the middle east highlighted that the most affecting factor from the given list on the survey that temperature and humidity were both the most affecting factor on the rate of decomposition of human remains. Interestingly, this respondent also mentioned these two factors within their other responses throughout the survey. With the Middle East experiencing high temperatures across the majority of the region, and high humidity levels present on the coastline, it is evident that both temperature and humidity would play a large role on the decomposition of human remains.

### *4.6.4*. South America

Being the world's fourth largest continent, South America consist of countries such as Argentina, Brazil, Ecuador, Uruguay and many others (Wheeler, 2015). The region comprises various landscapes and terrains, therefore, experiences a variety of climates and weather conditions. Vast areas of rainforest allow for high temperature and rainfall throughput the entire year, Savanna and Mediterranean terrain boast both high temperatures and significant rainfall, however the region does experience freezing temperatures within mountainous areas (Wheeler,2015).

Respondents from the survey stated that during extreme weather conditions, INTERPOL recommendations are followed, and specialized teams are deployed to recover and identify buried human remains. Survey participants were asked to rank the following decomposition factors; Temperature, humidity, burial circumstances, deposition site, entomological activity, scavenging and human body size/weight, in order of most to least affecting. The respondent from South America ranked human body size/weight as the most affecting factor, with temperature, deposition site, burial circumstances and humidity all being ranked the least affecting factors. The body weight and size can hugely affect investigation as it is believed that small bodies will decompose at a more accelerated rate than larger bodies (Sutherland, Myburgh, Steyn and Becker, 2013).

### *4.6.5.* Australasia

The world's smallest continent, Australasia homes four separate sub-regions; Micronesia, Melanesia, Polynesia and Australasia. The climate and environmental landscape vary across each sub-region with the majority of mainland Australasia consisting of desert scrub terrain, areas of extreme high temperatures with little rainfall. Like the Middle East, areas of the regions near the coastline are densely populated and home deciduous forest terrain. Survey participants were asked if standard recovery methods had to be altered due to weather conditions or certain environmental circumstances. Respondents from Australasia stated that weather is always considered when formatting a recovery plan, due to the uncontrollability of the weather in that region, recovery can be challenging as some weather conditions can result in loss of vital information. Survey participants were asked to rank the following decomposition factors; Temperature, humidity, burial circumstances, deposition site, entomological activity, scavenging and human body size/weight, in order of most to least affecting. The respondent from Australasia highlighted that the deposition site of the human remains was the most affecting factor as the location of the body is key to understanding further factors that may be present. Similar to the respondent from South America, the respondent also stated that body type was a highly affecting factor as this information can then introduce further factors, such as burial circumstances and entomology, into the investigation.

## *4.7.* Conclusion

By using a survey to explore how various regions of the world recover human remains from diverse burial environments provides a critical insight into how different forensic personnel operate and develop recovery techniques depending on environmental circumstances. Twenty-one survey respondents from five regions of the world including North America, Western Europe, South America, Middle East and Australasia were asked to explain the current methods used to recover human remains from sand, soil and water based burial sites. Respondents, of whom had various roles across the forensic science and law enforcement discipline disclosed the numerous methods used to operate recovery plans, real life examples of these recovery techniques were then studied. Within these responses, affecting factors were highlighted in order of importance, by the respondent's discretion. The environmental conditions, climate and terrain was further explored for each responding region, along with the variation of scavenging and technical challenges that may be faced within that region.

By understanding the variation of environmental characteristics of a potential burial site, investigative personnel can begin to estimate the condition of the human remains. Using the data from the practical

element of the study and similar human taphonomy research, it is clear that different environments can change the rate of decomposition. Therefore, by understanding how a certain burial environment may affect the human remains, a more accurate post-mortem interval and burial period estimation can be made.

## *5.0.* Thesis Conclusion

Decomposition of human remains is known to be affected by the burial environment, where those of primary importance are sand, soil and water, therefore the practical element of this research focuses primarily on those areas. In order to further understand the practical limitations, a survey was carried out aimed at forensic professionals to gain an understanding of challenges faced worldwide.

In order to understand the decomposition changes within a practical setting, the study was set up whereby pork loin pieces were buried within seven different burial environments. Buried at room temperature, within an environment which minimized light exposure to replicate real-world scenarios. Pig was used as a human analogue for this study as the UK currently does not allow for forensic research to be carried out on human remains, pigs are commonly used for research within various disciplines due to the similarities pigs and humans share. All-natural environments which were collected are located in Kent, UK. Soil A was collected from Elham, Soil B was collected from Sittingbourne, Kent, Water A was seawater collected from Herne Bay, Water B was pondwater collected from Canterbury and Water C was stream water collected from Lenham. Two commercially used environments were also used in the study, Soil C was commercial compost and the sand environment used was builders' sand.

The data derived from the soil burials within the practical element of the study showed that compost affected decomposition differently than the other soil environments. The weight loss percentage showed patterns which were different from soils A (Elham) and B (Sittingbourne). When applied to a real-world application, results found that the remains may have an accelerated muscle mass decrease and weight loss within a four-week burial period. The epidermis may also be severely discoloured due to the adhesion of soil particles to the outer skin layer. The environmental properties of the soil such as drainage should also be considered to understand how this may impact a possible cadaver decomposition island.

The findings from the sand environment concluded that over a two-week burial period, the muscle mass would decrease, causing extensive weight loss, the epidermis would firstly show abrasions from

sharp sand components penetrating the skin. However, the dehydrating properties of the sand combined with hot temperatures, would quickly harden the epidermis and cause severe discolouration to the skin.

From the practical results, seawater appeared to decompose at a decelerated rate compared to pond and stream water. The structural integrity of the meat samples within pond and stream water was extensively damaged with the anatomic layers being undistinguishable when recovered from stream water. When using these findings within a real-world application, it is possible to predict that human remains found in saltwater within a four-week burial period may be in better structural integrity than human remains found in pond or stream water. In the case of Naya Rivera, Rivera was submerged within lake water for a one-week burial period. Using findings from the practical project, it could be predicted that Rivera's body may have evidence of discolouration, a white pale appearance. At a one-week burial period, the muscle tissue would be extremely delicate, and the disarticulation of small joints may be evident. However, as mentioned in chapter four, different water types experience different scavenging patterns and activity, as scavenging is an uncontrollable variable within the real-life application, an accurate estimation of the presence of scavenging cannot be made.

The Munsell colour system is a renown worldwide application to measure soil colour, used within various science disciplines. The system allows for colour to be measured using a scientific method to ensure precise identification. Using the system to accurately measure skin colour change would be applicable within forensic investigation as skin colour annotation comparisons could help develop accurate post-mortem intervals. Applying this method to skin colour analysis was shown reliable and valid in Reeder's 2014 study, in which skin colour was perfectly measured within a medical cosmetic surgery setting (Reeder, Iosua, Gray and Hammond, 2014). Therefore, using the data from the current study along with recent applications of the method, there are sufficient grounds to which the application of the Munsell colour system for skin colour analysis, should be further studied and developed.

To further investigate burial environments, a survey was developed and distributed to various forensic professionals from all over the world. The survey was used to understand how different regions of the world experience diverse environments, therefore human body deposition and burial sites may vary around the world and consequently affect the rate of decomposition of human remains. Survey responses were used to explore standard methods and techniques for the recovery of human remains within sand, soil and water based burial circumstances. As the responding regions consist of member countries within INTERPOL, many of the recovery techniques disclosed were similar. Challenges faced by the professionals differed from region to region, North America and Western Europe faces harsh

winter conditions, such as freezing temperatures and turbulent winds which can compromise operations. Whilst the Middle East and parts of Australasia experience similar hot temperatures with high levels of humidity which were stated as a highly important affecting factor within their investigations. From the responses it was concluded that different regions of the world experience a broad range of temperatures, climates and terrain therefore each region may experience unusual human deposition and burial sites which ultimately may have an effect on the decomposition rate.

A common response from the survey was that there was no specific standard method or technique mentioned when recovering human remains from a sand-based environment, there is also no literature regarding sand based burial site recovery upon further research. The lack of standard sand recovery protocols may not affect all regions, but it is a limitation within the forensic investigation discipline. The data obtained by the practical study highlighted the physical changes and weight changes that can occur within the epidermis, adipose and muscle tissue when buried within a sand based burial environment over a four-week burial period. These research findings aim to contribute knowledge regarding sand-based burials and help aid the development of standard recovery protocols.

Human taphonomy has many important applications within the criminal justice system, some of these techniques are well established and have proved vital within Forensic Investigation. However, there are some limitations to current knowledge and areas which can be improved. This research aimed to further knowledge in not only practical scenarios but also to shed light on the limitations faced by forensic practitioners worldwide, by approaching those who are currently experiencing these challenges on a day-to-day basis. This research has shown how different environments affect decomposition, a factor which could be used to improve accuracy of PMI determination and has also suggested methods by which incorporating techniques, used in other areas of the discipline, such as that used for soil analysis. This research has focussed upon understanding decomposition under controlled circumstances, including temperature and removing factors such as entomological activity. Future research should focus upon introducing these variables and understanding how these affect the decomposition process and how this may be expanded to develop future recovery techniques.
This research will, therefore, serve as a starting point for future research to further investigate decomposition which will have a great impact within Forensic Investigation.

# Appendix

Table A.1

| | SOIL A | SOIL B |
|---|---|---|
| TEXTURE (Upper 30 cm of soil) | Loamy | Loamy |
| COVERAGE | England 15.5 %<br>Wales 24.4 % | England 3.7 %<br>Wales 0 % |
| DRAINAGE | Freely Draining | Freely Draining |
| FERTILITY | Low | Medium |
| HABITATES (Potential Vegetation) | Neutral and acidic pastures | Rich chalk and limestone pastures |
| LANDOVER | Arable<br>Grassland | Arable<br>Grassland at higher altitudes |
| CARBON | Low | Low |
| DRAINS TO | Local groundwater<br>Rivers | Chalk or limestone groundwater |
| WATER PROTECTION | Groundwater contamination with nitrate.<br>Enrichment of streams from soil erosion of this soil. | Vulnerable to leaching of nitrate to ground water. |
| GENERAL CROPPING | Soil has long grazing season, free drainage reduces the risk of damage to the soil and shortage of soil moisture acts as a limiting factor of yields. | Suited for various cereals and crops, but the land is extremely nitrate vulnerable. |

A.1

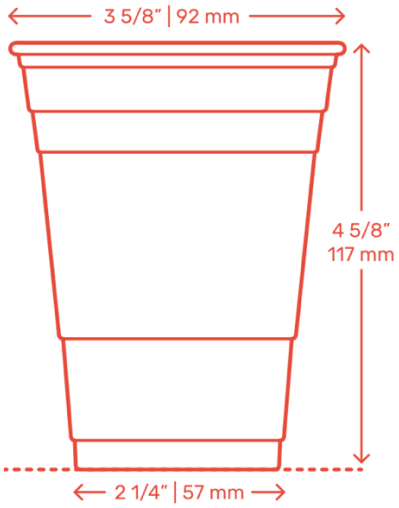



*Figure A.1 shows the standard dimensions of a red 'beer pong cup"*

A.2


*Figure A.2 shows post decomposed meat sample with the skin layer loosely bound to the body of the sample (figure 3.3 (h)).*

A.3


*Figure A.3 shows the wound like appearance of figure 3.3 (h).*

A.4

*Figure A.4 shows small quantity of an orange coloured slime substance found pooling around the meat sample*

A.5

*Figure A.5 shows the damaged muscle layer of figure 3.25 (h).*

A.6

*Figure A.6 shows the water environment once figure 3.17 (d) was recovered.*

A.7

*Figure A.7 shows sharp sand components penetrating the skin layer of figure 3.1(h).*

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