Estimation of Post-Mortem Interval Using Decomposition Scales for Hanging Bodies

by

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Abstract

The extent of decomposition of a body can be used, in conjunction with accumulated degree days (ADD), to provide an estimate of the post-mortem interval (PMI). PMI estimations are important in aiding police to narrow down the possible identity of a body, and to include or exclude suspects, and also to establish the order of death for inheritance purposes when two or more potential beneficiaries die at around the same time. Previous studies have shown the decomposition pattern in hanging bodies to be different from that of a body on the ground, but the sample sizes used have been small.

This study presents the results of a series of decomposition studies on hanging bodies in a variety of situations; clothed and unclothed, and fully or partially suspended. The study used domestic pigs (*Sus scrofa*) which enabled large enough sample sizes for statistical robustness. Pigs lying on the ground were used as controls. The pattern of decomposition in hanging pigs was found to differ sufficiently from that of pigs lying on the ground to require the creation of a novel decomposition scoring scale, which was used successfully to score both clothed and unclothed fully suspended bodies, as well as the upper, suspended, part of partially suspended bodies.

The presence of loose, lightweight clothing, which did not impede insect access, was found to affect both the pattern and rate of decomposition in hanging pigs, with the clothed bodies decomposing faster than the unclothed bodies ($p < 0.05$, $F_{2, 477} = 1238$).

The variations in the start weights of the pigs used for these studies was found to have a statistically significant effect on the rate of decomposition for both the hanging bodies and those on the ground (p < 0.05, $F_{5, 714}$ = 1962) but the effect was so small as to make no practical difference across the range of start weights encountered. The effect of variation in start weight may be of greater concern, however, in scoring very heavy, obese, bodies and may be exacerbated by the increased fat-to-muscle ratios encountered in such bodies.

Finally a set of ADD prediction tables were produced for the hanging and surface pigs. Further work is needed to establish to what extent these tables can be used for humans and, in light of the growing obesity problems in humans, to investigate the effect of weight and increased fat-to-muscle ratios on the pattern and rate of decomposition.

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Abbreviations

ADD	Accumulated degree days
ADH	Accumulated degree hours
ANOVA	Analysis of Variance
ARF	Anthropological Research Facility (Tennessee, USA)
ATP	Adenosine Tri-Phosphate
BMI	Body Mass Index
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CPSC	Consumer Product Safety Commission (USA)
DEFRA	Department for Environment, Food & Rural Affairs (UK)
PBS	Partial Body Score
PBSH	Partial Body Score for the Head
$PBSH_{hang}$	Partial Body Score for the Head of a hanging body
$PBSH_{surf}$	Partial Body Score for the Head of a body on the surface/ground
PBSL	Partial Body Score for the Limbs
$PBSL_{hang}$	Partial Body Score for the Limbs of a hanging body
$PBSL_{surf}$	Partial Body Score for the Limbs of a body on the surface/ground
PBST	Partial Body Score for the Torso
$PBST_{hang}$	Partial Body Score for the Torso of a hanging body
$PBST_{surf}$	Partial Body Score for the Torso of a body on the surface/ground
PMI	Post-Mortem Interval
RoSPA	The Royal Society for the Prevention of Accidents (UK)
SRL	Semi-Recumbent Lower
SRU	Semi-Recumbent Upper

TBS	Total Body Score
TBS_{hang}	Total Body Score for a hanging body
TBS_{surf}	Total Body Score for a body on the surface/ground
TRACES	Taphonomic Research in Anthropology: Centre for Experimental Studies (University of Central Lancashire, UK)
WHO	World Health Organization

1 Introduction

It is estimated that globally by 2020 there will be a death by suicide every 20 seconds, or 4320 suicides daily (Dogan *et al*., 2015). Hanging is the most common method of suicide. Hanging deaths also occur as the result of accidents, including in autoerotic activities, where there is a malfunction of the fail-safe mechanism, and the solitary and secretive nature of these activities means that bodies are not always found immediately and identification may be difficult.

Post-mortem interval (PMI) estimations are important in aiding police to narrow down the possible identity of a body, and to include or exclude suspects (Moffatt *et al*., 2016), and also to establish the order of death for inheritance purposes when two or more potential beneficiaries die at around the same time. One method of estimating post-mortem interval uses decomposition scores, to assess the degree of decomposition of the body, in conjunction with accumulated degree days (ADD) to provide a timeline. Studies have shown that patterns of decomposition vary in different situations, thus one decomposition scoring scale will not suffice; there is no “one size fits all” decomposition model (Parks, 2011). Various decomposition scoring scales have been produced including those by Megyesi *et al*. (2005) for bodies on a surface, Heaton *et al*. (2010) for submerged bodies, and Gruenthal *et al*. (2012) for charred bodies. Each of these scales reflects the decomposition patterns specific to the situation.

1.1 The Research Study

Studies have shown the decomposition pattern in hanging to be different from that of a body on the ground. Prior to this present study, however, there have been no decomposition studies of hanging bodies with large enough sample sizes (Chong Chin *et al*., 2010; Shalaby *et al*., 2000) to determine if a separate decomposition scoring scale, specific to hanging bodies, would provide greater accuracy in estimating PMI.

This study attempted to fill this gap through a series of decomposition studies on hanging bodies in a variety of situations; clothed and unclothed, and fully and partially suspended. The study used domestic pigs (*Sus scrofa*) to enable large enough sample sizes for statistical robustness. Pigs are the closest human analogues for this kind of study, and the results produced can be compared with known human hangings to assess if they are useful enough to be applied in estimating the PMI for hanged human bodies.

1.2 Aims of this Study

The principal aims of this study were to further the understanding of decomposition in hanging bodies and to investigate how the patterns and rates of decomposition may be used to more accurately estimate time since death.

A series of field studies using pigs in different hanging conditions (with pigs on the ground as controls) were carried out with the following aims:

- To investigate whether there were differences in the rates and patterns of decomposition between the hanging and control pigs.

- To produce an amended or new decomposition scoring scale for hanging pigs if necessary.

- To investigate whether the sex of the pig affected the rates and patterns of decomposition.

- To investigate if there were significant differences in the decomposition rate and pattern for clothed hanging bodies.

- To investigate what difference it makes to the decomposition process if a body is partially suspended.

The specific objectives of the various field studies are given in the introduction to each experiment.

1.3 Outline of Thesis

This introductory section is followed by a review of the literature relating to hanging; the process of decomposition and decomposition patterns; the importance of accurate post-mortem interval estimation, and the use of decomposition scoring and accumulated degree days in making these estimations; the effect of insects and clothing on decomposition; and the use of pigs as human analogues.

Chapter 3, to avoid repetition in each experiment, describes the materials and methods that were common to all the experiments and the experimental design, including the use of hanging frames, scavenger proof cages, and data loggers for temperature collection. The reader may wish to refer back to this chapter when reading the materials and methods sections of the chapters describing the field experiments.

Chapters 4, 5, and 6 describe the field experiments, with each chapter following the same format of introduction; materials and methods, describing any amendments or specific changes from the general approach that were needed for that experiment; results; and a discussion section specific to that experiment.

Chapter 7 contains analyses of the combined data on hanging and control pigs longitudinally across the three years of the field experiments. This includes the effect of start weight on the decomposition score to ADD relationship, and the consistency of the decomposition score to ADD relationship over the period.

Finally, Chapter 8 provides a general discussion of the research with conclusions and suggestions for future studies.

2 Literature Review

2.1 Hanging

World wide, hanging is one of the most commonly used ways of committing suicide (Thomas and Gunnell, 2010), and in many countries it is the leading method. It is the most common method in England and Wales, accounting for about 2000 deaths a year (Bennewith *et al*., 2005; Gunnell *et al*., 2005), with a clear pattern showing the number of men to be consistently higher than women by a ratio of approximately 5 to 1 (Thomas and Gunnell, 2010). To exclude foul play the circumstances of a hanging should be carefully examined, particularly in the case of females where this is an uncommon method of suicide (Bowen; 1982). The frequency of use of hanging and its reported increase in incidence may be the result of a mix of factors. It is seen as easy, inexpensive, readily available and reliable, while being clean and avoiding disfigurement (Biddle *et al*., 2012; Thomas and Gunnell, 2010; Thomas *et al*., 2013). Possibly one of the biggest factors resulting in its prominence in suicide is its success rate. Hanging is effective; the case fatality rate for hanging has been reported as 70% (Gunnell *et al*., 2005) and between 69% and 84% in an American study from 2000 to 2010 (Baker *et al*., 2013). This is probably due to the mechanism of death in hanging.

Hanging is a form of ligature strangulation in which the force applied to the neck is derived from the gravitational pull of the weight of the body or part of the body (Ferris, 2000; Turvey, 2000). A weight of 2 kg is all that is needed to block the jugular vein and venous return to the heart (Gunnell *et al*., 2005; Sikary *et al*., 2016; Turvey, 2000). The body does not need to be fully suspended for death to occur (Bennewith *et al.*, 2005; Ferris, 2000) and may be found with the feet touching the ground. In a study of 162 deaths by hanging, occurring in 24 English Coroners' jurisdictions within a six month period, nearly 50% of hanging bodies were found to be not fully suspended, and had feet touching the ground or were kneeling or semi-recumbent (Bennewith *et al.*, 2005). Gunnell *et al.* (2005) looked at 2251 hangings from a review of 15 suicide studies, covering the period 1964-94 and eight countries, noting that around 50% of hangings were not fully suspended and had the ligature attachment below head height.

Although most deaths from hanging are the result of suicide (Ferris, 2000; Sikary *et al.*, 2016), this is not always the case; they can also be the result of homicide or accident. Ferris (2000) states that "Homicidal hanging, with the relatively rare exception of lynching, is very rare." Accidental hanging may happen with small children, particularly toddlers, as their heads weigh proportionately more than their bodies compared to adults, and their muscular control and trachea are not fully developed, so death occurs more quickly if the neck is constricted (RoSPA, 2015). Children's cots are often near windows and blinds where they can become entangled in the blind cords, resulting in approximately one death a month in the USA (CPSC, n.d.). Children may also become caught up in ropes, their own clothing or cot attachments, although this is relatively uncommon (Bowen, 1982; Ferris, 2000). Children and young adults may also die as the result of a 'choking game' where they induce non-sexual euphoria through cerebral hypoxia (Byard and Winskog, 2012). Anthropologists describe Eskimo children and South American Yahgans inducing partial strangulation for exhilaration (Ueno *et al.*, 2003).

It should be noted that children do commit suicide. It is the 2nd or 3rd most common cause of death in children and adolescents worldwide, and hanging is the most common method used (Mendes *et al*., 2015; Pakis *et al*., 2010). A study of child suicide in Portugal (Mendes *et al*., 2015) noted that, whilst child suicide was rare, hanging was the most common method employed. Austin *et al*. (2011), in two studies over two and five years, found that while overall suicide rates in adolescents were decreasing, the incidence of hanging was increasing.

Accidental death in autoerotic practices results when there is a failure in the safety release mechanism which usually forms part of the routines. This is usually a secretive and solitary activity (Ueno *et al*., 2003) practiced in secure and secluded locations (Byard and Winskog, 2012), which may lead to a delay in discovery (Komar *et al*., 1999) – most outdoor hangings occur in rural woodland. There are an estimated 500 to 1000 autoerotic deaths per annum in the U.S.A., and this figure is believed to be conservative (Sauvageau and Racette, 2006; Turvey, 2000). Relatives will often remove any potentially embarrassing items, such as pornography, before calling the police (Byard and Winskog, 2012; Ueno *et al*., 2003). Autoerotic hangings occur almost exclusively in men (Bowen, 1982; Byard and Winskog, 2012; Ueno *et al*., 2003). However, certain criteria must be fulfilled before the hanging is classed as autoerotic, and this may lead to an underestimation of female deaths as they don't fit the criteria used, and are usually naked and without elaborate props (Byard and Winskog, 2012; Turvey, 2000; Ueno *et al*., 2003). Most deaths from autoerotic asphyxia are the result of hanging or the use of a ligature (Sauvageau and Racette, 2006).

Among countries for which data are available, hanging is known to be the most common method of committing suicide in Galicia (in northwest Spain), Saudi Arabia, Hungary, Belgium, Norway, England and Wales, Turkey, Lithuania, Germany, Japan (Ambade *et al*., 2015), and Australia (Austin *et al*., 2011), and is the second most frequently used method in Portugal, Sri Lanka, and the U.S.A. In the case of the U.S.A., firearms remain the most used method except, paradoxically, in military bases or onboard ship where hanging is most common as personnel do not have access to firearms unless they are in training or on guard duty (Clark and Kerr, 1986). Hanging is also one of the most common suicide methods in India (Ambade *et al*., 2015) and China (Sun *et al*., 2012) although it is not the primary method.

One of the reasons hanging is so 'easy' to carry out is the ubiquity of the items needed. Whilst the methods used to commit suicide have changed over time, a recent study by Thomas *et al*. (2013) concluded that this was due to the physical availability of the method. This is borne out in a study of physician suicide (Austin *et al*., 2013) in which 88.9% of the cases examined (8 out of 9) died from lethal drug self administration, contrasting with the general public.

Much has been made of the influence of the internet and social media in possible copycat suicides, but there is no rigorous empirical evidence of the impact of the internet (Biddle *et al*., 2012). However, whilst steps could be taken to minimize the availability of ligatures and suspension points in institutions such as hospitals and prisons (Baker *et al*., 2013; Bennewith *et al*., 2005; Gunnell *et al*., 2005), nothing can be done to limit access to these in the general community. In a bid to prevent copycat events the reporting of suicides in public places may be restricted by local authorities (Dogan *et al*., 2015).

Finally, it is estimated that by 2020 there will be one suicide globally every 20 seconds (Dogan *et al*., 2015). Clearly, as hanging is the most common form of suicide worldwide, it can be expected that the incidence of hangings will only increase.

2.2 Estimating Post-Mortem Interval

For forensic anthropologists and the police, the estimation of post-mortem interval (PMI) is an important step in the investigation of any death and the identification of unknown bodies, narrowing down the pool of missing people to whom the individual body could belong, and providing a time frame from which suspects may be excluded or included (Moffatt *et al*., 2016).

The estimation of how long a person has been dead is far from simple, the progress of decomposition being a complex process of inextricably interrelated variables (Mann *et al*., 1990). Whilst the process of decomposition has become no less complex, the understanding of its progress has improved. There are many methods of estimating PMI, including entomology, biochemical markers, cadavaric signs and putrefaction, but the determination of PMI remains a difficult and complex task (Tracqui; 2000). The process of decomposition in humans is now well understood and one method by which the PMI can now be estimated is to use decomposition scoring in conjunction with the accumulated average temperature (Megyesi *et al*., 2005).

2.3 Accumulated Degree Days

Accumulated Degree Days (ADD) is measured by taking the cumulative average daily temperature from the time of death to the time of final measurement. Thus at an average daily temperature of 10 °C it would take 10 days to reach 100 ADD. The same ADD figure would result from 5 days at 20 °C. ADD signifies the accumulation of thermal energy. When a given amount of thermal energy is put into a carcass the same amount of reaction should occur (Simmons *et al*., 2010a), such that the same body score for decomposition will be seen. Current work indicates that this may not be quite as straightforward as previously accepted, and adjustments for season of death may need to be factored in (Bates and Wescott, 2016; Dautartas *et al*., 2016; Simmons *et al*., 2016).

Because the use of ADD automatically incorporates adjustments for yearly, seasonal, and within season variation, it has many advantages over a model based on a count of days alone. The use of ADD allows for prediction models to be developed (Michaud and Moreau, 2011). Vass *et al*. (1992) predict human skeletonisation will have occurred by 1285 ±10 ADD based on the absence of volatile fatty acids, produced from the breakdown of tissues during decomposition, in the soil below a body. To estimate PMI, the ADD is calculated using temperature readings from the nearest weather stations. This is not without problems as the nearest weather station may not reflect the temperature at the site (Dabbs, 2010, 2015). To compensate for this, data loggers are left for a number of days at the site where the body was found. These readings are then compared with those from the weather stations so that a correction factor can be applied to the weather station data recorded prior to the body being found.

2.4 Decomposition Scoring

Using systematic observation of decomposition rates and patterns of bodies within a given environment, the patterns of decomposition can be seriated to allow the production of a scale of decomposition descriptions specific to that environment

Decomposition scoring is used to give a value to each milestone of the decomposition process. This score then forms part of the calculations used to estimate PMI. Discolouration, bloating, liquefaction, and advanced decay or skeletonisation are all decomposition phases following a coded timeline, and these phases are markers for indicating the elapsed time since death (Campobasso *et al*., 2001). However, the process of decomposition is not made up of discrete stages, but is a continuous process with the stages merging and overlapping. Thus, the determination of decomposition stages is a somewhat subjective decision, depending on the perception of the observer (Michaud and Moreau, 2011), with different people defining many decomposition stages. Mégnin (1894) at the end of the 19th century, produced possibly the first table describing eight waves of arthropod invasion on human cadavers, mostly using bodies from inside closed rooms, linked to the decomposition changes of the corpse and noted that these arthropods may differ with season and site. More recently Adlam and Simmons (2007) and Oliviera and Vasconcelos (2010) described four stages of decomposition: fresh, bloat, decay, and dry or skeletonised. Payne (1965), in his study of summer carrion of the baby pig, had two separate sets of stages in his study; using six stages where insects had access: fresh, bloated, active decay, advanced decay, dry, and remains; and five stages for the insect-free pigs: fresh, bloating and decomposition, flaccidity and dehydration, mummy stage, and desiccation and disintegration. Archer (2004), whilst acknowledging that the stages observed were similar to those seen by Payne, produced five different stage descriptors.

Various factors affect the decomposition process which can differ from body to body, from environment to environment, and even from one part of the same corpse to another (Campobasso *et al*., 2001). Differential decomposition within a body was noted in the scale produced by Megyesi *et al*. (2005), which allows for this by dividing the body into three areas and scoring these areas separately. The Partial Body Scores (PBS) for each region are added together to give a Total Body Score (TBS) for the observed decomposition.

Parks (2011) noted that a "one size fits all" decomposition model is unrealistic. This can be extended to include the manner of death. A scale for scoring drowned bodies was produced by Heaton *et al*. (2010), who noted in their study that the decomposition pattern for bodies in water was different from that described by Megyesi *et al*. (2005), who did not include any bodies recovered from water. A scale for scoring charred bodies was produced by Gruenthal *et al*. (2012) to encompass the different patterns found in burnt bodies.

When scoring the state of decomposition of a body, or body region, the observer must select the scale stage that best fits the largest number of scoring criteria. The scoring scale that best matches the environmental circumstances of a given body should, in turn, provide the most relevant and appropriate scoring criteria from which to choose.

2.5 Process and Patterns of Decomposition

Decomposition starts within minutes of death as the body's cells start to self-destruct by autolysis, the result of enzymatic self digestion caused as the cells become anoxic. This occurs first in the cells that are most metabolically active with high rates of Adenosine Tri-Phosphate (ATP) production such as the liver, intestines, stomach and digestive organs (Gill-King, 1997; Vass, 2001). *Algor mortis* occurs as the body temperature changes to match the ambient temperature. This usually involves the body cooling, but in hot environments the body's temperature may increase. *Pallor mortis* or paling of the skin occurs immediately after death, particularly in white or pale skins, as gravity causes the still fluid blood to pool to the lowest point leading to *livor mortis* (lividity). Initially this discolouration is not fixed and pressure will result in a white area which then re-fills with blood when the pressure is removed. As the blood solidifies and clots the discolouration remains and pale or white areas are left within the lividity where pressure has been applied. This can be important forensically in showing the position of the body after death, and if it has been moved since death; this may also give rise to the possibility that the body has been moved from one geographical location to another which could make ADD calculations less accurate and thus affect the PMI estimation.

Rigor mortis sets in usually within 2 to 6 hours of death as loss of ATP results in muscular stiffening, and cellular cytoplasm gelling (Gill-King, 1997; Vass, 2001). The rigidity wears off, usually within 18 hours, as decomposition causes the muscle structure to break down. The process of *rigor mortis* is sensitive to temperature, progressing rapidly with hot temperatures and potentially taking days when temperatures are below 4 °C. It has also been noted (Tracqui, 2000) that the onset of rigidity may be delayed in hanging.

As the body moves into anaerobic decomposition, or putrefaction, the carbohydrates, proteins and fats break down to produce alcohol and toxic gases including ammonia, hydrogen sulphide, methane, pyruvic acid, cadaverine and putriscine (Gill-King, 1997). This results in bloating of the body. The characteristic smell is caused primarily by the cadaverine and putriscine. As bilirubin and biliverdin from the liver break down in the caecum in the lower right section of the abdomen, which is high in anaerobic bacteria, this produces hydrogen sulphide which reacts with the haemoglobin to form sulphaemaglobin. As this and the oxidation of bile pigments continue, there is a gradual change in colour to green moving through purple to black. This discoloration in the superficial vessels causes the marbling often seen on the abdomen. Gas is produced in the intestinal tract and, in males, gas from the peritoneal space may be pushed through the inguinal canal into the scrotum, causing swelling.

The contents of the intestinal tract and the lining itself break down to form purge fluid which, with the gas in the intestines, purges from the mouth, nose and rectum. The quantity of fluid purged is not great and after purging active decay begins and insect activity is the main destructive influence.

2.6 Effects of Insects

Previous studies have demonstrated that the two factors most influencing decomposition are temperature and insect activity (Cross and Simmons, 2010;

Simmons *et al*., 2010a). Bodies left exposed for any length of time become more vulnerable to consumption by scavengers. The primary scavengers fall into the groups of insects, birds, rodents, plus larger carnivores and, in water, aquatic animals (Rodriguez, 1997). All of these have an impact on the decomposition rate (Payne, 1965; Simmons *et al*., 2010a). Particularly in the early stages of decomposition, the processes, including insect activity, are dependent on many environmental conditions including temperature, humidity, and the specific scavengers present.

As bodies decompose the gut bacteria produce large volumes of gas and the release of this gas attracts flies, particularly some blow flies (*Diptera: Calliphoridae*), which begin laying eggs on exposed areas (Campobasso *et al*., 2001). After the eggs hatch and the maggot masses increase in size, their own metabolic activity causes an increase in the internal temperature of the animal. This can fluctuate between 5 to 10 °C above the ambient temperature (Heaton *et al*., 2014; Simmons *et al*., 2010b).

Temperature has an effect on the speed of biochemical processes and on insect activity; it is the most important variable influencing maggot development (Campobasso *et al*., 2001). Increase in temperature increases the rate of decomposition such that time between death and skeletonisation is much shorter in tropical than temperate climates (Oliviera and Vasconcelos, 2010). Conversely very low temperatures can inhibit or stop decomposition where maggot masses have not become established within the body where they can remain active (Heaton *et al*., 2014; Huntington *et al*., 2007).

Forensic entomologists use insect data such as developmental stage and species succession to calculate the estimated PMI. However, the use of insects to estimate PMI is subject to many potential sources of error (Moffatt *et al.*, 2016). Maggots migrate away from the body at times specific to their species, thus the oldest insects may not be on the body (Anderson, 2011). Minimum PMI can be estimated from the insects found but the longer the PMI, the less precise the PMI estimate becomes (Amendt *et al.*, 2007). Temperature data obtained from the nearest weather stations may not reflect the actual microclimate (Dabbs, 2010, 2015), which can be particularly important if the body is inside a building (Amendt *et al.*, 2007).

2.7 Effects of Clothing

While many decomposition studies are carried out on naked bodies, making observation easier, clothing is commonly present on the bodies of forensic cases (Dillon and Anderson, 1995; Komar, 1998). This is also true of hangings, where bodies may be found fully clothed (Clark and Kerr, 1986; Hejna and Bohnert, 2013) or, as most autoerotic deaths are due to hanging, partially clothed, usually in female underwear (Byard and Winskog, 2012), or naked. Insect activity is important in the process of decomposition and clothing may hamper arthropod access to the body, delaying oviposition and maggot activity. It is important to understand the effects that clothing may have on the rate and pattern of decomposition, as these could affect the techniques used for PMI estimation.

Experiments and studies on the effect that clothing and wrapping bodies has on oviposition and the rate and pattern of decomposition have produced conflicting results. Sample sizes have ranged from one or two (Dillon and Anderson, 1995; Goff, 1992) to Komar's review (1998) of 16 carcasses and Card *et al*'s (2015) study using 20. Both pigs (Anderson, 2011; Card *et al*., 2015; Dillon and Anderson, 1995; Dillon and Anderson, 1996; Kelly, 2006) and human cadavers (Dautartas, 2009; Miller, 2002) have been used. Additionally, retrospective studies by Campobasso *et al*. (2001), Haglund (1997), and Mann *et al*. (1990) have provided further information.

Experiments comparing the rate of decomposition between clothed and unclothed bodies carried out by Dautartas (2009) and Miller (2002) using cadavers, and by Card *et al*. (2015) and Kelly (2006) using pigs, showed that whilst differences between the bodies were observed, the presence of clothing had no statistically significant effect on the rate of decomposition.

The largest study by Mann *et al*. (1990), a retrospective study of 150 bodies from the Anthropological Research Facility (ARF) in Tennessee, produced a table of variables affecting the decay rate of the human body. Scoring was subjective and used a scale of 1 to 5 with 5 having the greatest impact. The scores do not indicate if the effect is positive or negative, only its level of impact. Clothing received a low impact score of 2 and the report concluded that the presence of clothing aided in speeding up decay by providing maggots with protection from sunlight. The report, however, gives no indication of how many of the 150 bodies in the study were clothed and contributed to this finding. The same conclusion, that clothing sped up the process of decomposition, was reached by Anderson (2010) and Dillon and Anderson (1995), but the authors' reasoning related to clothing providing more locations for ovipositing.

Card *et al*. (2015), in a study of 10 clothed and 10 unclothed pigs, also observed that clothing provided additional ovipositing sites, but did not agree with the finding that the decomposition rate was increased. A retrospective study of twenty individuals in states of advanced decomposition or partial skeletonisation by Komar (1998) concluded, contrary to Mann *et al*.'s (1990) findings and in agreement with Haglund's (1997), that clothing was found to protect the underlying tissues from animals and weather, resulting in delayed decomposition rates. However, as this was a retrospective study no information was available on the progression of decomposition within individuals, so it was not possible to determine when the difference in decomposition rate occurred.

Goff's (1992) study, using a pig carcass wrapped in two blankets rather than clothed, found that wrapping impeded oviposition and delayed decomposition by 2.5 days. Initial observations were from an adult human who had been wrapped in two blankets. Following this an experiment was carried out treating a single pig in the same manner, which showed the same 2.5 day delay in oviposition. Delays in ovipositing have not been reported in other studies. Kelly *et al*. (2009), using three groups of two pigs – loosely wrapped, clothed, and unclothed – found no difference in the decomposition time, with insects ovipositing on all six carcasses on the first day. Studies by Grassberger and Frank (2004) and Marchenko (2001) also found no difference in the oviposition timing, but did report a delay in decomposition.

Work by Aturaliya and Lukasewycz (1999), in which they maintained a flow of dry air across the carcasses, found that the presence of clothing helped to desiccate carcasses by wicking fluid away from the skin and, through evaporation, to accelerate the rate of mummification. The subjects of this experiment were adult mice, making its application to human bodies equivocal.

In conclusion, controlled studies with larger sample sizes appear to indicate that clothing has no significant effect on the rate of decomposition; retrospective studies and small sample size studies report an effect – interestingly, both to increase and to decrease the rate of decomposition.

2.8 Decomposition of Hanging Bodies

Whilst many individuals are found relatively quickly if the hanging occurred in the home, often as a result of suicide or autoerotic activities (Byard and Winskog, 2012), when the hanging has occurred outdoors or in a remote location bodies may remain undiscovered for longer periods (Komar *et al*., 1999).

It might be expected that hanging bodies may display a different pattern of decomposition, and thus might also benefit from a specific decomposition scoring scale to reflect this when scoring decomposition to calculate PMI. Shalaby *et al*. (2000), using a hanging pig and a pig on the ground, studied the differences in rates and patterns of decomposition, finding significant differences in the rates of decomposition of the two bodies. The rate at which biomass reduced was slower in the hanging carcass during the bloat and decay stages. There are also reasons to suspect that the species of insects attracted to a hanging body may differ if the carcass is not touching the ground (Chinery, 1976). A sample size of one individual does not, however, provide validated data, and further experiments using larger numbers are needed to see if the results are repeatable and consistent.

When a body is hanging there is the potential for the whole body surface to be exposed to the drying effect of winds, which could increase the possibility of mummification or have a greater effect on the mummification rate than for a carcass on the ground. In addition, female *Diptera* recognise mummified skin as an inhospitable substrate for larval stages and do not lay there (Campobasso *et al.*, 2001). Where rapid dehydration occurs, typical of dry windy environments, this reasonably explains the low external maggot activity observed (Campobasso *et al.*, 2001). De Jong *et al.* (2011) noted that mummified skin may act as insulation, so there is also the possibility that internal temperatures may be affected, changing the environment for any insects and impacting internal ADD calculations.

Disturbance of carcasses has been shown to have a significant effect on the rate of biomass loss during decomposition (Adlam and Simmons, 2007; Cross and Simmons, 2010) due to the displacement of necrophagous insects. Unless a hanging body is in partial contact with the ground, crawling insects and maggots are unlikely to return to the body once they fall into the drip zone, the area directly below the body (Shalaby *et al.*, 2000). Once in this drip zone, and unable to return to the carcass, the insects may continue to feed on material falling from the body. Thus the maggot mass within a hanging animal may be less than that within an animal on the ground, where the maggots remain within the body cavity. A smaller maggot mass within the hanging body may affect the rate of biomass reduction mediated by insects. There may be changes in the internal temperatures as the maggot masses are disturbed (Adlam and Simmons, 2007) and as maggots are lost through gravity and movement. In a study using rabbit carcasses it was found that, whilst individual elements of the decomposition process were affected by repeated disturbance of a carcass, over time the decomposition was not significantly altered

(Adlam and Simmons, 2007). In a study using rat carcasses it was reported that the repeated weighing of carcasses did not statistically affect the rate of biomass loss (De Jong *et al*., 2011). The masses involved were, however, very small (grams and milligrams) and the authors noted that a further study with larger animals such as pigs, and with more intensive sampling during decomposition stages, could be carried out to investigate the validity of the technique used (De Jong *et al*., 2011). In a study carried out using pigs it was found that tissue loss in disturbed carcasses was indeed adversely affected, and was slower than in the undisturbed control group (Cross and Simmons, 2010).

2.9 The Use of Pigs as Human Analogues

For many taphonomic studies the use of human cadavers may be impractical or impossible. Some countries do not allow experimentation on human cadavers and, where research on human bodies is allowed, the use of human tissue is strictly controlled. In the UK this is governed by the Human Tissue Act (2004). There may also be restrictions in the availability of donated human cadavers and the existence of suitable research facilities (Simmons and Cross, 2013). However, the need for experiments to be carried out with sufficiently large sample sizes, and to be readily replicable, means suitable human analogues are required. The analogues must closely approximate human decomposition patterns, be readily available in sufficient numbers, not too expensive, and unlikely to arouse public objection (Catts and Goff, 1992).

Domestic pigs, *Sus scrofa*, are the most widely used human cadaver analogues in taphonomic experiments (Forbes *et al*., 2005; Myburgh *et al*., 2013; Paczkowski *et* *al*., 2015; Payne, 1965; Roberts and Dabbs, 2015; Schotsmans *et al*., 2012; Schotsmans *et al*., 2014a; Schotsmans *et al*., 2014b; Swindle *et al*., 2012; Wilson *et al*., 2007). Pigs are omnivores with a similar gut bacteria to humans (Anderson and Van Laerhoven, 1996). They have a body mass and muscle-to-fat ratio that is similar to a human and, like humans, are largely hairless (Anderson, 2010; Schoenly *et al*., 2006). In adipocere formation studies, porcine adipose tissue is the nearest and most reliable model for human adipose (Forbes *et al*., 2005). The skin has similar dermal collagen, its elastic content is more similar to humans than other animals, and porcine skin has been used for many years in the treatment of burns victims, the study of dermal healing, and for skin grafts (Dillon and Anderson, 1995, 1996). Additionally, the use of complete porcine heart valves for valve replacement in humans is common. Pigs, as quadrupeds do, however, have different limb proportions to bi-pedal humans.

Pigs are also considered reliable substitutes in entomological studies (Dillon and Anderson, 1995; Tabor *et al*., 2004). The activity of insects is one of the most important drivers of decomposition. Schoenly *et al*. (2007) found there to be sufficient overlap in the arthropod fauna found on pigs and humans to recommend the use of pigs as substitutes for humans in research. Based on 15 years of entomology studies (1987-2002) the use of a domestic pig (*Sus scrofa*) weighing approximately 23 kg (50 lb) was found to be a reliable model of a human corpse (Schoenly and Hall, 2002; Schoenly *et al*., 2006; Schoenly *et al*., 2007). Additionally the density, succession, and variety of arthropod species on a 23 kg (50 lb) pig were found to be comparable to those on a 68 kg (150 lb) pig (Catts and Goff, 1992; Schoenly and Hall, 2002; Schoenly *et al*., 2007).

In a study by Stokes *et al*. (2013), using soil microcosms, samples of human muscle were compared with muscle samples from pig, cow, and sheep. It was found that for the measure they were using the ovine muscle was the most similar to human, but that they all "afford close approximation in decomposition dynamics".

Whilst the value of using animals as human analogues for research, and how applicable the results are to human decomposition, may be open to debate (Simmons and Cross, 2013), there are many decomposition experiments which could be carried out on animals but which might cause ethical objections if carried out on human cadavers, e.g. gun shots, burning, hanging, etc.

3 General Materials and Methods

This Research was carried out during the months of May through August over a period of three consecutive years and consisted of a series of field experiments each with a specific set of objectives. To maximise consistency and repeatability, and to maintain scientific rigour, where possible the experimental design and methods used within the individual experiments were the same. This applied particularly to the equipment used and the methods of data collection, recording, and analysis. Some of the methods used were necessary to meet the requirements to minimize biohazards and comply with UK regulations.

All experiments described in subsequent chapters followed the same general experimental protocol outlined below. Where differences occurred these are noted in the subsequent chapters concerning each specific experiment.

This chapter describes the field site; the equipment used and the general preparation of the pigs; the methods of data collection; and the treatment of the animals from death to disposal at the end of the experiments.

3.1 The Field Research Site

The research was carried out at the University of Central Lancashire's Taphonomic Research in Anthropology: Centre for Experimental Studies (TRACES) facility (Cross *et al*., 2009). The site is situated near Burnley (53.77° N, 2.24° W) in the northwest of England. TRACES is a 13 acre outdoor site of sloping rough pasture land with areas of young trees, consisting of rowan, alder, birch, oak and pine, and is surrounded by fencing outside of which is sheep pasture and rough fell side. The site is 169 m above average sea level and exposed to southwesterly winds (Lapworth and McGregor, 2008). Rainfall is high in this part of the country, averaging 1294 mm per year (Met Office, 2010), and summer temperatures during the experimental period average 17 °C or 63 °F. Insects commonly found on the site that were of direct interest to these experiments are blow flies and beetles; particularly Silphidae, Histeridae, and Staphylinidae.

3.2 Animals

Domestic pig (*Sus scrofa*) carcasses were used in all of these experiments. The use of pigs as human analogues is a common practice (Anderson and Van Laerhoven, 1996; Catts and Goff, 1992; Huntington *et al*., 2007; Payne, 1965; Roberts and Dabbs, 2015; Spicka *et al*., 2011; Stokes *et al*., 2013) due to practical and ethical problems in sourcing sufficient human bodies for such studies. The pigs were bred for the domestic meat market, not for experimentation, and were killed on the farms by a licensed professional. To ensure biosecurity and prevent any inadvertent spread of disease during transportation from farm to the experimental site, each animal was placed into a body bag, which was sealed, before being transported in a vehicle with appropriate signage.

On arrival at the site, as each pig was removed from the body bag it was given a unique numbered ID label, reflecting its allocated group, which was attached to a hind limb using a cable tie. Each pig was weighed using a hanging scale from which the pig was suspended via a rope noose around a hind limb. The weight was recorded (to the nearest 5 g) and the sex was also recorded. All pigs were in experimental position within a few hours of this procedure.

3.3 Hanging Frames and Surface Enclosures

Hanging structures were constructed from scaffolding poles, with a pair of A-frames each supporting a horizontal ridge pole 2.5 m above the ground. Figure 3.1 shows a diagram of the A-frame layout, while Figure 3.2 shows one of the A-frames in use.

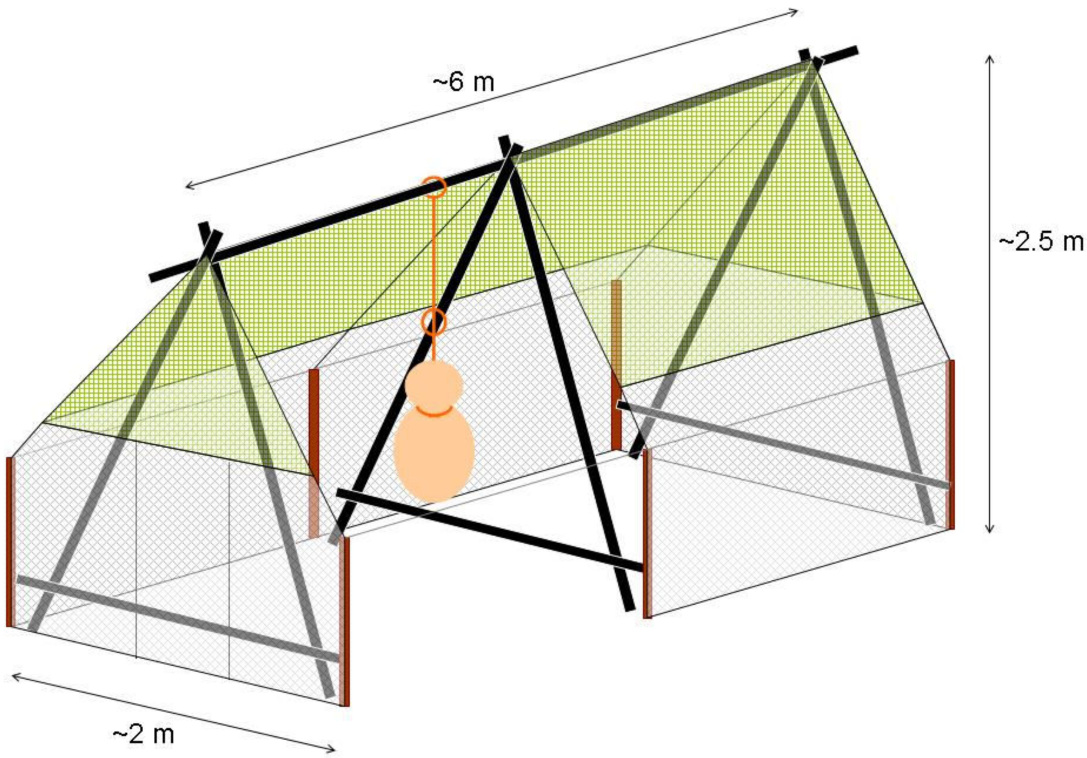

Figure 3.1 Diagrammatic representation of the scaffolding A-frames used for the hanging pigs showing the bird proof netting, chicken wire and approximate dimensions. The entry point was via a section of detachable wire in the centre of one end. Some sections of wire and netting have been left out for clarity.

Figure 3.2 Hanging pigs in one of the scaffolding A-frames at the start of the experiment.

These structures were covered in a scavenger proof chicken wire mesh to a height of 1 m, above which was attached bird-proof plastic netting. Thus, the entire structure was covered. Entrance into the frame was achieved via a detachable section of chicken wire. Neither mesh nor netting impeded insect access. On each ridge pole, spaced approximately 80 cm apart, five pig carcasses were hung by the neck using nylon rope tied in a noose. Nylon rope was used to avoid the problems, common to natural fibres, of rope stretching and shrinking with changes in moisture. Each noose was attached to the ridge pole using a butchers' hook, which suspended the carcass so that the hind limbs hung a minimum of 60 cm off the ground. It was anticipated that there would be some initial untwisting and stretching of the nylon rope and that the animals themselves might elongate, due to gravity, as decomposition progressed.

Each experiment had a group of pigs that lay directly on the ground. These are referred to below as control or surface pigs, with the term ‘control group’ referring specifically to a group of naked, fully non-suspended pigs, positioned so that they were lying on their sides directly on the ground surface. These surface pigs were placed 30 m from the hanging frames and spaced about five metres apart. Cages covered in scavenger proof mesh, which did not impede insect access, were placed over the surface pigs. A label identical to the one on the pig was attached to the scavenger proof cage (Figure 3.3).

Figure 3.3 The scavenger proof cages used to cover the surface pigs. The cage in the foreground shows one of the clothed pigs from Experiment 2.

3.4 Electronic Data Logging

Internal and external temperatures were recorded using EL-USB-1 Lascar Electronics self-contained data loggers (Lascar Electronics Ltd, Salisbury, U.K.). Each data logger was tested as follows: The loggers were programmed to collect data every 3 minutes for a period of 15 minutes. They were then left on the lab bench for 5 minutes; transferred to a fridge for 5 minutes; and then back into the lab. The recorded data were downloaded and checked to make sure the loggers were operating correctly. The loggers were fitted with new batteries and pre-programmed to record temperature at 6-hour intervals throughout each experiment. The casings of the data loggers were sealed with strips of parafilm around the joins to help prevent decomposition fluid or precipitation reaching the electronics. The data loggers remained in place until completion of the experiment when the data were retrieved. Any loggers expulsed naturally prior to this were returned to the lab and their data retrieved.

A data logger in a film-sealed case was inserted rectally into each surface pig and pushed internally using a bamboo rod to a distance of approximately 40 cm. The data loggers were placed internally to enable comparisons to be made between the core temperatures of the pigs and the external temperature, as it is known that maggots generate their own heat (Gallagher *et al*., 2010; Heaton *et al*., 2014; Huntington *et al*., 2007; Marchenko, 2001; Simmons *et al*., 2010b). The data logger arrangements for the hanging pigs differed for each experiment, due to experience gained throughout the study, and are described in the Materials and Methods section for each experiment. Each A-frame had an additional data logger, attached at a height of 1.5 m above ground, to record the ambient temperature.

The data loggers were set up to start recording temperatures every six hours from 07.00 hrs on the day the pigs were killed. Each daily average temperature was calculated from the 6-hourly recordings for the 24 hour period from 07.00 to 07.00 (as the average of the four readings taken at 13.00, 19.00, 01.00, and 07.00 hrs). The daily average temperature values were used to calculate the Accumulated Degree Days (ADD) values for the periods from the start of the study until each observation day. The ambient ADD was calculated from the external loggers attached to the hanging frames, and the internal ADD from the internally sited data loggers. The study periods commenced after the threat of frosts had passed, so no adjustments for temperatures at or below 0 °C were required in the ADD calculations (Megyesi *et al.*, 2005). All ADD figures were calculated using temperatures in degrees Celsius.

3.5 Observations

Throughout the experiments the pigs were examined for visible decomposition and this was recorded for three regions: head and neck, torso, and limbs. These observations included changes in colour, size, presence of maggots, decompositional fluids, changes in skin, and visibility of bone. For the hanging pigs the area directly below the pig, the drip zone (Shalaby *et al.*, 2000), was also examined for any maggots, intestines or bones that had fallen from them.

Each pig was photographed at each visit with the hanging pigs being photographed from front and side view. The photographs and written descriptions were used to enable decomposition scores to be given to each animal at each visit.

3.6 Insect Data Collection

At the same time as making observations of the decomposition features, the animals were checked for the presence of blow fly eggs and maggots, and larval and adult beetles. The dates at which beetle larvae were first seen on the surface pigs and on the hanging pigs were recorded. When beetles appeared on the pigs a sample was collected and identified. The numbers of beetles were not recorded.

Blow fly eggs, which are small rice shaped and white or yellowy in colour, are generally seen in small clusters or patches on the animals, particularly around the natural orifices in the head, the anus, and in the hanging pigs around the noose.

Beetle larvae do not look like adult beetles and are easily distinguished from them. The larvae of the beetles most commonly found on the TRACES site and associated with the carcasses are elongated and flattened in appearance with legs and antennae.

3.7 Disposal of Pig Carcasses

At the completion of each experiment the pig remains were sprayed with the food dye 'Brilliant Black BN' (E151) to comply with the Animal By-Product (Identification and Staining) Regulations 1995 and regulation amendments. The pig remains were then placed in leak-proof bags which were sealed for disposal at a DEFRA approved and licensed animal by-product renderer.

4 EXPERIMENT 1 – Comparing Decomposition Patterns and Rates Between Hanging Pigs and Pigs Laid on the Ground[1]

The aim of this first experiment was to compare the patterns and rates of decomposition in hanging bodies with those of bodies in direct contact with the ground, and to determine whether a different decomposition scoring scale is required for hanging bodies to enable more accurate PMI estimation. To achieve this, an experiment was carried out in the field using hanging pigs, fully suspended off the ground, and control pigs placed on the ground, with large enough sample sizes to ensure scientific rigour. Previously reported work that has been carried out on hanging body decomposition has been on small samples, and has been reported in case study format (Chong Chin *et al.*, 2010; Shalaby *et al.,* 2000), but would indicate that the pattern of decomposition is different from that observed in surface decomposition. The objectives of the experiment were to:

- record and compare the patterns and rates of decomposition of the hanging pigs and the control pigs lying on the ground;

- record the weights of the hanging pigs each week to enable comparison of the percentage weight loss between the males and females;

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[1] The results of this experiment have been published:

Lynch-Aird, J., Moffatt, C., Simmons, T. (2015). Decomposition Rate and Pattern in Hanging Pigs. *Journal of Forensic Sciences*, 60(5):1155-1163.

- record the arrival of the first beetle or larva on the control pigs and on the hanging pigs, or in the drip zones beneath the hanging pigs.

4.1 Materials and Methods

The general experimental method is described in Chapter 3. Twenty pigs (*Sus scrofa*) were used for this experiment. The pigs were killed and collected on the same day, and transported to the test site in a single delivery run. Several experiments using pigs were being run at this time. To ensure the allocation of pigs was random with no allocation by sex, size or other features, as they were unloaded from the transport, the pigs were allocated into groups, one group after another, and labelled uniquely to reflect their group.

For the hanging pigs, in addition to the rectally inserted data loggers, thermocouples were inserted into the thorax via the oesophagus, using a metal tube as a guide which was then removed (Figure 4.1). Once the pigs had been hung, the thermocouples were each attached to additional pre-programmed data loggers. To prevent rainwater damaging the data loggers the connection between the thermocouple and the data logger was wrapped in parafilm. The logger and junction were placed in a plastic bag sealed with duct tape, around the exit point for the leads, and the bag was then attached to the hanging rope above the head of the pig.

All pigs were put into position within an hour of each other on 29 May 2011 with the exception of one of the surface pigs which, due to lack of availability on the day, was killed and positioned one day later. No adjustments were made for the delay in setting out this pig when calculating the results, as the average ADD for the first day was less than 15, which represented only 1.6% of the full ADD range of 932 at the completion of this experiment, and the TBS scores for this pig were within the range of TBS scores for the other pigs within this group.

Figure 4.1 Insertion of thermocouple for attachment to temperature data logger.

Data collection took place every Monday and Thursday, until the end of the study (25 July 2011) for a total of 17 observation days. Average daily temperatures at this site during summer are around 17 °C, so visual changes associated with decomposition do not occur rapidly. At each visit, the physical state of the surface pigs was closely observed, recorded and photographed.

For scoring, each pig was treated as three distinct regions: head and neck, torso, and limbs. For pigs lying on the surface, scores for each of three regions were recorded using the scales developed by Megyesi *et al*. (2005) to produce a total body score (TBS_{surf}). Megyesi *et al*.'s system was adjusted to a baseline of zero by subtracting 1 from each of the regional scores; thus three from the overall TBS_{surf} value. Megyesi *et al*.'s (2005) decomposition scoring tables, with the adjusted scores, are shown in Appendix 1. Each scored part of the body thus starts with a score of zero when fresh. This approach better reflects the fact that, in a fresh condition, the body exhibits no visible decomposition. It also supports the fitting of regression lines through the origin and allows for an easier conversion between similar scales of different lengths (Gruenthal *et al*., 2012).

Photographs were taken and detailed descriptions recorded for the hanging pigs to enable seriation of the decomposition process and development of a comparable scoring system. Any differences in appearance which might have been sex-specific were also noted. The ground directly beneath the hanging pigs, termed the "drip zone" (Shalaby *et al*., 2000), was checked for any insects and examined for parts of the pigs that may have fallen, and these findings were recorded.

4.1.1 Sex and Weight of Pigs

The hanging group contained five females and five males, and the control group four females and six males.

The average weight of the hanging pigs at the start of the experiment was 33.15 kg with a standard deviation of 6.26 kg, and the average weight of the control pigs was 47.9 kg with standard deviation 8.8 kg. The difference in the weights between the two groups was unintentional and unforeseen. The expectation was that the pigs would all have been obtained from the same farm and would have been the same age and about the same weight; thus controlling the age and weight variables and not compromising the validity of the experimental results. On this occasion the pigs were bought from two different farms and, although killed and collected on the same day, the possibility of the pigs from different farms having greatly varying weights had not been considered. The animals for slaughter were chosen by the farmer and should have been of the same age, and weight, from each farm. They were killed and immediately placed in bags and in the transport as described in Chapter 3.

When several experiments are being carried out simultaneously at the site the control pigs are under observation by several researchers and on this occasion the controls were the last pigs to be unloaded from the transport. Consequently they were probably amongst the first loaded and from the first farm, whilst the hanging pigs were the first to be unloaded and would have been from the second farm. There was no reason to believe the pigs were of different weights when collecting them. The effects of the differing pig weights are considered in the Discussion section below.

4.1.2 Measuring Percentage Weight Loss of Hanging Pigs

At weekly intervals the weights of the hanging pigs were recorded using the suspended weighing scale on which they were originally weighed. This was hung next to the pig by a hook over the horizontal scaffold bar of the A-frame. The pig was moved carefully from the S hook it was hanging on onto the S hook of the weighing scale, weighed, and then returned to the hanging frame hook, ensuring minimal disturbance to the carcass.

4.1.3 Creation of a Scale for Hanging Body Score

Decomposition is a mosaic process, where different parts of the body decompose at different rates, which is why the system defined by Megyesi *et al*. (2005) scores the degree of decomposition present in the head and neck, torso, and limbs separately. The hanging bodies were scored over the same three regions. However, Megyesi *et al*.'s scoring scales were developed using data that contained only bodies lying on a substrate. The hanging pigs did not display the same decomposition features and hence could not be scored on this scale.

Using the characteristics of decomposition displayed by each pig at each ADD interval, a seriation was produced reflecting the most typical pattern over a known timeline, i.e. from known time of death. Scores were then allocated to each pig based upon a review of the written description and photographs recorded at each observation. Independent scores were given to the three regions: head and neck, torso, and limbs. These scores were added to give a total body score for hanging (TBS_{hang}) on this novel scale.

All scores were integers, with a baseline of zero equating to no visible decomposition. As the scale records scores of visible decomposition, a fresh body which does not show any such decomposition receives a score of zero points. Where body sections did not show the same levels of decomposition over the whole section, for example across all four limbs, then the score was an average of the two extremes, to the nearest integer.

4.1.4 Statistical Analysis

All data analyses were performed using the software R (R Development Core Team, version 3.1.1) and its LME4 package for mixed effects models (Bates *et al.*, 2015).

An attempt was made to model the relationship between the decomposition scores and the ADD using linear regression. Various simple transformations of the ADD values and decomposition scores were tried but none produced a sufficiently linear relationship.

Higher order polynomial regression models were therefore tried of the form:

$$TBS = a_0 + a_1.ADD + a_2.ADD^2 + ... + a_n.ADD^n$$

Inevitably there is a compromise to be made between the complexity (order) of the regression equation and the accuracy of the fit to the data (mean-square error). A chi-squared test was used to assess the significance of the fitting errors obtained with different order models. For each test, the order of the regression model used was increased until an adequate fit to the data was obtained, and within the constraint that the version of R being used only supported regression models up to order 5.

The fitted curves should not be extrapolated beyond the range of the recorded ADD values, and thus any suggestion that the decomposition scores might start to fall again at higher ADDs, outside the recorded range, should be ignored.

The rate of decomposition can be found by taking the first derivative of the fitted curve with respect to ADD:

$$\frac{d(TBS)}{d(ADD)} = a_1 + 2a_2.ADD + ... + n.a_n.ADD^{n-1}$$

It is then a straightforward matter to determine both the maximum rate of decomposition and the time (ADD) at which it occurred.

4.2 Results

The final observation date corresponded to 932 ADD. Data from the internal thermocouples in the hanging pigs could not be used as a measure of internal ADD since the majority of the loggers failed due to the ingress of moisture despite the efforts made to seal them. Therefore, ADD was calculated based on the temperatures recorded by the ambient data loggers attached to the hanging frames.

4.2.1 General Pattern of Decomposition

Figure 4.2 shows a sequence of photographs taken throughout the study for one hanging (H6, female) and one control pig (C9, male), while the paragraphs below provide a more comprehensive description of the observed patterns of decomposition in the hanging and control groups of pigs.

Initially the appearances of the hanging and control pigs were similar. On the first day of the study, as the pigs were removed from the bags, and as they were set out in the field, blow flies were observed landing on them. The flies continued to land on the carcasses as they were hung for weighing suggesting that colonisation would have occurred on the hanging carcasses in the same way as those on the ground had the carcass been hanging at time of death. The flies oviposited in the natural orifices in the head, around the anus, and in the skin creases, ostensibly showing no preference for either group of pigs. Eggs were also laid around the noose on the hanging pigs.

Once larvae had hatched and all the pigs had started to purge decomposition fluids at **147 ADD**, the patterns observed in the two groups diverged. The bowels had prolapsed in all the hanging pigs with some of the data loggers being avulsed; this did not occur in the control pigs. The testicles of the male hanging pigs were considerably more distended than those of the controls which never reached this level of swelling.

229 ADD: The maggots in the surface group remained visible and active, with wet decomposition destroying the throat tissue and opening the carcass. Beetle adults and larvae were also present. In contrast, maggots were no longer visible in the hanging pigs and no beetles or their larvae were seen. Drip zones had formed beneath the hanging pigs. These contained maggots which had fallen from the pigs in quantities from a few to volumes of approximately 240 ml.

279 ADD: All the pigs' heads had been largely consumed; 80% of the control pigs had part of the maxilla or mandible exposed whilst only 10% of the hanging pigs were showing any bone. Differences in the pattern of decomposition were evident. The hanging pigs were mummified with little visible external insect activity.

Maggots were evident only when they fell to the drip zone, at which point they effectively had no further impact on the hanging body.

385 ADD: The appearance of the hanging and control pigs was now very different. The control pigs could be seen to be decomposing, evincing clear moist decomposition with parts of the torso breached and bones visible. From this point there was little breaching of the hanging pigs and they became hanging 'empty pigs', with the pig appearing externally to be complete but with the internal organs decomposing or decomposed. The bowels of the hanging pigs had now prolapsed fully with some fallen to the ground.

459 ADD: Externally the hanging pigs displayed deflation and lengthening. Lifting the forelimbs showed active maggot activity in some of the axillae and some with breached skin. Two of the pigs had hind trotters just touching the ground so were raised back off the ground. No adult or larval beetles were observed on the pigs or in the drip zones. The control pigs had foaming maggot masses and bones visible, including mandibles, limbs, ribs, scapulae and vertebrae.

512 ADD: The intestines of the majority of the hanging pigs had dropped to the drip zones. All the hanging males had lost their intestines, as had 20% of the females. In the male pigs the scrotal sac opened and joined with the anal hole. In the controls there were few or no visible maggot masses on the skin, but these were still present beneath the skin.

591 ADD: In the hanging pigs the torso had become leathery. The stomach and lots of fat were in the drip zones and the first bones were found in the drip zones: ribs, scapulae and vertebra. Figure 4.3 shows exposed rib bones within the torso of one of the hanging pigs, seen through the axilla. The controls all had their head and some limb bones exposed.

631 ADD: The torsos of the hanging pigs had become mummified. The long bones and innominates were found in the drip zone. High rainfall had left the control pigs lying in pools of water and all of them had soft swollen skin and were fatty.

767 ADD: The hanging pigs were elongated, mummified and hard. In the control pigs all the heads were skeletonised and most of them had more than 50% of bones visible in the limbs and torso.

828 ADD: Prolonged heavy rainfall left all the pigs looking fatty and white where rehydrated. The control pigs were lying in rain water.

932 ADD: The hanging pigs were mummified and all remained hanging. All the controls now had more than 50% bone exposure on the head, limbs and torso.

4.2.2 Patterns of Decomposition in Male and Female Hanging Pigs

The pattern of decomposition displayed two main differences between the hanging male and female pigs: in overall torso shape and in the position of the final opening in the lower torso. The control pigs did not show the corresponding differences in shape.

At initial bloat, all the hanging pigs assumed an evenly swollen appearance with the limbs swollen and held out from the body. As the bloat subsided, the males deflated first on the upper torso, remaining swollen around the mid-torso with the greatest width around the umbilicus and penis. The scrotum also remained swollen. This shape was retained until fully deflated even though the penis and umbilicus had become open holes. The female pigs maintained an evenly swollen shape, appearing rectangular in frontal view and with no protrusion around the umbilical area. This shape was retained until fully deflated, leaving a pouch of skin drooping on the lower abdomen.

In both males and females the anus enlarged to around 10 cm in diameter early in the decomposition. In a hanging position the anus of a pig is not at the lowest part of the torso but higher and dorsal. In the males, as the decomposition progressed, the back of the scrotal sac decomposed joining with the anus and creating a much larger opening directly below the body (Figure 4.4) enabling bones to drop out. In the females the anus remained open only at the back with the pouch of stretched skin remaining from the bloating stage left hanging lower than the anus (Figure 4.5). Some bones collected in this pouch, below the anus, (Figure 4.6) and were still there at the end of the study period.

4.2.3 Timing of First Beetle Activity

The first beetles were observed on the control pigs at 57 ADD. The first beetles were observed on a hanging pig at 869 ADD with a beetle larva having been seen in the drip zone of a pig at 591 ADD.

15 ADD	57 ADD	147 ADD	229 ADD
All pigs: Both the hanging and control pigs showed effects of blood pooling.	**All pigs:** Bloated and displaying colour changes with clear marbling in some animals.	**All pigs:** Bloated and purging decomposition fluids; maggots on and in the head. **Hanging pigs:** All had prolapsed bowels and some of the anal data loggers had already been avulsed. The male pigs' testicles were considerably more swollen than in the control pigs.	**All pigs:** Maggot masses in mouth. **Hanging:** Few other maggot masses visible, but drip zones had formed beneath the pigs. **Controls:** Throats open and moist with visible decomposition; maggot masses visible on the underside.

Figure 4.2 Decomposition sequence for one hanging (H6, female) and one control pig (C9, male).

			
279 ADD **Hanging:** One hanging pig showed exposed bone. **Controls:** 80% of the control pigs had part of the maxilla or mandible exposed.	**338 ADD** **Hanging:** Little visible external maggot activity; skin slippage but no breaches of skin. **Controls:** Throat and chest open with visible maggot activity; some ribs visible.	**385 ADD** **Hanging:** Appeared externally to be complete but internal organs were decomposing; bowels fully prolapsed with some fallen to the ground. **Controls:** Could be seen to be decomposing; evincing clear moist decomposition with parts of the torso breached and bones visible.	**459 ADD** **Hanging:** Deflating and lengthening; active maggot activity in some of the axillae and in some the skin was breached. **Controls:** Foaming maggot masses; bones visible, including mandibles, limbs, ribs, scapulae and vertebrae.

Figure 4.2 (cont.) Decomposition sequence for one hanging (H6, female) and one control pig (C9, male).


512 ADD

Hanging: In male pigs the scrotal sac opened and joined with the anal hole. In 100% males & 20% females the intestines had dropped into drip zone.

Controls: Few or no visible maggot masses on the skin but maggots still present beneath the skin.


591 ADD

Hanging: Skin leathery. The stomach and lots of fat were in the drip zone. First bones found in the drip zone: ribs, scapulae and vertebra.

Controls: All heads and some limb bones exposed.


631 ADD

Hanging: All torsos mummified; long bones and innominates were found in the drip zone.

Controls: High rainfall had left the pigs lying in pools of water and all of them had soft swollen skin and were fatty.


714 ADD

Hanging: Maggot fall continuing into drip zone; torsos very deflated.

Controls: More bones exposed.

Figure 4.2 (cont.) Decomposition sequence for one hanging (H6, female) and one control pig (C9, male).

			
767 ADD	**828 ADD**	**869 ADD**	**932 ADD**
Hanging: Torsos were elongated, hard and mummified. **Controls:** All heads skeletonised and most of them had more than 50% of bones visible in the limbs and torso.	**All pigs:** Prolonged heavy rainfall left all the pigs looking fatty and white where re-hydrated. **Controls:** The control pigs were lying in rain water.	**All pigs:** Drying out after previous wet period.	**Hanging:** Pigs were mummified and all remained hanging. **Controls:** All the controls now had more than 50% bone exposure on the head, limbs and torso.

Figure 4.2 (cont.) Decomposition sequence for one hanging (H6, female) and one control pig (C9, male).

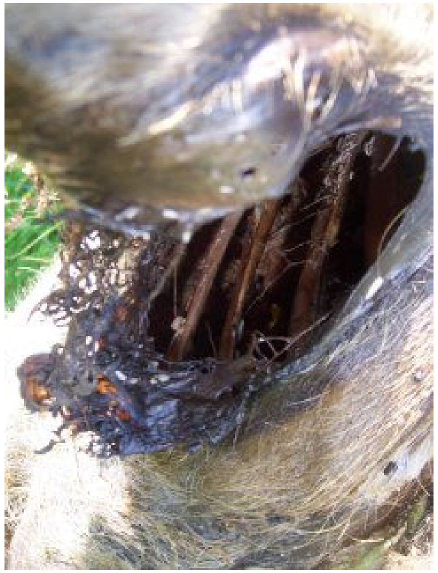

Figure 4.3 Showing the ribs in the torso of a hanging pig viewed through the breached axilla at 591 ADD.

Figure 4.4 Hanging male at 512 ADD. The arrow points to the anal opening extending beneath the body.

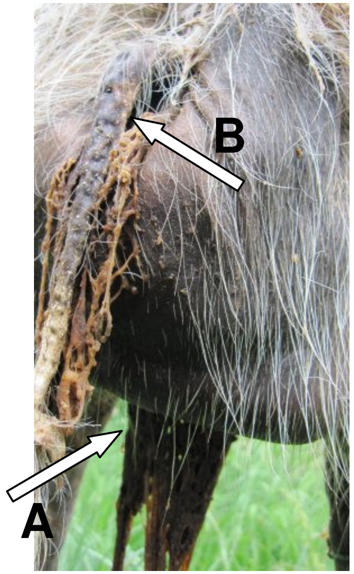

Figure 4.5 Hanging female at 600 ADD. Arrow A points to the pouch of skin hanging below the anal opening (arrow B).

Figure 4.6 Hanging female pig at the close of the experiment. The pouch of skin was cut open and the arrow points towards the bones which had collected in the pouch.

4.3 Total Body Score for Hanging Bodies (TBS_{hang})

The new scoring scale for hanging bodies was aligned with Megyesi *et al.*'s scale spanning the same decomposition range from fresh to dry bone and scoring the same body regions. The scale produced for scoring the hanging pigs is based on a score for the head and neck between 0 and 12 points to give a Partial Body Score Head ($PBSH_{hang}$); a score for the torso between 0 and 11 points to give a Partial Body Score Torso ($PBST_{hang}$); and a score for the limbs between 0 and 9 points to give a Partial Body Score Limbs ($PBSL_{hang}$). Total Body Score for Hanging (TBS_{hang}) was a sum of the three region scores and provided an overall measure of decomposition for the hanging body with a minimum score of 0 and a maximum of 32 points. Tables 4.1 to 4.3 list the decomposition scoring scales used for the three regions of the hanging pigs.

Table 4.1 Stages of hanging decomposition for the head and neck.

Score	Description
0	Fresh, no discolouration.
1	Swelling of head and neck.
2	Purging of decomposition fluids, darkening of skin to black, sinking in around eyes, some drying of snout and lips, most flesh still fresh.
3	Skin shrinking back from jaw, skin slippage.
4	Flesh sinking in around jaw and throat, drying of skin and lips.
5	Hair loss, drying shrinking snout.
6	Leathery skin, less than 10% bone visible.
7	Holes in or tearing of the skin.
8	Complete mummification, ears dry inflexible.
9	Partial mask formed where some of the skin is lifting from skull.
10	Skin like parchment, very thin and translucent with holes and tears forming.
11	Bone visible over more than 50% of skull, or detached mask for more than 75% of skull.
12	Dry bone which may still be hanging if attached by mummified tissue or may have fallen to the ground.

Table 4.2 Stages of hanging decomposition for the torso.

Score	Description
0	Fresh, no discolouration.
1	Bloating, red to green discolouration, swelling of males' testicles.
2	Colour changing from green to grey to dark grey / black.
3	Prolapsed bowel, purging of decomposition fluid.
4	Lower torso more swollen than upper. Penis and umbilicus are open holes on males.
5	Body elongated with some caving in of upper torso.
6	Anus open to diameter of 10 cm or greater, intestines protruding. Scrotum soft and shrivelling in males.
7	Drying and browning of skin, becoming leathery on upper torso.
8	Intestines dropped out of body, skin mummified. Scrotal sac open at back into anal opening on males.
9	Stomach dropped from body, ribs, scapulae and vertebrae dropped, flanks sunken, skin very greasy to touch.
10	Large loss of fat onto drip zone, torso drum like, innominates and long bones dropped.
11	Dry bone below carcass or visible beneath mummified skin, carcass may still be hanging.

Table 4.3 Stages of hanging decomposition for the limbs.

Score	Description
0	Fresh, no discolouration.
1	Reddening of skin, becoming dark grey, limbs swollen and extended out from the body.
2	Some skin slippage, drying of limbs at extremities.
3	Grey becoming black, forelimbs hanging in usual position.
4	Drooping forelimbs hanging loosely, disarticulated at shoulder.
5	Hind limbs hanging loosely, disarticulated at pelvis, loss of hind hooves, hair loss.
6	Mummification of lower end of limbs, skin colour dark brown, tears and holes in skin.
7	Bones in hanging bags of skin. Mummified with distal ends of limbs rock hard, skin stuck to bones.
8	Bones dropping through torso, scapulae first then humerus. Limb surface very greasy.
9	Dry bone below carcass or visible beneath mummified skin, carcass may still be hanging.

4.4 Analysis

In hanging pigs, the sexes showed significantly different patterns of loss of mass (χ^2 = 24.4, df = 3, p < 0.001), with females losing mass more slowly and retaining more mass throughout (Figure 4.7). The maximum rate of loss for males was

0.17% loss per ADD (at ADD = 483), and for females 0.13% loss per ADD (at ADD = 503).

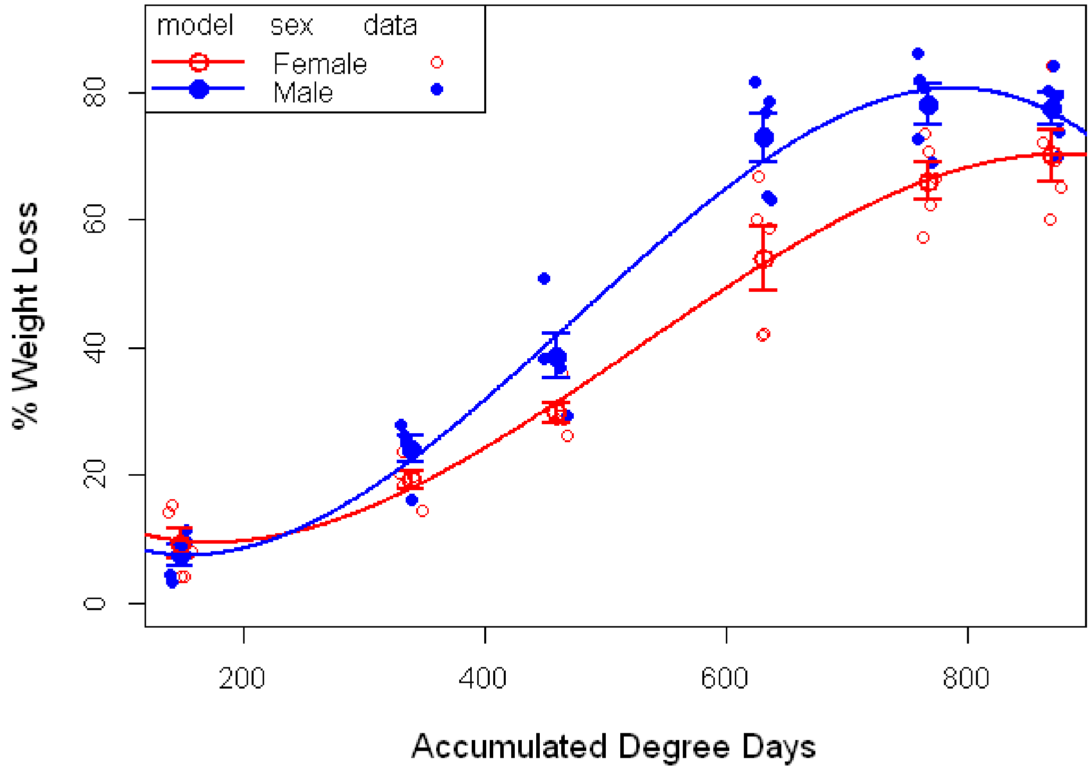

Figure 4.7 Differences in percentage weight loss between male and female hanging pigs to 900 ADD. The data points show the values for each sex at each value of ADD. The model lines are the polynomial regression (here fourth order) fitted values. Some jitter has been added to the ADD values of the data points for clarity.

When using the Total Body Score as the response variable, there was again a difference between sexes (χ^2 = 15.6, df = 2, p < 0.001), though this was not as large, and again, males showed a greater rate of decomposition (Figure 4.8).

This curve is a quadratic, and, as can be seen from the plot, maximum slope is found where ADD = 0; being 0.062 TBS_{hang} per ADD for females, and 0.068 TBS_{hang}

per ADD for males. Despite being statistically significantly different, the differences are therefore small.

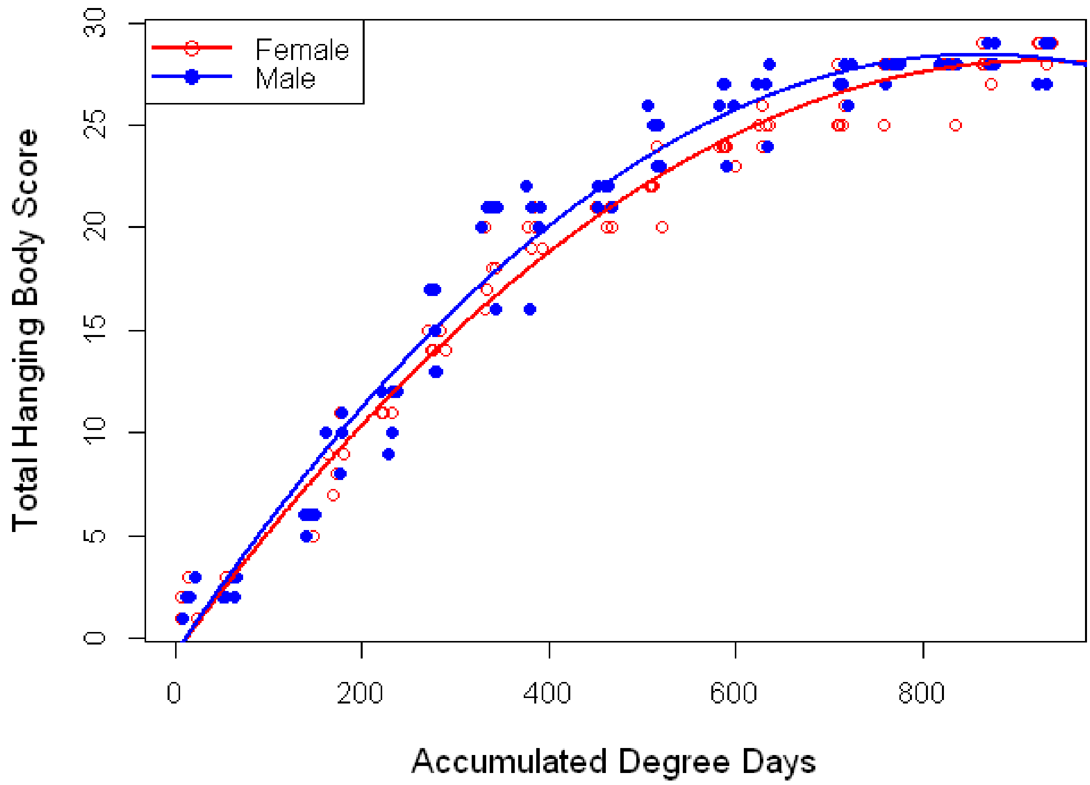

Figure 4.8 Rate of decomposition showing the difference between the male and female pigs using Total Body Scores for Hanging (TBS_{hang}) to 900 ADD. Jitter has been added to ADD for clarity.

Using the Total Body Score and Total Body Score for Hanging (TBS_{surf} and TBS_{hang}) to compare the rate of decomposition of surface and hanging pigs, a highly significant difference was evident ($\chi^2 = 104$, $df = 5$, $p < 0.001$), with hanging pigs reaching later stages of decomposition more quickly (Figure 4.9).

The behaviour in this case is more complicated (requiring a fifth order polynomial). In relatively early decomposition, e.g. around 150 ADD, decomposition rates are steeper and similar (controls: 0.051 TBS_{surf}/ADD, hanging: 0.060 TBS_{hang}/ADD); whereas later, when decomposition slows on the ground, hanging slows even more (e.g. at 650 ADD controls: 0.020 TBS_{surf}/ADD, hanging: 0.014 TBS_{hang}/ADD).

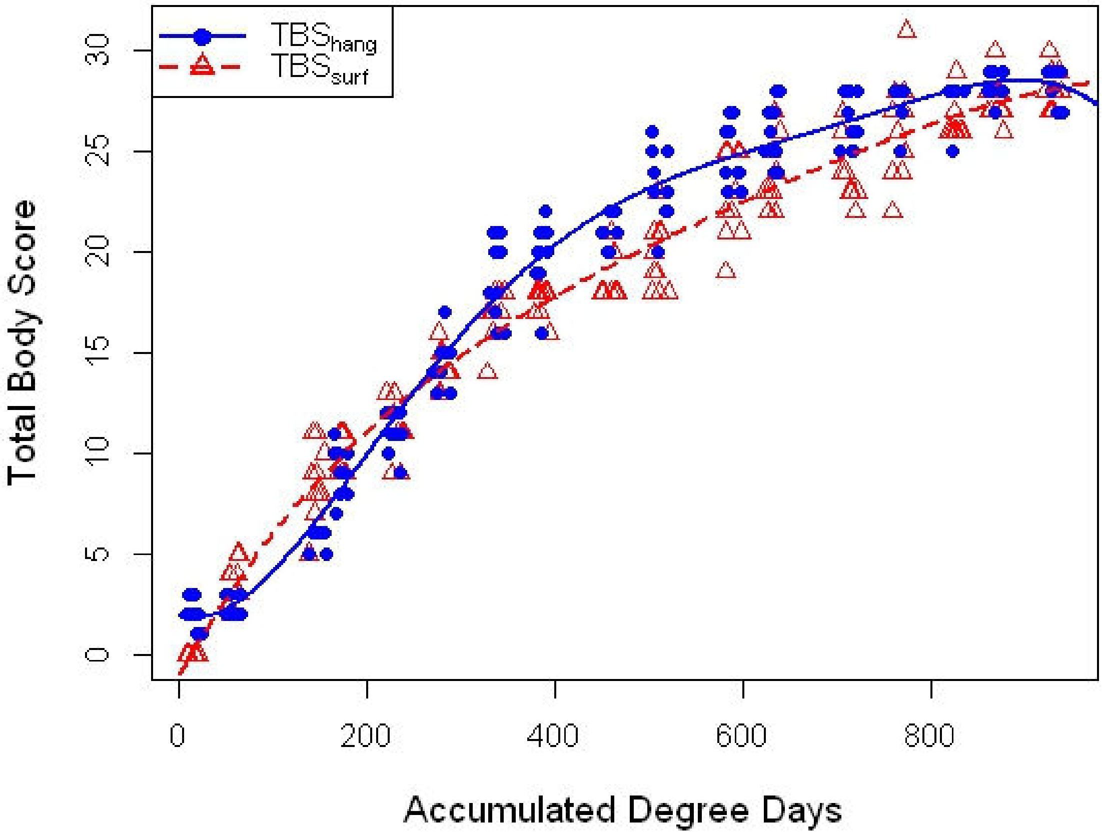

Figure 4.9 Comparison of decomposition rates of hanging and grounded pigs using Total Body Scores for hanging (TBS_{hang}) and surface (TBS_{surf}) pigs, respectively, to 900 ADD. Jitter has been added to ADD for clarity.

4.5 Discussion

This study showed the pattern of decomposition in hanging pigs differed from that in pigs lying on the ground to the extent that the construction of a new decomposition scoring scale was needed for the hanging pigs. The comparison of percentage weight loss between the male and female hanging pigs showed a clear difference between the sexes, which may be the result of the different shapes assumed by the male and female pigs as they decomposed. The corresponding decomposition scores for the two sexes did not, however, show a similar difference. These findings and other observations are discussed below.

4.5.1 Decomposition Scoring Scale for Hanging Bodies

The Megyesi *et al*. (2005) Total Body Score scale was produced using a retrospective cross sectional study of humans which, by its nature, provided a single snapshot of the stage of decomposition at which each individual was found, rather than a longitudinal study observing progressive changes in the same individuals over the whole decomposition process. Although Megyesi *et al*. studied many individuals covering much of the range of decomposition stages, there were no instances of hanging bodies. It appears from the findings of the hanging studies, including the present longitudinal study, that the pattern of decomposition in hanging bodies is markedly different, making Megyesi *et al*.'s scale unsuitable for scoring these bodies.

For their study, Megyesi *et al*. calculated ADD values using the daily average temperature records from the nearest national weather station for each body, while the PMI in each case was determined either from insect evidence or the associated police investigation (Megyesi *et al*., 2005). This approach would have led to uncertainties in the accuracy of both the ADD (Dabbs, 2010, 2015) and PMI values being used. For the present study the ADD was calculated from two temperature data loggers situated within 10 m of the pigs, with measurements at

6-hour intervals, while the PMI was known to within one hour. Both the ADD and PMI values for the present study can therefore be regarded as accurate with a high degree of confidence.

Decomposition scores generated using the new hanging scale cannot be directly compared with those from Megyesi *et al*.'s (2005) scale as they describe different patterns of decomposition; there is, currently at least, no established absolute scale of decomposition which could be used to link them. However, both scales span the same range of decomposition and, once adjusted for a zero baseline, assess the same body areas using the same point ranges. Furthermore, the new scale was constructed as far as possible so that a given score (for each body region) corresponded to a similar overall level of decomposition. Where the hanging and control groups did display common features these were generally awarded the same scores in both scales. Consequently, while it would be imprudent to read much into the detailed differences displayed in Figure 4.9, it is encouraging that the total body score plots for both the hanging and control groups show a broadly similar progression against ADD, and that the differences between the two groups matches the observed behaviour.

4.5.2 Mummification

The new scoring scale produced for hanging pigs includes mummification in the description of what is seen during the decomposition. Whilst it could be argued that it should not be in the scale as it is not a feature common to all decomposition, it was found to occur in all 20 hanging pigs of the present 2011 study; was also observed in a previous trial in 2010; and has been reported in case studies of human hangings (Komar *et al.,* 1999). This would indicate that mummification is a feature of hanging, much like adipocere is a feature of many immersed bodies.

Micozzi (1991) describes mummification as referring to all natural and artificial processes that bring about preservation of the body or its parts. Mummification may occur naturally as the result of a number of factors including heat, humidity, cold, wind, or the absence of air. Natural mummification may be deliberately enhanced by the way the body is treated or placed; for example, burying in hot dry sand, which is known to enhance the removal of water and speed up desiccation (Aturaliya and Lukasewycz, 1999).

The most common form of natural or spontaneous mummification is desiccation. Aufderheide (2011) says: "The interface of the skin surface with the body's environment is the principle determining variable for establishing the rate of a corpse water loss." This loss of water may result in desiccation and may lead to mummification of the skin and the preservation of some or all of the soft tissues.

In these experiments the action of the wind on the fully exposed hanging pig bodies is the most probable cause of their desiccation and mummification. The rate of desiccation was such that the internal decay continued unabated leaving the carcasses 'hollow' (Figure 4.6). The same feature may not be found where wind is not a relevant environmental factor or where humid conditions prevail.

4.5.3 Initial Weight of the Pigs

The average weight of the hanging pigs and the control pigs at the start of the experiment was significantly different: using a T test gave $t = 4.32$, $df = 18$ and *p* = 0.0004 at the 5% significance level. Although unintentional, this difference resulted from the way in which the pigs were allocated to the two groups and introduced an unexpected shortcoming into the experimental design where failing to control the weight variable may have undermined the validity of the results. To strengthen this part of the experimental design for future experiments it would be desirable to ensure all the pigs come from the same farm where it could be expected that they would be of the same age and roughly the same weight. The hanging decomposition scoring scale produced in this experiment should also be tested on pigs of different weights.

Chapter 7, which reports on results obtained using the combined data from all the experiments carried out in this study, covering a much wider range of pig weights, shows that the difference in weight would not in fact have made a difference to the production of the decomposition scoring scale.

4.5.4 Rate of Decomposition in Hanging and Control Pigs

Accepting that the two scales were comparable, and differences in scores between hanging and surface carcasses really did reflect the differences in decomposition, the difference in the rate of decomposition shown in the current study, with the hanging pigs lagging behind the controls in the early stages of decomposition, is in agreement with Shalaby *et al*. (2000) and the previous 2010 study. This difference may be attributed to the differences in levels of insect activity between the two groups. Insect access, particularly for Coleoptera (beetles), to the hanging pigs was limited and this may explain the delay in decomposition of the hanging pigs. Additionally, the action of gravity and movement disturbed the maggot masses causing maggots to fall from the hanging pigs to the drip zones below, thus decreasing the internal maggot masses. This has implications for calculating the PMI of hanging bodies as many are found with the feet in contact with the ground. If this has occurred at the time of hanging or rapidly after, the insect access is likely to be similar to that of a body on the ground.

4.5.5 Comparison of Weight Loss in the Male and Female Hanging Pigs

The differences in shape between the hanging males and females during much of their decomposition may be explained by the positioning of the urethral opening. In the males this is situated just posterior to the umbilicus and may thus provide another escape route for the gases produced during decomposition, making this point the widest as the gases gather there. The escaping gases may also attract insects, particularly Diptera, as the umbilicus and penis of the males soon became full of larvae and progressed to open holes.

This did not occur in the females where the urethral opening is just ventral to the anus, indicating that it is the urethral opening that is the weak point rather than the umbilicus. Without this escape route higher on the torso, the females retained a rectangular shape and, as they deflated, the skin which had remained stretched and swollen now formed a pouch of loose skin at the lower torso. This pouch of skin hung lower than the anal opening, so that disarticulated bones dropping down within the female pigs could become trapped here rather than falling to the ground. This contrasted with the males where, as the tissue of the swollen scrotum decomposed it became part of the anal hole. A single large opening directly beneath the pig was produced and this allowed bones to fall through more easily. Whilst of note in this study, this feature is unlikely to be of any significance when observing humans as, when hanging, the anal openings of quadrupeds and bipeds are not in the same place. In humans the anal opening would be directly below the body and the positioning of the human penis is also low down, not at the umbilical level, so the shape differences between the male and female pigs in late bloat and deflation may not be present in humans.

The weight loss started slowly, increased, and then slowed down toward the end of the decomposition as would be expected (Shalaby *et al*., 2000). The difference in decomposition pattern of the male and female pigs may account for the difference in percentage weight loss during decomposition, as bones were lost from the males through the anal opening. Whilst the rate of decomposition between the males and female pigs was shown to be statistically significant the actual difference was very small. The hanging pigs in this experiment were weighed weekly and in doing so it is inevitable that the maggot masses would have been disturbed. Adlam and Simmons (2007), suggest that the physical disturbance of a carcass may disrupt the feeding of the maggots and retard the rate of decomposition, but any such effect would be expected to be the same for both the males and females. Weight loss in soft tissues has been used by some authors (Payne, 1965; Payne *et al*., 1968; Shalaby *et al.,* 2000), as a way of assessing decomposition. This study has shown, however, that care is required in extending this principal to whole body weight loss. Past studies (Adlam and Simmons, 2007; Payne, 1965) have shown a correlation between decomposition rate and weight loss. This may not be the case where part of the body has been lost or dispersed.

4.5.6 Beetles

In a pilot study (unpublished) previously carried out at TRACES the rate of decomposition of hanging pigs was significantly different (faster) than in this study. A noticeable difference was the presence of beetles on the carcasses at an early stage thus increasing the diversity of insects. The number of species of insects recovered from hanging cases tends to be lower than for bodies lying on the ground (Goff and Lord, 1994). It has been reported that the greater the diversity of insects, the greater the rate of decomposition (Campobasso *et al.,* 2001) whilst a study by Chong Chin *et al.* (2010) noted that hanging altered the insects that colonised by excluding the ground living taxa.

Nine of the pilot study's hanging pigs had their hind limbs in contact with the ground for some or all of the time between 54 ADD and 159 ADD before being raised up. During this time, effectively, these pigs were not hanging. Whilst the beetles most commonly found on the pigs at the study site, Silphidae, Histeridae and Staphylinidae, are all strong fliers, Chinery (1976) states "Beetles can and do fly well, but relatively little time is spent in flight; beetles are very much insects of the ground and low vegetation". The pigs' hind limbs resting on the ground would have provided the beetles with an easy means to reach the hanging pigs and the pilot study suggested that they may have taken advantage of this route.

Additionally, between 54 ADD and 200 ADD five of the pilot study pigs herniated the intestine providing another site for the release of volatile gases, attracting flies and providing a moist access to the carcass for oviposition. It was noted that four of these five pigs were male. In pigs, unlike humans, the intestines do not usually lie above the inguinal canal, but in the hanging position the gravity and pressure of gases may have acted on them pushing into the inguinal canal and causing them to herniate.

4.5.7 Internal Temperature Measurements

This experiment intended to compare the internal and external temperatures of the pigs using internal data loggers and thermocouples, but these failed to record over the duration of the study period or were deactivated by decomposition fluid and/or rain. The experience gained did, however, lead to changes and improvements in the way that the data loggers were prepared for the subsequent experiments.

4.5.8 Effects of Heavy Rainfall

Also noted was the change to the appearance of bodies on the ground when they had become sodden and waterlogged following prolonged rain. This rehydrating of the tissues and fats gave the bodies the appearance of being 'fresher' than prior to the rain. This may give the impression that the progression of decomposition is less advanced and lead to a lower TBS_{surf} which, in turn, will impact the PMI calculations possibly providing an inadvertently lowered PMI. An accurate PMI is important in establishing the events surrounding a death and creating a timeframe when searching for missing persons. It may, therefore, be prudent to check the amount of rainfall and duration in the days prior to a body being found if it does look particularly fatty, and make allowances for the apparent retardation of decomposition. To ensure that PMI calculations are not inadvertently lowered it may be necessary to increase the range of dates within which the PMI falls.

5 EXPERIMENT 2 – The Effect of Clothing on the Decomposition Pattern and Rate in Hanging and Surface Pigs

Hanged bodies[2] are found in various stages of dress and undress ranging from fully clothed through semi-clothed to naked; the latter two being common in autoerotic hangings where death has resulted from a failure of the safety release mechanism. In Experiment 1 (Chapter 4) it was shown how the decomposition patterns differed over time, using Accumulated Degree Days (ADD), for 'naked' hanging and surface bodies. Results from other experiments (Anderson, 2010; Aturaliya and Lukasewycz, 1999; Campobasso, *et al.,* 2001; Card *et al*., 2015; Dautartas, 2009; Goff, 1992; Haglund, 1997; Kelly, 2006; Komar, 1998; Mann *et al.,* 1990) with clothed, wrapped and unclothed bodies have reported different effects on the decomposition rates and the patterns. As Total Body Score (TBS) scores are obtained from the decomposition pattern, and these are used with the ADD to calculate the estimated PMI, it is important that any effects due to the presence or absence of clothing are known so that, if necessary, adjustments can be made to the calculations.

The aim of this experiment was to investigate the effect of clothing on the decomposition pattern and rate of hanging pigs and pigs in direct contact with the ground (surface pigs). The objectives were to:

[2] In British English people are 'hanged' and animals are 'hung'.

- record the patterns and rates of decomposition of clothed and unclothed hanging and surface pigs;

- compare the rates of decomposition between the clothed and unclothed hanging pigs, and between the clothed and unclothed surface pigs; and

- compare the patterns and rates of decomposition between the hanging clothed pigs and the clothed pigs lying on the ground.

The experiment also provided more decomposition data to add to those already collected at the same site for (unclothed) hanging and surface pigs in previous years.

5.1 Materials and Methods

This experiment used 40 pigs (*Sus scrofa*), killed as described in the General Materials and Methods (Chapter 3), which were allocated randomly to four equal groups: hanging unclothed (H/U), hanging clothed (H/C), surface unclothed (S/U) and surface clothed (S/C), and labelled uniquely to reflect their group. The H/U group was therefore equivalent to the hanging group in the other two experiments, while the S/U group was equivalent to the control group.

As in Experiment 1, all the surface pigs, clothed and unclothed, had pre-programmed data loggers inserted into the rectum as described in General Materials and Methods.

5.1.1 Sex and Mean Weight of Pigs

The S/C group contained six females and four males, while the other three groups each had five males and five females. The mean weight of the hanging pigs, H/C and H/U, was 26.29 kg, with a standard deviation of 2.36 kg; and for the surface pigs, S/C and S/U, the average weight was 27.28 kg, with a standard deviation of 5.02 kg. A t-test showed that there was no significant difference in the weights of the pigs between the two groups (t = 1.75, df = 38, p = 0.08).

5.1.2 Hanging Pigs

Because of the failure of the thermocouples used in the hanging pigs and the early avulsion of the anally inserted data loggers in Experiment 1, changes were made to enable measurement of internal temperature in the hanging pigs.

The wires connecting the thermocouples to the data loggers were fragile and may have been one of the causes of their failure to record in the first experiment. To avoid this happening again the pre-programmed data loggers were sealed with parafilm then placed inside leak-proof tubes, the openings of which were smeared with petroleum jelly. The lids were fitted and the junction sealed with duct tape. Wire was wrapped around the top of each tube with a length of about one metre of free wire which, once the pig was hung, was attached to the hanging rope to prevent the tube becoming lost into the pig, or dropping out of it, as decomposition progressed (Figure 5.1). The data loggers were inserted into the thorax using the same techniques as for Experiment 1.

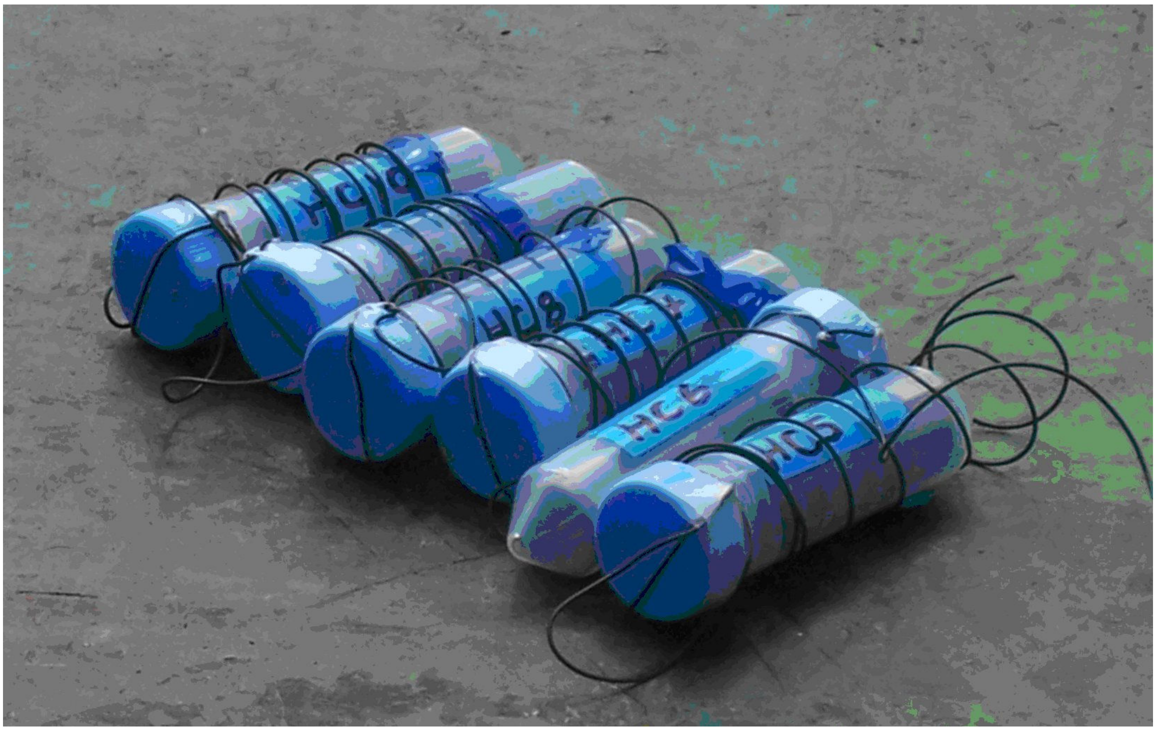

Figure 5.1 Data loggers sealed in 50 ml conical centrifuge tubes with wires for use with the hanging pigs. The wires were attached to the hanging ropes once the loggers had been inserted into the pigs.

5.1.3 Clothing the Pigs

Immediately after the anal data loggers had been inserted, the pigs in the S/C group were dressed in identical white cotton tee shirts, black cotton boxer shorts, and a webbing belt. This was to ensure that they were left unclothed for as short a time as possible. As pigs have short legs, boxer shorts were used to mimic trousers. A loosely tied belt was included as it is common to wear one with trousers and this may result in restriction during bloat. The H/C pigs were clothed in the same way and had the data loggers inserted into the thorax after being dressed.

5.1.4 Data Collection Intervals

All the pigs were put into position in a two-hour period on 29 May 2012. Data collection occurred every other day until 635 ADD, when decomposition had slowed, and then at four day intervals until the end of the study at 1034 ADD (29 July 2012), for a total of 24 observation days. However, on two occasions prior to 635 ADD, the data collections took place at four day intervals, rather than every other day, corresponding to an interval of approximately 50 ADD. The first occasion followed heavy rainfall of 11.5 cm in a 24 hour period before data collection was due, and the second occasion was to comply with safety regulations which did not allow researchers to visit the site alone (staff illness meant it was not possible to have the required minimum of two people on the site).

5.1.5 Data Collection

Data collection for the unclothed pigs was carried out and recorded as described in the General Materials and Methods chapter. The decomposition pattern was relatively easy to observe in the unclothed pigs. However, the presence of clothing, which covered most of the clothed pigs, made the observation impossible if the clothing was not moved.

To make comparisons between the clothed and unclothed pigs the same areas needed recording but with as little disturbance of the pigs and insects and larvae as possible. To achieve this, the observations of the clothed pigs were made initially with the clothes in place. The bottom end of the shorts legs were then lifted carefully to observe any changes that could be seen beneath the shorts. The bottom of the tee shirt was carefully lifted to observe changes beneath this and around the belted area. Finally, where possible, the sleeve of the tee shirt was lifted to observe changes in the axilla and on the fore limb. Great care was taken to lift the clothing gently and replace it as quickly as possible to minimize the disturbance of the maggots or insects beneath the clothing.

5.1.6 Decomposition Scoring

Visible decomposition of the S/C and S/U pigs was scored using Megyesi *et al.*'s system (2005) adjusted to a baseline of zero to give TBS_{surf}. The H/C and H/U pigs were scored using the new hanging scale developed in Experiment 1 to give TBS_{hang}.

5.1.7 Statistical Analysis

For the analysis, data for the H/U and S/U pigs were taken from all three years' experiments. Since the data were not collected at the same ADD values each year, this provided TBS scores for a larger number of actual ADD data points. The combined group analysis in Chapter 7 showed that the results for H/U and S/U pigs were consistent across all three experiments.

Experiment 1 and the analysis in Chapter 7 further showed that the sex of the pigs and their initial weight did not affect the TBS, so weight and sex variables were not considered in this experiment. All data analysis was performed using the software R (R Development Core Team, version 3.1.1) and its 'arm' package (Gelman and Su, 2015). Linear regression of TBS versus ADD was carried out for each treatment group and, using the summary table from this, simulations were performed (Gelman and Hill, 2006) enabling comparisons to be made at the same selected set of ADD values, with a fixed interval of 100 ADD, despite the data having been collected at different ADD values during each year's experiment.

The linear regression model produced a line of best fit, but the summary report gave the errors for the intercept and slope. The simulation then used the error structure in the model to give a large number of possible TBS values at each ADD;

with errors from which a mean and standard deviation were produced. Graphs produced using this method are clear and include errors making them easier to interpret than one showing the regression model directly (Moffatt and Simmons, 2014).

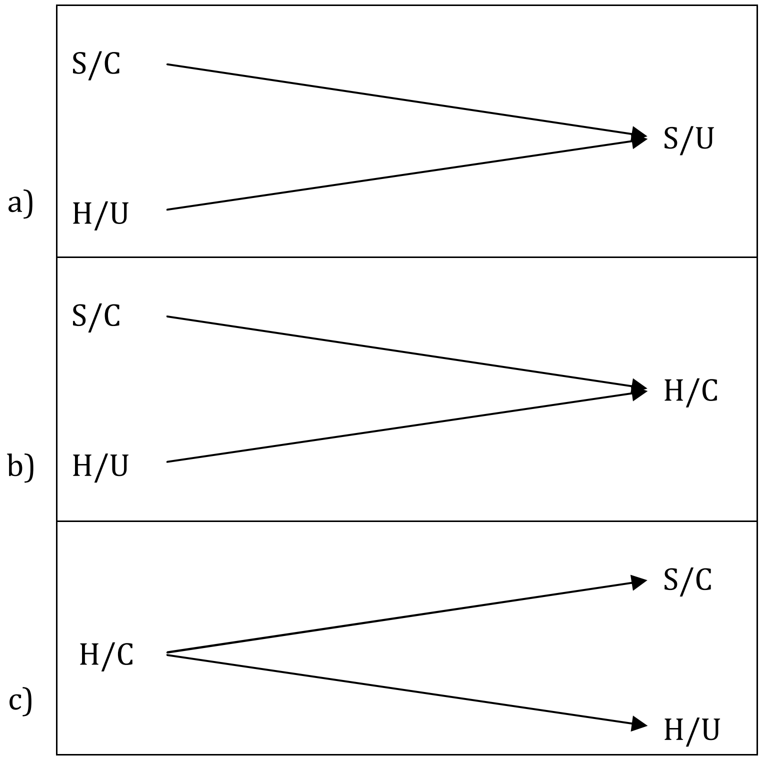

Figure 5.2 Group pairings used for TBS comparisons: a) the S/C and H/U groups were compared to the S/U group; b) the S/C and H/U groups were compared to the H/C group; c) the latter enabled the H/C group to be compared to the H/U group, and also to the S/C group.

The TBS against ADD responses were compared for the four groups as illustrated in Figure 5.2. The S/C and H/U groups were compared against the S/U group (Figure 5.2a), and the S/C and H/U groups were compared to the H/C group (Figure 5.2b); with the latter enabling the comparison of the H/C to the H/U group, and the comparison of the H/C to the S/C group (Figure 5.2c) without the need for a large number of graphs. 10,000 simulations were performed for each of the four group-pair comparisons, with the simulations generating the TBS difference values between the two groups in each case.

5.2 Results

The two existing decomposition scoring scales used in Experiment 1 proved to be sufficient and appropriate for scoring the clothed groups: the S/C group and the S/U group were scored successfully using the scale developed by Megyesi *et al.* (2005), again adjusted for a baseline of zero, while the H/C group was scored using the same scale as the H/U group, developed during Experiment 1.

5.2.1 General Pattern of Decomposition

As the pigs were being removed from the body bags, flies were seen to land on them, but no eggs were seen on any of the animals before clothing them. Flies continued to land on the pigs once they had been placed in the field. Over the following few days, eggs were observed around the hanging nooses, and in the natural orifices around the anus and head in all four sets of pigs. Additionally, eggs were laid in the creases of the clothing and beneath the tee shirts, particularly around the waistband of the shorts.

The H/U pigs displayed a different pattern and rate of decomposition from the S/U pigs. Furthermore the H/C and H/U pigs differed from each other in their rate and pattern of decomposition. However, there were no significant differences between the S/C and S/U pigs in their pattern and rate of decomposition. Descriptions of the main differences between the groups, for a range of ADD values, are given below.

Figure 5.3 and Figure 5.4 show the progression for one pig from each group through the decomposition process. Figure 5.3 compares one of the H/C pigs with one of the H/U pigs; while Figure 5.4 does the same for an S/C pig and an S/U pig. Not all the sampled ADDs are represented since on some occasions no obvious changes had occurred between successive visits.

110 ADD: Hanging Pigs: In the H/U pigs, the bowels were starting to protrude and in the males the umbilicus and testes were swelling. These changes were not seen in the H/C pigs. (Observation was via the leg of the shorts.)

Surface Pigs: Maggots were present and visibly active on the heads and in the mouths of all the surface pigs. There were no noticeable differences between the two groups.

167 ADD: Hanging Pigs: Both groups of pigs had protruding bowels, drying snouts and visible skin slip on the head and torso. In all the male pigs the umbilicus/penis area was swollen. A drip zone, containing a few maggots, had formed beneath two of the pigs (one clothed, one unclothed).

Surface Pigs: All animals had maggot masses around the head, and the males had swollen umbilicus/penis with maggots present (the same as in the hanging group). The only obvious difference between the two groups was the presence of maggots just under the epidermis in the S/C pigs, and eggs around the waistband of the shorts beneath the tee shirts.

197 ADD: Hanging Pigs: Differences in appearance were now apparent between the H/C and H/U pigs. All the H/C pigs displayed swelling and discolouration of the lower abdomen on the right side, with four of this group having small holes in the skin and larger skin breaches forming in this area. One H/C pig had an open hole on the left lower side with a maggot mass clearly visible. The skin was deteriorating beneath the wet clothing and sticking to the shorts. Beneath the wet clothing, maggot activity was clearly visible on and beneath the epidermis. During observation the shorts were not detached from the skin where sticking had occurred.

In the H/U pigs all the bowels had now prolapsed. Maggots were not visible on the unclothed pigs and were seen only where they had fallen into the drip zone. Drip zones had formed below the pigs with most containing a small quantity of maggots, from a teaspoonful to about 100 ml.

Surface Pigs: Most of the pigs had some bone visible on the head. Differences in appearance were not great, the most obvious being the hind limbs which in the S/C pigs remained relatively fresh looking whilst the S/U pig limbs showed browning and drying.

224 ADD: Hanging Pigs: Little change was evident in the appearance of the H/U pigs. In the H/C group the skin beneath the shorts was wet and disintegrating with maggots clearly visible. The skin of the lower abdomen, on the right-hand side, was breached in five of the pigs. The prolapsed bowel of one of the pigs was caught in the shorts. Maggots were active and visible in the axilla of the H/C pigs and four pigs had clear breaches of the skin.

Surface Pigs: The main difference between the two groups was the degree of decomposition around the lower abdomen. This was greater in the S/C pigs with marked increase in maggot activity and tissue removal under the shorts and around the waistband. The skin around the breached areas was brown and drying.

284 ADD: Hanging Pigs: There was a marked difference in the destruction of the axilla with 90% of the H/C group having breached axilla compared with 40% of the H/U group. The bodies of the H/U pigs were elongating and the lower limbs were disarticulated in 60% of the pigs compared to 30% of the H/C group. In all of the pigs the anus had become a large open hole.

The shorts from one of the pigs had slipped from the body into the drip zone. The intestine of this pig had fallen through the shorts two days earlier and the whole of the lower abdomen, anus and area beneath the pig (in its hanging position) had become one open hole. The drip zone for this pig contained the shorts, maggots and a bone.

Surface Pigs: Visible differences were still not marked. The abdomens were open in four of the S/U pigs and six of the S/C pigs with bones visible in two of the latter. The most obvious difference was the presence of small holes around the areas where the waist band of the shorts was in contact with the skin and where there were maggots on the skin beneath the tee shirt. It should be noted that the weather had been very wet and as a result all the clothes were wet or damp.

326 ADD: Hanging Pigs: All of the H/C pigs had breached open lower abdomens on the right side. Three of these had completely open lower abdomens from front to back and the shorts had fallen into the drip zone. The lower section of the pigs, covered by the shorts, remained wet, soft and maggoty with more eggs being laid under the tee shirts.

In the H/U pigs the skin was drying and hardening. The appearance of the H/U pigs had not changed greatly although their shoulders and upper backs were dry and hard. This drying and browning was also occurring in the H/C pigs where the shoulders were not covered by the tee shirts.

Surface Pigs: For both groups the heads of most pigs had over 50% of the bone visible. The S/C group had bones visible in four of the animal torsos with none visible in the S/U pigs. One S/C pig had bones visible on one of the hind limbs where it had been covered by the shorts.

361 ADD: Hanging Pigs: All the animals were very, very, wet; it had been raining almost constantly.

Surface Pigs: All the animals were very, very, wet; it had been raining almost constantly. Bones were visible in the torsos of three S/U pigs and in the limbs of five. The S/C pigs had bones visible in the limbs of three pigs. Only two of the S/C pig torsos had visible bone. On the previous visit bone could be seen in four S/C animals but maggot masses were covering these in three of the four cases noted previously. One of the two S/C pigs where bone was observed this time had shown no bone previously.

418 ADD: NOTE: a month's worth of rain, 114 mm, had fallen in a 24 hour period since the previous visit and all the animals were very wet.

Hanging Pigs: The limbs of all the pigs were mummified. All of the H/C pigs had vertebrae and ribs present in their drip zones or visible in their breached bodies. The guts of this group had either fallen, or were protruding from the lower abdomen at the front of the torso and/or below the pig where the anus had opened through. Most of the H/C group also had areas in the upper torso and axilla where the skin was tearing or had opened into large holes. Only one H/U pig had any bone in the drip zone.

Surface Pigs: There was very little difference in the numbers of pigs within each group showing bone in the torso; and all of these had less than 50% of bone showing. All pigs showed areas of dry mummifying skin. The weather was dry and although the S/U pigs had dry skin on their upper surfaces this was not the case with the S/C pigs, where the clothing remained wet.

457 ADD: Hanging Pigs: No great changes in appearance.

Surface Pigs: 90% of the S/U pigs had bones visible in the torso with the remaining skin browning and drying. 40% of the S/C pigs had bone visible in their torso, although for two pigs where bone had been visible previously none could be seen as active maggot masses, beneath the clothing, were covering the previously seen bones.

497 ADD: Hanging Pigs: 90% of the H/U pigs were now mummified with hardened shoulders and backs. There were clear differences in the drip zones: 80% of the H/C pig drip zones contained vertebrae and 70% contained ribs, whilst for the H/U pigs 20% contained ribs and vertebrae. Shorts now remained on only three pigs, the rest of the shorts having slipped off the pigs and fallen into the drip zones along with four of the tee shirts.

Surface Pigs: All the S/U pigs had exposed bones in the torso with the skin on the upper surface of all but one of these pigs dry and mummifying. Maggot activity was present in some animals where the tissue on the ground remained wet and sodden. In the S/C pigs bone was visible in all but one of the torsos. The clothing on the pigs remained sodden and the skin in the abdominal area was wet with maggot activity. The skin on the backs of these pigs, despite being beneath wet clothing, was brown and drying on most of the pigs.

559 ADD: Hanging Pigs: The skin on both the H/C and H/U pigs was becoming greasy and fatty. The lower abdomen was open in the entire H/C group, with the lower half of one of the bodies now detached and in the drip zone. All the H/C pigs had ribs and vertebrae in their drip zones. All the H/C group had open abdomens and much of the rest of the torsos had tears and holes, with bones caught or clearly visible. Four of the H/U group had bones in the drip zone and three of the pigs had tears and holes in the upper torso.

Surface Pigs: All pigs were on very wet ground and had rehydrated fat. The S/C pigs appeared to have retained a more rounded pig shape than the S/U; looking more intact. However, the amount of bone visible in both groups was very similar.

599 ADD: Hanging Pigs: All of the H/C pigs had vertebrae and ribs in their drip zones, but vertebrae and ribs were only found in 30% of the H/U pig drip zones. Long bones and innominates were present in the drip zones of both groups.

Surface Pigs: The S/C pigs still retained a more rounded pig shape with the S/U pig bodies having a collapsed appearance. There was little difference in the amount of bone visible between the two groups and both groups had active maggots in some of the pigs.

634 ADD: Hanging Pigs: All the H/C and H/U pigs were mummified. The H/U groups had much greater skin destruction with more than 50% of the bones visible, either on the ground or through the holes and tears in the skin. Three of the pigs in the H/C group had the lower part of their bodies, from about mid torso down, in the drip zone with the bones clearly visible where the tissue has been destroyed. A fourth pig in the H/C group had the lower portion of the body attached only by threads of skin. One of the H/C pigs had vertebrae and ribs falling out in one piece.

Surface Pigs: All the pigs were very wet with hydrated fat and softened skin. The skin on the upper surface of the S/U pigs was detached from the bones and lay blanket-like on the bones. The skin of the S/C pigs was wet and maggot masses were visible, surrounding bones, beneath the shorts in the fat of two pigs.

698 ADD: Hanging Pigs: All the pigs were mummified with little change in the appearance of the H/U pigs. The H/C pigs had continued to lose limbs.

Surface Pigs: S/U pigs: More than 50% of the skeleton was visible either through the very thin covering of mummified skin lying on the uppermost surface or visible when the detached skin blanket was lifted. The skin covering the S/C pigs appeared to be more intact; it was attached to fat and could not be lifted to view beneath it. Where the skin was not attached in this way the bones were clearly visible and not covered in tissue. The clothing was wet.

770 ADD: Hanging Pigs: The skin on some of the H/U pig torsos showed tearing and holes forming, through which bones were falling or could be seen. This occurred mainly on the front of the torso. The H/C pig torsos had many tears and holes in both the back and the front of the animal. Where the lower bodies of the H/C pigs had fallen into the drip zones the bones were visible and largely clean of any tissue.

Surface Pigs: The skin on the S/U pigs was mummified. Where skin was present on the torso it was detached and when lifted the bones beneath were visible and clean of tissue, although there was fat on the ground around them. This was not the case with the S/C pigs where skin remained wet and attached to fat, and occasionally the clothing, and could not be easily moved. However, bones that were visible were clean without tissue adhering. There was still some maggot activity in the fat.

867 ADD: Hanging Pigs: All pigs were mummified. The pigs which had been clothed (H/C) were clearly distinguishable from the H/U animals, the former having torsos with many tears and holes and, for many, the lower portions detached from around the area of the shorts waistband. The H/U pigs still, largely, retained the appearance of an elongated deflated pig, although the skin was tearing on many of them.

Surface Pigs: The clothes remained on the pigs, and the clothing and the skin beneath it remained wet, throughout the experiment. Skin and fat remained on and around the S/C pigs although the bones were clearly visible through this and did not have tissue adhering to them. The S/U pigs had little skin remaining or it was a mummified detached blanket which could be lifted to expose the bones beneath.

1033 ADD: Hanging Pigs and Surface Pigs: There was no real change in the appearance of the pigs. However, the weather had been very wet and some maggots were seen on the surface of the pigs. These were few in numbers; in the tens rather than hundreds or thousands.

5.2.2 Timing of the First Beetle Activity

An adult beetle was first observed on one of the surface pigs at 110 ADD, but this evaded capture and so was not identified. At 326 ADD the first adult beetle, Staphylinidae, was seen in the drip zone of a H/C pig, on fallen gut. This beetle also evaded capture and could not be further identified, but the most commonly found Staphylinidae at this site are *Creophilus maxillosus.* The first adult beetle was seen on the hanging body of a pig at 457 ADD, on the outside of the tee shirt of one the H/C pigs. This beetle was identified as Silphidae *Thanatophilus rugosus.*

Figure 5.3 Decomposition sequence for one H/C (HC1, male) and one H/U pig (H1, female).

418 ADD.

457 ADD.

497 ADD.

559 ADD.

634 ADD.

698 ADD.

Figure 5.3 (cont.) Decomposition sequence for one H/C (HC1, male) and one H/U pig (H1, female).

770 ADD. | 867 ADD.

Figure 5.3 (cont.) Decomposition sequence for one H/C (HC1, male) and one H/U pig (H1, female).

110 ADD. | 167 ADD. | 224 ADD.

Figure 5.4 Decomposition sequence for one S/C (CC3, female) and one S/U pig (C6, male).

284 ADD.

326 ADD.

361 ADD.

418 ADD.

457 ADD.

497 ADD.

Figure 5.4 (cont.) Decomposition sequence for one S/C (CC3, female) and one S/U pig (C6, male).

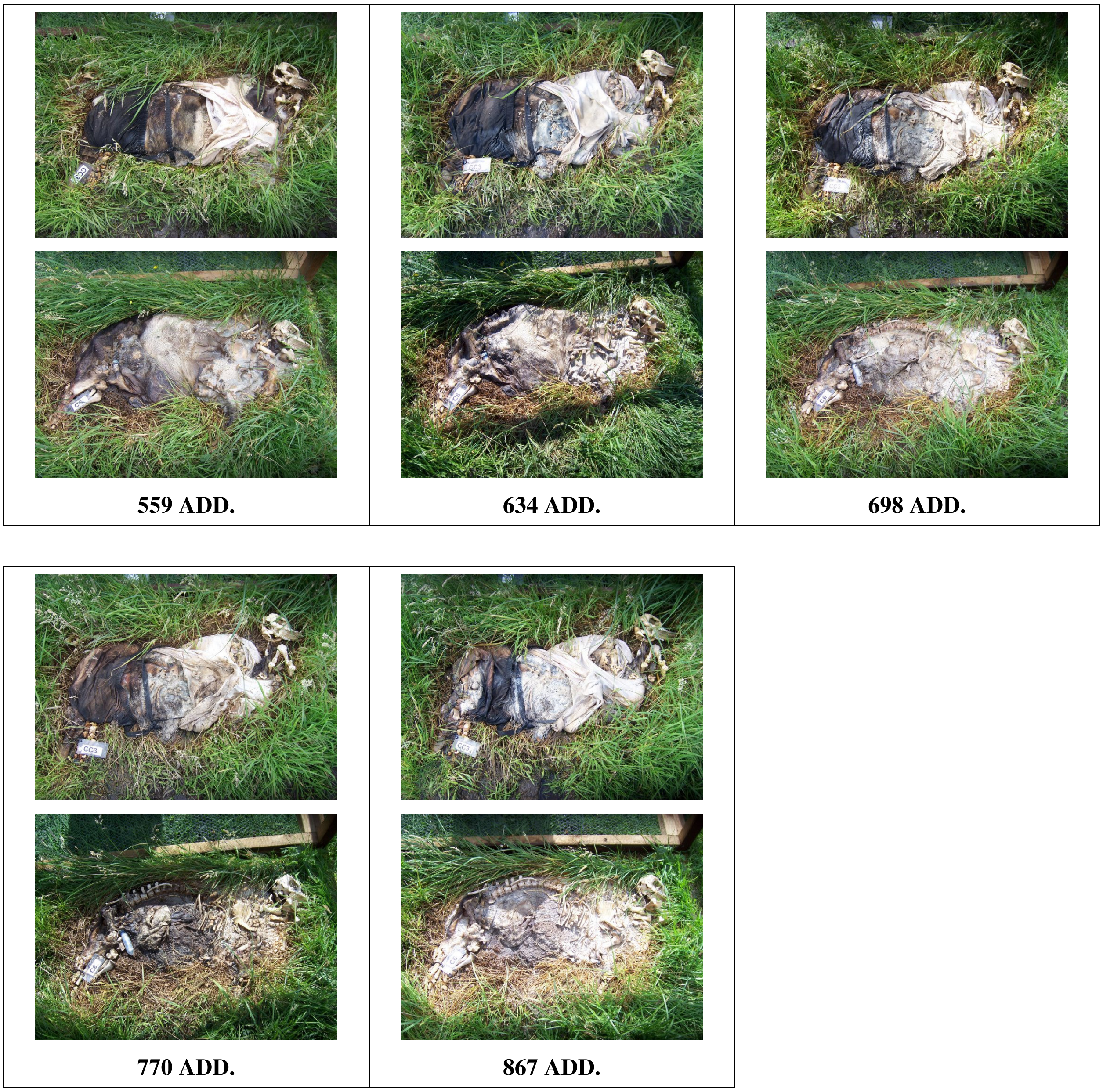

Figure 5.4 (cont.) Decomposition sequence for one S/C (CC3, female) and one S/U pig (C6, male).

5.3 Analysis

The rate of decomposition did not differ significantly between the S/C and S/U pigs, but did differ from that of the hanging pigs. Figure 5.5 shows the difference in rate during the decomposition between these groups.

The S/U group was taken as the reference for the y-axis zero in the graph. As described in the Materials and Methods section, the analysis generated the differences in TBS, at each ADD, between the S/C group and this reference, and between the H/U group and the reference. Negative values on the graph indicate a lower TBS than the S/U for that ADD value and positive values a TBS higher than the S/U at that ADD value.

Figure 5.5 shows that there is no significant difference in the TBS values between the two surface groups, with the S/C TBS points or error bars falling on the S/U (reference) line, i.e. overlapping and not differing from it. The H/U group, however, is clearly different with a lower TBS than both surface groups at the start, but with a steady increase in (relative) TBS as ADD increases, and reaching the later stages of decomposition (higher TBS) faster.

Figure 5.6 illustrates the difference in rate between the H/C group (taken as the reference) and the H/U and S/C groups. As before the H/C group is shown with a TBS value of zero across the ADD range, and the differences in the TBS values of the H/U and S/C groups are plotted. The difference in TBS between the groups show the H/U pigs reaching later stages of decomposition earlier than the S/C pigs, but slower than the H/C pigs. Only one group of surface pigs (S/C) is used in Figure 5.6 since Figure 5.5 shows there to be no significant difference between the decomposition rate of the S/C and S/U groups. The hanging pigs decomposed faster than the surface pigs and the H/C pigs decomposed at a faster rate than all of them.

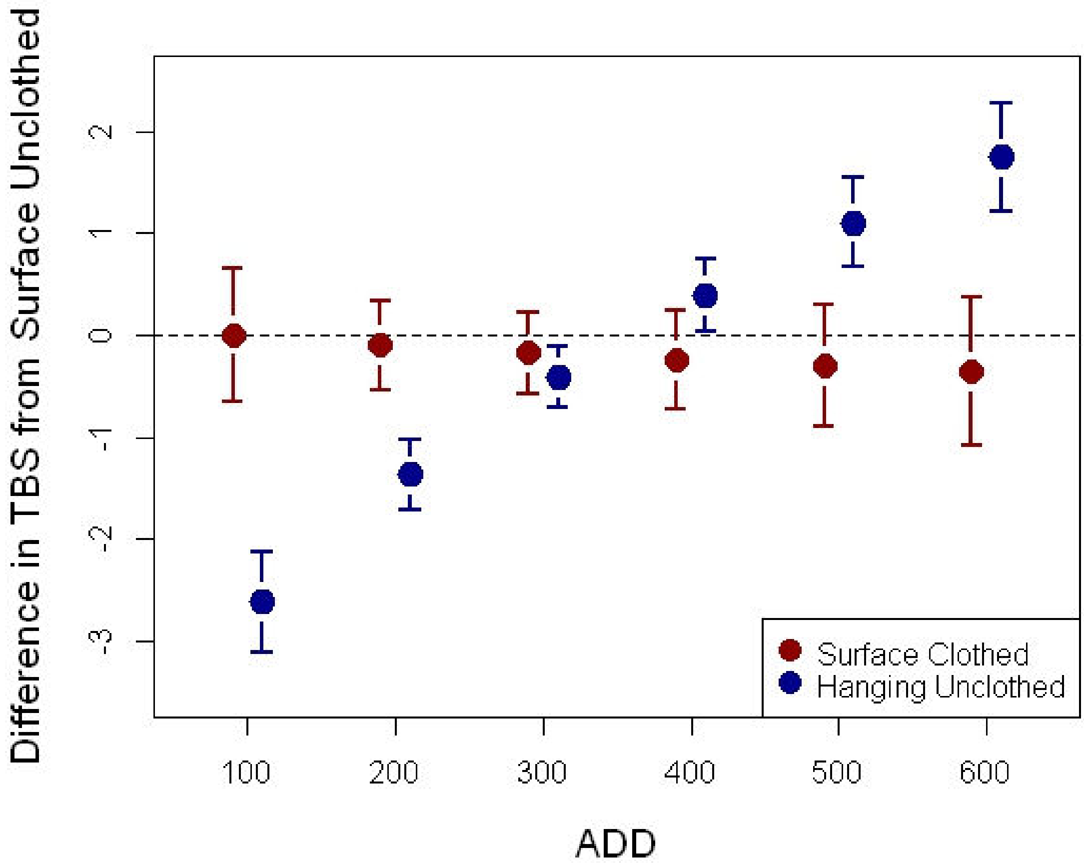

Figure 5.5 Differences in the rate of decomposition of the S/C and H/U groups, compared to the S/U group as the reference. The results were derived from 10,000 simulations per group based upon linear regression models. Some jitter has been added to the ADD values at the data points to add clarity and the error bars show 95% confidence intervals.

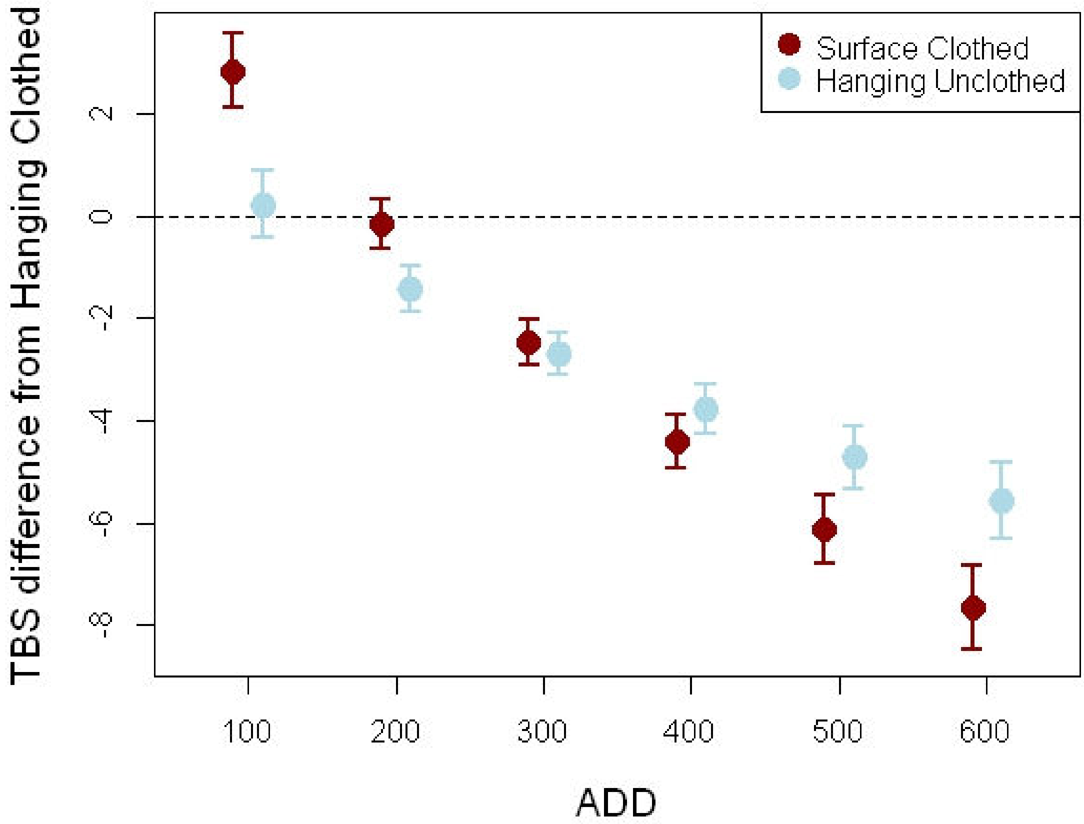

Figure 5.6 Differences in the rate of decomposition of the S/C and H/U groups, compared to the H/C group as the reference. The results were derived from 10,000 simulations per group based upon linear regression models. Some jitter has been added to the ADD values at the data points to add clarity and the error bars show 95% confidence intervals.

5.4 Discussion

The experiment showed that the same scoring scales that were used previously for H/U and S/U groups could be applied to clothed pigs in similar situations.

As in Experiment 1, the results from this experiment showed that the hanging pigs (H/U) displayed a different pattern and rate of decomposition from the control

(S/U) pigs. Furthermore, the H/C and H/U pigs differed from each other in their rate and pattern of decomposition. There were no significant differences, however, between the S/C and S/U pigs in their pattern and rate of decomposition. This is described in more detail below.

It was also found that the rate of decomposition in all four groups of pigs, at the chosen test site and time of year, was sufficiently slow that performing the data collections every other day was unnecessary; it would have been sufficient to examine the pigs at three or four day intervals.

5.4.1 Hanging Pigs

The most likely explanation for the differences in decomposition between the H/C and H/U pigs is that the presence of the clothing provided a more favourable environment for the maggots. The ovipositing flies showed no preference for H/C or H/U pigs. This may have been because the clothing, which was of a light material and loose fitting, did not impede access to the usual ovipositing sites on the head, which was not covered, or around the genitalia and anus which could be reached via the legs of the shorts. This indifference to the presence of clothing when ovipositing was also noted by Kelly *et al*. (2009).

However, additional eggs were laid on the outside of the clothing, in the creases in the material, but these did not appear to hatch, with few if any maggots seen in the area and eggs remaining in the creases. Whilst eggs were laid beneath the tee shirts along the waistband of the shorts, eggs were not seen on the torsos of the H/C pigs other than in the usual crease areas of the axilla and groin; the waistband of the shorts appeared to be treated as another damp crease. This laying of eggs and subsequent hatching around the waistband and shorts was also noted by Kelly *et al*. (2009).

Once the eggs had hatched the clothing made a noticeable difference to the behaviour of the maggots. The H/U pigs were fully exposed to the weather with the wind and, infrequently, sun, which quickly dried the skin and any maggots thereon. The maggots rapidly moved from the laying sites to inside the head and torso where they were protected from the weather. Maggots prefer to colonise areas which are sheltered and warm (Anderson, 2010; Campobasso *et al*., 2001; Mann *et al*., 1990). The clothing provided a microclimate on the body of the pig with protection from the weather and maggots were able to remain beneath the clothing on the surface of the pig. The weather during this experiment was particularly wet and the clothes on the pigs were always wet or damp, which meant that the skin beneath them remained damp and flexible for most of the experiment. In some areas, particularly around the waist band, the skin beneath the clothing became very wet and thin with the later stage instars appearing to be able to eat through the flexible skin leaving small holes in it. It may be that in drier conditions this would not have been the case.

"The interface of the skin surface with the body's environment is the principle determining variable for establishing the rate of a corpse water loss" (Aufderheide, 2011). Where the skin is exposed to the air, and particularly to draughts, wind or dry air, the transfer of water from the underlying tissues, via the skin to the air, may result in desiccation and mummifying of the skin. The rate of desiccation may be altered by the presence of clothing which can act to increase or impede the water loss. Where clothing is loosely in contact with the skin, it tends to act as a wick, drawing water away from the skin and increasing the rate of desiccation. This desiccation is further accelerated if there is airflow (Aturaliya and Lukasewycz, 1999). When the clothing remains wet, as was the case in this experiment, it impedes the removal of water and delays or prevents the process of dehydration. This may lead to faster breakdown of the skin, as it is kept wet and pliable, accelerating its loss of integrity and the rate of destruction.

A major difference in the patterns of decomposition was in the lower torso from the waist band of the shorts down. There are a number of reasons that could account for this. The shorts were wet because of the rain and because of the decomposition fluid which was released from the bowel, and in the case of the males the umbilicus / penis, wicking along the material. This would have kept the shorts damp for longer even without rain. The damp shorts, in turn, kept the skin beneath them very damp and flexible. The experiment found that in all of the H/C pigs the lower right portion of the abdomen became swollen and had active maggot activity quickly rupturing through the skin, which continued to decompose. The breached area contained gut and faeces. It may be that the extra bacterial action in the gut produced more gas and pressure on the soft flexible tissue and caused the breach. The area around this breach became more rapidly destroyed. This did not happen in the H/U pigs whose skin was not so wet or flexible. It is, however, improbable that this feature would be significant in the decomposition pattern of hanging humans as the positioning of the intestines differs in this area between humans and pigs. In the human the large intestine loops around the outer portion of the abdomen but in the pig the large intestine is found in tight spirals in the left hand side of the abdomen and the small intestine, where most of the bacterial digestion takes place, lies in the right hand side (Swindle *et al*., 2012).

When the bowel prolapsed in the H/C pigs it was contained, at least initially, within the shorts keeping the gut close to the groin of the pig, and adding to the moist conditions, rather than falling from the pig as in the H/U pigs. One of the features of hanging animals is that once a maggot falls from the body it is unable to gain access again and thus has no further impact on the hanging animal, although it may continue to feed on material in the drip zone. Feeding maggot masses are very active with maggots constantly writhing around within the mass as part of their feeding and thermoregulatory behaviour (Charabidze *et al*., 2011; Heaton *et al*., 2014). The shorts provided a physical barrier to the maggots falling and in the experiment it could be seen, clearly, that the numbers of maggot below the H/U pigs were far greater than beneath the H/C pigs. From this it would be reasonable to assume that the maggot masses within the H/C pigs remained larger and this would have helped to consume the pig more quickly.

The presence of maggots on the torso of the H/C pigs and the holes in the skin that they made destroyed the integrity of the skin. The formation of tears in the skin as the bodies elongated, stretching the skin, and the large numbers of maggots around the waistband of the shorts resulted, for some of the pigs, in the lower section of the torso becoming detached from the upper torso and falling from the animals into the drip zone.

Active maggot masses are known to move bones, and dentures in the case of humans, some distance from the body (Haskell *et al*., 1997) and to move clothing

(Kelly *et al*., 2009; Komar, 1998). Such movement of bones and clothing was observed in this experiment, although the distances moved were not great. In one of the hanging pigs the lower torso became detached and dropped to the ground early in the decomposition process when the feeding maggot masses would have been very active. This section of pig was found to have been moved some feet from the drip zone. There was no evidence of any large scavengers having been in the cage. This is worth noting as it may make a difference to how far away from the hanging remains articles of clothing and bones from within them may be found. Bones were moved around beneath the H/U pigs but generally not far from the drip zone; usually by the time they fell to the ground there was little in the way of visible tissue adhering to them and the numbers of maggots in the drip zone would not have been as great as an active mass falling with part of the clothed torso.

5.4.2 Surface Pigs

There was no significant difference in the rate or in the patterns of decomposition between the S/C and S/U pigs. All the surface pigs were laid directly upon the ground which, because of very high levels of rainfall, remained wet throughout the entire experiment. This meant that the lower surfaces of the pigs were always wet and clothing soaked up water from the ground. Despite being constantly wet the clothing showed little deterioration. These results may be different in different weather conditions where clothing could provide protection from drying sun and wind.

Reports on the effects of clothing on the rate of decomposition vary from showing accelerated decay, via no effect, to delaying the rate of decomposition (Mann *et al*., 1990). A retrospective study of the work carried out at the Anthropology Research

Facility Knoxville concluded that clothing accelerated the rate of decomposition. This study, whilst having the advantage of a large number of human subjects (150 bodies had been observed over 10 years by students and faculty members), was not a controlled experiment and the data reported for each of the case studies would not be expected to be consistent in content or format. The conclusion reached was that the clothing provided protection from sunlight for the maggots. Campobasso *et al*. (2001), also making a retrospective study, found clothing could slow down the post-mortem cooling, favouring putrefaction, and additionally provided protection, from inclement weather, for the larvae.

Work by Dautartas (2009), Kelly (2006), and Miller (2002) found that, whilst clothing had a noticeable effect on the decomposition, this was not borne out by the statistics which showed no significant differences between the rate for clothed or unclothed carcasses. This experiment also found that there was no statistically significant difference in the rate of decomposition for the surface groups.

Delay in decomposition was reported by Haglund (1997) and Komar (1998) with clothing cited as protecting the tissue by restricting the access to the carcass by scavengers. Delay was also reported by Goff (1992) whose experiment involved wrapping a carcass in cotton blankets and securing them, and who found that insect access was delayed by 2.5 days. Kelly (2006) also had a wrapped carcass but this carcass was loosely wrapped and the insects were able to access it at the same time as they accessed the unwrapped and clothed carcasses. Whilst the last two experiments were on wrapped rather than clothed carcasses, they show that the level of access to the carcass by insects is important in dictating the rate of decomposition.

Work by Aturaliya and Lukasewycz (1999) found that the presence of clothing helped to desiccate carcasses by wicking fluid away from the skin and, through evaporation, to accelerate the rate of mummification. This was not found to be the case in this experiment, but the constant rain and high humidity would not have been conducive to evaporation at the rate seen by Aturaliya and Lukasewycz as they maintained a flow of dry air over the carcasses during their experiment.

The current experiment used light, loose clothing and insects were able to access the normal ovipositing sites without great obstruction. However, clothing used in winter and inclement weather may consist of multiple layers of heavy materials or even include balaclavas, obstructing the mouth and nostrils, and these may show results more aligned with those of Goff.

The results of the current experiment, with clear differences in the decomposition of the hanging pigs but not the surface pigs due to the presence of clothing, coupled with the range of results reported elsewhere, indicate that there may be more factors that need to be taken into consideration. The presence, quantity and type of clothing may act together with the weather conditions to alter the decomposition rate. These are factors which need to be taken into consideration when estimating the post-mortem interval of a clothed body.

6 EXPERIMENT 3 – Comparing the Decomposition of Partially Suspended (Semi-Recumbent) Pigs with Fully Suspended Hanging pigs and with Fully Recumbent Pigs in Direct Contact with the Ground

The aim of this experiment was to investigate whether a semi-recumbent body displays the same decomposition patterns as a body in direct contact with the ground, or a fully suspended hanging body, or whether it displays some intermediate pattern. The objectives of the experiment were to:

- record and compare the patterns and rates of decomposition of fully suspended hanging pigs, partially suspended semi-recumbent pigs, and control pigs lying directly on the ground;

- determine whether the decomposition scoring scale for bodies on the ground or the scale for hanging could be used with the partially suspended pigs to determine PMI, or whether an intermediate scale would be needed.

The results of the experiment should help to increase the accuracy of determining the PMI in semi-recumbent bodies.

Additionally the observations of the hanging and control pigs provided the opportunity to add to the known data on decomposition in hanging pigs and pigs lying on the ground, with data already collected from the same site in previous years. This increased the overall sample size available for any statistical analysis, and could be used for looking at the effects, if any, of the changing weather conditions at that site.

6.1 Materials and Methods

Thirty pigs (*Sus scrofa*), were allocated randomly into three groups: hanging, control, and semi-recumbent. Killing, weighing, and sequential labelling of the pigs followed the approach described in the General Materials and Methods chapter, as did the pre-programming of data loggers and the preparation and placement of the hanging pigs and the control pigs in direct contact with the ground. The semi-recumbent pigs were hung by the neck in the same manner as the hanging pigs except the lower portion of their bodies, the rump, and the hind legs were left resting on the ground (Figure 6.1).

The semi-recumbent pigs were placed in separate A-frames from the fully suspended hanging pigs. The frames were set out in a line close to each other so that conditions would be as similar as possible in terms of sun and wind exposure and tree shade. The hanging and semi-recumbent pigs were placed in alternate frames. They were not mixed in the frames as previous experiments had shown beetles appearing early in the animals in contact with the ground, while beetles were not found on the hanging pigs and it was thought the lower portions of the semi-recumbent pigs might also attract beetles earlier and introduce a close population of beetles that had not been present with the hanging pigs in previous experiments. It is improbable that a fully suspended human body would be found alongside a semi-recumbent hanging body as the nature of hanging tends to be solitary. A final consideration was that the hanging pigs were much heavier than previously and it was not clear whether they might stretch to touch the ground.

All the pigs were put into position within a 2 hour period on 22 May 2013. The ground beneath the control and semi-recumbent pigs was very wet with some surface water.

Figure 6.1 The position of a semi-recumbent pig, supported from a scaffolding A-frame.

6.1.1 Sex and Mean Weight of Pigs

The hanging group contained seven males and three females; the semi-recumbent group contained five females and five males; and all ten pigs in the control group were male. This resulted from the random allocation of the pigs to their respective groups. However, the results from Experiment 1 showed that the sex of the pig had no statistically significant effect upon the decomposition rate in the control or hanging pigs.

The average weight of the hanging and semi-recumbent groups was 57.7 kg, with a standard deviation of 5.7 kg, while that of the control group was 46.6 kg with a standard deviation of 6.6 kg. The pigs weighed almost twice as much as the pigs in the previous year's experiment and, although the pigs were allocated as they were unloaded from the transport, the controls were lighter than the hanging pigs.

6.1.2 Data Loggers

The hanging and semi-recumbent pigs had pre-programmed data loggers inserted into the thorax, using a metal tube as a guide which was then removed. The data loggers were sealed and placed inside leak-proof centrifuge tubes which were, additionally, sealed with duct tape. A length of wire was wrapped around the top of each tube and attached to the hanging rope to prevent the tube becoming lost into, or dropping out of, the pig.

Two pre-programmed data loggers were also attached to each of the four hanging A-frames. Two data loggers were used in each cage to allow one to be removed from each cage and downloaded during the experiment to examine the progression of ADD up to that point.

6.1.3 Data Collection and Collection Intervals

Data collection took place every Monday and Thursday until 22 July, giving a total of 19 observation days, and was carried out and recorded in the same manner as described in the General Materials and Methods chapter.

6.1.4 Decomposition Scoring

Visible decomposition of the control pigs was scored using Megyesi *et al.*'s system (2005) adjusted to a baseline of zero to give TBS_{surf}. The hanging, fully-suspended pigs were scored using the new hanging scale developed in Experiment 1 to give TBS_{hang}.

Initially the semi-recumbent pigs were scored using both scales to assess the whole body until it became clear the upper and lower portions of the animals were displaying different decomposition patterns such that there was no longer a consistent surface or hanging decomposition pattern across the whole pig. From this point on, as the decomposition progressed, the pigs were scored as two separate sections. The portion resting on the ground and part way up the body, i.e. the lower limbs and lower torso, was designated as semi-recumbent lower (SRL) and scored using the same scoring scale as the control pigs. The upper body portion not resting on the ground, i.e. the upper torso, upper limbs, and the head and neck, was designated as semi-recumbent upper (SRU) and scored using the same scoring scale as the fully suspended pigs. Both scales were applied to both sections of the semi-recumbent pigs until it became clear they were displaying different decomposition patterns.

6.1.5 Statistical Analysis

The SRL scores constituted a Partial Body Score (PBS), being the sum of the scores for the lower torso and limbs (PBST + PBSL), i.e. without a score for the head and neck, and so varied between 0 and 20, rather than 0 and 32 for the whole body scores. Therefore, for comparison purposes, the torso and limb scores of the control pigs were similarly added to give the corresponding partial body score $PBS_{surf} = PBST_{surf} + PBSL_{surf}$ which also varied between 0 and 20 and is referred to below as the Control Lower score.

The TBS versus ADD was plotted for the hanging pigs and the SRU scores, and for the Control Lower and SRL scores, to provide an initial visual comparison.

Because the effect of ADD on TBS is not the same across the ADD range there is no simple ratio of increase in TBS for increase in ADD and when plotted the relationship was a curve. Prior to running the linear regression analysis and ANOVA, a simple transformation of the ADD and TBS values was performed to improve the linearity of the response, between the transformed variables, thereby improving the fit of the model generated by the linear regression analysis and increasing the validity and relevance of the sensitivity analysis based on the response gradients of the model. Following some investigation the data were pre-treated by excluding those data points having ADD ≤ 35 or ADD ≥ 625. These ADD values were excluded as at ADD ≤ 35 very little change had occurred in the appearance of the pigs since death, and in humans the individual should still be recognisable, and at ADD ≥ 625 there was again very little change in the appearance of the pigs. The square root of the remaining ADD values was then used. These transformations increased the linearity of the response prior to running the linear regression analysis.

The linear regression analysis generated an output table showing the gradients for the fitted model, and the TBS values at the zero intercepts on the √ADD and start weight axes. Having an intercept for a start weight of zero, an impossible weight, would not have provided a useful reference point, since the corresponding TBS would be zero, independent of ADD. The mean start weight of 54.0 kg was used as the reference instead, and this value was subtracted from each of the individual start weights (making 54 kg the new intercept point). This did not affect the gradient of the fitted curve, nor the *p* value, but it did mean the intercept would be at a weight of 54 kg.

Similarly at zero ADD the TBS would always be zero, independent of the start weight. The mean ADD of the data points, with $35 < ADD < 625$, across all three experiments was 282 ADD. The corresponding square root is 16.8, and this value was subtracted from each of the individual √ADD values (making 282 ADD the new intercept point). Again this did not affect the fitted gradient or *p* value, but gave an intercept value that was more relevant; in this case at 282 ADD

The last two data adjustments meant that, when using the output table from the linear regression analysis to calculate what effect a change in start weight of 1 kg, or a change of 1 ADD, would make to TBS, this would be for an initial start weight of 54 kg and at 282 ADD.

6.2 Results

Flies were seen landing on the bodies of the pigs as they were being removed from the body bags, and continued to land on them when they were placed into position on the field. The flies were observed, over the following few days, laying eggs in the natural orifices and around the head and anus in all of the pigs. In addition eggs were laid around the nooses of the hanging and semi-recumbent pigs.

The hanging pigs and the upper portions of the semi-recumbent pigs were scored using the scales developed in Experiment 1 (Chapter 4), and the control pigs and the lower portions of the semi-recumbent pigs were scored using the scoring scale developed by Megyesi *et al*. (2005) adjusted for a zero baseline. The decomposition patterns of the upper and lower sections of the semi-recumbent pigs followed the same stages and sequences as described by these scoring scales, making them both sufficient and appropriate for scoring the animals in this experiment.

6.2.1 General Pattern of Decomposition

All three groups of pigs showed similar features for the first few days (discolouration and bloat), and this is reflected in the initial stages of both scoring scales.

From 197 ADD onwards the patterns of decomposition differed between the hanging and control pigs, while the semi-recumbent pigs started to display features of both the hanging and the control pigs. Within 253 ADD the decomposition pattern of the semi-recumbent pigs had started to become more similar to the hanging pigs for the upper portion of the body which was not in contact with the ground, while the portion of the body in contact with the ground looked similar to that of the control pigs. These differences between the groups are described below for a range of the ADD values.

Figure 6.2 shows the differences and similarities between the groups at the same ADD values. The photographs are set out with the semi-recumbent pig displayed between the hanging, above it, and the control, beneath it, to make comparing the similarities between them easier.

97 ADD: Most of the hanging pigs needed to be re-hung as their weights had caused the ropes to stretch and the metal S hooks to stretch. The hooks had to be replaced with ropes pulling the support loop, previously hung from the S hook, closer to the horizontal bar of the A-frame. All the pigs appeared remarkably fresh and, despite having been out for 9 days, only one pig in each group had visible maggots. The weather had been wet and windy with the coldest spring since the early 1960s, which may have affected the flies ovipositing.

165 ADD: Hanging: All the pigs had a swollen head, torso and limbs and the majority were starting to prolapse the bowel. The males had swollen testes and umbilicus/penis. More than half of the animals had started to purge. A few had drying skin on the snout and neck.

Semi-Recumbent: All had swollen heads, limbs and torso and all were purging decomposition fluid. 60% had drying skin on the snout and the neck around the noose rope.

Control: All had a swollen head with four pigs having maggot masses visible in the mouth. All torsos were swollen with 60% showing small patches of drying skin on the abdomen. 90% were purging decomposition fluid.

226 ADD: Hanging: All had drying snouts with lips drying and retracting. Maggots were visible in the mouths of 50% of the pigs. All pigs had swollen limbs protruding from a swollen torso with the bowel prolapsing. All had maggots visible on the torso and showed evidence of purging. In the males the umbilicus/penis area and the testes were swollen. Four pigs had skin slip on the lower abdomen.

Semi-Recumbent: All animals had a swollen head with drying snouts and lips. Some pigs had brown drying skin on the necks particularly around the noose. They all had a swollen torso with 50% showing skin slip on the lower abdomen. One animal had a breached lower left abdomen/groin. 50% of the animals had maggots and/or eggs in the crease between the lower limb and abdomen; in these pigs the abdomen was almost resting on the lower limbs. All limbs were swollen with upper limbs extended away from the body. All pigs had been purging.

Control: All animals had a swollen head which had started changing colour to dark grey or black. Their torsos were swollen although some of these were no longer rock hard but soft. The colour had changed to dark grey or black in 60% of the pigs. The limbs remained swollen with a couple of animals displaying skin slip and some hair loss.

The first beetle was seen on a control pig but was too quick to catch!

302 ADD: Hanging: The skin was drying on all of the pigs' heads, three of the heads had a small amount (less than 10%) of bone showing. The skin on the shoulders and backs had also started to dry. The torso of each pig remained bloated but no longer taut and the chest area had become sunken in some of the pigs.

The lower abdomens had become dark grey and all had prolapsed bowels. All the male pigs had swollen testes, and in three of the males the umbilicus and penis had formed two separate holes. Both holes had combined to form one hole in one of the other males, with a loop of gut protruding from the left side of the lower abdomen.

The limbs of all the pigs were still extended but some had started to droop.

A drip zone had formed below one of the pigs; this contained only maggots and faeces.

Semi-Recumbent: All the pigs had dry skin on their heads which had started to harden and mummify. The throats and necks were also drying and turning brown. Three of the pigs had dry mummifying skin on their backs. The upper and lower torso had started to look different with the lower torso having maggots in the groin abdomen crease area of eight pigs. This area was breached and open in four of the pigs with active maggot masses visible. The upper torsos were not breached but some had patches of dry hard skin.

The upper limbs had started to droop in most of the animals and in all the pigs the lower limbs were wet, with maggots in the groin creases even if they were not breached.

Control: All showed darkening and drying of parts of the head. Four pigs had foaming maggot masses in their mouths and breached throats. The ground side of the head and throat was wet in most of the pigs. Three had maggots in the testes and anus; the testes in the other seven were drying and blackening. Four pigs had the ground side of the torso open with maggots present. Most of the pigs had maggots in the axillae and groin.

353 ADD: Hanging: The pigs had elongated as the bloat decreased. This, combined with stretching of the rope, suggested some of the animals would soon be very close to touching the ground, with little hope of being able to lift them higher because of the height of the suspension bar. All pigs had dry snouts and most had sunken throats with the lips retracting and some skin slip. Only one pig still had maggots visible in the mouth. In all pigs the torso had started to deflate and become dark grey or black; all the bowels had prolapsed. The axillae of the upper limbs were breached in more than half the pigs. Most pigs had some skin slippage. Drip zones had formed beneath nine of the pigs and all contained maggots in quantities from a teaspoonful to about 100 ml.

Semi-Recumbent: The decomposition pattern was clearly different between the upper and lower sections of the animals requiring the use of two scoring scales. From this point on the hanging scale was more suited to the upper section of the body, and the amended Megyesi *et al*. (2005) scale was used for the lower section. All pigs had drying snouts, caved in throats, and drying skin on the head. Less than half had active maggot masses in the mouth. Three pigs had drying skin around the shoulders and top of the back. The lower abdomen was wet and soft with maggots in the groin and leg creases. In the males maggots were present in the umbilicus/penis and the testes were breached. Small holes were seen in the skin of the lower torso.

Control: All pigs had some maggot activity around the mouth and/or throat. In the majority the throat had 'caved in'. Moist decomposition could be seen. The majority of the pigs had breached axillae with maggots visible there and in the open anus and testes. Maggots were also present in the penis/umbilicus of three pigs. The limbs were darkening with maggots visible in the groin of most pigs, with breaches of the groins visible in some. Small holes were noted in the skin.

410 ADD: Hanging: Three pigs needed raising to prevent them touching the ground and in all cases it was possible to do so using an additional noose.

All the heads were dry and mummifying with the skin becoming leathery and little or no maggot activity visible. All the torsos were elongating post bloat with the skin becoming dry and leathery on the shoulders and backs. The limbs were dark coloured and drooping. The anuses were open, with a diameter greater than 10 cm.

Semi-Recumbent: All heads were dry and mummifying. The skin on the shoulders and back of the upper torso was dark and mummifying. The upper limbs were disarticulated. In contrast the lower torso had wet breached skin and visible maggot activity. Half of the pigs had visible bone in the groin and or lower limbs. In one of the animals a trail of maggots could be seen in a mass 1 m away from the animal and crawling through the grass.

Control: All heads had moist decomposition in the throat and ground side, with some mummifying of the skin on the upper side of the head. All torsos had areas of drying skin with maggot activity visible where the skin was breached. Bone was visible in the torso and limbs of four pigs.

469 ADD: Hanging: All heads were mummified with bone visible in most of the heads and/or in the mouths.

Semi-Recumbent: All heads were mummified with bone visible in 90%. All upper torsos were mummified. Lower torsos were breached with active maggots and disintegration of the skin leaving lower limb bones visible in 90% of the pigs.

Control: Maggot activity visible in all pigs, skin on upper surface drying to form a mummified blanket on most pigs. Bone was visible in the torsos of five pigs with limb bones visible in 90% of the pigs.

525 ADD: Hanging: All pigs were mummified with bone visible on the head and in one pig visible within the torso, through a hole in the skin. Drip zones contained maggots with two containing hooves.

Semi-Recumbent: No change in the head and upper torso; all were mummified and hard with some having holes or tears. This changed where the torso was in contact with the ground. Here the skin was black and disintegrating or destroyed. The area below and in front of the pig, where the lower limbs lay, was fatty and contained visible bones including some ribs. Some animals had a few maggots still visible. Ribs were visible in the fat. One pig remained almost intact in appearance: the upper torso was mummified and there were maggots in the groin but little other visible activity.

Control: All pigs had bone visible in the torso, on the head and in the limbs. The skin was dry and mummified on the upper surface of most of the pigs. Most had maggot activity under the skin where the body had become sodden in the rain.

575 ADD: Hanging: Two pigs were touching the grass and were raised up, no beetles or beetle larvae were visible on them. All pigs were mummified. Vertebrae, ribs, innominates and intestines were seen in some of the drip zones. In the male pigs the anus and scrotum now formed one hole.

Semi-Recumbent: All pigs had mummified heads with bone visible and parchment-like skin. The upper torsos were mummified. Two pigs remained swollen but with hard dry skin. Lower torsos consisted of disintegrating skin with visible bones in all but one pig. Limb bones were visible or could be felt in the mummified skin.

Control: All pigs had a covering of mummified skin, some of which was still attached to the head or the limbs. Beneath this bones were visible with some fat and a few maggots. No skin visible on the groundside of the pig; bones were visible.

632 ADD: Hanging: No change in appearance overall. However, in three of the males the testicles were visible. Drip zone beneath one pig contained vertebrae, long bones, scapula, ribs and an innominate.

Semi-Recumbent: Upper torso and head were dry and mummified. Lower torso had bone visible within a fatty mass and mummified skin. No identifiable torso left.

One exception to this was the pig which remained swollen: the lowest part of the lower torso was covered in hundreds of beetle larvae.

Control: The skin on the upper part of the pigs was mummified and in most cases could be lifted to show bones beneath. Most bones were still fatty, although some bones were clean. Maggot masses could still be seen in the axillae or anus of a few pigs.

674 ADD: Hanging: Four pigs had small holes in the skin of the torso and three pigs had their dried intestine dropped through the anus or in the drip zone.

Semi-Recumbent: Upper torso and head were mummified. Lower torso consisted of bones and fat with small amount of mummified skin. One pig still had an identifiable lower torso with bones visible and hundreds of beetle larvae (Figure 6.3).

Control: Dry mummified skin on top of bones and fat. Some bones were clean and largely fat free and some remained in fat where the pig was on very wet ground. The skin could be lifted from all the pigs.

761 ADD: Hanging: All pigs were mummified, the torsos were hard and hollow sounding and bones could be felt through the skin. Vertebrae, ribs, innominates, long bones and scapula were found in the drip zones. Bones could be seen caught in the congealed fat in the anus. The first beetle larvae were found in the drip zone.

Semi-Recumbent: The upper torso could be lifted from the lower torso from which it was completely separate. There was no change in the lower torso. One pig remained soft around the lower abdomen where beetles were present. Ribs were seen in the bones on the ground below the upper torso mingled with the lower limb bones. Lots of maggot pupae could be seen inside the torso. Beetle larvae were present in the fat of two pigs.

Control: All the skin was mummified and could be detached; the bones beneath were largely clean with only a small amount of desiccated tissue or fat adhering.

829 ADD: Hanging: All pigs were mummified with some holes and tears in the skin. Some pigs appeared elongated and empty looking. Maggots were seen in the axilla of one pig.

Semi-Recumbent: No change in appearance, upper torsos were hard and hollow.

Control: Beneath the mummified skin the bones were largely clean and greasy.

923 ADD: Hanging: The pigs were hollow sounding and light, moving easily if touched. The skin was fatty.

Semi-Recumbent: The upper torsos resembled the hanging pigs, being dry, hard and sounding hollow. They could also be moved easily.

Control: Beneath the mummified skin some of the bones were in 'hydrated' fat, a few had dried tissue attached, most were clean and greasy. The bones of the head were clean and dry.

989 ADD: Hanging: No change in appearance of the pigs. Large amounts of fat could be seen in the drip zones.

Semi-Recumbent: No change in appearance although there was a lot of fat on the ground and ribs and scapula had fallen from some of the upper torsos.

Control: All pigs covered by some amount of detached mummified skin beneath which were greasy and clean dry bones.

1078 ADD: The data loggers were extracted and the pigs removed for disposal. (A few hanging pigs were left to see what would happen over the next few months.)

Hanging: When removing the data loggers some of the pigs were opened up completely down the front. Bones could be seen adhering to the mummified skin (Figures 6.4 and 6.5).

Semi-Recumbent: No change in appearance. Figure 6.6 shows how the mummified upper torso had separated, and could be lifted away from, the lower torso. At the end of the experiment the upper torsos were found to contain numerous pupae cases.

Control: No visible changes.

2 ADD	13 ADD	97 ADD

Figure 6.2 Decomposition sequence for one hanging, one semi-recumbent, and one control pig.

165 ADD | **226 ADD** | **353 ADD**

Figure 6.2 (cont.) Decomposition sequence for one hanging, one semi-recumbent, and one control pig.

410 ADD	469 ADD	525 ADD

Figure 6.2 (cont.) Decomposition sequence for one hanging, one semi-recumbent, and one control pig.

575 ADD	632 ADD	674 ADD

Figure 6.2 (cont.) Decomposition sequence for one hanging, one semi-recumbent, and one control pig.

761 ADD | 829 ADD | 923 ADD

Figure 6.2 (cont.) Decomposition sequence for one hanging, one semi-recumbent, and one control pig.

Figure 6.2 (cont.) Decomposition sequence for one hanging, one semi-recumbent, and one control pig.

Figure 6.3 One of the semi-recumbent pigs showed a large mass of *Necrodes littoralis* (Silphidae) beetle larvae, these were present on both sides of the pig, at 674 ADD.

Figure 6.4 and Figure 6.5 Bones could be seen adhering to the mummified skin of the hanging pigs at 1078 ADD.

Figure 6.6 The mummified upper torso of the semi-recumbent pigs had separated, and could be lifted away from, the decomposed lower torso (1078 ADD).

6.3 Statistical Analysis

When the TBS values for the hanging pigs and the TBS scores for the upper section of the semi-recumbent pig were plotted against the square root of ADD, the slopes for both were very similar (Figure 6.7).

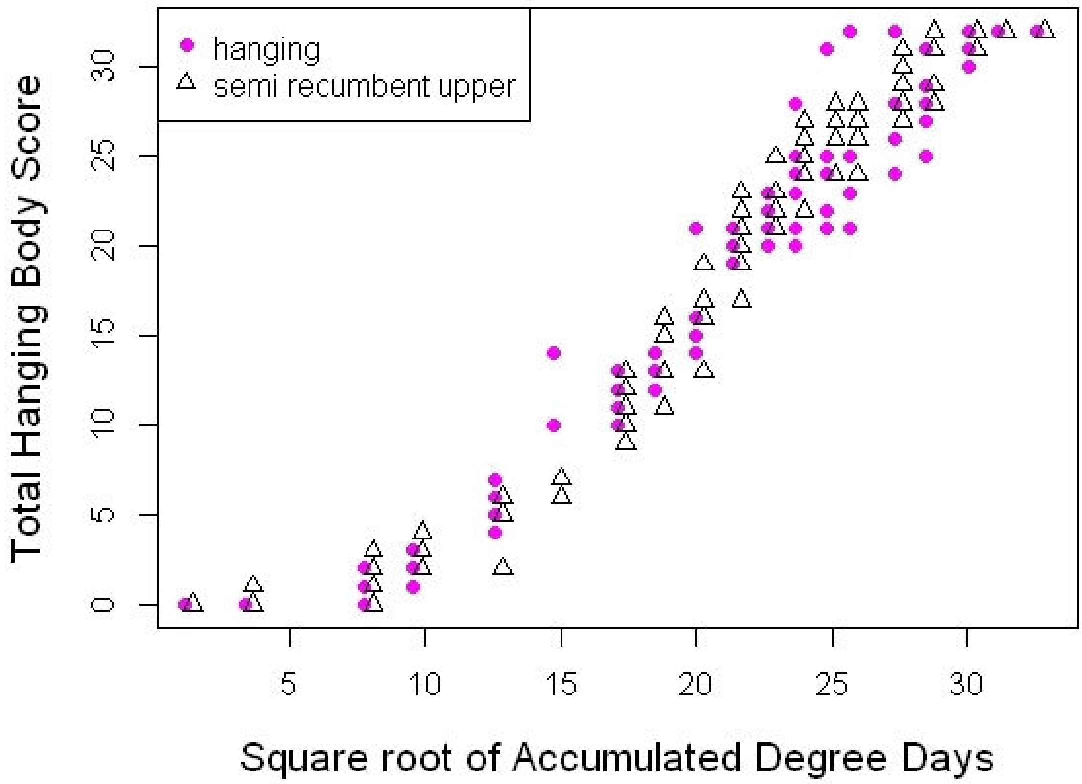

Figure 6.7 Total Body Scores for Hanging (TBS_{hang}) for the upper sections of the semi-recumbent pigs and the hanging pigs scored using the hanging scoring scale from Experiment 1. Some offset has been added to the ADD values at the data points to add clarity.

Plotting the $PBS_{surf} = PBST_{surf} + PBSL_{surf}$ for the control pigs, and PBS = PBST + PBSL for the semi-recumbent pigs, the PBS values can be seen to be overlapping (Figure 6.8).

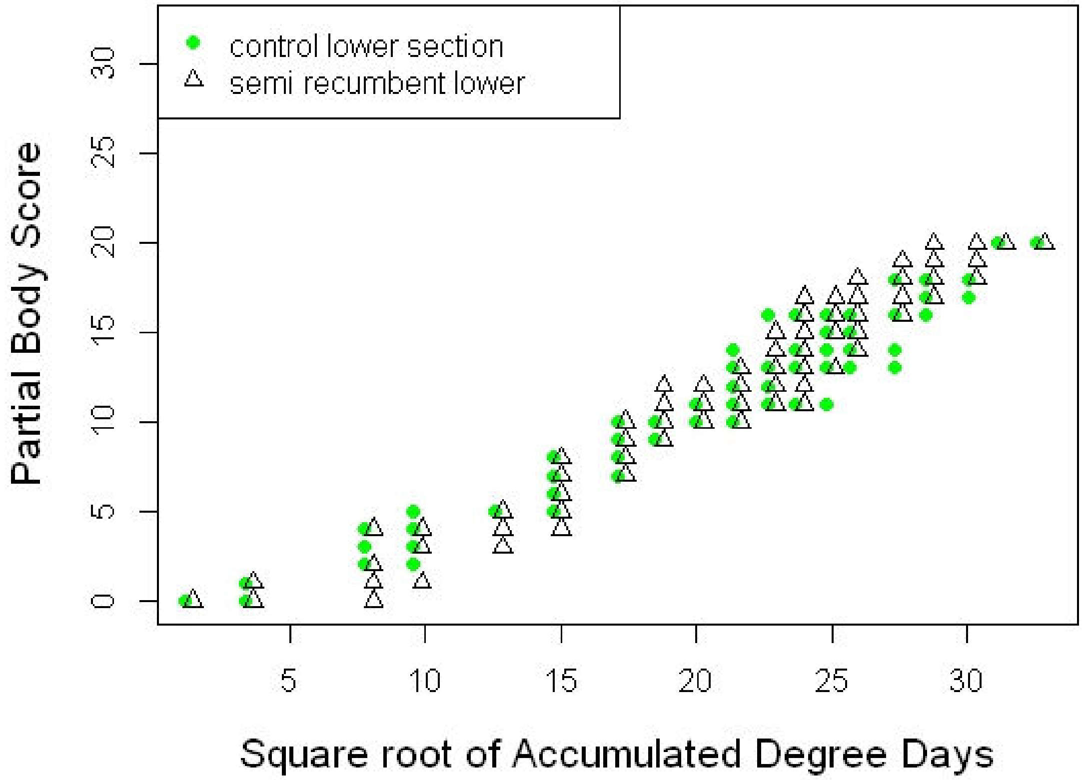

Figure 6.8 Partial Body Scores (PBST + PBSL), lower limbs and torso, for the lower sections of the semi-recumbent pigs, and the limbs and torso of the control pigs scored using the modified Megyesi *et al.* (2005) scoring scale. Some offset has been added to the ADD values at the data points to add clarity.

Comparing the TBS versus ADD responses for the hanging pigs and the upper section of the semi-recumbent pigs, ANOVA produced a *p* value of $p = 0.53$, $F_{2,197} = 1402$. Thus there is no statistically significant difference between the two groups in their TBS versus ADD responses.

When the scores of combined ($PBST_{surf} + PBSL_{surf}$) response to ADD was tested for the Control Lower and SRL groups there was no statistically significant difference with ANOVA giving a p value of $p = 0.8$, $F_{2, 197} = 1157$.

Treatment was shown to have a statistically significant effect on the TBS when start weight was included in the linear regression. For both SRL and Control Lower $p < 0.001$, $F_{5, 194} = 487.8$, and for both Hanging and SRU $p < 0.001$, $F_{5, 194} = 576.9$. The effects of this are shown in Table 6.1 below.

Table 6.1 Sensitivities of the TBS responses to changes in the start weight and ADD around a reference point of 282 ADD and a start weight of 54.0 kg. The Semi-Recumbent Lower and Control Lower have partial body scores (PBS) out of a possible 20 points using the amended Megyesi *et al*. (2005) scoring scale. The Semi-Recumbent Upper and Hanging are TBS scored on the Hanging scale from a possible 30 points.

Scenario	**Control Lower (total score of 20)**	**Semi-Recumbent Lower (total score of 20)**	**Hanging Pigs**	**Semi-Recumbent Upper Body**
Start weight = 54.0 kg & ADD = 282	8.10 PBS	8.00 PBS	11.95 TBS	11.87 TBS
To gain an increase of 1 TBS	+56.3 ADD	+43.63 ADD	+24.05 ADD	+29.93 ADD
Increase of 1 kg in the start weight	+0.01 TBS	+0.01 TBS	–0.03 TBS	–0.03 TBS

6.4 Discussion

This experiment showed that the semi-recumbent pigs did not require a new scale in order to score their decomposition, but that the scales used to score the hanging pigs and the control pigs were sufficient. The hanging and control pigs showed different patterns of decomposition between their groups, as in the previous two experiments, with the semi-recumbent animals displaying similar decomposition patterns to both the hanging and control pigs. The upper sections of the pigs could be scored using the hanging pig decomposition scoring scale from Experiment 1, and the lower sections using the amended Megyesi *et al*. (2005) scoring scale, with a clear delineation between the two sections. If the entire body were present, either scoring scale could be used but the hanging scale could be used to score all three body sections, while the Megyesi *et al*. scale could only be applied to the lower torso and limbs.

Decomposition is a complex and continuous process making the determination of discrete stages difficult and subjective, leading to different researchers identifying different decomposition stages (Adlam and Simmons, 2007; Archer, 2004; Campobasso *et al*., 2001; Oliviera and Vasconcelos, 2010; Payne, 1965). In 2011, Parks noted that it was unrealistic to have a "one size fits all" decomposition model. Other researchers produced scales for scoring decomposition in circumstances where the decomposition patterns were specific to the conditions of death or discovery. Megyesi *et al*. (2005) produced a scale for bodies on the surface based on Galloway *et al*.'s (1989) method; Heaton *et al*. (2010) for submerged bodies; Gruenthal *et al*. (2012) for charred bodies. Where decomposition patterns are not sufficiently different from current scoring scales a new scale may not be warranted, even if the location and situation of the body is different.

After death, the body is the subject of a battle between decomposition and desiccation (Micozzi, 1991), the outcome of which depends on the body's immediate environment and factors such as the temperature, humidity, and insect access. The outer surface of the body loses water to the air with the rate of loss dictated by various factors including heat, aridity, and air flow.

Natural desiccation occurs in desert regions such as north Africa, Australia, costal zones of Chile and parts of the United States, and northern Mexico (Micozzi, 1991). External desiccation may not reach to the internal organs, where the decay is largely driven by bacteria and enzymes and may continue whilst the outer skin surface mummifies (Aufderheide, 2003). However, the rate of desiccation may be very fast in hyper-arid regions such as the Sahara, Gobi, and the Atacama, where, if desiccation occurs quickly enough before the onset of decay, the decay may be arrested and mummification may be complete, leaving internal organs largely intact (Aufderheide 2003, 2011; Micozzi, 1991). It is probable that the smaller the body the more likely this is, as the surface area to volume ratio is higher with a relatively larger surface area for the loss of water to occur over.

Mummification can take place in conditions other than hot dry deserts, as can be seen in the mummified hanging pigs from this experiment, where desiccation is the result of almost constant airflow over the exposed bodies. Mummified humans have been found in the remote mountainous region of Laguna de los Momias in Peru (Aufderheide, 2003) where the climate is predominantly rain and fog. At this site more than 200 mummies were found which appeared to be the result of natural mummification. There was no evidence of enhanced mummification, nor was assistance such as evisceration seen where it was possible to view the perineum, abdomen or chest.

Most naturally occurring mummies have no internal organs or soft tissues left as these have decomposed. Examples of more visible differential decomposition can be seen where bodies have been found indoors in bed. Here the body beneath the covers may be decayed or decaying whilst hands and arms outside the bed covers have mummified. A body of an 18 year old girl, who had been buried in a shallow grave, was found to have some areas of the body reduced to skeletal elements, the upper limbs mummified, and the lower limbs converted to adipocere, a fatty substance usually occurring in very wet or submerged bodies. This grave, which was in clayish soil, had been subjected to large quantities of rain and, clearly, different body parts had undergone different forms of decay and mummification (Cunha and Pinheiro, 2007). The semi-recumbent pigs in this experiment also displayed distinctly differential decomposition between the mummified upper, suspended, and skeletonised lower, unsuspended, sections of the bodies.

6.4.1 Semi-Recumbent Upper Section (SRU)

The suspended portion of the semi-recumbent pigs followed the same pattern of decomposition and mummification as the fully suspended pigs, with both exposed to the wind and sun in the same way. This mummification continued to the point where the lower body, in contact with the ground, had been destroyed; Figure 6.9 shows this clear demarcation. A few maggots can be seen on the outside of the mummified skin although it was more usual to see none.

Figure 6.9 Showing the delineation between the mummified upper body and the decomposed lower body of one of the semi-recumbent pigs.

The mummified skin probably acted in the same way as in the fully suspended pigs, providing protection from sun and adverse weather conditions for the maggots (Campobasso *et al*., 2001) which rapidly move inside the head and off the exposed surface of the torso. As the decomposition progressed the lower section and upper section of the pig became detached from each other. As a result of this separation, combined with the action of maggot mass writhing and gravity, maggots would have fallen through the open torso onto the decomposing carcass beneath, effectively forming the hanging drip zone. In the case of a fully suspended pig, once fallen, the maggots would have difficulty regaining access to the carcass and would be dependent on food fall from the body above. In the semi-recumbent case the maggots did not need to move back since a food supply was readily available in the carcass beneath. The maggots did not appear to move back up into the upper section and none were seen on the outside of the pigs.

The experiment using clothed hanging pigs (Chapter 5) found the quantity of maggots in the drip zone beneath the unclothed pigs was greater than beneath the clothed pigs, where maggot loss was impeded as they were caught in the clothing. Since the opening beneath the semi-recumbent upper bodies was much larger than in a fully suspended pig, the maggot loss would be greater with less to prevent the fall. This did not, however, slow the decomposition of the upper bodies.

Despite large numbers of adult beetles and beetle larvae on the lower sections of the pigs, none were seen on the outside of the upper sections or at the transition area, although access to the upper section would not have been difficult. Presumably there was sufficient food supply in the lower sections.

As the mummification progressed, the upper torso became stretched and took on the appearance of an empty coat with the bottom resting on the ground. This could be lifted easily and would move in the strong winds.

6.4.2 Semi-Recumbent Lower Body (SRL)

The lower sections of the pigs were resting directly on the ground, which remained damp or wet for much of the experiment, and their decomposition pattern was the same as the control pigs. The skin around the groin area was rapidly breached and active foaming maggot masses were visible. These maggots, although present on the outside of the lower abdominal and flank areas, were not seen to move up onto to the upper sections of the pigs. Where the upper torso was an open hole, the maggots dropped onto the lower section adding to the already present maggot masses. These maggots were not observed moving back to the upper torso, although this was still in contact with the lower section for much of the time, presumably continuing to feed on the lower section.

A blanket of mummified skin formed on the upper exposed surface of the control pigs and remained there, albeit detached from the bones beneath. In the semi-recumbent pigs the skin on the lower section did not form a mummified covering but remained wet and pliable possibly aided by the maggot foam and fall, and decomposition fluid from the upper section. This soft skin would be more attractive to ovipositing flies and easier for the maggots to eat. The protection afforded to the maggots on the control pigs from the mummified skin could have been provided by the mummified upper torso which maintained its shape providing a tent which reached down to the ground or just above it. The presence of numerous pupae cases within the upper torsos at the end of the experiment would indicate that these provided a suitable environment for the post-feeding maggots to pupate.

Adult beetles and beetle larvae were present on the lower section of most of the pigs but were not seen on the upper section. The Silphidae are some of the most commonly found beetles on this site. One pig had large numbers of beetle larvae *Necrodes littoralis* (Silphidae) and some adult beetles on the lower section, particularly the flanks, with no maggots observed on it. There was no obvious explanation for this.

The decomposition of the semi-recumbent lower section followed the same pattern as the controls and could be scored using Megyesi *et al.*'s (2005) scoring scale. However, as only the limbs and torso can be used the maximum score possible is 20 and this would make it difficult to use the prediction equations created for a full body score to calculate the PMI. The process of decomposition across the body is not uniform (Campobasso *et al.*, 2001; Megyesi *et al.*, 2005) and a simple scaling up of the decomposition score would not reflect the level of decomposition that would have occurred in the head at that stage, thus decreasing the accuracy of the PMI estimate for that individual. Comparing the partial body scores from the 30 control pigs used across the entire study showed that the heads were further decomposed than the torso and limbs at the same ADD. The ADD data points examined were 279 ADD, 282 ADD and 303 ADD these being the closest points, for each year, to the 282 ADD used for the calculations in this experiment.

While the results of this experiment found that the effect of start weight on TBS was statistically significant, in practice it doesn't make a large enough difference to the TBS values. Although the semi-recumbent lower section of the pig and the truncated scoring for the control pigs showed that the TBS would increase with an increase in start weight, an increase of 100 kg would be required to see an increase of 1 TBS. Why this should show as an increase is not clear. However, these pigs were scored out of a maximum possible 20 points since the heads could not be included. This makes it difficult to compare the trends with those of the full body score. The effect of start weight on TBS is examined more fully in Chapter 7 using results from across all three experiments.

Within these results it can be seen that the hanging and semi-recumbent upper bodies show the same levels of TBS response to ADD, and that the lower sections of the semi-recumbent bodies and controls are different to the upper body groups, but show the same level of TBS response, to ADD, as each other.

While the results may not be directly applicable to scoring semi-recumbent hangings for humans, there is no reason to believe that the decomposition pattern of the upper body would not follow that of a fully suspended hanging body, or that the lower section would not follow the pattern of a body on the surface. This being the case the use of the hanging scale would provide scores for all three body sections and should be easier to use than the partial score provided by the lower section when estimating the post-mortem interval.

7 Analysis of the Combined Data Set and ADD Prediction Tables for Hanging and Surface Bodies

7.1 Introduction

After completion of the experiments, and following the statistical analysis for the first experiment, it became clear that using the largest possible set of data to carry out some parts of the analysis would provide a clearer picture of what was occurring. In each of the three experiments carried out in this study, groups of hanging and control pigs were studied at the same geographical site and the same time of year over three consecutive years. The decomposition of all the pigs was assessed by the same observer using the same observation and data collection techniques. This ensured there were no inter-observer errors, and reduced the likelihood of variations in the method used.

This chapter presents an analysis of the combined data set from all three experiments to determine:

- The degree of consistency in the TBS versus ADD responses for the 30 hanging pigs and 30 control pigs from the three experiments.

- The effect of the initial weight of the pigs on their rate of decomposition using data from 60 pigs, comprising the 30 hanging and 30 control pigs.

- A set of ADD prediction tables for hanging pigs and for control pigs using TBS data from the 30 hanging pigs and the 30 control pigs from all three experiments.

Regression analysis can be applied to the observed TBS and ADD values to produce an equation giving the expected TBS for a given ADD, with ADD as the explanatory variable. Depending on the complexity and order of the regression equation, it may be possible to invert it to obtain an expression giving the expected ADD corresponding to an observed TBS. In general, however, it will not be possible to obtain confidence intervals for the ADD values in this way, but a PMI estimate must always be given as a range of ADD values, or the corresponding dates, with the accompanying confidence level.

To obtain the required confidence intervals a form of inverse prediction can be used, such as that employed by Moffatt *et al*. (2016), to produce prediction tables that give the expected ADD value, and the ADD ranges for various confidence levels, for each possible TBS value. The tables given below for the control and hanging pigs will enable these results to be compared with those from human cases to assess the validity of using pigs as human analogues in these two situations.

7.2 Method

Data from a total of 60 pigs were used: 10 fully suspended hanging pigs and 10 control pigs laid directly onto the ground for each of the three experiments conducted over consecutive years. The decomposition of the two groups of pigs was scored in the same way for each experiment, as described in the General Materials and Methods chapter (Chapter 3), to provide Total Body Scores (TBS) and Accumulated Degree Days (ADD) values for each observation day. All the control pigs were scored using the scale developed by Megyesi *et al*. (2005), adjusted to range from 0 to 32, as a score of zero more logically quantifies the state of no decomposition described by Megyesi *et al*. (2005) as fresh (Moffatt *et al*., 2016); whilst the new scale developed in Experiment 1 (Chapter 4) was used for all the hanging pigs. The temperature data for the ADD calculations were collected from the data loggers attached to the hanging frames as described in the General Materials and Methods chapter.

7.2.1 Statistical Analysis

7.2.1.1 Data Pre-Treatment and Transformations

The various data analyses all required the use of linear regression analysis as a first step. However, as can be seen from Figures 7.1 and 7.2, the TBS versus ADD responses for the control and hanging pigs do not follow a straight line, so the data was pre-treated prior to each test.

For the inter-year consistency and the effect of start weight tests, the data was first filtered to remove the data points having ADD ≤ 35 or ADD ≥ 625 (the same range of ADD values examined in the decomposition analysis undertaken for Experiment 3). At very low ADD values, as the decomposition is first getting underway, and at high ADD values, as the TBS reaches the mid-20's and skeletonisation occurs, it would be expected that the relationship between TBS and ADD may show a greater degree of variability than during the period when the majority of decomposition occurs. Filtering the data in this way removed these tail regions and enabled the analysis to focus on the main period of decomposition.

The aim of the inter-year consistency test was to investigate to what extent the relationship between TBS and ADD varied across the different years, rather than trying to explore the nature of that relationship *per se*, so no further pre-treatment of the data was required.

To explore the effects of the pig start weight a more linear relationship between the (transformed) TBS and ADD values was required so that the gradients of the fitted linear models could be used to examine the rates of variation (sensitivities) in the TBS responses (as the dependent variable). Having pre-filtered the data as described above, it was found that the (transformed) TBS versus ADD response could be made fairly linear by taking the square root of the ADD values.

Offsets were also applied to the start weight and $\sqrt{ADD}$ values. This did not affect the fitted response gradients produced by the linear regression analysis, but was done for convenience to make interpreting the results simpler. A start weight of zero is not possible, thus the mean start weight of 40.4 kg was used as the reference instead, and this value was subtracted from each of the individual start weights. Similarly, at zero ADD the TBS would always be zero, independent of the start weight. The mean ADD of the remaining data points, with $35 < ADD < 625$, was 282 ADD. The corresponding square root is 16.79944, and this value was subtracted from each of the individual $\sqrt{ADD}$ values.

To produce the ADD prediction tables it was necessary to use the full set of available data, to cover the full range of TBS and ADD values. The method used to calculate the tables, however, required the (transformed) TBS versus ADD response to be as linear as possible, and simply taking the square root of the ADD values (equivalent to squaring the TBS values) was no longer good enough.

For the control pigs it was found to be sufficient to raise the power of the TBS values by an appropriate power factor. The power factor used was chosen using an iterative manual search to maximise the corresponding coefficient of determination between the transformed TBS values and the (untransformed) ADD values.

For the hanging pigs a more complex transformation was required due to the S-curve running through the untransformed TBS versus ADD response (Figure 7.2). In this case an offset was first subtracted from the TBS values, with the offset value chosen to line up with the inflection point of the (approximate) S-curve. The overall TBS versus ADD response could then be linearised by raising the offset TBS values by an appropriate power factor. It was found that a single power factor could be used for both 'halves' of the response, on either side of the inflection point. The offset and the power factor used were again both chosen using an iterative manual search to maximise the corresponding coefficient of determination between the transformed TBS values and the (untransformed) ADD values.

7.2.1.2 Inter-Year Consistency Test

To test the consistency of the relationship between the TBS and ADD data across the three experiments for the hanging and control groups, the data for each group were pre-treated as described above, and then linear regression analysis was carried out followed by ANOVA.

7.2.1.3 Effects of Start Weight

To investigate the effect of the start weight of the pigs, and using ADD as the explanatory (x axis) variable, the data for each group were pre-treated as described above. A least squares linear regression was then carried out between TBS and √ADD and an ANOVA carried out to determine whether start weight had a significant effect on the rate of decomposition.

7.2.1.4 Prediction Tables

To produce the prediction tables all the values of TBS_{surf} and TBS_{hang} were used to produce least squares linear regression models for the control and hanging groups against ADD as the explanatory variable. Prior to running the regression analyses the TBS values were transformed as described above to provide a more linear response against ADD. It was not found to be necessary to transform the ADD values.

Regression analysis was then used to fit linear models to the transformed TBS versus ADD responses. Finally the Inverse Prediction approach described by Moffatt *et al*. (2016) was used to create ADD prediction tables for the hanging data and the control data, showing the expected ADD estimates and the corresponding

ADD ranges for various confidence intervals across the range of possible TBS values.

7.3 Results

7.3.1 Consistency Across Successive Years

For 35 < ADD < 625 the ANOVA showed the year had no statistically significant effect on the TBS to ADD relationship returning a *p* value of $p = 0.953$, $F_{5,714} = 1261$.

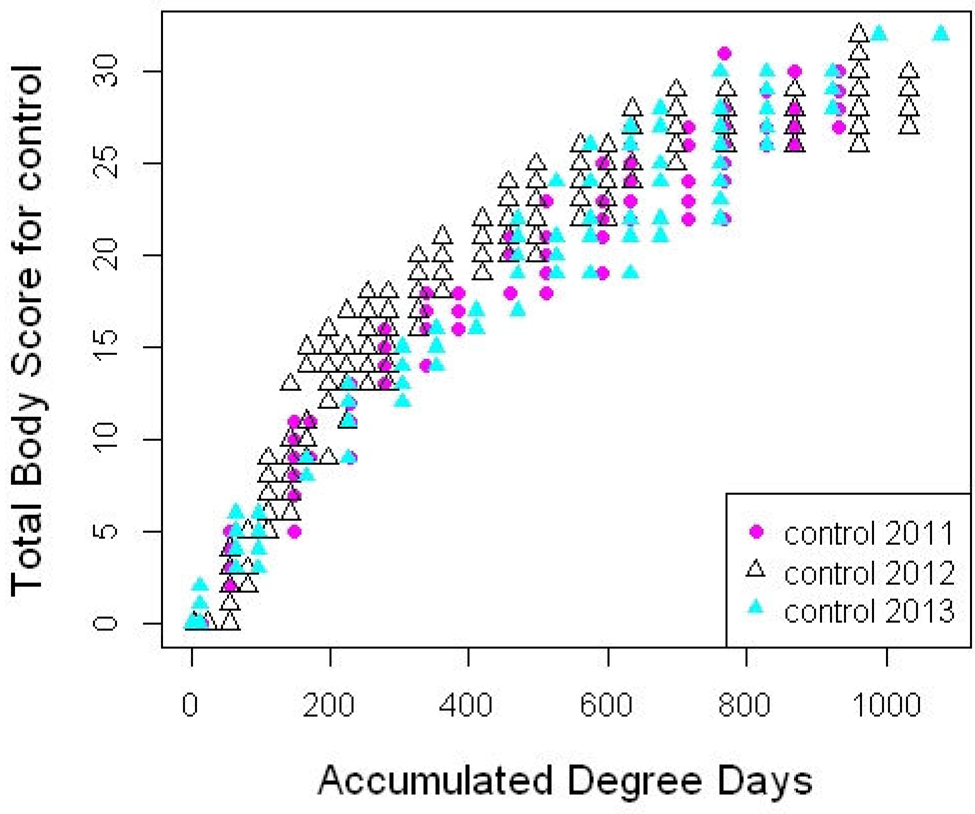

Figure 7.1 Total Body Score plotted against Accumulated Degree Days for all the control pigs for years 2011, 2012 and 2013.

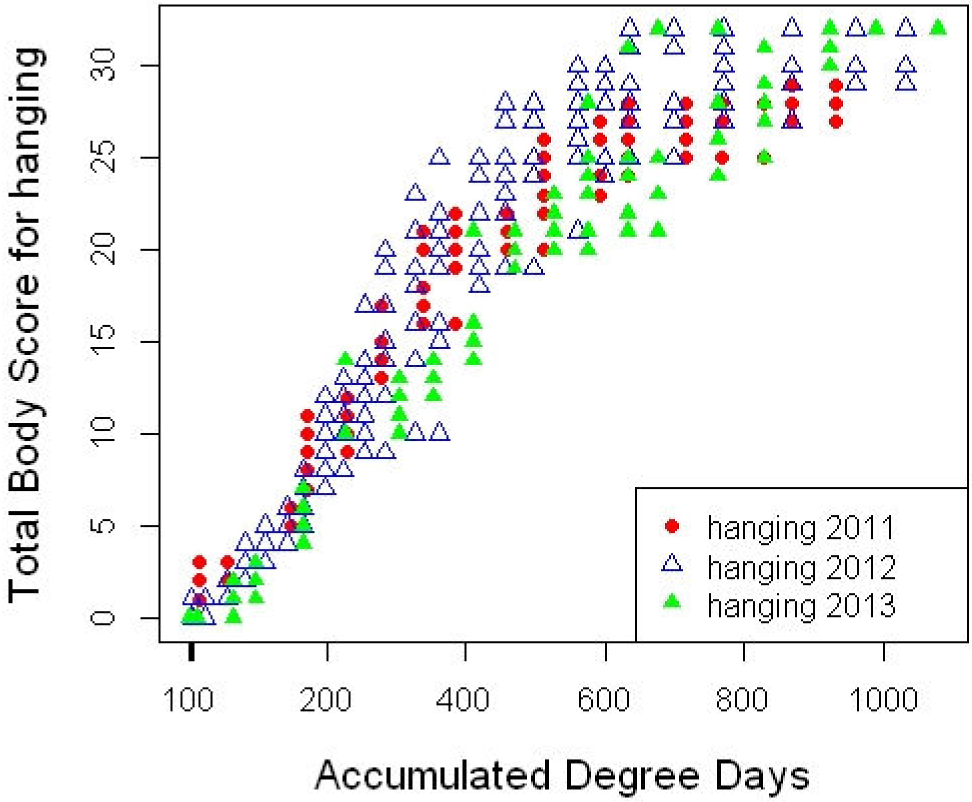

Figure 7.2 Total Body Score plotted against Accumulated Degree Days for all the hanging pigs in years 2011, 2012 and 2013.

Figures 7.1 and 7.2 provide a visual comparison of the TBS versus ADD data sets from the three experiments for each of the two groups, hanging and control. These show that there is indeed a high degree of consistency between the three years.

7.3.2 Sensitivity of TBS responses

From the linear regression analysis, for a pig with a start weight of 40.4 kg at 282 ADD (square of 16.8):

TBS for a control pig: 14.30 with a 95% confidence interval of ±0.20

TBS for a hanging pig: 13.74 with a 95% confidence interval of ±0.49

At this point (282 ADD) the control pigs, as a group, had decomposed faster than the hanging pigs. (In practice the TBS values would always be integers, but non-integer values are useful here for exploring the sensitivities in the TBS responses to changes in the independent variables.)

Table 7.1 provides a summary of the sensitivities of the TBS responses to changes in start weight and ADD.

7.3.2.1 Effect of Increase in Start Weight on Decomposition Scoring

The analysis showed that the pig start weight had a statistically significant effect on the rate of decomposition measured by TBS and ADD, for both the hanging pigs and the control pigs, with a p value of $p < 0.05$, $F_{5, 714} = 1962$.

For an increase of 1 kg in the start weight (40.4 kg), at 282 ADD the rate of decomposition for the hanging pigs, as measured by the total body score, slowed more than that of the control pigs (Table 7.1).

7.3.2.2 Effect of Increase in ADD on Decomposition Scoring

For an increase in the $\sqrt{ADD}$ of 1 at 282 ADD, and a start weight of 40.4 kg, there was an increase in the TBS for both the control and hanging pigs. At this point the hanging pigs were decomposing at a faster rate than the control pigs. For an increase of 1 in the $\sqrt{ADD}$ the increase in TBS was 8.5% for the control pigs and

11% for the hanging pigs. A higher change in ADD was needed to produce an increase of 1 in the TBS for the control pigs than for the hanging pigs (Table 7.1).

Table 7.1 Sensitivities of the TBS responses to changes in the start weight and ADD around a reference point of 282 ADD and a start weight of 40.4 kg.

Scenario	**Control Pigs**	**Hanging Pigs**
Start weight = 40.4 kg & ADD = 282	14.30 TBS	13.74 TBS
To gain an increase of 1 TBS	+28.1 ADD	+22.5 ADD
Increase of 1 kg in the start weight	–0.09 TBS	–0.10 TBS

7.3.3 ADD Prediction Tables

Tables 7.2 and 7.3 show the estimated Accumulated Degree Days (ADD) in °C and various prediction intervals for the possible range of Total Body Scores for the control pigs, on the surface, (TBS_{surf}) and for the hanging pigs (TBS_{hang}) using the statistical analysis given in the Method section above. The grey cells show negative TBS values, which could not occur in practice, but which are predicted from the data 'spread' and have been included purely for completion of the table. In practice these values should be read as zeros. Figures 7.3. and 7.4 display the same data in a graphical format. The 'wiggles' in Figure 7.4 are a consequence of applying the offset when transforming the TBS values.

Table 7.2 Showing the estimated Accumulated Degree Days (ADD) in °C and prediction confidence intervals for Total Body Scores, TBS_{surf}, for the control pigs, on the surface, using the statistical analysis described in the Method section above. Note: the greyed out areas show negative TBS values which could not occur in practice but which are predicted from the data 'spread' and have been included purely for completion of the table.

TBS_{surf}	Lower Limit			ADD Estimate	Upper Limit		
	95%	75%	50%		50%	75%	95%
0	-148	-83	-46	**7**	60	98	162
1	-145	-81	-43	**10**	63	101	165
2	-139	-74	-37	**16**	69	107	171
3	-129	-65	-28	**25**	79	116	180
4	-118	-54	-16	**37**	90	128	192
5	-104	-40	-2	**51**	104	142	206
6	-88	-23	14	**67**	120	158	222
7	-69	-5	32	**86**	139	176	240
8	-49	15	53	**106**	159	196	260
9	-27	37	75	**128**	181	218	282
10	-3	61	99	**152**	205	242	306
11	23	87	124	**178**	231	268	332
12	50	114	152	**205**	258	296	359
13	80	144	181	**234**	287	325	389
14	110	174	212	**265**	318	356	419
15	143	207	244	**298**	351	388	452
16	177	241	279	**332**	385	422	486
17	213	277	314	**367**	420	458	522
18	250	314	351	**404**	457	495	559
19	289	353	390	**443**	496	534	598
20	329	393	430	**483**	536	574	638
21	371	434	472	**525**	578	616	679
22	414	478	515	**568**	621	659	723
23	458	522	560	**613**	666	703	767
24	504	568	606	**659**	712	749	813
25	552	616	653	**706**	759	797	861
26	600	664	702	**755**	808	845	910
27	650	714	752	**805**	858	896	960
28	702	766	803	**856**	910	947	1011
29	755	819	856	**909**	962	1000	1064
30	809	873	910	**963**	1017	1054	1118
31	864	928	966	**1019**	1072	1110	1174
32	921	985	1022	**1076**	1129	1167	1231

Table 7.3 Showing the estimated Accumulated Degree Days (ADD) in °C and prediction confidence intervals for Total Body Scores, TBS_{hang}, for the hanging pigs using the statistical analysis described in the Method section above. Note: the greyed out areas show negative TBS values which could not occur in practice but which are predicted from the data 'spread' and have been included purely for completion of the table.

TBS_{hang}	Lower Limit			ADD Estimate	Upper Limit		
	95%	75%	50%		50%	75%	95%
0	-224	-149	-104	**-41**	21	66	141
1	-187	-112	-67	**-4**	58	103	178
2	-152	-76	-32	**31**	93	138	213
3	-119	-43	1	**64**	127	171	246
4	-88	-12	32	**95**	158	202	278
5	-59	17	61	**124**	187	231	306
6	-32	43	88	**151**	213	258	333
7	-8	67	112	**175**	237	281	357
8	13	89	133	**196**	258	303	378
9	31	106	151	**213**	276	320	396
10	44	120	164	**227**	290	334	409
11	52	127	172	**234**	297	341	417
12	59	135	179	**242**	304	349	424
13	73	148	193	**255**	318	362	438
14	90	166	210	**273**	336	380	456
15	112	187	231	**294**	357	401	477
16	136	211	255	**318**	381	425	501
17	162	238	282	**345**	407	452	527
18	191	267	311	**374**	436	481	556
19	222	298	342	**405**	467	512	587
20	255	331	375	**438**	501	545	620
21	291	366	410	**473**	536	580	656
22	328	403	447	**510**	573	617	693
23	366	442	486	**549**	611	656	731
24	407	482	526	**589**	652	696	772
25	449	524	568	**631**	694	738	814
26	492	568	612	**675**	737	782	857
27	537	613	657	**720**	783	827	903
28	584	659	704	**766**	829	873	949
29	632	707	752	**814**	877	921	997
30	681	757	801	**864**	926	971	1047
31	732	807	851	**914**	977	1022	1097
32	784	859	903	**966**	1029	1074	1149

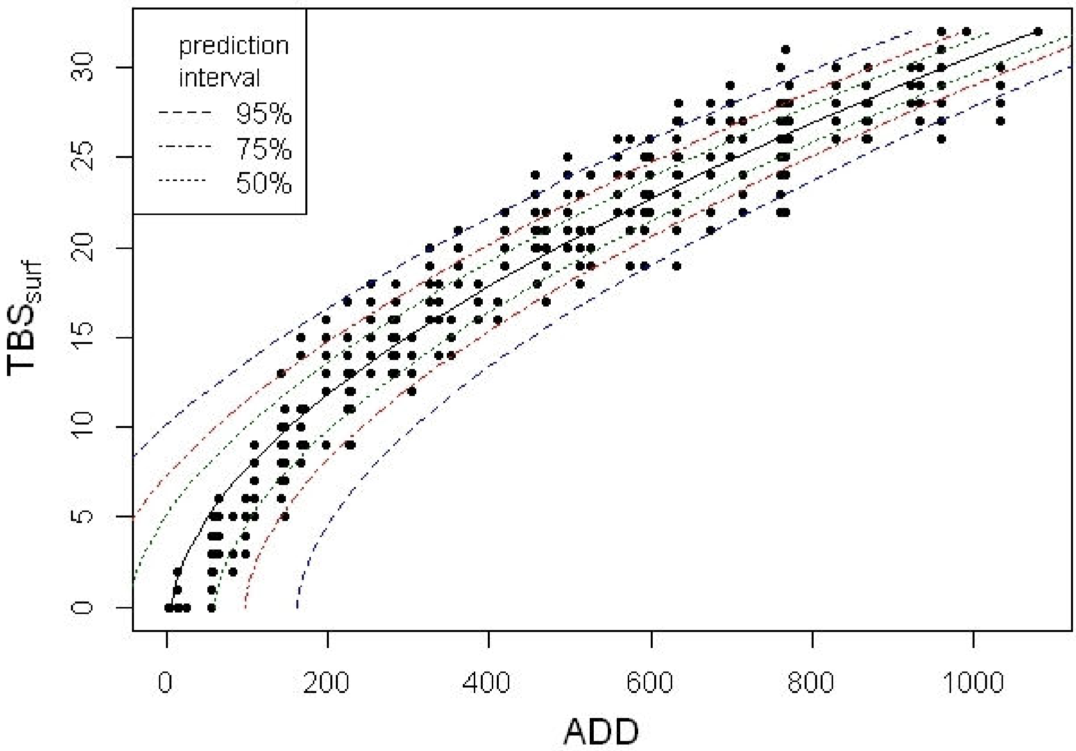

Figure 7.3 Total Body Score TBS_{surf} against Accumulated Degree Days (ADD), for the control pigs, showing estimates and inverse prediction intervals from the linear model overlaid.

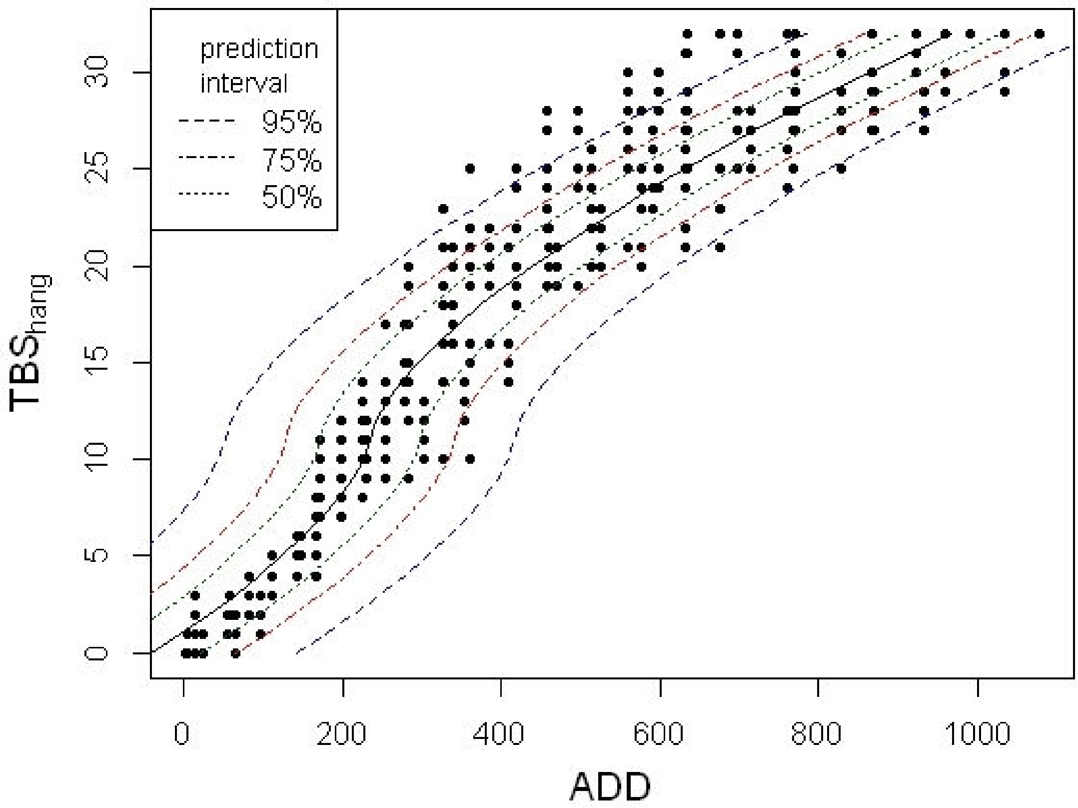

Figure 7.4 Total Body Score TBS$_{hang}$, of hanging pigs against Accumulated Degree Days (ADD) showing estimates and inverse prediction intervals from the linear model overlaid. The kinks in the curves result from applying an offset to the TBS values as described in the Method section.

7.3.3.1 Linear Regression Lines Used for the ADD Prediction Tables

The central "ADD Estimate" values shown in Tables 7.2 and 7.3 were produced by inverting the fitted line equations, for TBS versus ADD, generated by the linear regression analysis.

For the control pigs the TBS$_{surf}$ values were raised to the power of 1.72 with the fitted regression line for TBS$_{surf}^{1.72}$ versus ADD giving a coefficient of determination of $r^2 = 0.94$. The high value of r^2 indicates that the regression line was a relatively good fit.

The regression line equation for the control pigs was:

$$TBS_{surf}^{1.72} = 0.36317 \times ADD - 2.64$$

which can be inverted to give:

$$ADD_{est} = (2.64 + TBS_{surf}^{1.72}) / 0.36317$$

$$\Rightarrow ADD_{est} = 2.64 / 0.36317 + TBS_{surf}^{1.72} / 0.36317$$

$$\Rightarrow ADD_{est} = 7.27 + 2.754 \times TBS_{surf}^{1.72}$$

As an example, for an observed TBS_{surf} value of 18 the corresponding ADD estimate (as shown in Table 7.2) is:

$$ADD_{est} = 7.27 + 2.754 \times 18^{1.72} = 404$$

For the hanging pigs the TBS values were first offset by an adjustment of 11, so that an original TBS_{hang} of 11 would become 0 and any TBS_{hang} values below 11 would become negative. For convenience these offset TBS values are represented below using $B = TBS_{hang} - 11$. The resulting offset TBS values, B, were then raised to the power of 1.51. However, where the original TBS_{hang} was less than 11, making the offset TBS value B negative, this negative argument was first changed to positive, then raised to the required power and the result reverted back to negative to get the required value for the transformed TBS. The fitted line for the transformed TBS versus ADD had a coefficient of determination of $r^2 = 0.92$, again indicating that the regression line was a relatively good fit.

For the hanging pigs, the transformed TBS values can be represented as:

$$\mathrm{sgn}(B) \times |\,B\,|^{1.51}$$

where $B = \mathrm{TBS}_{hang} - 11$; $|B|$ represents the absolute value of B, such that $|B| = B$ when $B \geq 0$, and $|B| = -B$ when $B < 0$; and $\mathrm{sgn}(B)$ represents the sign of B, such that $\mathrm{sgn}(B) = +1$ when $B \geq 0$, and $\mathrm{sgn}(B) = -1$ when $B < 0$.

The regression line equation was:

$$\mathrm{sgn}(B) \times |\,B\,|^{1.51} = 0.13555 \times \mathrm{ADD} - 31.765$$

which can be inverted to give:

$$\mathrm{ADD}_{est} = (31.765 + \mathrm{sgn}(B) \times |\,B\,|^{1.51}) / 0.13555$$

$$\Rightarrow \mathrm{ADD}_{est} = 31.765 / 0.13555 + \mathrm{sgn}(B) \times |\,B\,|^{1.51} / 0.13555$$

$$\Rightarrow \mathrm{ADD}_{est} = 234.3 + 7.38 \times \mathrm{sgn}(B) \times |\,B\,|^{1.51}$$

Example calculations for both positive and negative values of B are given in Appendix 2.

(Note: sufficient decimal places have been shown that the ADD estimate values shown in Tables 7.2 and 7.3 can be reproduced to within ±0.5 ADD.)

7.4 Discussion

7.4.1 Comparison Between Years

For the hanging and control groups of pigs the relationship between TBS and ADD is consistent across the three years' experiments.

7.4.2 Effect of Start Weight on Decomposition

Whilst the start weight of the pig has a statistically significant effect on the rate of decomposition, because of the large increase in weight needed to result in a measurable change in TBS it may make very little difference to the actual score, especially given the scoring is restricted to whole numbers (integers). In order to effect a decrease of 1 to the total body score for a hanging pig at 282 ADD the weight would have to increase by 11.6 kg, and for a control pig by 10.5 kg. The pigs used in this study ranged in weight from 19.5 kg to 69.2 kg. The TBS scoring tables used to calculate PMI range from 0 for a fresh body to 32 for total skeletonisation (clean skeleton) with TBS score being the sum of the score for three areas, the head and neck, the torso, and the limbs. As the TBS scores are assigned to the state of visible decomposition it is clear that large weight increases would be necessary before visible changes to the decomposition were evident.

7.4.3 Pig Weight Differences and this Study

The pigs used for these experiments were not bred for experimentation but bought from farmers breeding for the consumer market. Growth rate in pigs bred for eating is rapid and an increase in age of a few weeks makes a great difference to the size and weight of the pigs. Ideally, to remove or at least minimize the variables possibly acting on the decomposition rate, the pigs used in all the experiments would have been of approximately the same size and weight. Because the experiments were carried out at roughly the same time each year (to enable sharing of the control pigs with other researchers and thus minimize the number of animals that needed to be slaughtered), and the farmers could not guarantee the pigs would be ready for killing at the same weight each year, this meant that it was not possible to ensure that the pigs were all approximately the same size year on year or, indeed, in the same year, particularly when the pigs came from several farms. Consequently, the dependence on the farmers' decision on when and which pigs would be ready for slaughter when we required them resulted in a large variation in pig weight.

7.4.4 Obesity

The current, worldwide, increase in obesity may mean that effects on TBS brought about by increased body weight will have to be taken into account when calculating the PMI estimate. "The worldwide prevalence of obesity more than doubled between 1980 and 2014" (WHO, 2015). In adult humans weight ranges are delineated using the BMI (Body Mass Index) which is calculated by dividing the body weight in kilograms by the square of the height in metres, although this measure does not take into account the known differences in the amount of normal fat deposition between males and females, or between races, or for athletes. BMI tables are readily available. For an adult 1.75 m tall the 'normal' BMI range of 18.5 to 24.9 would equate to a weight range of 56.7 kg to 76.3 kg. The pigs used in these experiments ranged from 19.5 kg to 69.2 kg, the heaviest being towards the upper end of the normal BMI range for a 1.75 m adult human.

The use of pigs as human analogues is well established (Forbes *et al.*, 2005; Myburgh *et al.*, 2013; Paczkowski *et al.*, 2015; Roberts and Dabbs, 2015; Schotsmans *et al.*, 2012; Wilson *et al.*, 2007). Pigs have similar gut bacteria to humans (Anderson and Van Laerhoven, 1996). They are largely hairless, and their body mass and muscle-to-fat ratios are similar to adult humans (Anderson, 2010; Catts and Goff, 1992). Furthermore, the arthropod species density is similar on a decomposing adult human and comparable sized pig (Anderson, 2010; Catts and Goff, 1992; Schoenly and Hall, 2002; Rodriguez and Bass, 1983; Schoenly *et al.*, 2006). Hence they are widely used as human analogues.

Worldwide, in 2014, over 1.9 billion adults (39%) were overweight and 600 million (13%) were obese (WHO, 2015), so the reality of having bodies with a start weight in the 90 kg to 140 kg range is increasing. At these increased weights the effect on TBS, seen in these experiments, may become a problem. If TBS is lower than currently expected at a given ADD this leads to the prospect that accuracy of PMI estimation is compromised with the time since death being under estimated. Further studies with carcasses in the obese and morbidly obese weight ranges may be necessary to quantify the effects of higher start weights on TBS. Additionally, as excess weight gain in humans tends to be composed of 60% to 80% fat and 20% to 40% lean mass, the use of pigs as human analogues (Anderson, 2010; Catts, 1992;

Schoenly *et al.*, 2006; Swindle *et al.*, 2012) may not be appropriate for decomposition studies on obese bodies, and the results obtained may not be valid.

The pigs used in this study were sub-adult age range, at around 16-20 weeks, and as such the weight differences between them were due mainly to increase in muscle, in contrast to the weight gained in obese humans which is largely fat. These pigs were produced as pork pigs (with lean meat) and would normally be slaughtered young. Large heavy pigs could be used and those kept for bacon may weigh between 175 and 220 kg. These are, however, still largely lean meat. There are pigs bred for their high lard content but it is not clear whether these would be suitable analogues for obese adults.

It cannot be assumed that the decomposition rate and pattern in obese individuals or high lard pigs will remain the same as in these experiments. The presence of high levels of fat may act to decrease the rate at which a body cools by acting as an insulator (Tracqui, 2000) and the consumption of the carcass by necrophagous insects and maggots may alter if it has a high fat content. Fat contains less water than lean muscle.

It should also be noted that obesity levels in children are also rising, with WHO figures for 2013 showing 42 million children under 5 to be overweight or obese – a problem which may further complicate the issues of calculating PMI for juveniles.

7.4.5 ADD Prediction Tables

Work by Megyesi *et al.* (2005) used a scoring scale, based on an earlier scale by Galloway *et al.* (1989), to score decomposition in human cadavers. The resulting

TBS values were combined with accumulated degree days (Vass *et al*., 1992) to estimate post-mortem interval using statistical analysis and a more scientific approach than was previously in use. Later use of this work identified flaws in the formula produced, the application of which can lead to inaccurate estimates of time since death. These flaws have been addressed in a paper by Moffatt *et al*. (2016) which included prediction tables for estimating ADD, and confidence intervals, from a given TBS value.

The prediction tables produced in this study use the same method. For both the hanging pig and control pig data, the fitted regression line equation can be inverted to estimate the ADD value most likely to be associated with a given TBS value. As that ADD value increases or decreases the TBS value is less likely to be associated with it, but the corresponding confidence intervals cannot be obtained directly. The use of the inverse prediction method employed by Moffatt *et al*. (2016), and reapplied here, allows the appropriate ADD confidence intervals to be calculated as a function of the observed TBS.

The resulting tables provide a quick and simple way to determine the most likely ADD value for any given TBS value, and the confidence intervals around the ADD. When combined with the local temperature data, the estimated time since death can thus be calculated, together with the prediction intervals giving the range of time on either side of the central estimate.

The regression line equation and the resulting ADD prediction table (Table 7.2) for the control pigs can be compared with that produced by Moffatt *et al*. (2016) for a subset of the human cadavers originally studied by Megyesi *et al*. (2005). The ADD prediction table produced by Moffatt *et al*. has a dramatically wider range of ADD values than those shown in Table 7.2, extending as far as 16,830 for the 95% upper confidence limit for the maximum TBS_{surf} value of 32. Moffatt *et al*. raised the TBS_{surf} values to the power of 1.6, rather than the value of 1.72 used here, but by far the biggest difference in the two analyses is that Moffatt *et al*. took the base-10 logarithm of the ADD values. While this resulted in a high value for the coefficient of determination of $r^2 = 0.91$ in the linear regression analysis, the use of the logarithm function makes the estimated ADD values at higher TBS values extremely sensitive to any errors in the original data set; and the data set was somewhat sparse with only four data points above 280 ADD. In fairness the authors did draw attention to these limitations, and their revised analysis is still a significant improvement on the original results of Megyesi *et al*. (2005).

In contrast, the prediction tables presented here have been prepared using a large data set which, generally speaking, should increase the accuracy of the statistical analysis on which they are based. Each of the 30 pigs involved in this study was observed and scored regularly and repeatedly throughout the decomposition process, rather than the single point observations that were used in Megyesi *et al*.'s original study (being based on photographs taken after each of the bodies was found). Furthermore, the ADD values for the present study were derived from temperature measurements made in the immediate vicinity of the pigs, while Megyesi *et al*. had to rely on data from nearby weather stations, which nevertheless could still differ significantly from the conditions local to each body (Dabbs, 2010, 2015).

It should be borne in mind, however, that the ADD prediction tables presented here have been prepared using data from pigs and may not be directly applicable to humans. To get the same level of accuracy for humans would require data from a large number of individuals for whom the time of death was known and for whom observations started at death. This coupled with accurate temperature data for the surrounding area (Dabbs, 2010, 2015), plus any necessary site-specific correction factor, would provide a data set equivalent to that used in the production of the tables from this study.

The existence of 'body farms' and taphonomic research sites using human cadavers makes this more feasible but would require many bodies and much cooperation. In the UK, human cadavers are not used for this type of research thus pigs, which are the best human analogues available, have been used instead, with the advantage that larger numbers could be studied at the same location over a period of several years and differing weather conditions. Consequently there was less chance of obtaining 'odd' one-off results.

It is perhaps interesting to note that the power factor of 1.51, which was used in transforming the TBS_{hang} values prior to the linear regression analysis, is very close to the ratio of 3:2 between the volume and surface area of a three-dimensional object. It may be tempting to ask if this relates in some way to the progression of the decomposition of a hanging body, or its consumption by maggots, and furthermore whether the difference between this power factor and the value of 1.72 used with the control pigs relates somehow to the collapsing of the bodies lying on the ground affecting the available surface area. At this point, this can only be speculation but it may indicate another line of future investigation.

8 Discussion and Conclusions

This was the first thorough, robust and qualitative study into the decomposition of hanging bodies using large numbers of subjects. The primary aim was to develop a method for estimating the post-mortem interval (PMI) of hanging bodies based on decomposition scoring and accumulated degree days (ADD). The findings showed distinct differences between the patterns of decomposition in hanging and surface pigs, leading to the production of a novel decomposition scoring scale for hanging bodies.

The new scale scored the same body regions over the same scoring ranges as the scale produced by Megyesi *et al*. (2005) for bodies lying on a substrate, but started with a score of zero for a fresh body making it more intuitive to use (as opposed to a score of 3 in the original Megyesi *et al*. scale). The new scoring scale also shared many of the same decomposition descriptors as the Megyesi *et al*. scale, and was constructed as far as possible so that a given score (for each body region) corresponded to a similar overall level of decomposition. Consequently, the differences in the total body score (TBS) versus ADD responses for the hanging and control pigs did appear to match the observed differences in the overall rates of decomposition. Amendments were made to some of the decomposition descriptors to reflect observed behaviour that was specific to pigs. This can be seen in the scoring sheet for the torso, where the change in shape of the male pigs and the opening of the penis and umbilicus to one hole are scored. This reflects a difference in the pig anatomy that would not be seen in humans. These amendments would need to be removed, as would the use of fore and hind limbs and snout, and appropriate changes made, in order to use the new scoring scale with hanging human bodies. Such differences are obvious and should not cause difficulties.

The new decomposition scale for hanging bodies was found to be sufficient and appropriate for scoring both fully suspended bodies and the upper, suspended, part of partially suspended bodies, as well as both naked and clothed bodies. The decomposition scale produced by Megyesi *et al*. (2005) was found to be similarly sufficient and appropriate for scoring clothed and unclothed bodies lying fully on the ground, and also the lower, unsuspended, portions of partially suspended bodies. Semi-recumbent bodies could, therefore, be scored using either scale but the hanging scale is expected to give better results due to the ability to include the head in the decomposition assessment.

The presence of loose, lightweight clothing, which did not impede insect access, was not found to significantly affect the rate of decomposition in the bodies lying on the ground. For the hanging pigs, however, the presence of clothing was found to affect both the pattern and rate of decomposition, with the clothed bodies decomposing faster than the unclothed bodies. Studies into insect access to bodies which have been wrapped, rather than clothed, have reported delays in blowfly arrival from 1 to 13 days (Ahmad *et al*., 2011; Goff, 1992). As some autoerotic practices include wrapping of the body, although the face may be unobstructed, this delay should be borne in mind.

Whilst the study was robust and carried out over a number of years, it was conducted with the intention of increasing the accuracy of PMI estimation for human bodies, rather than pigs, for use in aiding victim identification. Clearly it would be preferable to use humans for such a study, but this would require a large number of humans for whom the time and cause of death were known. Preferably the bodies should be of the same size, age and weight, and should be studied at the same time and throughout the whole decomposition process from fresh through to skeletonisation. This would be a difficult if not impossible set of criteria to fulfil. A further complication is that some countries, such as the UK, do not allow these sorts of experiments to be carried out on humans. It is therefore considerably easier, and often necessary, for human analogues, such as the domestic pig (*Sus scrofa*) to be used (Forbes *et al*., 2005; Myburgh *et al*., 2013; Paczkowski *et al*., 2015; Roberts and Dabbs, 2015; Schotsmans *et al*., 2012). Pigs have the advantages of being easily obtainable and similar to humans in their decomposition process (Catts and Goff, 1992). It should usually be possible to use animals of the same size, weight, and age, with known times and methods of death, and which are unlikely to be suffering from any illnesses. Their diet, environment, and possibly even parents will have been the same, thus decreasing the variables that might affect the decomposition rate or pattern.

However, the fact remains that pigs are not humans and the degree to which the decomposition rates observed in this study, expressed as TBS against ADD and converted into the ADD prediction tables, apply to humans is currently unknown. The first step towards validating the ADD prediction tables for hanging bodies would be to collect decomposition TBS_{hang} scores from hanged bodies where the time of death is known or fairly confidently known, using the hanging body decomposition scoring scale presented here, and to compare the associated ADD with the corresponding ADD predictions for the observed TBS_{hang}. An assessment could then be made as to whether any differences in the actual and predicted ADD values fall within an acceptable confidence interval that would allow the tables to be used, or whether there is a consistent difference which would allow the ADD prediction tables to be used in conjunction with some form of correction factor. This would not, however, replace the need for eventual human testing – consistent results obtained from testing chloroform on dogs would never have given the same results as when chloroform was tested on humans.

An unintentional shortcoming in the experimental design led to a wide range of weights in the pigs used. This did, however, provide an unplanned opportunity to investigate the effect of start weight on the decomposition rate and showed that a large increase in weight, of about 10 kg, was required to produce a change in value of 1 in TBS. Within the scope of this study this meant that the pig start weight had an effect that would make only a negligible difference to PMI estimates.

The shortcoming in experimental design which led to the wide range of pig start weights could have been avoided if the pigs had been sourced from the same farm at the same age each year. More pragmatically, if it had been known prior to allocation into groups and weighing, i.e. if it had been noticed on the farms that the pigs differed by such a great amount, the allocation into groups could have been done by weight, ensuring this study had animals of similar weight over the three years. To minimise the number of pigs slaughtered and maximise their use, taphonomic experiments at the study site are coordinated to ensure the control pigs (on the ground) are shared by multiple researchers and experiments. This meant that, while the start of experiments was usually at the end of May, the sourcing of pigs and exact start dates were determined by the site manager and could, therefore, not be controlled across the three years of this study.

The opportunity to explore the effect of start weight on decomposition has also presented another set of, as yet unanswered, questions and suggested areas for future work: For reasons given earlier the use of humans for decomposition studies is not always possible, and the domestic pig is considered the best available substitute for decomposition studies because of its similarities to humans, including skin, diet, digestive fauna, and muscle-to-fat ratio (Anderson, 2010; Anderson and Van Laerhoven, 1996; Catts and Goff, 1992). Changes in the human diet, which is not as well controlled as that of a farm-bred pig, have resulted in humans becoming increasingly fatter, with the rate of increase in obesity levels showing little evidence of slowing down (WHO, 2015). This presents a potential problem with the use of pigs in future studies because of the difference in the way in which humans and pigs gain weight within the normal to morbidly obese range for humans. As humans gain excess weight the ratio of fat to muscle changes with the percentage of fat increasing. The pigs within the normal human adult weight range are juveniles of 16 to 20 weeks (20 week old pigs used in this study could weigh as much as 69 kg). As pigs continue to gain weight to their adult size this weight is gained mostly as muscle. While an adult pig may weigh the same as a morbidly obese adult human, their muscle-to-fat ratios will be very different. The likelihood of having human bodies in the 90 kg to 140 kg range is increasing. This raises the following questions: Does a morbidly obese adult human decompose differently from a normal weight adult and, if so, does this mean that the pig is no longer a good substitute at these weights? Will the rate and pattern of decomposition differ between the trunks of morbidly obese male and female humans, as females tend to lay down fat between the skin and torso muscles whilst males tend to accumulate the fat beneath the muscle layer and around the organs? Do insects differentiate between the fat and muscle? If the muscle-to-fat ratio does make a difference, then an additional complication is that scientists are now using clustered regularly interspaced short palindromic repeats (CRISPR) to breed pigs with higher muscle mass (Hall, 2016).

The use of ADD as the explanatory variable for the progress of decomposition is based on the accepted, and seemingly logical, premise that, if a given amount of thermal energy is put into a carcass the same amount of reaction should occur, such that the same body score for decomposition will be seen, regardless of the timescale over which this takes place. On this basis the same degree of decomposition is expected after, say, 200 ADD whether it was as the result of 20 days at 10 °C, or 10 days a 20 °C, or 100 days at 2 °C. The inter-year consistency test conducted as part of this study appears to support this approach, but these experiments were all conducted at a location and time of year when the average daily temperature was always above freezing.

The two most important influences on the rate of decomposition are temperature and insect activity (Cross and Simmons, 2010; Mann *et al*., 1990; Simmons *et al*., 2010a) and the above use of ADD assumes that insect activity is unaffected within the temperature range used. Forensic entomologists use insects to determine the minimum time since death based on known species succession to the corpse, the temperatures required for the insect eggs to hatch, and the known length of time for larval development through the instar stages – all of which differ from insect to insect – to calculate minimum ADH (accumulated degree hours). In calculating the

ADH for any insect the accumulation of degree hours does not start until the critical hatching temperature for that insect has been reached.

Forensic anthropologists, however, calculate ADD values by accumulating the degree days for any day, or part day, when the temperature is above freezing (Megyesi *et al*., 2005). But if insects do not hatch before, for example, 4 °C (and it is not clear if this is for all the eggs, any eggs at all, or a critical mass of eggs) then the insect activity may still not have occurred by a given ADD value if the temperature did not rise above the critical threshold on any of those days.

Conversely, if there are established maggot masses present which are generating their own heat, and the temperature drops below 0 °C (halting the accumulation for ADD), the decomposition may continue unabated or at a slower rate, but the ADD value would be lower than might be expected from the observed TBS. Huntington *et al*. (2007) reported that maggots continued to feed and grow whilst stored in a morgue at a temperature of 4 °C. Marchenko (2001) provides a table giving the lower development temperature of *Protophormia terraenova* as 7.8 °C (this is usually the most abundant species found at the study site) and *Calliphora vicina* as 2 °C. If maggots had hatched at an expected temperature of, say, 4 °C, what would be the effect on them of several days at below this temperature if they had not yet established masses? The experiments in this study did not encounter these issues, being conducted during the summer in a temperate climate where the temperatures were neither high nor very low. Elsewhere in the world, or at different times in the year, the situation would be different and this may impact the use of ADD. Studies, reported this year (Bates and Wescott, 2016; Dautartas *et al*., 2016; Simmons *et al*., 2016), are looking at whether the accepted use of ADD as a means of levelling out seasonality and geographical location is as straightforward as has previously been accepted.

It is recognised that the cause of death and the environment in which a body decomposes have an effect on the pattern of decomposition. To address this decomposition scoring tables, which better reflect these differences, have been produced for specific situations including charred bodies (Gruenthal *et al*., 2012), submerged bodies (Heaton *et al*., 2010), and now hanging bodies. Work has also been carried out to determine the differences for bodies in mass graves, where the situation is further complicated by the surrounding soil types and conditions. It would seem that if the reliance on ADD having compensated for seasonal and geographical differences is not as straightforward as has been accepted, then specific decomposition scoring tables may be needed not only for different causes of death and physical decomposition sites, but also to reflect the seasons. There may be significant weather changes between time of death and discovery.

Temperatures were collected during the experiments to enable ADD to be accurately calculated. It was not intended, as part of the experimental design, to record rainfall as part of the general data collection. However, at the end of Experiment 2, as the weather had been extremely wet throughout the whole experiment, attempts were made to collect rainfall figures from the on-site weather station. This had not been used for collecting temperature data since temperature data loggers were attached to the hanging frames. Unfortunately, the on-site weather station was found to have failed and no data was available. After completion of this study rainfall data was requested, and received, from the Meteorological Office. The nearest available weather station was Bingley 2

(53.81° N, 1.87° W, 262 m). Using this data the average rainfall, in millimetres, for the months of June and July were calculated for the three years (Table 8.1).

Table 8.1 Average monthly rainfall data (mm) recorded at the nearest available Meteorological Office weather station (Bingley 2, 53.81° N, 1.87° W, 262 m) during the three years of the study.

Average Monthly Rainfall (mm)	2011	2012	2013
June	60.2	141.4	24.0
July	52.2	145.8	97.8

It can be seen that the rainfall figures for 2012 were significantly higher than the other two years. It must, however, be borne in mind that this data is from the nearest weather station to the experimental site, but is still some 15.9 miles away and at an altitude of 262 m above average sea level compared to 169 m for TRACES. It is unlikely that the rainfall would be exactly the same and, as confirmed in conversation with the Met Office, the differences in rainfall from fell side to fell side can be significantly different over small distances. This data does show, though, that for the general area the rainfall over these three years was not consistent.

Lastly, these experiments took place outdoors and most hangings occur indoors, which leads to the question: Would the results have been the same if they had been carried out indoors, where insect access to the bodies may have been impeded? Indoor decomposition rates tend to be slower than those outdoors and this is attributed to delayed insect access (Bhadra *et al.*, 2014; Catts and Goff, 1992). Both Charabidze *et al.* (2015) and Reibe and Madea (2010) urge caution in quantifying the pre-appearance time of insects found indoors. Decomposition experiments with hanging bodies should therefore be repeated indoors, where the results may be very different from outdoors where the temperatures vary and the insects have free access. Houses may maintain a relatively high temperature, 18 °C is considered comfortable, suitable for insect egg hatching but if the temperatures outside are sub-zero for extended periods would this impact on the insect arrival times? One of the features of hanging decomposition found in all the hanging pigs in this study was mummification, due to the result of wind drying, and it has been added to the decomposition scoring scale. Would the rate of mummification be sped up or slowed down indoors by the presence of central heating and air conditioning, or would it not occur at all, requiring amendments to the hanging decomposition scoring tables?

8.1 Areas for Further Work

During the course of this research a number of questions arose, which could not be addressed within the scope of these experiments, but which highlight areas in which further research could be conducted.

8.1.1 Validation of PMI Prediction Tables for Use With Humans

Because of restrictions in the UK on the use of human cadavers, as is the case in many other countries, all this work was carried out using the domestic pig *Sus scrofa* which is widely considered to be the most suitable human analogue for decomposition studies. These experiments were carried out, however, to increase the accuracy with which post-mortem interval estimations for hanging human bodies can be calculated for use in forensic case work. The PMI prediction tables produced as part of this study for hanging bodies and bodies on the ground need to be validated for use with human cadavers.

Ideally longitudinal studies of hanging human bodies would provide the information required to determine if the PMI values given in the tables are within an acceptable range of accuracy to be used as they are; or if they could be used with a correction factor; or if they require recalculating from human observational data. Initial studies could be carried out using decomposition scoring data taken from bodies found in forensic cases and for whom the time of death is known with some accuracy.

8.1.2 Use of Pigs as Human Analogues for Decomposition Studies

Pigs are used as human analogues in decomposition studies for many reasons including legality, the numbers of pigs that can be used, cost, acceptability, and the ability to control for weight and size, and to decrease the number of variables within an experiment. One of the main reasons the pig is considered such a good human analogue is the ratio of fat to muscle, which is similar to that of a human at the same weight. However, as obesity becomes more prevalent in humans, the similarity in muscle-to-fat ratio changes and becomes very different; bringing into question whether the pig will continue to be a suitable analogue.

Further research is needed to establish whether this change in muscle-to-fat ratio has a significant effect on the decomposition pattern and rate for humans in the obese and morbidly obese ranges, and whether it impacts the decomposition scoring scales and PMI prediction tables used to estimate time since death.

Note should be taken to observe for any differences between males and females, as the pattern of fat distribution is different between the sexes and may have an effect on the pattern of decomposition and insect activity.

8.1.3 Use of Accumulated Degree Days (ADD)

ADD has been used throughout these experiments and is used by forensic anthropologists in calculating PMI estimates because it incorporates adjustments for seasonal, inter-seasonal and annual temperature variations. However, recent work indicates that it may not be as straightforward as has been previously accepted.

ADD accumulates temperature only when it is above 0 °C, and assumes that insect activity is unaffected within the temperature ranges used. Work is needed to look at:

- The effects of long periods of low temperature, above 0 °C but below the laying and hatching temperature thresholds of flies associated with decomposition.

- The effects of periods of low temperature, 0 °C and below, on the insect activity once maggot masses have been established, when activity may be continuing but ADD scores are not accumulating.

- The effects of periods of high temperature at the start of decomposition and when maggot masses are established. Maggot masses may not be able to establish or maintain viability if temperatures are too high and the mass temperature cannot be controlled through the maggots' normal thermoregulatory behaviour.

- Whether the speed with which temperatures rise or fall has an effect on insect activity and the ability of the maggot mass thermoregulatory behaviour to compensate for the temperature changes.

This work could be of use in refining the accuracy of ADD calculations which are currently critical to the calculation of PMI estimates.

8.1.4 Rainfall and Hanging Bodies

A feature of decomposition in the hanging bodies in this experiment has been the desiccation, caused by the wind, and mummification of the naked hanging bodies.

In the experiment with clothed hanging pigs this mummification did not take place in the same way. Throughout the experiment rainfall was high and the clothing worn by the pigs never dried out. Loose clothing, in contact with the skin, would normally be expected to have a wicking action and, where there was airflow or wind, this should accelerate the water loss from the epidermis, desiccating the body faster than would be the case for a naked body. Wet clothing in contact with the skin has the effect of slowing the desiccation and, in the case of constantly wet clothing, of stopping it.

These experiments with hanging clothed pigs need to be repeated in conditions where the clothing is not constantly wet. Different results may also be obtained if the hanging bodies are clothed in heavier or tighter clothing.

8.1.5 Indoor Versus Outdoor Decomposition

Mummification was a common feature of the hanging bodies studied in these experiments, where the bodies were exposed to the drying effects of wind. If the degree of mummification of a body hanging indoors is more advanced relative to the rate at which insects are able to gain access to the body, this may impede the decomposition, relative to a body hanging outdoors, since desiccated skin is an inhospitable environment for oviposition. Conversely, if mummification is not a common feature of bodies hanging indoors, then decomposition may advance more quickly indoors than outdoors. Decomposition experiments with hanging bodies should be repeated indoors to investigate:

- Whether mummification occurs at all or at a different rate, and the effects that central heating and air conditioning have on the rate of mummification.

- The effects of differential air temperatures between the indoor and outdoor environments on insect arrival and activity.

- How the interplay between changes to the rate of mummification and any delays in insect access affect the overall rate of decomposition.

8.2 Conclusion

This study provided a robust and quantitative investigation into the decomposition pattern and rate in hanging bodies with the intention that the results would be of use in increasing the accuracy of PMI estimation in hanged humans. The study, which used *Sus scrofa* as human analogues, showed very clear differences in the rate and pattern of decomposition between hanging pigs and controls on the ground. It is expected that equally clear differences will be found between humans who have been hanged and others decomposing on the ground. The ADD prediction tables produced provide a quick and simple way of predicting the ADD from observed TBS and further work should be carried out to use human results to test and validate them. Whilst this study has answered the questions it set out to address, it has raised a number of additional questions for further investigation.

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10 Appendices

10.1 Appendix 1: Megyesi *et al.*'s (2005) Decomposition Scoring Scales (Used for Scoring Pigs Lying on the Ground)

The following tables show the decomposition scoring scales developed by Megyesi *et al.* (2005) for scoring the decomposition of human bodies. Each of the scores shown has been adjusted by subtracting 1 from the original scores given by Megyesi *et al.*, so that a fresh body receives a total decomposition score of zero.

Table 10.1 Megyesi *et al.*'s (2005) adjusted decomposition scoring scale for the head and neck.

Score	Description
Fresh	
0	Fresh, no discolouration.
Early Decomposition	
1	Pink-white appearance with skin slippage and some hair loss.
2	Gray to green discoloration: some flesh still relatively fresh.
3	Discoloration and/or brownish shades particularly at edges, drying of nose, ears and lips.
4	Purging of decompositional fluids out of eyes, ears, nose, mouth, some bloating of neck and face may be present.
5	Brown to black discoloration of flesh.
Advanced Decomposition	
6	Caving in of the flesh and tissues of eyes and throat.
7	Moist decomposition with bone exposure less than one half that of the area being scored.
8	Mummification with bone exposure less than one half that of the area being scored.
Skeletonization	
9	Bone exposure of more than half of the area being scored with greasy substances and decomposed tissue.
10	Bone exposure of more than half the area being scored with desiccated or mummified tissue.
11	Bones largely dry, but retaining some grease.
12	Dry bone.

Table 10.2 Megyesi *et al.*'s (2005) adjusted decomposition scoring scale for the torso.

Score	Description
	Fresh
0	Fresh, no discolouration.
	Early Decomposition
1	Pink-white appearance with skin slippage and marbling present.
2	Gray to green discoloration: some flesh relatively fresh.
3	Bloating with green discoloration and purging of decompositional fluids.
4	Postbloating following release of the abdominal gases, with discoloration changing from green to black.
	Advanced Decomposition
5	Decomposition of tissue producing sagging of flesh; caving in of the abdominal cavity.
6	Moist decomposition with bone exposure less than one half that of the area being scored.
7	Mummification with bone exposure of less than one half that of the area being scored.
	Skeletonization
8	Bones with decomposed tissue, sometimes with body fluids and grease still present.
9	Bones with desiccated or mummified tissue covering less than one half of the area being scored.
10	Bones largely dry, but retaining some grease.
11	Dry bone.

Table 10.3 Megyesi *et al.*'s (2005) adjusted decomposition scoring scale for the limbs.

Score	Description
	Fresh
0	Fresh, no discolouration.
	Early Decomposition
1	Pink-white appearance with skin slippage of hands and/or feet.
2	Gray to green discoloration; marbling; some flesh still relatively fresh.
3	Discoloration and/or brownish shades particularly at edges, drying of fingers, toes, and other projecting extremities.
4	Brown to black discoloration, skin having a leathery appearance.
	Advanced Decomposition
5	Moist decomposition with bone exposure less than one half that of the area being scored.
6	Mummification with bone exposure of less than one half that of the area being scored.
	Skeletonization
7	Bone exposure over one half the area being scored, some decomposed tissue and body fluids remaining.
8	Bones largely dry, but retaining some grease.
9	Dry bone.

10.2 Appendix 2: Example ADD Estimate Calculations for a Hanging Pig

These examples are for the inverted TBS_{hang} versus ADD regression line equation given at the end of section 7.3.3.1:

$$ADD_{est} = 234.3 + 7.38 \times \text{sgn}(B) \times |\, B \,|^{1.51}$$

where $B = TBS_{hang} - 11$; $|B|$ represents the absolute value of B, such that $|B| = B$ when $B \geq 0$, and $|B| = -B$ when $B < 0$; and $\text{sgn}(B)$ represents the sign of B, such that $\text{sgn}(B) = +1$ when $B \geq 0$, and $\text{sgn}(B) = -1$ when $B < 0$.

As an example in which a negative value for B is encountered: for an observed TBS_{hang} value of 2, $B = 2 - 11 = -9$, and the corresponding ADD estimate (as shown in Table 7.3) is:

$$ADD_{est} = 234.3 + 7.38 \times \text{sgn}(-9) \times |\, -9 \,|^{1.51}$$

$$\Rightarrow ADD_{est} = 234.3 + 7.38 \times -1 \times 9^{1.51}$$

$$\Rightarrow ADD_{est} = 31$$

Where the argument B does not return a negative value the calculation is simpler. For example for $TBS_{hang} = 22$, $B = 22 - 11 = 11$, and the corresponding ADD estimate (as shown in Table 7.3) is:

$$ADD_{est} = 234.3 + 7.38 \times sgn(11) \times | 11 |^{1.51}$$

$$\Rightarrow ADD_{est} = 234.3 + 7.38 \times 1 \times 11^{1.51}$$

$$\Rightarrow ADD_{est} = 510$$

10.3 Appendix 3: Start Weight, Sex, and Age Tables for the Pigs Used in the Three Experiments

10.3.1 Experiment 1

20 pigs were used for Experiment 1; 10 hanging pigs and 10 control pigs. The pigs for the two groups came from different farms, but all were expected to be about 16 weeks old.

Table 10.4 The start weights and sex of the pigs used in Experiment 1.

Hanging Group			Control Group		
Label	**Sex**	**Weight (kg)**	**Label**	**Sex**	**Weight (kg)**
H1	M	31.00	C1	M	55.00
H2	F	19.50	C2	F	36.00
H3	F	35.50	C3	M	51.00
H4	F	37.00	C4	F	52.00
H5	F	37.00	C5	F	41.00
H6	F	42.50	C6	M	55.00
H7	M	35.50	C7	M	57.00
H8	M	28.00	C8	F	50.00
H9	M	34.50	C9	M	51.00
H10	M	31.00	C10	M	31.00

10.3.2 Experiment 2

40 pigs were used for Experiment 2, with 10 pigs in each of four groups: hanging unclothed; hanging clothed; surface unclothed (equivalent to the control groups in the other two experiments; and surface clothed. The pigs all came from the same farm and were all about 16 weeks old.

Table 10.5 The start weights and sex of the pigs used in Experiment 2.

Hanging Unclothed Group			**Hanging Clothed Group**		
Label	**Sex**	**Weight (kg)**	**Label**	**Sex**	**Weight (kg)**
H1	F	28.15	HC1	M	23.30
H2	F	24.00	HC2	F	28.70
H3	M	29.00	HC3	F	23.60
H4	M	26.90	HC4	F	24.75
H5	F	29.40	HC5	F	25.75
H6	M	24.55	HC6	M	28.40
H7	F	29.55	HC7	M	24.75
H8	M	25.85	HC8	F	23.20
H9	M	28.25	HC9	M	22.35
H10	F	25.15	HC10	M	28.25

Table 10.5 (cont.) The start weights and sex of the pigs used in Experiment 2.

Surface Unclothed Group			**Surface Clothed Group**		
Label	**Sex**	**Weight (kg)**	**Label**	**Sex**	**Weight (kg)**
C1	F	34.20	CC1	F	38.50
C2	M	22.10	CC2	M	28.50
C3	F	25.35	CC3	F	29.55
C4	M	31.95	CC4	M	30.85
C5	M	31.55	CC5	F	21.75
C6	M	32.10	CC6	M	31.80
C7	F	30.80	CC7	M	20.90
C8	F	24.50	CC8	F	25.25
C9	F	32.75	CC9	F	31.00
C10	M	21.25	CC10	F	22.80

10.3.3 Experiment 3

30 pigs were used for Experiment 3, with 10 pigs in each of three groups: hanging; semi-recumbent; and control. The pigs all came from the same farm and were all about 20 weeks old.

Table 10.6 The start weights and sex of the pigs used in Experiment 3.

Hanging Group			Semi-Recumbent Group			Control Group		
Label	**Sex**	**Weight (kg)**	**Label**	**Sex**	**Weight (kg)**	**Label**	**Sex**	**Weight (kg)**
H1	M	56.70	HS1	M	49.20	C1	M	56.20
H2	F	60.40	HS2	F	64.40	C2	M	43.40
H3	F	63.90	HS3	F	54.90	C3	M	41.80
H4	M	64.20	HS4	M	51.90	C4	M	40.90
H5	M	56.40	HS5	F	62.00	C5	M	54.80
H6	F	60.70	HS6	M	51.10	C6	M	36.60
H7	M	69.20	HS7	M	57.10	C7	M	54.00
H8	M	48.70	HS8	F	61.70	C8	M	43.70
H9	M	52.40	HS9	M	60.10	C9	M	48.90
H10	M	55.60	HS10	F	53.00	C10	M	45.60

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PAPER

ANTHROPOLOGY

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Decomposition Rate and Pattern in Hanging Pigs

ABSTRACT: Accurate prediction of the postmortem interval requires an understanding of the decomposition process and the factors acting upon it. A controlled experiment, over 60 days at an outdoor site in the northwest of England, used 20 freshly killed pigs (*Sus scrofa*) as human analogues to study decomposition rate and pattern. Ten pigs were hung off the ground and ten placed on the surface. Observed differences in the decomposition pattern required a new decomposition scoring scale to be produced for the hanging pigs to enable comparisons with the surface pigs. The difference in the rate of decomposition between hanging and surface pigs was statistically significant ($p = 0.001$). Hanging pigs reached advanced decomposition stages sooner, but lagged behind during the early stages. This delay is believed to result from lower variety and quantity of insects, due to restricted beetle access to the aerial carcass, and/or writhing maggots falling from the carcass.

KEYWORDS: forensic science, forensic anthropology, hanging, decomposition, postmortem interval, accumulated degree days, pig carcasses

Worldwide, hanging is one of the most commonly used ways of committing suicide (1); it is the most common method in both England and Wales, accounting for about 2000 deaths a year (2). Many individuals are found relatively quickly if the hanging occurred in the home, often as a result of suicide or auto-erotic activities (3,4); however, when the hanging has occurred outdoors or in a remote location, bodies may remain undiscovered for longer periods. Although using decomposition scoring and accumulated average temperature to calculate the postmortem interval (PMI) is possible, Parks has noted that a "one size fits all" decomposition model is unrealistic (5). A scale for scoring submerged bodies and a predictive equation for calculating PMI was produced by Heaton et al. (6), who found that the decomposition pattern for bodies in water was different from that described by Megyesi et al. (7) based solely on terrestrially deposited cases.

When comparing the rate and pattern of decomposition of a single hanging pig and one pig on the ground, Shalaby et al. (8) found that the rate at which mass decreased was slower in the hanging carcass and that each stage of decomposition was prolonged. In the absence of replication, conclusions from such a small study must be treated with caution; however, there are reasons to suspect that the species of insects attracted to a hanging body may differ if the carcass is not touching the ground (9). Unless a hanging body is partially in contact with the ground, crawling insects would be unlikely to return to the carcass if they fall into the drip zone (8), where they may continue to feed on any material falling from the body. In addition, when a body is hanging outdoors, a greater surface area of the body will be exposed to the drying effect of wind, which could increase the possibility and/or rate of mummification. Blow flies (Diptera; Calliphoridae) are less likely to lay eggs on leathery or mummified skin (10). Physical disturbance of carcasses has also been shown to have a significant effect on the rate of mass loss during decomposition (11,12) due to the displacement of necrophagous insects. The maggot mass within a hanging animal may, therefore, be smaller than that within an animal on the ground, where the maggots are more likely to remain within the body cavity. A smaller maggot mass inside a hanging body may affect the rate of weight loss mediated by insects.

This study presents a comparison of pattern and rate of decomposition in pigs (*Sus scrofa*) hung, fully suspended, by the neck, with others on the ground surface. We use "rate" to mean the change in decomposition with respect to accumulated degree days (ADD), which is a variable incorporating time. Based upon the findings of Shalaby et al. (8), the hypothesis on which this experiment was based was that decomposition in hanging carcasses would be slower than in those on the surface of the ground. The research required the development of a new Total Body Score for Hanging (TBS_{hang}) scale, for scoring the decomposition of hanging bodies, to complement the existing Total Body Score (TBS_{surf}) scale for bodies in contact with a substrate (7). Used in conjunction with ADD, this new scale may provide a more accurate determination of PMI for hanging bodies.

Materials and Methods

The research was carried out at the University of Central Lancashire's Taphonomic Research in Anthropology Centre for Experimental Studies (TRACES) facility (13) in the northwest of England; TRACES is a 13-acre outdoor site consisting of slop-

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ing rough pasture land with areas of young trees, consisting of rowan, alder, birch, oak, and pine.

Twenty pigs (*S. scrofa*), killed within an hour before with a captive bolt gun, were numbered serially as they were removed from body bags and allocated into two equal groups. The first ten removed were assigned to the "hanging" group and the second ten to the "surface/control" group. The hanging group contained five females and five males and the control group four females and six males. As they were removed from the body bags, they were weighed to the nearest 5 g using a rope noose tied around a hind limb and an S hook attached to a hanging scale on a fixed frame. All pigs were put into position within an hour of each other on 28 May 2011 with the exception of one of the surface pigs which, due to lack of availability on the day, was killed and positioned one day later.

An EL-USB-1 Lascar Electronics self-contained data logger (Lascar Electronics Ltd., Salisbury, U.K.; the authors have no financial interest) in a film-sealed case was inserted into the anus of each pig and pushed internally using a bamboo rod to a distance of approximately 40 cm. The loggers had been preprogrammed to record temperature at 6-h intervals throughout the experiment. The data loggers remained in place until completion of the experiment. The pigs in the hanging group also had thermocouples inserted into the thorax via the esophagus in the event that the loggers in the anus were expulsed through gravitational force prior to completion of the study. The data loggers were placed internally to enable comparisons to be made between the core temperatures of the pigs and the external temperature, as it is known that maggots generate their own heat. This also facilitated comparisons between the internal temperatures of the hanging and surface pigs in the hopes that it might provide indirect information concerning maggot mass size differences in these groups.

Two hanging structures were constructed from scaffolding poles, where a pair of A-frames supported a horizontal ridge pole 2.5 m above the ground. These structures were covered in a scavenger proof chicken wire mesh to a height of 1 m, above which was attached bird-proof plastic netting. Thus, the entire structure was covered and researchers' entrance into the frame was achieved via a detachable section of chicken wire. Neither mesh nor netting impeded insect access. On each ridge pole, spaced approximately 80 cm apart, five pig carcasses were hung by the neck using nylon rope tied in a noose. Each noose was attached to the ridge pole using a butchers' hook, which suspended the carcasses so that the hind limbs were hung a minimum of 60 cm off the ground. Each hanging structure had an additional data logger, attached at a height of 1.5 m above ground, to record ambient temperatures. The second group of 10 pigs was placed 30 m distant on the ground spaced about 5 m apart. The cages were covered in scavenger proof mesh which did not impede insect access.

The observation and data collection interval for this study was approximately every 50 ADD; because the average daily temperatures in the north of England are only 12–15 °C, this approximates twice a week (on day 3 and day 7 of each week), until the end of the study (25 July 2011) for a total of 17 observation days. At each visit, the physical state of the surface pigs was closely observed and photographed, with scores for each of three regions (head and neck, torso, and limbs) recorded to produce TBS_{surf} (7). Photographs were taken and detailed descriptions recorded for the hanging pigs to enable seriation of the decomposition process and development of a comparable scoring system. Any differences in appearance which appeared to be sex specific were also noted. The ground directly beneath the hanging pigs, or the "drip zone" (8), was examined and sampled for any insects and parts of the pig that may have fallen. At weekly intervals, the weight of each hanging pig was recorded, measured using the weighing scale on which they were originally weighed. This scale was hung by a hook over the horizontal scaffold bar of the A-frame next to the pig, and the pig was moved carefully from the S hook it was hanging on onto the weighing S hook and then returned to the hanging frame hook. Also noted were the dates at which blow fly eggs and maggots, and larval and adult beetles were first observed on the carcasses of both groups.

The ambient ADD was calculated from the external loggers attached to the hanging frames, and the internal ADD was calculated from the internally sited data loggers and thermocouples. Data from the temperature data loggers were downloaded. The daily average temperature was calculated from the 6-h recordings, and the ADD was calculated for the periods from the start of the study until each observation day. The study period commenced after the threat of frosts had passed, so no adjustments for temperatures at or below 0 °C were required in the ADD calculations (14). All ADD figures were calculated using temperatures in degrees Celsius.

Hanging Body Score Scale

Decomposition is a mosaic process, where different parts of the body decompose at different rates, which is why the system defined by Megyesi et al. (7) independently scores the degree of decomposition present in the head/neck, torso, and limbs. The hanging bodies were scored in the same three regions. Using the characteristics of decomposition displayed by each pig at each ADD interval, a seriation was produced reflecting the most typical pattern over a known timeline. Scores were then allocated to each pig based upon a review of the written description and photographs recorded at each observation. Independent scores were given to the three regions: head and neck, torso, and limbs. These scores were added to give a TBS_{hang} on this novel scale. All scores were integers with a baseline of zero equating to no visible decomposition. As the scale records scores of visible decomposition, a fresh body does not show any such decomposition and receives a score of zero points. Where body sections did not show the same levels of decomposition over the whole section, for example, across all four limbs; then, the score was an average of the two extremes, to the nearest integer. The surface pigs were scored using Megyesi et al.'s system (7) which began at 3 for a fresh body, as 1 is the fresh score for each of the component body parts; head, torso, and limb. This can cause some complication, as regression lines are not through the origin and conversions between scales are more convoluted (15). Therefore, the scales have been converted to begin at zero (Tables 1–3) simply by the subtraction of 1 point from each of Megyesi's head, torso, and limb scores (7). Total body scores were otherwise unaltered, merely progressing from 0 to, for example, 12 for the head, rather than from 1 to 13. We feel this better reflects the fact that, in a fresh condition, the body exhibits no decomposition.

Statistical Analysis

Linear models were used to explore the relationship between ADD and measures of decomposition. Such relationships rarely produce a straight line and, while a simple mathematical transformation of ADD is often adequate to produce one, in these

TABLE 1—*Stages of hanging decomposition for the head and neck ($PBSH_{hang}$). (Northwest England Summer 2011).*

Score	Description
0	Fresh, no discoloration
1	Swelling of head and neck
2	Purging of decompositional fluids, darkening of skin to black, sinking in around eyes, some drying of snout and lips, most flesh still fresh
3	Skin shrinking back from jaw, skin slippage
4	Flesh sinking in around jaw and throat, drying of skin and lips
5	Hair loss, drying shrinking snout
6	Leathery skin, less than 10% bone visible
7	Holes in or tearing of the skin
8	Complete mummification, ears dry inflexible
9	Partial mask formed where some of the skin is lifting from skull
10	Skin like parchment, very thin and translucent with holes and tears forming
11	Bone visible over more than 50% of skull, or detached mask for more than 75% of skull
12	Dry bone which may still be hanging if attached by mummified tissue or may have fallen to the ground

TABLE 2—*Stages of hanging decomposition for the torso ($PBST_{hang}$). (Northwest England Summer 2011).*

Score	Description
0	Fresh, no discoloration
1	Bloating, red to green discoloration, swelling of males' testicles
2	Color changing from green to gray to dark gray/black
3	Prolapsed bowel, purging of decompositional fluid
4	Lower torso more swollen than upper. Penis and umbilicus are open holes on males
5	Body elongated with some caving in of upper torso
6	Anus open to diameter of 10 cm or greater, intestines protruding. Scrotum soft and shriveling in males
7	Drying and browning of skin, becoming leathery on upper torso
8	Intestines dropped out of body, skin mummified. Scrotal sac opens at back into anal opening on males
9	Stomach dropped from body, ribs, scapulae and vertebrae dropped, flanks sunken, skin very greasy to touch
10	Large loss of fat onto drip zone, torso drum like, innominates and long bones dropped
11	Dry bone below carcass or visible beneath mummified skin, carcass may still be hanging

TABLE 3—*Stages of hanging decomposition for the limbs ($PBSL_{hang}$). (Northwest England Summer 2011).*

Score	Description
0	Fresh, no discoloration
1	Reddening of skin, becoming dark gray, limbs swollen, and extended out from the body
2	Some skin slippage, drying of limbs at extremities
3	Gray becoming black, forelimbs hanging in usual position
4	Drooping forelimbs hanging loosely, disarticulated at shoulder
5	Hind limbs hanging loosely, disarticulated at pelvis, loss of hind hooves, hair loss
6	Mummification of lower end of limbs, skin color dark brown, tears and holes in skin
7	Bones in hanging bags of skin. Mummified with distal ends of limbs rock hard, skin stuck to bones
8	Bones dropping through torso, scapulae first then humerus. Limb surface very greasy
9	Dry bone below carcass or visible beneath mummified skin, carcass may still be hanging

cases, it was not. Instead, we used a polynomial regression which fits a more complex curve, of the form:

$$\text{decomp} = a_0 + a_1 \times \text{ADD}^1 + a_2 \times \text{ADD}^2 \ldots + a_n \times \text{ADD}^n.$$

The maximum rate of decomposition can, therefore, be found by calculus. Extensions of the polynomial curves beyond the data points may well suggest a reversal of decomposition, but these should be ignored, as the models are applicable only within the ADD range encountered in data collection.

A compromise between the fit of the curve and parsimony was made using goodness of fit comparisons. Significance tests for decomposition curve differences were carried out by a comparison of models by means of a chi-squared test. All analyses were conducted using the software R (16), using the lme4 (17) package for mixed-effects models.

Results

There were a total of 17 observation periods, the last of which corresponded to 932 ADD. Data from the internal thermocouples in the hanging pigs could not be used as a measure of internal ADD as the majority of the loggers failed due to the ingress of moisture despite efforts made to seal them. Therefore, ADD was calculated based upon the temperatures recorded by the ambient data loggers attached to the hanging frames, and internal carcass temperatures could not be compared between surface and hanging pigs.

Initially, the appearances of the hanging and control pigs were similar. On the first day of the study as the pigs were removed from the bags, as well as when they were set out in the field, blow flies were observed landing on them. These blow flies oviposited in the natural orifices in the head, around the anus, and in the skin creases, showing no preference for either group of pigs. Eggs were also laid around the noose on the hanging pigs. Once larvae had hatched and all the pigs in both groups had started to purge decomposition fluids at 147 ADD, the patterns observed in the two groups diverged. By 229 ADD, the maggots in the surface group remained visible and active, with wet decomposition destroying the throat tissue and opening the carcass. Beetle adults and larvae were also present in the surface group. In contrast, maggots were no longer visible in the hanging pigs, and no beetles or their larvae were seen. By 279 ADD, all the surface pigs' heads had been largely consumed, and differences in the pattern of decomposition pattern were evident. The greater surface area exposure of the hanging pigs to wind and sun led to drying and mummification, inhibiting insect access and further oviposition. Hence, little external insect activity was visible; maggots were evident only when they fell to the drip zone, at which point, they effectively had no further impact on the hanging body. The general pattern of decomposition for the control and hanging pigs is summarized by ADD in Table 4.

The shape of the hanging males and females differed as the decomposition progressed. At initial bloat all the hanging pigs assumed an evenly swollen appearance with the limbs swollen and held out from the body. As the bloat subsided, the males deflated first on the upper torso, remaining swollen around the midtorso with the greatest width around the umbilicus and penis. The scrotum also remained swollen. This shape was retained until fully deflated even though the penis and umbilicus had become open holes. The female pigs maintained an evenly swollen shape, appearing rectangular in frontal view and with no protrusion around the umbilical area. This shape was retained until

TABLE 4—*General pattern of decomposition for the control and hanging pigs (Northwest England summer 2011).*

ADD	Hanging pigs	Control pigs
147	Bodies were bloated and had started to purge decomposition fluids. Maggots present on and in the head. All animals had prolapsed bowels and some of the anal data loggers had already been avulsed. The testicles of the male pigs were considerably more swollen than in the control pigs.	Bodies were bloated and had started to purge decomposition fluids. Maggots present on and in the head.
229	Maggot masses visible in the mouth. Very few additional maggot masses visible. Drip zones, as named by Megyesi et al. (7), had now formed beneath the pigs. The maggots falling onto the drip zones varied from a few to approximately 240 ml (2 cupfuls).	The control pigs appeared to be decomposing faster. Maggot masses visible in the mouth. The throats of the control pigs were open and moist with visible decomposition. Maggot masses were visible on the underside of the control pigs
279	10% of the hanging pigs displayed exposed bone in the head region.	80% of the control pigs had part of the maxilla or mandible exposed.
385	From this point there was little breaching of the hanging pigs and they became hanging "empty pigs," with the pig appearing externally to be complete but with the internal organs decomposing or decomposed. The bowels had now fully prolapsed with some loops of intestine fallen to the ground.	The appearance of the control pigs was now very different from the hanging group. The controls could be seen to be decomposing, evincing moist decomposition with parts of the torso breached and bones visible.
459	Externally, the hanging pigs displayed deflation and lengthening. Lifting the forelimbs showed active maggot activity in some of the axillae and in some the skin was breached. Two of the pigs had hind trotters just touching the ground. The rope was reknotted to raise them off the ground. No beetles or larvae were observed on the pigs or in the drip zone.	Foaming maggot masses and bones were visible, including mandibles, limb bones, ribs, scapulae, and vertebrae.
512	The hanging pigs were starting to lose their intestines, which had dropped to the drip zone. In the male pigs, the scrotal sac was opened and joined with the anal hole. All the hanging males had lost their intestines, as had 20% of the females.	Few or no visible maggot masses on the skin, but these were still present beneath the skin.
591	Torsos had become dry but still flexible, feeling leathery. The stomach and quantities of fat were in the drip zone. The first bones were found in the drip zone: these included ribs, scapulae, and vertebra.	All animals displayed bone exposure of the head and some limb bones.
631	The torsos of the hanging pigs had become mummified. Long bones and innominates from either or both sides of the body were found in the drip zone.	High rainfall had left the control pigs lying in pools of water, and all of them had soft swollen skin and were fatty.
767	The hanging pigs were elongated, mummified, and hard.	All the heads were skeletonized. The majority of animals had more than 50% of the bones visible in the limbs and torso.
828	Prolonged heavy rainfall left all the pigs looking fatty and white where rehydrated.	Prolonged heavy rainfall left all the pigs looking fatty and white where rehydrated. The control pigs were lying in rain water.
932	The hanging pigs were mummified and all remained hanging.	All the controls now had more than 50% bone exposure on the head, limbs, and torso.

fully deflated, leaving a pouch of skin drooping on the lower abdomen. Figure 1 Illustrates progression of decomposition, in one pig, throughout the study.

In both males and females, the anus enlarged to around 10 cm in diameter early in the decomposition. In a hanging position, the anus of a pig is not at the lowest part of the torso but higher and dorsal. In the males, as the decomposition progressed, the back of the scrotal sac decomposed joining with the anus and creating a much larger opening directly below the body (Fig. 2) enabling bones to drop out. In the females, the anus remained open only at the back with the pouch of stretched skin remaining from the bloating stage left hanging lower than the anus (Fig. 3). Some bones collected in this pouch, below the anus (Fig. 4), and were still there at the end of the study period. The first beetle larvae were observed on the hanging pigs at 869 ADD, some 640 ADD later than in the surface group.

Total Body Score for Hanging Bodies (TBS_{hang})

The scale produced for scoring the hanging pigs is based on a score for the head and neck between 0 and 12 points to give a Partial Body Score Head ($PBSH_{hang}$); a score for the torso between 0 and 11 points to give a Partial Body Score Torso ($PBST_{hang}$); and a score for the limbs between 0 and 9 points to give a Partial Body Score Limbs ($PBSL_{hang}$). Total Body Score for Hanging (TBS_{hang}) was a sum of the three region scores and provided an overall measure of decomposition for the hanging body with a minimum score of 0 and a maximum of 32 points. Tables 2–4 list the decomposition scoring scales used for the three regions of the hanging pigs.

In hanging pigs, the sexes showed significantly different patterns of weight loss ($\chi^2 = 24.4$, df = 3, $p < 0.001$), with females losing weight more slowly and retaining more mass throughout (Fig. 5). This slope for males was 0.17% loss per ADD (at ADD = 483), and this slope for females was 0.13% loss per ADD (at ADD = 503).

When using "Total Body Score" as the response variable, there is again a difference between sexes ($\chi^2 = 15.6$, df = 2, $p < 0.001$), although this is not as large, and again, males show a greater rate of decomposition, as illustrated in Fig. 6. This curve is a quadratic, and, as can be seen from the plot, maximum slope is found where ADD = 0, which is 0.062 TBS_{hang} per ADD for female, and 0.068 TBS_{hang} per ADD for male; thus, despite being significantly different, the differences are small.

Using the Total Body Score/Total Body Score for Hanging (TBS_{surf}/TBS_{hang}) to compare the rate of decomposition of surface and hanging pigs, a highly significant difference was

FIG. 1—*Hanging female pig showing progression of decomposition over the range of Accumulated Degree Days (ADD) (Northwest England Summer 2011).*

FIG. 2—*Hanging male pig at 512 ADD (Northwest England Summer 2011). The arrow points to the anal opening extending beneath body.*

FIG. 4—*Hanging female pig at the close of the experiment, 950 ADD (Northwest England Summer 2011). The pouch of skin was cut open and the arrow points toward the bones which had collected in the pouch.*

FIG. 3—*Hanging female pig at 600 ADD (Northwest England Summer 2011). Arrow A points to the pouch of skin hanging below the below anal opening (arrow B).*

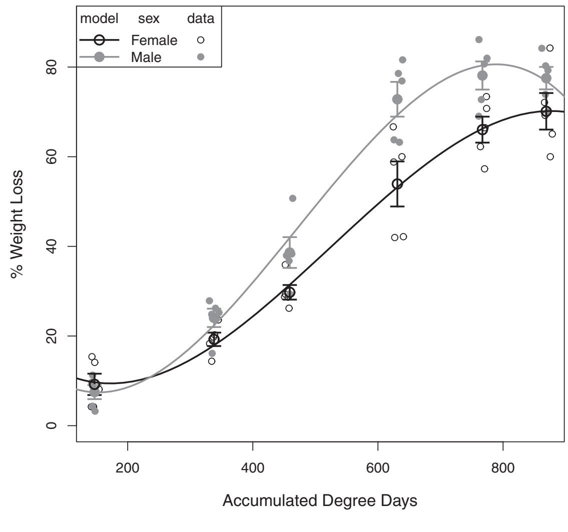

FIG. 5—*Differences in percentage weight loss between male and female hanging pigs to 900 ADD (Northwest England Summer 2011). The model points show mean values for each sex at each value of ADD. The model lines are the polynomial regression (here fourth order) fitted values. Some jitter has been added to the ADD values of the data points for clarity.*

evident (χ^2 = 104, df = 5, p < 0.001), with hanging pigs reaching later stages of decomposition more quickly (Fig. 7). Hence, the results of the experiment did not support the hypothesis; hanging pigs, in fact, decomposed more rapidly in the latter stages of decomposition than those on the surface of the ground.

The situation here is more complicated, requiring a fifth-order polynomial. In relatively early decomposition, for example, around 150 ADD, decomposition rates are steeper and similar (ground surface: 0.051 TBS_{surf}/ADD, hanging: 0.060 TBS_{hang}/ADD); whereas later, when decomposition slows on the ground,

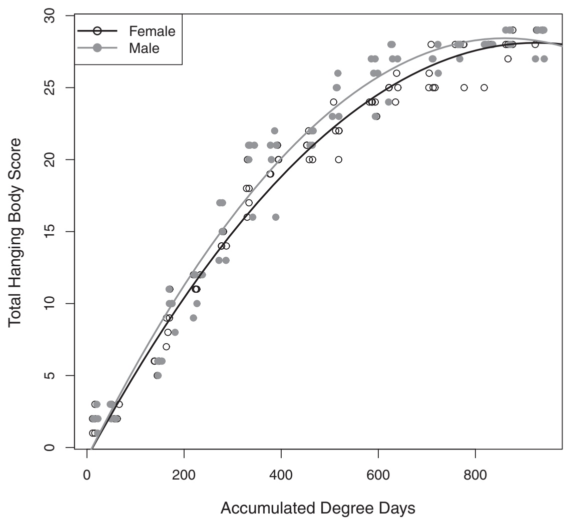

FIG. 6—*Rate of decomposition showing the difference between the male and female pigs using Total Body Scores for Hanging (TBS_{hang}) to 900 ADD (Northwest England Summer 2011). Jitter has been added to ADD for clarity.*

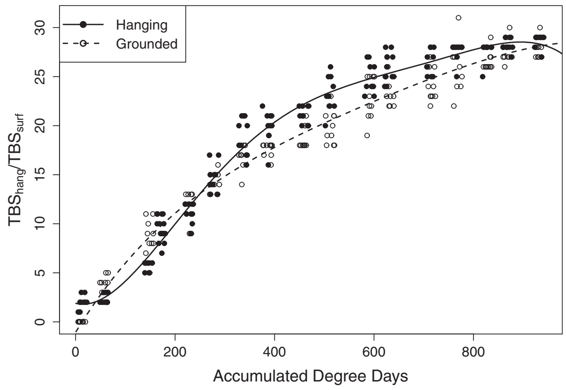

FIG. 7—*Comparison of decomposition rates of hanging and grounded pigs using Total Body Scores for Hanging (TBS_{hang}) and Surface (TBS_{surf}) pigs, respectively, to 900 ADD (Northwest England Summer 2011). Jitter has been added to the ADD values for clarity.*

hanging slows even more (e.g. at 650 ADD grounded: 0.020 TBS_{surf}/ADD, hanging: 0.014 TBS_{hang}/ADD).

As the relationship between ADD and body score followed curves when comparing sex and treatment, simple quantitation of the patterns is challenging. It is not appropriate to give an "average" rate of decomposition based upon a single point (e.g. a TBS of 10 at 200 ADD) as the relationship up until that point is not a straight line. This means that rate of decomposition is different for every value of ADD. An alternative would be to present the formulae for the lines, but being fifth-order polynomials, these are unwieldy and we believe unhelpful to most readers. Besides, overall patterns are of greater interest than deterministic models where one would plug in a value of ADD and get out a value of TBS. This would not be appropriate for a study such as this which uses pig carcasses as surrogates for human cadavers. Therefore, it is suggested that Figs 6 and 7 are the most convenient way of communicating the relationship between ADD and TBS in these cases.

Discussion

Accumulated degree day constitutes the accumulation of thermal energy (18), and when a given amount of thermal energy is accrued by a carcass, a similar degree of decomposition should be apparent, yielding comparable decomposition scores for equivalent ADD. Accumulated degree days as calculated from ambient temperature records provide the best measure of temperature over time for decomposition studies, enabling comparison of data from different seasons, years, and geographical areas. It is well established that maggot activity produces heat and the maggot mass-related internal carcass temperatures may be 5–10 °C above the ambient temperature during this time (19). As increased temperature escalates the rate of decomposition, factoring in the increased maggot generated heat when considering ADD may allow for more accuracy in predicting PMI. This study hoped to compare the internal and external temperatures of the pigs using internal data loggers and thermocouples, but these failed to record over the duration of the study period or were deactivated by decomposition fluid and/or rain.

The difference in shape between the hanging males and females during much of their decomposition may be explained by the positioning of the urethral opening. In the males, this is situated just posterior to the umbilicus and may thus provide another escape route for the gases produced during decomposition, making this point the widest as the gases gather there. The escaping gases would also attract insects, particularly Diptera, with the umbilicus and penis of the males soon becoming full of larvae and progressing to open holes. This did not occur in the females where the urethral opening is just ventral to the anus, indicating that it is the urethral opening that is the weak point rather than the umbilicus. Without this escape route higher on the torso, the females retained a rectangular shape and, as they deflated, the skin which had remained stretched and swollen now formed a pouch of loose skin at the lower torso. This pouch of skin hung lower than the anal opening, so that disarticulated bones dropping down within the female pigs could become trapped here rather than falling to the ground. This contrasted with the males where the tissue of the swollen scrotum decomposed and it became part of the anal hole. A single large opening directly beneath the pig was produced and this allowed bones to fall through more easily. While of note in this study, this feature is unlikely to be of any significance when observing humans as, when hanging, the anal openings of quadrupeds and bipeds are not in the same place. In humans, the anal opening would be directly below the body and the positioning of the human penis is also low down, not at the umbilical level, so the shape differences between the male and female pigs in late bloat and deflation may not be present in humans.

The weight loss started slowly, increased, and then slowed down toward the end of the decomposition as would be expected (8,20). The difference in decomposition pattern of the male and female pigs may account for the difference in percentage weight loss during decomposition, as bones were lost from the males through the anal opening. While the rate of decomposition between the males and female pigs was shown to be statistically significant, the actual difference is very small. The hanging pigs in this experiment were weighed weekly, and in doing so, it is inevitable that the maggot masses would have been disturbed. Researchers (11,12) suggest that the physical disturbance of a carcass may disrupt the feeding of the maggots and retard the rate of decomposition, but any such effect would be expected to be the same for both the males and females. Weight loss in soft tissues is a true measure of decomposition. This study has shown, however, that care is required in extending this principal to whole body weight loss. Past studies (12,20) have shown a correlation between decomposition rate and weight loss. This may not be the case where part of the body has been lost or dispersed, for example, in scavenging or in the case of the hanging pigs in skeletal element loss via gravity.

The Megyesi et al.'s. (7) Total Body Score scale was produced using a retrospective cross-sectional study of humans which, by its nature, provided a single snapshot of the stage of decomposition at which each individual was found, rather than a longitudinal study observing progressive changes in the same individuals over the whole decomposition process. Although Megyesi et al. studied many individuals covering the range of decomposition stages, there were no cases involving hanging bodies. It appears from the findings of the hanging studies, including the present longitudinal study, that the pattern of decomposition in hanging bodies is markedly different, making Megyesi et al.'s scale unsuitable for scoring these bodies.

The new scoring scale produced for hanging pigs includes mummification in the description of what is seen during the decomposition. While it could be argued that it should not be in the scale as it is not a feature common to all decomposition, it was found to occur in all 20 hanging pigs of the present 2011 study and was also observed in a previous trial in 2010, which would indicate that it is a feature of hanging, much like adipocere is a feature of many immersed and buried bodies. The characteristic mummification may be due to the higher surface area of the carcass being exposed to sunshine and wind, which dry the body out quickly. The same feature may not be found where wind is not a relevant environmental factor or where humid conditions prevail.

Decomposition scores generated using the new hanging scale cannot be directly compared with those from Megyesi et al.'s scale as they describe different patterns of decomposition; there is, currently at least, no established absolute scale of decomposition which could be used to link them. However, both scales span the same range of decomposition and, once adjusted for a zero baseline, assess the same body areas using the same point ranges.

For their study, Megyesi et al. calculated ADD values using the daily average temperature records from the nearest national weather station for each body, while the PMI in each case was determined either from insect evidence or the associated police investigation. For this study, the ADD was calculated from two temperature data loggers situated within 10 m of the pigs (21), with measurements at 6-h intervals, while the PMI was known to within 1 h. Both the ADD and PMI values for this study should, therefore, be more accurate than those used in Megyesi et al.'s study.

In a pilot study (unpublished data) at TRACES conducted in the previous year, the rate of decomposition of hanging pigs was significantly different (faster) than in this study. A noticeable difference was the presence of beetles on the carcasses at an early stage thus increasing the diversity of insects. It has been demonstrated that the greater the diversity of insects, the greater the rate of decomposition (10). Nine of the pilot study's hanging pigs had their hind limbs in contact with the ground for some or all of the time between 54 ADD and 159 ADD before being raised up. During this time, effectively, these pigs were not hanging. Beetles can and do fly well, but relatively little time is spent in flight; beetles are very much insects of the ground and low vegetation (9). The pigs' hind limbs resting on the ground would have provided the beetles with an easy means to reach the hanging pigs, and the pilot study demonstrated that they took advantage of this route.

Additionally, between 54 ADD and 200 ADD, five of the pilot study pigs herniated the intestine providing another site for the release of volatile gases, attracting flies and providing a moist access to the carcass for oviposition. It was noted that four of these five pigs were male. In pigs, unlike humans, the intestines do not usually lie above the inguinal canal, but in the hanging position, the gravity and pressure of gases may have acted on them pushing them into the inguinal canal and causing them to herniate.

The difference in the rate of decomposition, shown in this study with the hanging pigs lagging behind the controls in the early stages of decomposition, is in agreement with Shalaby et al. (8) and the pilot study. This difference may be attributed to the differences in levels of insect activity between the two groups. Insect access to the hanging pigs, particularly for Coleoptera (beetles), was limited and this may explain the delay in decomposition of the hanging pigs. While many egg masses were laid by blow flies around the noose, these desiccated unhatched and thus contributed to limiting the quantity of maggots on the hanging pigs. Additionally, the action of gravity and movement disturbed the maggot masses causing maggots to fall from the hanging pigs to the drip zones below, thus decreasing the internal maggot masses. This has implications for calculating the PMI of hanging bodies as many are found with the feet in contact with the ground. If this has occurred at the time of hanging or rapidly after, the insect access is likely to be similar to that of a body on the ground. Thus, the rate of decomposition, at least initially, may be less like that of a body suspended totally off the ground. Further investigative studies are currently underway.

Also noted was the change to the appearance of bodies on the ground when they had become sodden and waterlogged following prolonged rain. This rehydrating of the tissues and fats gave the bodies the appearance of being "fresher" than prior to the rain. This may give the impression that the progression of decomposition is less advanced and lead to a lower TBS_{surf} which, in turn, will impact the PMI calculations possibly providing an inadvertently lowered PMI. An accurate PMI is important in the establishing the events surrounding a death and creating a timeframe when searching for missing persons. It may, therefore, be prudent to check the amount of rainfall and duration in the days prior to a body being found if it does look particularly fatty and make allowances for the apparent retardation of decomposition. To ensure that PMI calculations are not inadvertently lowered, it may be necessary to increase the range of dates with in which the PMI falls.

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